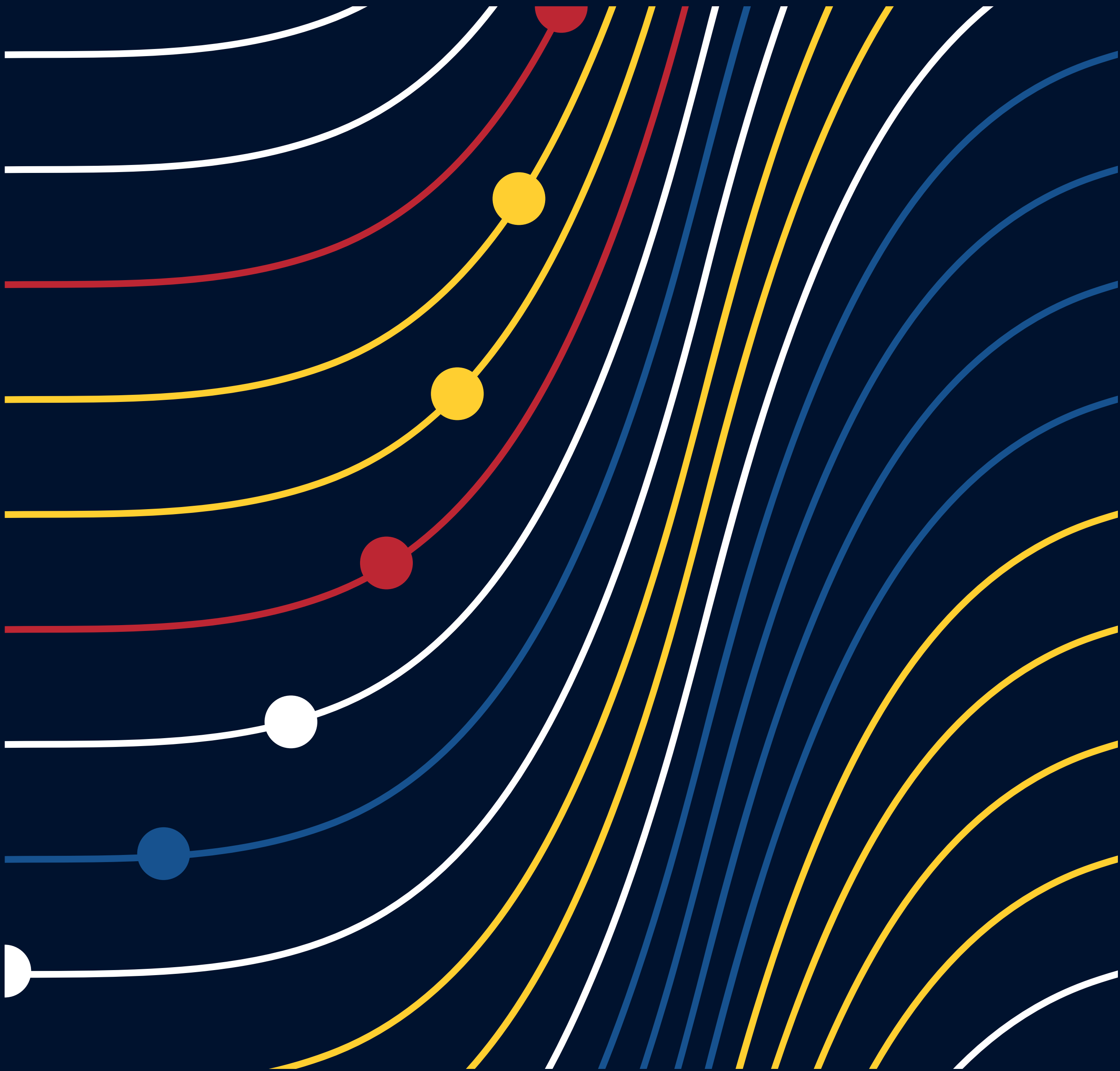

THE BREAKTHROUGH EFFECT IN ASEAN: HOW TO TRIGGER A CASCADE OF TIPPING POINTS TO ACCELERATE ASEAN'S GREEN GROWTH

BEZOS EARTH FUND
SYSTEMIQ
KADIN Net Zero Hub

ENDORSEMENTS

"The green transition is the global growth story of the 21st century. We need to ensure ASEAN as a region seizes the green growth opportunity in the next decade. I urge governments, investors and business leaders in ASEAN to use this foundational study to understand which actions they can prioritize today to drive the level of emissions cuts needed to get us on track for limiting global temperature rise to 1.5°C. It is encouraging to see low-carbon solutions in the power and road transportation sectors in ASEAN are already reaching cost parity with high-emitting incumbents. Supporting these technologies even more through enabling policies and smart investments could trigger tipping points faster. Working hand in hand across companies and with governments, we can seize this opportunity. The time is now."

SHINTA KAMDANI
Coordinating Vice Chairman for Maritime, Investment and Foreign Affairs at the Indonesia Chambers of Commerce and Industry (KADIN)

"The numbers are clear on the funding gap for climate. We should be investing $2.4 trillion per year in net-zero solutions in emerging economies and developing countries (excluding China). Right now, we are only reaching 20% of this target. While the gap in climate funding ('what') is widely acknowledged, there is less clarity on understanding the reasons ('why') behind it and the strategies ('how') to close this gap. The Breakthrough Effect in ASEAN offers a blueprint by identifying the opportunities for breakthroughs in net-zero solutions within ASEAN and outlines both the reasons ('why') behind seizing these opportunities and the strategies ('how') to unlock them."

MARI PANGESTU
Special Envoy for the G20 Bali Global Blended Finance Alliance, Former World Bank Managing Director of Development Policy and Partnerships

"The choices made by businesses and governments in the next decade will decide whether Indonesia can tap into its green growth opportunity. This is why at KADIN Net Zero Hub, we have been actively spearheading private sector climate action for a net-zero future. We believe there is no more time to reinvent the wheel, and hence our Hub aims to raise ambitions, share knowledge and data to replicate what works for Indonesian companies to accelerate their transition journey.

The Breakthrough Effect in ASEAN is a foundational piece of work for the Hub. It sets the framework for the conditions and levers to reach sectoral tipping points that can unlock ASEAN's green growth. With this framework, private and public sector have a common target to realize – ensuring smarter decisions to effectively translate the vision into action. We look forward to work together with businesses and the government to unlock these tipping points for a better ASEAN and a better Indonesia."

DHARSONO HARTONO
Chairman Indonesian Chambers of Commerce and Industry's (KADIN) Net Zero Hub and Carbon Center of Excellence

"INA focuses on investing in green energy and transformation as part of its commitment to responsible investing. We are committed to support Indonesia in moving towards a sustainable energy future. The Breakthrough Effect in ASEAN helps us in realizing this by identifying opportunities for investments in low-carbon solutions that can create significant growth and value, speeding up the shift towards a net-zero world."

ARIEF BUDIMAN
Deputy CEO of Indonesia Investment Authority (INA)

ENDORSEMENTS

"Six of nine planetary boundaries that regulate the stability and resilience of the Earth system have been transgressed – suggesting that Earth is now well outside of the safe operating space for humanity. In the face of these negative climate tipping points, we are now also seeing the shift to a low-carbon economy picking up speed. We are finally waking up to the challenges facing all our economies, and governments and businesses are doing more than ever to decarbonize and support a more sustainable kind of growth. However, we are still not moving fast enough. The key now will be getting a critical mass of leaders to drive their nations and industries towards critical positive tipping points in adoption of low-carbon solutions, in order to accelerate our transition. The Breakthrough Effect in ASEAN shows how governments and companies can do precisely this, and unlock tremendous opportunities as a result."

PAUL POLMAN
Board member at Systemiq and co-author of "Net Positive: how courageous companies thrive by giving more than they take"

"The original 'Breakthrough Effect' report painted a global picture focused on the technological developments which will be relevant across the world. But specific tipping points will differ by country or region as global technology trends interact with differences in local renewable resources, consumption patterns and local policy settings. Insights on likely tipping points are most actionable when understood at this country/regional specific level. The Breakthrough Effect in ASEAN explores when and where across the region tipping points of falling cost or growing demand will create investment opportunities, and sets out the actions that should be taken by governments and companies to accelerate the shift towards a net-zero economy."

ADAIR TURNER
Chair, Energy Transitions Commission

"The UN's Global Stocktake synthesis report, released in September 2023, shows that despite some progress since the Paris Agreement was forged in 2015, the world is still far off track from reducing emissions enough to keep temperature rise to safe levels. It has a big chance of overshooting 1.5 degrees mark. Indeed, in April 2022 the IPCC said, "it is almost inevitable that we will temporarily exceed this [1.5 °C] temperature threshold but could return to below it by the end of the century."

How policymakers, business leaders and others respond to the Global Stocktake findings at COP28 will help determine whether the world confronts the climate crisis or continues to fall victim to it.

The Breakthrough Effect in ASEAN is a great analytical reference to understand the most potential low-carbon solutions need to be activated in ASEAN region to help ASEAN policymakers, business leaders and others making right decisions and effective actions in achieving our global climate targets."

NIRATA 'KONI' SAMADHI
Country Director at World Resources Institute (WRI) Indonesia

"ASEAN is an important and one of the world's most climate-vulnerable regions that still heavily relies on fossil fuels. This is where key zero-emissions technologies deployment can help speed up the transition away from the highly emitting incumbents. To do so, however, it requires political decisions and commitment from governments to ensure that there are strong policies and regulations in place to support and accelerate the transition. Energy planners need to understand about these net-zero technologies so that they can be featured in respective long-term energy plans, leaving the highly emitting incumbents behind. "The Breakthrough Effect in ASEAN" report captures exactly what governments and the private sector could do to bring about "tipping points" in several key energy sub-sectors in the region."

FABBY TUMIWA
Executive Director of the Institute for Essential Services Reform

ENDORSEMENTS

Indika Energy is already actively actioning the targets set out at The Breakthrough Effect in ASEAN. At the heart of our ambitious transition vision – getting to net-zero by 2050 and generating at least 50% of our total business from non-coal streams – is to diversify our investments in net-zero solutions. We have diversified to three of the six priority sectors identified in the report namely electric two-wheelers (ALVA), electric buses (INVI), and the power sector through green energy investments. We see net-zero as the only future for us and The Breakthrough Effect in ASEAN has reinforced our commitment. I hope more will join us in tapping into this green growth opportunity, collectively bringing forward positive tipping points to accelerate the transition into a net-zero economy."

AZIS ARMAND
Vice President Director and Group CEO of PT Indika Energy Tbk.

"Electric two-wheelers are not just an opportunity to decarbonize, but also a huge growth opportunity for Indonesia and for the wider ASEAN region. Looking at The Breakthrough Effect in ASEAN framework, there is definitely a lot of room to improve in terms of hitting both affordability and attractiveness. Existing products are usually affordable but not very attractive, or the other way around. At MAKA Motors, our goal is to develop a product that is both affordable and attractive for Indonesian users. We take an R&D-first approach to ensure we have the best product at the right price. We hope more players in the industry across ASEAN will join us in seizing this huge growth opportunity as the Breakthrough Effect in ASEAN has clearly highlighted."

RADITYA WIBOWO
Founder and CEO of MAKA Motors

At Adaro, we are committed to support the Indonesian government's commitment to reduce greenhouse gas (GHG) emissions, including measures to achieve net-zero emissions (NZE) by 2060 or earlier. We aim to do by this by transforming into a bigger, greener Adaro by expanding into transition minerals and renewable power such as solar, wind and hydro.

The Breakthrough Effect in ASEAN complements our efforts by pinpointing, both for companies and governments, the opportunities for investments and barriers that must be removed so that change become irresistible and unstoppable for the region's green ecosystem. We look forward to collaborate with fellow partners in the system to action on the targets that has been set out, only together can we seize the green growth potential for ASEAN and for Indonesia."

DHARMA DJOJONEGORO
CEO at Adaro Power

Although ASEAN is one of the most climate-vulnerable regions in the world, it also has massive potential for green growth, industries, and jobs. "The Breakthrough Effect in ASEAN" offers concrete solutions to trigger socioeconomic tipping points that could unlock these opportunities in prioritized sectors most relevant to the region. Amazon is the world's largest corporate purchaser of renewable energy, and on a path to powering its global operations with 100% renewable energy by 2025. ASEAN economies can do much more to increase the availability and affordability of renewable energy—and massively scale opportunities for inbound corporate investments in this space in the process. The report identifies specific recommendations in this regard, including leveling the playing field for renewable power project developers, and enabling direct investments (via power purchase agreements) for corporate consumers. We hope ASEAN government leverage corporate consumer demand to boost the renewable energy sector, as this will also bring associated capital, green jobs, the proliferation of green technologies, and a tangible opportunity to meet national climate targets."

GENEVIEVE DING
Head of Sustainability Strategy Policy for APAC and Japan, co-author of the 2023 Green Economy Report

ENDORSEMENTS

"The Breakthrough Effect in ASEAN has immense potential to unlock tipping points in this region. This will help not only to drive decarbonization, but also allow countries in the region to secure their places as leaders in the zero-carbon transition. We know that we need to move from incremental change to systems change that takes off swiftly, and the Bezos Earth Fund is thrilled to support this work that will trigger those transitions."

KELLY LEVIN
Chief of Science, Data and Systems Change at the Bezos Earth Fund

"The Breakthrough Effect in ASEAN report demonstrates the importance of supporting disruptive technologies to solve climate challenges and the need for catalytic capital from philanthropy to help scale early-stage solutions. ASEAN can be a petri-dish for these solutions to grow at a global scale."

NG BOON HEONG
CEO of Temasek Foundation

"Understanding climate intersectionality is critical in strengthening climate action and in reimagining how climate funding is being mobilized. "The Breakthrough Effect in ASEAN" has conveyed this message very clearly, putting a spotlight on intersectionality across high-emitting sectors. It underscores how high-emitting sectors of the economy do not exist in isolation – they are highly inter-connected, and zero emission solutions in one sector can influence transitions in multiple sectors simultaneously.

As Asia's number 1 social investor network, AVPN have actively promoted this understanding through our Climate Pathfinders program. The program aims to help decision-makers of philanthropic organizations and other grant-making bodies to propel progress in critical areas to reshape the regional policy agenda and enable the more effective deployment of capital towards climate action. We look forward to leveraging "The Breakthrough Effect in ASEAN" insights to collectively galvanize public-private-philanthropic actions into the transition, mobilizing capital smarter and more strategically to accelerate the region's green growth."

TRISTAN ACE
Chief Product Officer of AVPN

ABOUT THE BREAKTHROUGH EFFECT IN ASEAN

"The Breakthrough Effect in ASEAN: How to Trigger a Cascade of Tipping Points to Accelerate ASEAN's Green Growth" report was produced by Systemiq and the Indonesia Chamber of Commerce and Industry's (KADIN) Net Zero Hub, supported by the Bezos Earth Fund.

This report is a regional follow up of the global Breakthrough Effect report that shows how parts of the global economy could move rapidly toward zero emissions, with far-reaching effects across 10 of the highest-emitting sectors, by identifying positive socioeconomic tipping points in zero-carbon solutions for specific sectors. It identifies two super-leverage points, specific policies or actions, that could accelerate the region's green growth by triggering a cascade of tipping points across a total of eight sectors that represent 50% of ASEAN's emissions.

The team that developed this report are Abindra Soemali, Nicholas Omar, Widharmika Agung, Mark Meldrum, Daniel Kurniawan and Mossele Ambarita with significant input and expertise from Octavianus Bramantya (KADIN Net Zero Hub), Lloyd Pinnell, Leonardo Buizza, Jason Martins, Philip Lake, Carolien van Marwijk Kooy, Achim Teuber, and Tilmann Vahle (Systemiq).

We are deeply grateful to many individuals who have generously contributed their time and expertise to interviews to develop this report including Dharma Djojonegoro (Adaro Power), Shihab Ansari Azhar (International Finance Corporation), Kartik Gopal (International Finance Corporation), Yoga Adiwinarto (Desmobi), Ryosuke Fujioka (ASEAN-Japan Economic and Industrial Cooperation Committee), Fabby Tumiwa (Institute for Essential Services Reform), Deon Arinaldo (Institute for Essential Services Reform), Raditya Wibowo (MAKA Motors), Clorinda Wibowo (World Resources Institute Indonesia), Rezky Khairun Zain (World Resources Institute Indonesia), I Made Vikannanda (World Resources Institute Indonesia), Yudithia (Adidas), Sheila Shek (Adidas), Anya Sapphira (H&M), Saraswati Hapsari (H&M), Siripha Junlakarn (Energy Research Institute), Priscilia (Meratus), Brigita Darminto (University of Oxford), Jephraim Manansala (Institute for Climate and Sustainable Cities), Golda Hilario (Institute for Climate and Sustainable Cities), Baskara Rosadi Van Roo (Electrum), and Zulfikar Yurnaidi (ASEAN Centre for Energy).

Contributors and their organizations do not necessarily endorse all findings or recommendations of the report.

ABOUT SYSTEMIQ

Systemiq, the system-change company, was founded in 2016 to accelerate the achievement of the Sustainable Development Goals and the Paris Agreement, by transforming markets and business models in five key systems: nature and food, materials and circularity, energy, urban areas, and sustainable finance. A certified B Corp, Systemiq combines strategic advisory with high-impact, on-the-ground work, and partners with business, finance, policymakers and civil society to deliver system change. Systemiq has offices in Brazil, France, Germany, Indonesia, the Netherlands, and the UK.

ABOUT KADIN NET ZERO HUB

Indonesia Chamber of Commerce and Industry (KADIN) commits to the net-zero movement. In addition to declaring its own pledge as a Net Zero Organization, KADIN also started an initiative that is now known as KADIN Net Zero Hub to act as a bridge between the global movement and Indonesian companies. KADIN acknowledges that there is a lot of information to be taken in by companies intending to join the global net-zero movement, and this is the reason why KADIN Net Zero Hub was established.

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EXECUTIVE SUMMARY

CONTEXT

2023 is already on track to be the hottest year on record.[1] Across the world, we have seen an increase in climate-related disasters from wildfires in Canada to floods in China. For ASEAN, the impacts of climate change are especially relevant as the region is one of the most climate-vulnerable in the world. Myanmar, the Philippines, Thailand, and Vietnam are already among the 10 countries in the world that have suffered the most in human and material terms from climate-related weather events over the past 20 years.[2]

In the face of these climate damages, we are now seeing the transition to a low-carbon economy picking up speed. Positive socio-economic tipping points for climate solutions are increasing at a rapid pace—offering an opportunity to rapidly increase the deployment of zero-emission solutions, drastically cut emissions, decouple economies from volatile fossil fuels, and create green industries and jobs in the process. What is clear from these trends is that for ASEAN to unlock its green growth potential, acting on climate will not "just" be an economic cost but rather it is an opportunity to unlock new and better forms of growth. To unlock green growth, one of the biggest points of leverage is to focus on triggering positive socio-economic tipping points.

Socio-economic tipping points arise when a set of conditions are met, allowing new low-carbon technologies or practices to out-compete incumbent, carbon-intensive solutions. After a tipping point is crossed the new solutions start to become adopted at mass market scale, this adoption only drives further improvements, and the incumbent solutions are left behind.

Socio-economic tipping points are not new; this is how markets work. Multiple historical examples of rapid technological transitions demonstrate that new solutions can take over a market in just a few years. In several cases, a rapid increase in deployment took place after some threshold of relative affordability was passed (e.g., India's subsidies that makes electric buses more affordable). The switch is also often supported by the new solution being more attractive to customers for non-cost reasons (e.g., electric two-wheelers (E2Ws) in China have better ranges, which enhances market attractiveness) or if accessibility is widespread (e.g., telecommunications infrastructure build-out in Indonesia, which enabled high smartphone penetration rate).[3]

LOW-CARBON TECHNOLOGIES ARE IMPROVING EVERY YEAR—DECLINING IN COST AND IMPROVING IN PERFORMANCE. THE OPPORTUNITY NOW IS FOR ASEAN TO HARNESS AND SUPPORT THESE TECHNOLOGIES TO TRIGGER TIPPING POINTS IN THE REGION.

In 2021, solar and wind were already the cheapest sources of new power in 90% of countries and accounted for >75% of all new capacity additions globally.[4] Battery electric vehicles jumped from less than 5% of the car market in 2020 to a 14% share in 2022, as electric vehicles already hold cheaper lifetime costs than diesel/petrol and will even be cheaper to produce by 2025. The question becomes: what opportunities exist in ASEAN to harness new technologies, to create tipping points in the region? This report seeks to identify a possible first wave of tipping points for the ASEAN region, it highlights these tipping points as targets to shoot for and profiles precisely the conditions and levers to reach them. With this framework and insight, the report aims to galvanize governments, corporates, and investors to pull the levers needed to trigger tipping points and unlock green growth.

[1] Bloomberg (2023), "This Year Is Already on Track to Be the Hottest Ever Recorded."
[2] Germanwatch (2018), Global Climate Risk Index 2019.
[3] See Figure 1 & 2 in Section 1.
[4] BloombergNEF (2022), Energy Transition Factbook 2022.

SECTOR TIPPING POINTS

In ASEAN, low-carbon solutions in the power and road transportation sectors are reaching cost parity with high-emitting incumbents; supporting these technologies could trigger tipping points.

Just like the rest of the world, ASEAN is experiencing declining technology costs in many low-carbon solutions. However, the competitiveness of these solutions in any given country or region is heavily influenced by local policies and market conditions. The main point is clear: there is a growing economic incentive to shift away from high-emission practices which are also becoming higher-cost practices.

In ASEAN's power sector, cost parity has been reached for some of the tipping points.[5] For example, the levelized cost of electricity (LCOE) of new-build solar is already cheaper than the LCOE of new coal/gas power plant in several countries—namely Vietnam, Thailand, Malaysia, and the Philippines—and could already be cheaper in the remaining countries—i.e., Cambodia, Myanmar, Laos, and Indonesia—if the right conditions are put in place. This difference between countries largely stems from higher market uncertainty in some countries due to weaker enabling policy environment. To better analyze and understand the current state and progress of each ASEAN country's power sector, it is useful to categorize the countries into two groups[6]: 1) stronger enabling policy environment, and 2) weaker enabling policy environment.

To bring forward the tipping point and unlock S-curve adoption of solar and solar + storage in the second group, changes to the enabling policy environment are needed. These changes do not always constitute direct financial support to early projects to prime the market, there are also important non-cost measures such as: 1) streamlining new renewables procurement via standardized competitive auctions and streamlined permitting, 2) supporting site development and land acquisition for solar projects, and 3) updating market rules to properly consider and support solar and solar + storage generation assets.

In ASEAN's road transport sector, E2Ws have already reached parity to their internal combustion engine (ICE) counterpart on total cost of ownership (TCO) basis. However, E2Ws adoption status in ASEAN is nascent, E2Ws only captured ~2% of the market in 2021.[7] This is due to, in large part, the higher sticker price than ICE vehicles, accessibility concerns (i.e., charging infrastructure, whether public plug-in chargers or battery swap stations), and attractiveness aspects (i.e., branding and quality assurance, and low-cost financing options, especially for the retail market). That said, companies—startups and regional firms, global E2W original equipment manufacturers (OEMs), and ICE two-wheeler (2W) incumbents—have recently started to enter the market, especially in Indonesia, Vietnam, and Thailand which represent 90% of the ASEAN 2W fleet today.

Fleets, such as ride-hailing, food delivery, and logistics, are expected to become the first movers for the early market adoption due to their competitive advantage of procuring E2Ws. High-end retail market is expected to follow suit once there is more brand awareness and quality assurance in E2W products. As most ASEAN countries have an ambitious 100% 2W electrification target in 2035/2040, more fiscal support from the government (e.g., purchase or OEM subsidies) are expected to lower sticker price to price parity with ICE 2W—an increase in manufacturing investments in the region can also push down the sticker price of E2Ws as it can typically enjoy various tax incentives, including being exempt from import tax. The availability of better financing rates and options due to increased lender confidence (lower perceived risk) in the product will also accelerate the electrification of the mass retail E2W market in ASEAN.

Electric buses are also set to become cheaper than conventional diesel buses on a TCO basis in a few years, driven by further decline in battery cost and improved financing. Two main challenges with e-bus adoption are currently the high upfront cost capital requirement and the relatively young existing diesel bus fleets, making it difficult to fully convert the fleet rapidly. However, the existence of innovative business model/financing, which separates asset ownership (e.g., lease-and-operate model), can help operators alleviate the high upfront cost requirement. Imposing a mandate for e-buses that starts small and scales can also be important to encourage operators into first deployments to familiarize with the technology and prepare for mass adoption as the tipping point is reached.

In the other sectors assessed in this report, such as industrial heat and shipping, low-carbon technology solutions are more nascent though advancing quickly. To advance the solutions in these sectors given their current stage, the focus at present should be on supporting first commercial deployments.

In ASEAN's industrial heat sector, the adoption of low-carbon direct electrification solutions is still in its infancy. Low-temperature heat (<150 °C) can use

[5] There are four tipping points for solar and solar + storage in the power sector. This will be explained and discussed in the following sectoral deep dive of the power sector (page 37-42).
[6] The grouping also considers solar deployment status (by the end of 2022) as a proxy of market maturity, VRE planning in each country's power development plan, as well as Regulatory Indicators for Sustainable Energy (RISE) score by the World Bank (adapted from ADB et al. (2023), Renewable Energy Manufacturing: Opportunities for Southeast Asia).
[7] McKinsey & Company (2023). The real global EV buzz comes on two wheels.

industrial heat pumps and this solution could reach a competitive levelized cost of heat (LCOH) with gas or coal shortly, in select countries. A full 1:1 replacement of fossil-fueled steam boiler is technically feasible and may be economically viable, although it largely depends on the specific industrial process heat application and its heating temperature needs (e.g., high-pressure steam for sterilization in the food industry is a good use-case). In certain contexts, heat pumps can also become an attractive energy-efficiency measure for interim decarbonization.

Medium-to-high temperature heat (150–600 °C), using electric thermal energy storage (ETES), is in early stages of commercialization though commercial deployments are beginning. ETES, also known as "heat battery", can directly connect to off-grid renewables; where such electricity supply is available these solutions can already be competitive. The economics are further improved when the solution is designed to deliver combined heat and power.

In the shipping sector, alternative liquid fuels will be required for deep-sea long-haul shipping, as opposed to electrification via electric engines with battery or hydrogen fuel cells for short-haul shipping. While a range of options exist, green ammonia and green methanol are expected to play the largest role. Given the additional supply constraint that green methanol production has of needing to source sustainable CO_2, green ammonia was selected as the fuel of focus in this study.

For green ammonia for shipping, ASEAN's contribution to production is expected to be limited. This limitation arises from the region's relatively modest renewable energy resources, making it less competitive for cost-effective green hydrogen production compared to places like Australia, which has lower-cost solar power generation. Instead of production, ASEAN is positioned to play a strategic role as a beneficiary of green shipping corridors. Essentially, it serves as a facilitator for the use of green ammonia as a fuel for shipping. This is because ASEAN is strategically located at the crossroads of major shipping routes, responsible for at least 10% of global shipping volume. Singapore, in particular, will play a significant role in this context, as it currently accounts for over 20% of global bunkering demand. Additionally, the existing ammonia infrastructure in ASEAN's ports underscore the region's importance in supporting the global shipping sector's efforts to decarbonize.

Nickel processing will be important in the value chain for the energy transition. Low-carbon technologies, especially batteries that use Cathode Active Material (CAM) technology, need Grade I nickel. Two countries in ASEAN, Indonesia and the Philippines are key producers of nickel, with existing production accounting for ~10% of nickel mining globally and ~22% of global nickel reserves. In the region, ~US $50bn has been invested in the nickel value chain over the past five years.

The increase in nickel demand must be met with low-carbon nickel processing methods that utilize renewable electricity and electrified heat. Using projected nickel production routes, mandating renewables use in nickel-related industrial parks can create ~1.7–2.8 GW demand for low-carbon solutions for power, depending on scenario.

Currently, both low-carbon solutions still encounter barriers of mass-market adoption. This could be navigated with innovative business models for variable renewable energy (VRE), such as leasing methods with minimum capital expenses. With the right timing, the ASEAN region can further unlock enabling conditions for power and medium-to-high industrial heat, creating a cascading effect into the low-carbon solution ecosystem.

TIPPING CASCADES

The Breakthrough Effect in ASEAN has pinpointed two super-leverage points, capable of triggering a cascade of tipping points in eight sectors, representing 50% of ASEAN's emissions.

A leverage point is where a small intervention can cause a large effect. The "super-leverage points" identified in the report not only cut emissions in one key sector, but also support faster changes in other parts of the economy.

High-emitting sectors of the economy do not exist in isolation from each other—they are highly inter-connected, and low-carbon solutions can influence transitions in multiple sectors simultaneously. For example, the demand for electric vehicles is driving demand for lithium-ion batteries, which is bringing them down in cost. Lower-cost batteries help the power sector to decarbonize by lowering the cost of solar/wind + storage solutions.

Links between sectors suggest that focused effort on crossing a tipping point in one sector could increase the chances of triggering tipping points in other sectors, producing "tipping cascades." This report also introduces the concept of "super-leverage points," which are specific policies or actions with relatively low cost, and potential to trigger a tipping point in one sector that itself can support tipping points in other sectors.

Two such "super-leverage points" were identified for the ASEAN region:

1. **Zero-emission vehicles mandate for two-wheelers and buses:** This policy can accelerate the transition to electric vehicles, particularly in the road transport sector, creating demand for batteries, positively affecting the power sector and heavy-road transport.

2. **Renewable energy mandate in nickel processing industrial parks:** Shifting to low-carbon heat and power sources in nickel production can lead to cascading effects in the broader power sector and industrial heat for other sectors.

This report has laid out key sectoral tipping points that can unlock ASEAN's green growth. It has precisely outlined the conditions and levers to reach them, creating a framework for stakeholders to work together to realize them. Given the region's unique position both in terms of its vulnerability and its strategic role in global decarbonization, we believe ASEAN can play a leading and thriving role as it builds its green industrial economy—bringing economic, health, and environmental benefits simultaneously.

THE CHOICES MADE BY ASEAN COUNTRIES IN THE NEXT DECADE WILL DECIDE IF THE REGION CAN TAP INTO ITS GREEN GROWTH OPPORTUNITY.

KEY ACTIONS

Specific action points were identified for both the public and private sector across prioritized sectoral tipping points which constitute 39% of ASEAN's total greenhouse gas (GHG) emissions (see Figure ES-1). These actions range from policy and regulatory support to market interventions that can influence economic behavior, market dynamics, and industry practices for low-carbon solutions.

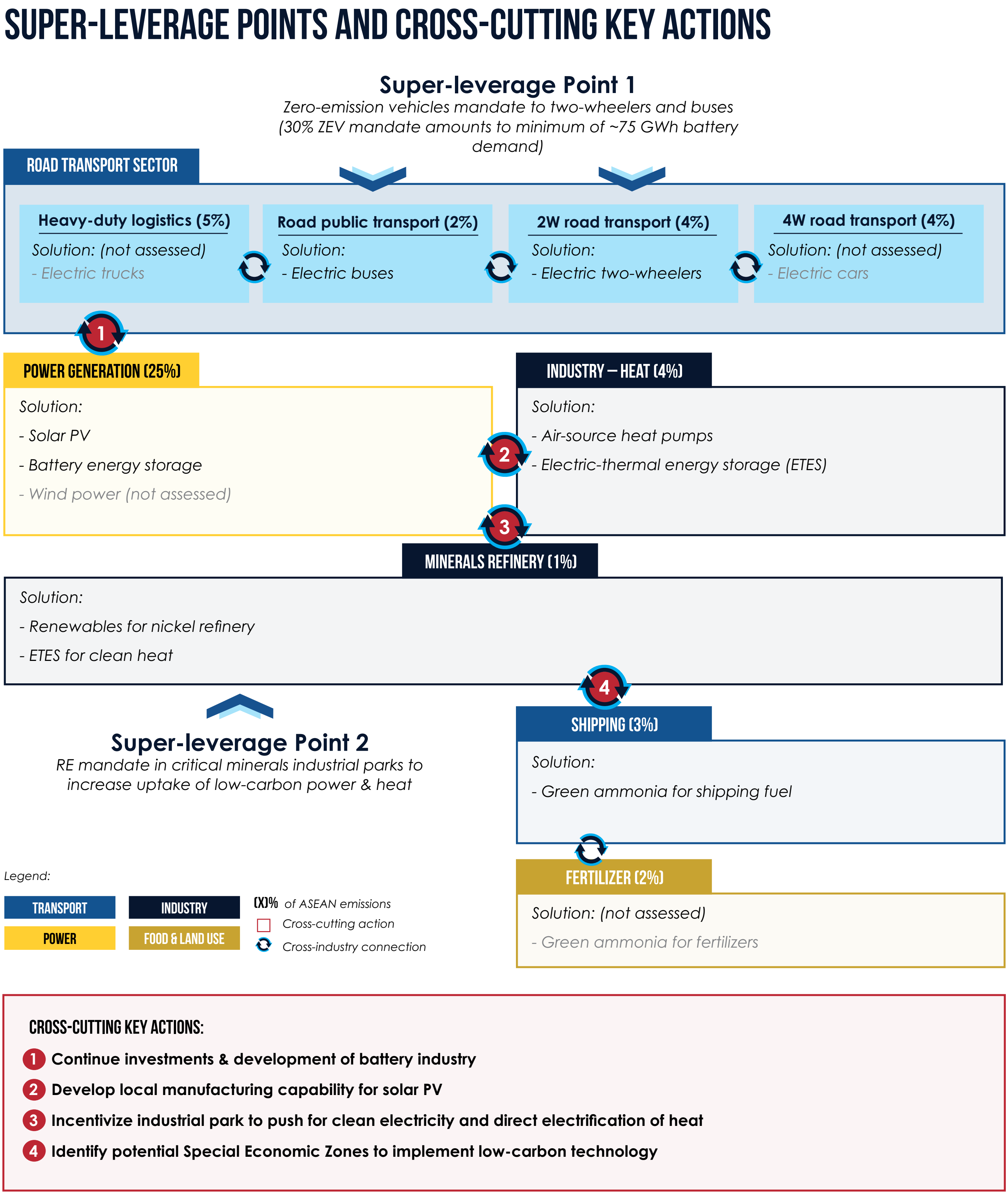
Figure ES-1a. Summary of six priority sectors in ASEAN and key actions to bring forward tipping points in ASEAN

Sector, Emissions [$MtCO_2e$] (%ASEAN)	Low-carbon solutions	Tipping point enabling condition[1]: Affordability	Tipping point enabling condition[1]: Attractiveness	Tipping point enabling condition[1]: Accessibility	Key actions
Power[2] 675 (25%)	Solar (VRE) + Battery energy storage	GROUP 1: Green	GROUP 1: Amber	GROUP 1: Amber	**Government:** Create enabling policy and regulatory environment to enable accelerated uptake of variable renewable energy. Specific key actions include: 1) setting an ambitious VRE deployment target (toward achieving net-zero) and streamlining national coal phase-out, 2) improving market rules/design by removing barriers (e.g., navigating overcapacity) and providing support to VRE deployment, 3) investing in the grid infrastructure to increase grid reliability, and 4) enabling power wheeling to increase the accessibility of renewable energy for captive markets. **Private sector:** Continue investing in local solar PV and battery manufacturing to secure local supply chains and push down local prices; and develop market coalitions for products using low-carbon electricity.
		GROUP 2: Amber	GROUP 2: Red	GROUP 2: Red	
Two-wheelers 100 (4%)	Electric two-wheelers	Amber	Amber	Red	**Government:** Deploy targeted subsidies to support research and development and manufacturing for OEMs to tip sticker price competitiveness. **Private sector**: Provide low-cost financing for electric two-wheelers and continue investing in battery and E2W manufacturing.
Buses 70 (2%)	Electric buses	Amber	Amber	Red	**Government:** Create regulatory framework to enable innovative business models (e.g., lease and operate, Mobility-as-a-Service model); and deploy targeted subsidies to support research and development and manufacturing for OEMs to tip sticker price competitiveness. **Private sector:** Explore innovative financing for e-buses, such as the carbon financing scheme in Thailand with Switzerland under Article 6.2 of the Paris Agreement (see Section 3 on electric bus for more details).
Industrial heat 105 (4%)	Heat pumps	Amber	Amber	Amber	**Government:** Provide regulatory and financing support for direct electrification of heat. Specific key actions include: 1) providing incentives (e.g., preferential tariff for clean heat, grants, incentives) to clean heating or provide disincentives to the incumbent solution (e.g., carbon tax to incumbent fuels), 2) increasing energy efficiency/air quality/emissions standards in the industrial sector, 3) setting a mandate for industrial parks for the electrification of heat; and 4) specific to ETES, streamline permitting for captive power, including enabling power wheeling for off-site VRE generation. **Private sector:** Advance technology introduction of air-source industrial heat pumps and ETES; provide low-cost financing support for direct electrification (e.g., by principal off-takers); and develop market coalitions for products using low-carbon heat.
	Electric-thermal energy storage (ETES)	Red	Amber	Amber	
Shipping 65 (3%)	Green ammonia for shipping fuel	Red	Amber	Red	**Government:** Impose stricter environmental regulations and carbon taxation to international ports to incentivize and accelerate the shift to low-carbon shipping; start identifying potential Special Economic Zones to develop green corridors in the region. **Private sector:** Develop market coalitions for products using low-carbon shipping.
Minerals refinery 30 (1%)	VRE + storage and ETES	Red	Amber	Red	**Government:** Impose mandate to use clean electricity and heat for critical minerals refinery. **Private sector:** Identify potential sites to implement low-carbon technology.

Affordability · Attractiveness · Accessibility

Source: Systemiq analysis. Notes: [1] Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date. Please see Section 3 for further details on the assessment. [2] Analysis on the power sector was divided into two groups: countries with stronger (G1) and weaker enabling policy environment (G2) (see Section 3 for more details).

Figure ES-1b. Identified super-leverage points and cross-cutting key actions to trigger tipping cascades across sectors



SECTION 1

HOW TIPPING POINTS WORK

Positive socio-economic tipping points can occur where new solutions cross a threshold in affordability, attractiveness, or accessibility compared to incumbent solutions.

Progress toward tipping points is often driven by reinforcing feedback loops in the development and diffusion of new solutions, where increases in production lead to higher performance and lower cost, which in turn lead to greater adoption and even more production. The reinforcing feedback loops can be driven by different effects, for example, learning by doing effects, economies of scale, the emergence of complementary technologies, and the spread of new social norms (see Box 1).

Once a tipping point is reached, these reinforcing feedbacks become more powerful than the balancing feedbacks (such as opposition from incumbents) that have been resisting change. Consumers, producers, and investors shift decisively toward the new technology, and do not look back. The transition acquires a self-accelerating momentum. When close to being reached, tipping points can be triggered by small interventions that alter the balance of competition between new technologies and incumbents.[8]

[8] T. M. Lenton (2020), "Tipping positive change," *Philosophical Transactions of the Royal Society B: Biological Sciences.*

HISTORICAL AND RECENT EXAMPLES

Socio-economic tipping points are not new; this is how markets work.

History is rife with examples of rapid transitions that prove new solutions can scale up from niche applications to virtually total adoption within a market in just 1–2 decades.[9] Complex commonplace manufactured goods, such as cars, refrigerators, and microwaves, have done so in this timeframe and even in the case of major infrastructure or energy systems, similar patterns have been seen. In other cases, the transition to new solutions played out over longer periods, highlighting the need for concerted action to accelerate the pace of change for zero emission solutions to scale in time to meet our global climate goals.

For many new solutions, there is evidence that rapid increase in deployment took place after some threshold of relative affordability was passed, often supported by improved availability or attractiveness. See Figure 1 and 2 below for US and UK data on the adoption curves for a sample of infrastructure and energy systems and manufactured goods—supporting explanations are provided in the global Breakthrough Effect report.

Large-scale industrial and economic transitions often start with a disruptive technological innovation.

New types of solutions initially find a use in a niche market, where they offer an important improvement relative to the existing solution. After reaching a tipping point, these can break into mass market adoption and expand to other markets, radically reshaping the economy in the process. For example, the invention and refinement of the steam engine triggered a massive expansion of coal mining and the creation of a rail transport network in England. This helped propel the industrial revolution.[10] A similar phenomenon could be underway with the advent of low-cost renewables. These may bring forward a new era of electrification across the economy as more and more sectors reach their respective tipping points thanks to cheaper and more accessible zero-carbon power.

[9] See Box 2 for stages of technology adoptions.
[10] A. Smith et al. (2005), "The governance of sustainable socio-technical transitions," *Research Policy*.

Figure 1. The historical adoption of a sample of infrastructure and energy systems

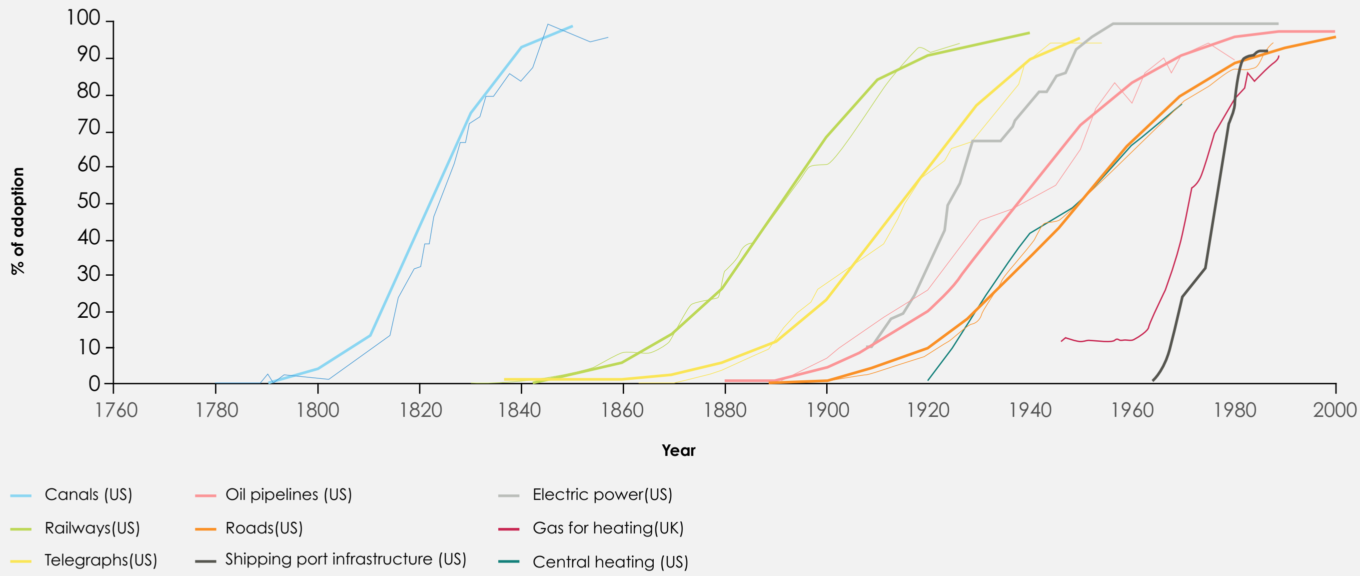
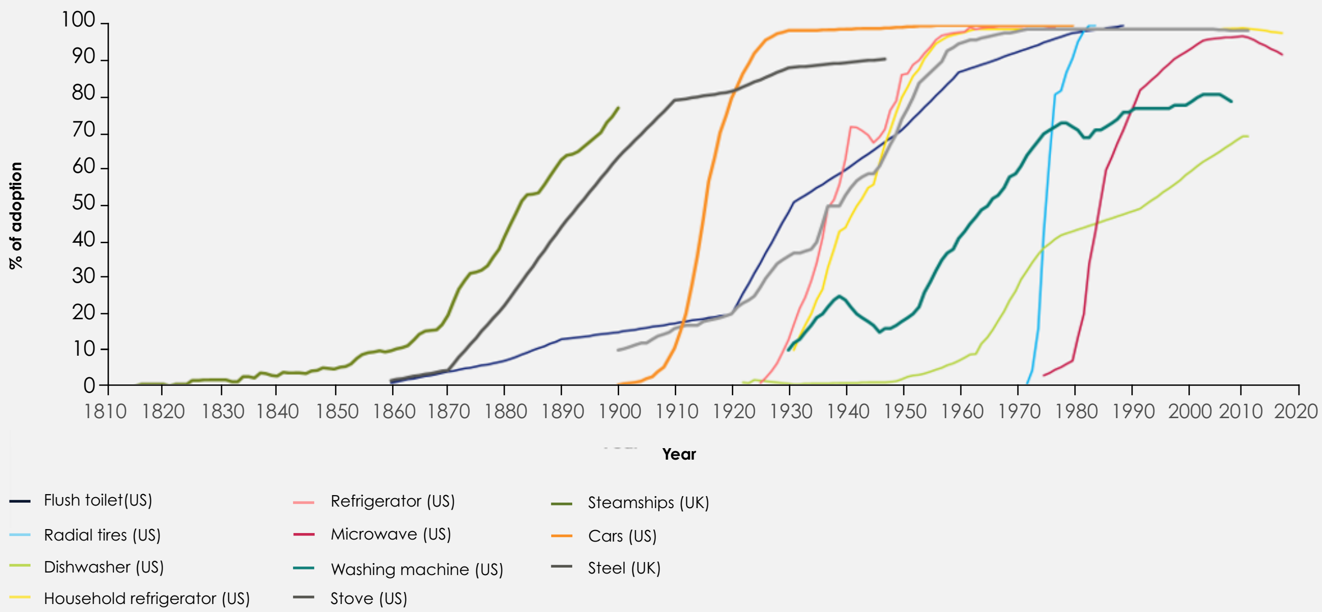


Figure 2. The historical adoption of a sample of manufactured goods



BOX 1. REINFORCING FEEDBACK LOOPS

Tipping points depend on the feedback loops that determine the behavior of all dynamic systems, including sectors of the economy. A reinforcing feedback loop occurs when an increase in a variable leads to a further increase in the same variable. For example, greater deployment of a technology leads to lower costs, and lower costs lead to greater deployment. This dynamic can drive exponential growth in adoption of the new technology. A balancing feedback occurs when an increase in a variable leads to a decrease in the same variable. For example, policy to encourage the deployment of new solutions can result in a backlash from incumbents, leading to weaker policy.

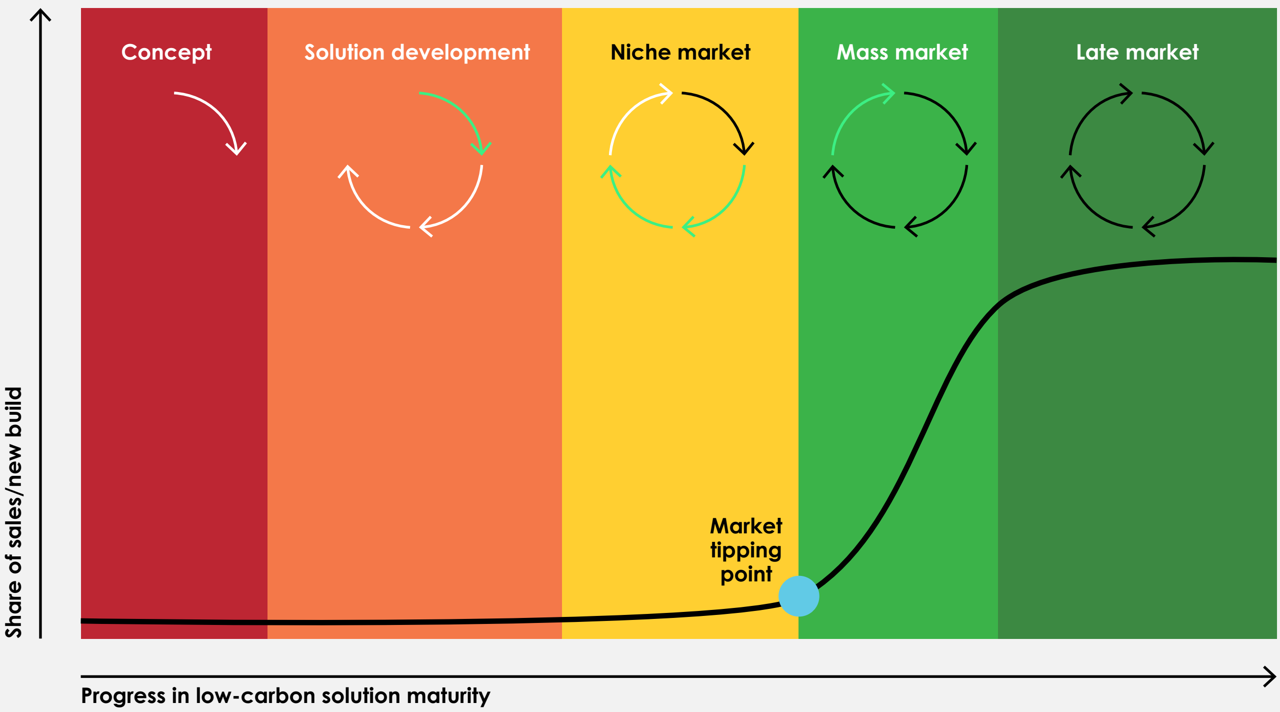
The interaction of these two kinds of feedback loops creates the typical S-curve shape of a technology transition. Early in the transition, reinforcing feedbacks can drive the development of new technologies but at the same time, balancing feedbacks dominate the behavior of the sector as incumbent technologies and business models are resilient against attempts to disrupt them.

At the tipping point, reinforcing feedbacks overcome balancing feedbacks, driving exponential growth in adoption of the new solution, and decline in use of the old. Beyond this point, the transition is likely to be irreversible, and can stay on course despite short-term volatility (e.g., supply chain bottlenecks), although its pace can still be influenced by many factors.

There are several distinct types of reinforcing feedback loops. They will often exist simultaneously. The most important types include:

- **Learning by doing:** Where the deployment of a technology leads to greater innovation that improves the product and lowers costs as production is optimized, this increases the net benefits and encourages further deployment.
- **Economies of scale:** Where increased scale of production spreads fixed costs across greater volumes, and leads to more effective division of labor, this lowers unit-costs of production and in turn encourages increased rate of adoption.
- **Technological reinforcement:** Where the more something is used, the more additional technologies or practices emerge that make it more useful.
- **Network and coordination effects:** Where the more economic agents take a similar action, the greater the advantages to others of doing the same.
- **Self-reinforcing expectations:** Where expectations on future market size trigger investments that grow the market, therefore meeting/exceeding expectations and triggering further investment.
- **Contagion of social norms:** Where new solutions can spread rapidly through social communication after crossing into early majority adoption (also referred to as Rogers' Diffusion Innovation Theory).

BOX 2. FIVE STAGES OF TECHNOLOGY ADOPTION TOWARD MARKET MATURITY



Five stages of technology adoption toward market maturity

1. **Concept:** Early-stage innovation drives the development of new solutions. This stage requires trial periods to explore different possibilities before a viable option is identified, where publicly funded research and development programs complement private sector experimentation.

2. **Solution development***: Solutions are being piloted at demonstration scale to show proof of concept, often through public-private partnerships. This stage requires strong public financial support to de-risk investment in first-of-a-kind (FOAK) commercial projects (e.g., via concessional loans and grants, early market support, etc.).

3. **Niche market***: The solution is taken up by early adopters, connecting supply and demand to provide initial scale. This stage requires establishing and growing the consumer base and improving solution competitiveness; buyer coalitions and blended/green finance are crucial to increase deployment.

4. **Mass market***: The solution reaches early majority adoption as it outcompetes the incumbent (start of the steep part of the S-curve). Demonstration of profit generation drives broader market participation, supported by expanded access to capital as financing is reallocated from old to new solutions. This stage requires re-designing markets in favor of the new solutions through new regulatory frameworks and schemes to initiate the phase-out of the incumbent solution.

5. **Late market**: The solution reaches large-scale adoption. At this stage the focus shifts to institutionalization, such as setting and enforcing new standards and managing the implications of declining industries.

*For the sectoral analysis, **only stages 2 to 4** will be considered as we are looking at solution adoption prior to the tipping point.

TIPPING POINTS CAN BE TRIGGERED THROUGH ADDRESSING THREE KEY ASPECTS: AFFORDABILITY, ATTRACTIVENESS, AND ACCESSIBILITY

AFFORDABILITY

A critical variable in relation to tipping points is cost-competitiveness, which depends crucially on scale.

As new technologies or practices emerge, they often follow sharp cost declines as their production increases. This phenomenon, referred to as "Wright's Law", predicts that costs fall as a function of cumulative production, driven by the reinforcing feedbacks of learning by doing and economies of scale. The net result is that less time and resource is needed for each subsequent unit of production.

Further, as the new solutions approach cost parity with incumbent alternatives, incentives emerge to reallocate finance from the assets of the old system to those of the new. This can increase the cost of capital for the old system and accelerate the shift from old to new.

Targeted government policies can accelerate cost declines of technologies. For example, the Indian government subsidy program to OEMs to incentivize the purchase of electric and hybrid vehicles was proven to accelerate the adoption of the technology. As a result, electric bus sales saw a 308% increase in 2019 followed by a 250% increase the year after. This scale growth drives declines in unit cost.

Additionally, the speed of cost declines depends crucially on the characteristics of the solution in question. The technologies that display the sharpest cost reductions as output increases tend to be those that are small in size and easily replicable. As these are less complex to manufacture and have shorter lifetimes, they typically see faster learning rates and knowledge diffusion with increased production. Companies have greater opportunity to improve production processes that are continuously repeated.[11]

ATTRACTIVENESS

Apart from costs, non-cost benefits or improved performance relative to the existing solution is typically also necessary.

New solutions often need to possess certain attributes that set them apart from incumbents across dimensions other than cost, such as higher quality or reliability, or new capabilities. In the early stages of deployment, this can be crucial for allowing new solutions to gain a foothold in the market. Niche market segments that place priority on these attributes may adopt the solution despite cost disadvantages present in the early stages. For example, early buyers of electric vehicles were in large part attracted by the novelty value and green credentials these offered and were willing to accept the substantial price premium relative to conventional cars.[12] This is evident in China where electric two-wheelers gained an initial foothold with the benefit of lower air pollution, soon reached a tipping point, then phased out internal combustion engine two-wheelers within two decades and reached market saturation by 2016.

The emergence of new laws and regulations can also have a major influence on the attractiveness of new solutions. For example, emission trading systems (ETS) have been scientifically proven to have a positive correlation toward renewable energy uptake.[13]

Broader socio-economic and cultural shifts can also cause certain products to gain relevance and appeal. For example, cultural shift toward digital convenience and mobile-first lifestyles has led to the widespread adoption of e-commerce in Southeast Asia, with adoption nearing full adoption in both urban and suburban consumers.[14]

[11] C. Wilson et al. (2020), "Granular Technologies to Accelerate Decarbonization," *Science*.
[12] Bain & Company (2019), Tipping Points: When to Bet on New Technologies.
[13] M. Yu et al. (2017), "Impact of Emissions Trading System on Renewable Energy Output," *Procedia Computer Science*.
[14] Google, Temasek, and Bain & Company, (2022), e-Conomy SEA (Southeast Asia) 2022

ACCESSIBILITY

Many types of new solutions require supporting infrastructure to be in place before large-scale adoption can take off.

For technologies that enable multiple downstream uses, developing the required supporting infrastructure opens the pathway to large-scale application, shifting the system into a new era. Building out renewable energy generation, and transmission and distribution networks, for example, is key to enabling electrification of multiple energy consuming sectors in transport, industry, and buildings. Indonesia's telecommunications infrastructure build-out has resulted in ~80% smartphone penetration rate in 2023 and is estimated to reach 91% by 2028, enabling online services like ride-hailing and e-commerce to be widely adopted in the region.[15]

Figure 3. Tipping point framework

	AFFORDABILITY	ATTRACTIVENESS	ACCESSIBILITY
Definition	Critical variable in relation to tipping points is **cost-competitiveness** of low-carbon solutions, which depends crucially on scale.	**Non-cost/financial benefits or improved performance** from low-carbon solution relative to the existing solution in place.	Many types of low-carbon solutions require **supporting infrastructure** to be in place before adoption at large-scale.
Drivers	• Technology cost (both upfront or TCO) • Supportive subsidy (in early market) • Switching cost or complexity	• Reliability of technology • Push from market or consumers • Behavorial change in industry • Product-market fit	• Infrastructure availability • Technology availability in the region
Examples	India's FAME Initiative, has increased affordability to electric buses, leading to improved TCO of e-buses through subsidies for authorized OEMs.	Early buyers of electric two-wheelers (E2W) in China were driven by product-market fit in terms of vehicle range, and E2Ws phased out internal combustion by 2016.	Telecommunications infrastructure build-out in Indonesia enabled online services like ride-hailing and e-commerce to be widely adopted in the region.

[15] Smartphone penetration rate in Indonesia from 2019 to 2021 with forecasts until 2028; Statista (2023).

BREAKTHROUGH TECHNOLOGIES

The reinforcing feedback effects described above are driving rapid cost reductions in several technologies that are core to the low-carbon transition. The cost of solar and wind has plummeted over the last 10 years, largely due to learning-by-doing and economies-of-scale effects made possible by market-creating policies and the replicable nature of these technologies. As prices have fallen, demand for renewables has increased, attracting more firms to enter the market and compete to drive costs even lower. The same phenomenon is underway for other modular technologies that leverage and enable low-cost renewable energy, including, most importantly, batteries and hydrogen electrolyzers.

Most projections have systematically underestimated the rate of cost reductions for these technologies, due primarily to an underappreciation of strength of the reinforcing feedbacks. For example, the average projected annual cost reduction for solar PV from 2010–2020 was 2.6% (with a maximum of 6%), whereas realized figures over this period were in fact 15% per year.[16] Short-term factors such as supply chain bottlenecks can disrupt this trend, as seen with wind power from 2012–2014, but this provides a strong incentive for businesses to find solutions to these challenges and resume cost reductions. Some experts argue that most cost projections today continue to underestimate the potential cost reduction in future years relative to historical trends.[17]

Solar and wind: These have now become the **cheapest source of new bulk power** in countries representing 90% of electricity generation.[18] If current trends continue, solar is set to become the cheapest form of power generation almost everywhere in the world within the next five years even when energy storage costs are added.[19]

Batteries: The cost of lithium-ion battery cells declined by 97% in the last three decades, with **costs halving in just four years** from 2014–2018.[20] Their cost is highly likely to continue to fall substantially as rising electric vehicle demand drives production at greater scale, with 150 giga-factories in operation globally today compared to just one five years ago.[21]

Electrolyzers: The cost of electrolyzers—the technology core to producing green hydrogen—has fallen by 50% in the last 10 years. We are now seeing a rapid acceleration in deployment plans across the world, with **installed capacity increasing by ~80% in 2021**, and 680 large-scale hydrogen project proposals now in place.[22] The cost to produce green hydrogen is expected to fall 50–60% by 2030, meaning that achieving $2/kg without subsidy is feasible within the next five years.[23]

16 Average refers to 2,905 past projections by integrated assessment models for the annual rate at which solar PV system investment costs would fall between 2010 and 2020. Way, R. et al. (2022), Empirically Grounded Technology Forecasts and the Energy Transition, *Joule*.

17 Current projections refer to selection of optimistic scenarios from integrated assessment models (IAMs) and IEA studies. Ibid.

18 BloombergNEF, (2022), Global LCOE Benchmarks 1H 2022.

19 F. Nijsse et al. (2022), "Is a Solar Future Inevitable?," University of Exeter - *Global Systems Institute Working Paper Series*.

20 M. S. Ziegler and J. E. Trancik (2021), "Re-examining rates of lithium-ion battery technology improvement and cost decline," *Energy & Environmental Science*.

21 Benchmark Mineral Intelligence (2021), Global Battery Arms Race.

22 Hydrogen Council and McKinsey (2022), Hydrogen Insights 2022.

23 RMI (2021), Fuelling the Transition: Accelerating Cost-Competitive Green Hydrogen.

Heat pumps: The cost of heat pumps—though varying by applications, geography, and market—has been declining with a 10% global learning rate in the literature.[24] The International Energy Agency (IEA) projected that heat pump cost for vapor compression applications will fall from $950/kW in 2019 to $873/kW in 2030 and $779/kW in 2050.[25] While the cost decline is not as significant compared to solar + storage technologies, its coefficient of performance (i.e., efficiency) has improved by more than 70% since the early 1990s for air-to-water heat pumps due to technological innovations.[26]

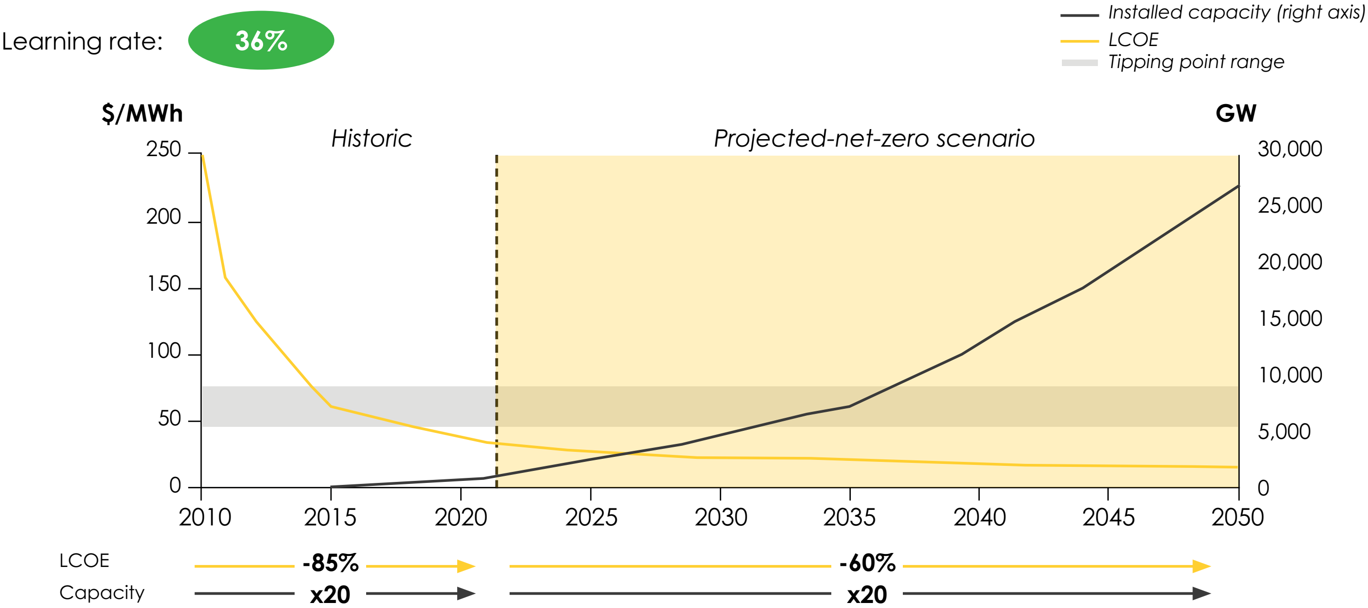
Figure 4 below shows the historical and potential future trajectory for the costs of the two key energy transition technologies, as production increases in line with what would be required to achieve a net-zero economy by 2050. A continuation of the historical learning rate suggests that substantial cost reductions are expected as output scales up. The figures also highlight the tipping point range for these technologies, where their costs reach a level that makes them economically competitive against fossil-based incumbents (e.g., solar and wind power LCOEs reaching parity with those of new gas-fired power plants).

Local dynamics will influence the rate of cost reduction at the local level. In certain regions/countries, delayed cost reductions can be experienced due to misalignment to local dynamics, e.g., policies. For example, the average system cost of building a utility-scale solar power plant is generally higher in ASEAN compared to the rest of the world due to the higher market uncertainty and perceived risk of investments. As a result, investments into these technologies are faced with higher development and financing costs, inhibiting economies of scale to be reached.[27] Hence, there is significant role for policy and market levers to breakdown these barriers both from the demand and supply-side; accelerate the rate of cost reduction at a local level.

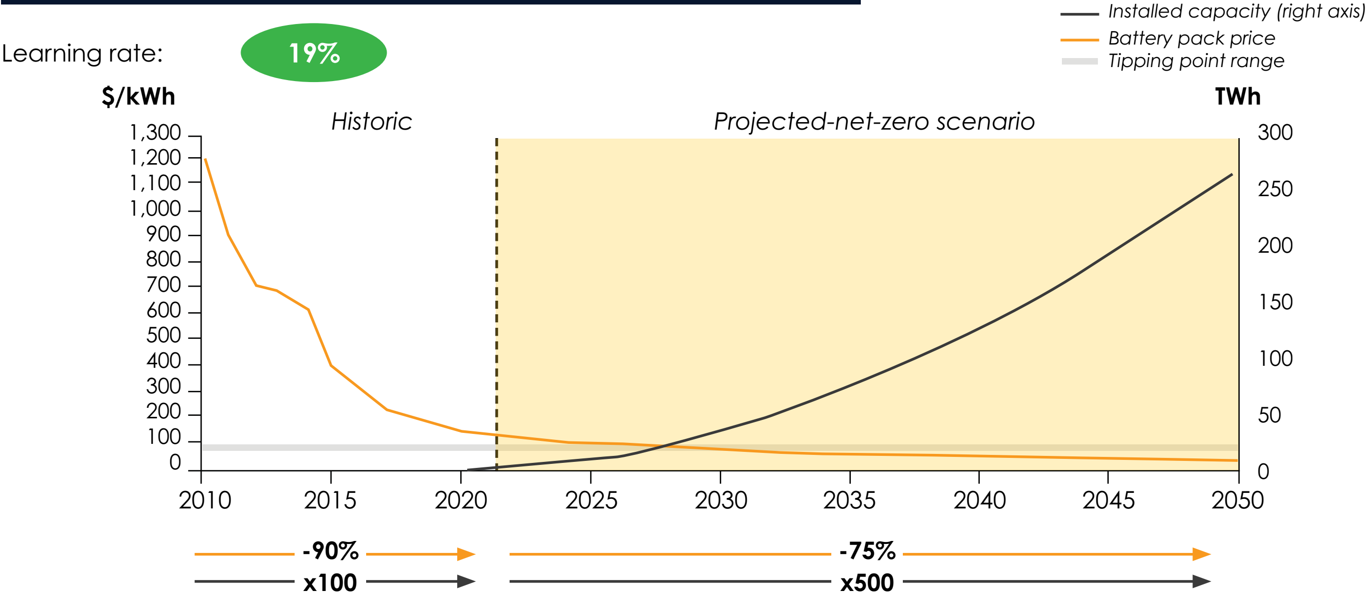
[24] R. Haas et al. (2022), "Technological learning: Lessons learned on energy technologies," WIREs Energy and Environment.
[25] IEA (2020), Energy Technology Perspectives: Special Report on Clean Energy Innovation.
[26] IEA (2022), The Future of Heat Pumps.
[27] IRENA (2023), Renewable power generation costs in 2022; IRENA & ACE (2022), Renewable energy outlook for ASEAN: Towards a regional energy transition.

Figure 4. Learning curve of solar PV and lithium-ion batteries

HISTORICAL AND PROJECTED LCOE VS. INSTALLED CAPACITY FOR POWER FROM SOLAR PV



HISTORICAL AND PROJECTED BATTERY PACK COST VS. INSTALLED CAPACITY FOR LITHIUM-ION BATTERIES



Note: For Solar PV: Tipping point range shows current LCOE from new gas-based power (global average)—i.e., cost at which renewables become cheaper than fossil-based alternative. Projections refer to deployment required for scenario in which net zero is achieved globally by 2050; in slower transition scenarios costs decrease by less over the same period due to more gradual capacity instalment. [1] Learning rate calculated as the percentage decrease in total cost following a doubling in installed capacity; refers to learning rate observed over 2010–2020. [2] Cost reduction for solar PV (utility-scale) refers to unsubsidized LCOE.

For Li-ion batteries: Tipping point range for lithium-ion batteries refers to level required for purchase cost parity of BEVs with conventional passenger vehicles. Tipping point range for electrolyzers refers to electrolyzer capital costs supporting green hydrogen prices of $1.5–2.0/kg H_2, where decarbonization of hard-to-abate sectors becomes cost effective (excluding long-distance aviation). Projections refer to deployment required for scenario in which net zero is achieved globally by 2050; in slower transition scenarios costs decrease by less over same period due to more gradual capacity instalment. [1] Increase in installed capacity for li-ion batteries refers to total change in global generation for battery packs in GWh across all sectors. Lithium-Ion battery cost reductions refer to decrease in capital costs for 4-hour utility-scale storage, P2X electrolyzer cost refers to capex for utility scale plants of >1GW.

Source: Our World in Data (2020); Lazard (2021), Levelized Cost of Energy Analysis v15; Mission Possible Partnership (2022); IEA (2020), Net-Zero by 2050; ETC (2021), Making Clean Electrification Possible. IRENA (2020), Empirically Grounded Technology Forecasts and the Energy Transition; BloombergNEF (2022), New Energy Outlook [3] Mission Possible Partnership (2022); NREL (2021), Annual Technology Baseline, IEA (2020), Net-Zero by 2050; ETC (2021), BloombergNEF 2020 Electric Vehicle Outlook and 2020 Lithium-ion Battery Price Survey.

SECTION 2

IDENTIFYING POSITIVE TIPPING POINTS FOR THE ASEAN REGION

While the original Breakthrough Effect report provides a global overview, identifying tipping points in the top 10 high-emission sectors, with the analysis focused on global cost curves, this report has a regional focus and encompasses regional circumstances that impact progress toward tipping points such as policy.

This report zeroes in on tipping points that are particularly relevant to the ASEAN region. In most cases, these tipping points will occur at the level of individual countries or regions. This will happen as global advancements in technology lead to cost reductions and intersect with local factors such as government policies, renewable energy availability, energy demands, and unique local dynamics.

The main goal of this report is to identify these regional tipping points, highlighting them as targets and profiling precisely the conditions and levers to achieve them. Through this framework, this report aims to catalyze action across government, corporates, and investors to unlock levers to trigger tipping points.

WHY ASEAN?

ASEAN's vulnerability to the impacts of climate change and its strategic role for global efforts in decarbonization makes it a critical region to accelerate climate action.

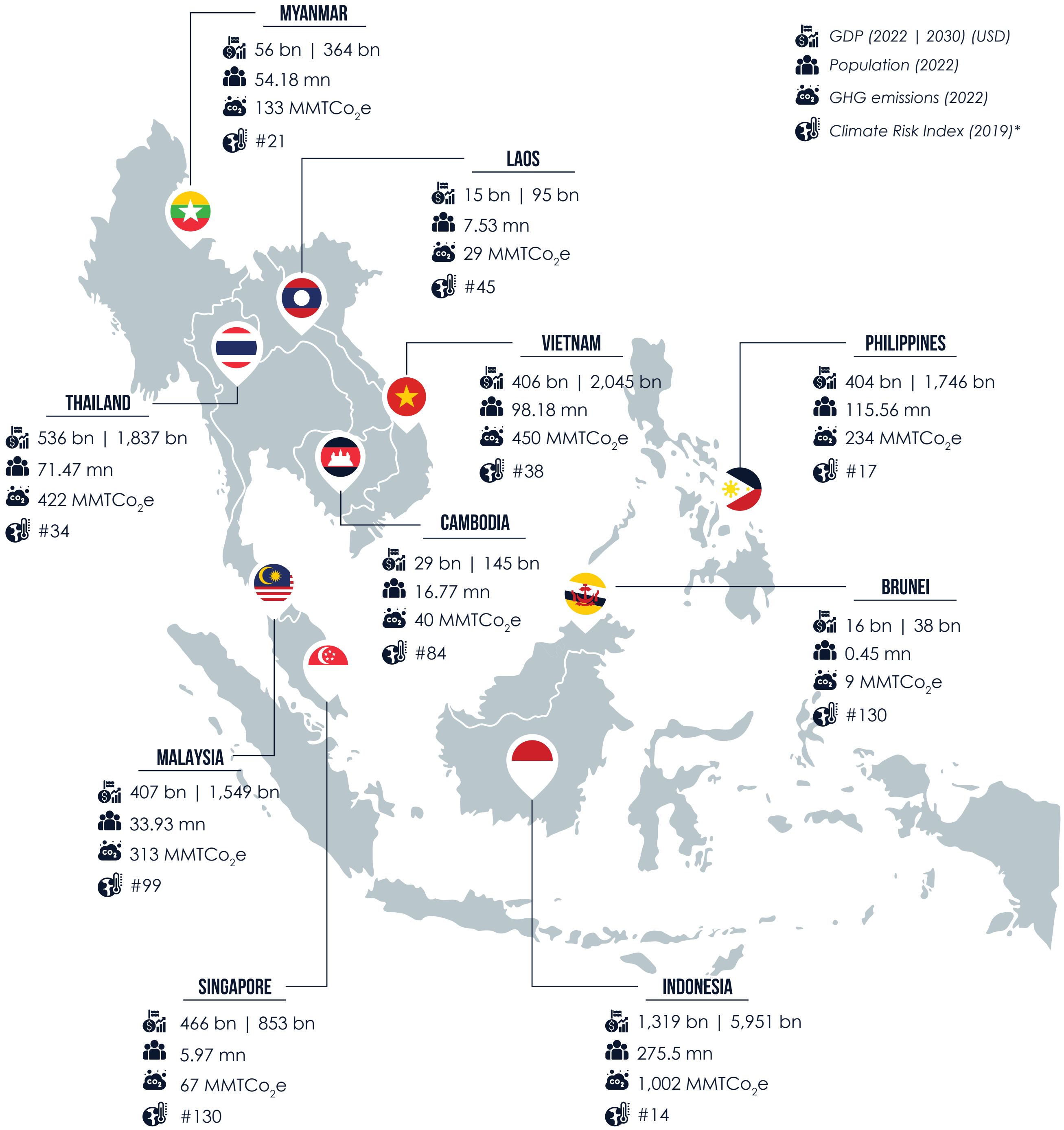
For ASEAN, the impacts of climate change are especially relevant as the region is one of the most climate-vulnerable in the world. Myanmar, the Philippines, Thailand, and Vietnam are already among the 10 countries in the world that have suffered the most in human and material terms from climate-related weather events over the past 20 years.[28] Floods alone accounted for over 60% of all disaster events that occurred from 2012–2019. Over the same period, floods affected more than 70 million people and ~$900 billion worth of capital stock.[29] From an economic standpoint, the impacts of climate change could cut the region's GDP by 35% by 2050, further threatening the livelihoods of communities in ASEAN.[30]

At the same time, ASEAN has a strategic role for global efforts in decarbonization in multiple sectors. ASEAN is blessed with abundant natural resources including critical minerals for the energy transition. Indonesia alone accounts for 22% of the global nickel reserves while 18% of the global rare earths reserves are in Vietnam.[31] Both are critical minerals for electric vehicles (EVs) and battery development, of which the region has one of the largest market potentials—accounting for 20% of the global two-wheeler fleet.[32] Furthermore, ASEAN is strategically located at the crossroads of major shipping routes, contributing to at least 10% of the world's shipping volume. Singapore alone accounts for 20% of global bunkering demand, underscoring the region's significance in shaping the future of low-carbon global shipping.

The choices made by ASEAN countries in the next decade will decide if the region can tap into its green growth opportunity. Given the region's unique position both in terms of its vulnerability and its strategic role in global decarbonization, ASEAN can play a leading and thriving role as it builds its green industrial economy. From a high-carbon growth development model the economy is still reliant on coal and private transportation, ASEAN can shift toward a low-carbon growth where zero-emission solutions become the engine of growth—bringing economic, health, and environmental benefits simultaneously.

[28] Germanwatch (2018), Global Climate Risk Index 2019.
[29] The AHA Centre (2018), ASEAN Risk Monitor and Disaster Management Review (ARMOR).
[30] UK Government (2021), Adaptation and Resilience in ASEAN: Managing Disaster Risks from Natural Hazards.
[31] US Geological Survey (2023), Mineral Commodity Summaries.
[32] BloombergNEF (2020), Electric Vehicle Outlook 2020.

Figure 5. ASEAN's key macroeconomic and climate-vulnerability data



ASEAN REGIONAL CONTEXT

- **Land-use change, power, transport, and industrial processes** are ASEAN's major sources of emissions.
- **6 out of 10 ASEAN countries** are in the top 50 countries with the **highest climate risk index.**
- **4 out of 10** are already among the top 10 countries that have **suffered the most from climate-related weather events** over the past 20 years.
- **11.8 years** is the average age of ASEAN's coal fleet, making it the world's youngest.
- **125+ GW of coal plants i**s the majority source of power for ASEAN.
- **~20% of global fleet of two- and three-wheelers** is located in ASEAN.

Notes: *) Sourced from Germanwatch. 2021. Global Climate Risk Index 2021, ranking 180 countries with the highest number being the most climate vulnerable

SCOPE OF THE BREAKTHROUGH EFFECT IN ASEAN

While the global Breakthrough Effect report covered 10 hard-to-abate sectors: power, light-duty road, heavy-duty road, building heating, fertilizer, steel, shipping, aviation, food and agriculture, and avoided land-use change, The Breakthrough Effect in ASEAN study will focus on prioritized sectors most relevant to the region.

The study has conducted a prioritization exercise to determine the sectors to be included in this analysis of a first wave of tipping points that the region could drive. This list is by no means a comprehensive view on all climate action required, nor even a comprehensive view of all potential tipping points in the region. It is a start. The list could be considered the easier wins. However, even for the solutions in this list, reaching tipping points will not be easy nor will it happen independently. Rather, it will require concerted efforts, pushing the levers that can create the conditions to unlock tipping points.

This initial list was selected based on four parameters:

1. **Regional socio-economic relevance:** Sectors important for the economy and people's well-being, like transportation.

2. **Global trade impact:** Sectors in which ASEAN has a notable and impactful role within the trade balance or value chain.

3. **Regional emissions contribution:** Sectors that contribute to a significant portion of regional emissions.

4. **State of readiness for respective low-carbon solutions:** Sectors that have readily available low-carbon solutions that are ready for mass adoption.

Figure 6. Prioritized sectors in The Breakthrough Effect in ASEAN

	Geographic Relevance*	Impact to global value chain	GHG Emissions ($MTCO_2e$ and % of total)	Low-carbon solution deployment readiness[3]
POWER	*Important for low-carbon economy*	▼	675 25%	*Solar VRE + storage* 10
TWO-WHEELERS	*Main mode of transport*	▼	100 4%	*Electric vehicles* 10
BUSES	*Long-term solution for road transport*	▼	70 2%	*Electric vehicles* 10
INDUSTRIAL HEAT	*Impacts key industries (e.g., textile, F&B)*	▲	105 4%	*Direct electrification* 6-8
SHIPPING	*Intersection of many global routes*	▲	65 3%	*Green ammonia for fuel* 5
MINERALS REFINERY	*One of the largest reserves globally*	▲	30 1%	*VRE + storage + heat electrification* 8
CEMENT	*Key industry for infrastructure*	–	135 5%	*No clear cut solutions* ?
STEEL	*Key industry for infrastructure*	–	55 2%	*H_2-based direct reduction iron* 6
CHEMICAL - FERTILIZER	*Important to food system & economy*	▼	45 2%	*Green ammonia* 7
RESIDENTIAL	*High population numbers*	▼	50 2%	*Electrified cooling* 10
LAND USE - DEFORESTATION	*One of largest forest covers globally*	▲	575 22%	*Multiple solutions* ?
LAND USE - FOOD	*Big part of culture and livelihood*	▲	400 14%	*Alternative protein* 5

Legend: High, Medium, Low, Very Low, Priority sectors

After assessing sectors based on these parameters, there are six sectors that were shortlisted and will be the focus of the analysis namely:

1. **Power:** The electricity sector is the largest contributor to ASEAN's GHG emissions (25% in 2020), making it one of the most important sectors to decarbonize as ASEAN countries grow and develop their economy. Today, ASEAN is still one of the most fossil-fuel-reliant regions in the world with almost half of its power coming from coal. While renewables, particularly solar and wind power, have experienced a large ramp-up in deployment globally (85% of new generating capacity in 2022), its deployment in ASEAN is still entering niche adoption on average.

2. **Road transport—two-wheelers:** Two-wheelers represent one of the main modes of transportation across the region, accounting for 4% of ASEAN's total emissions in 2020. ASEAN is also home to 20% of the global 2Ws fleet, therefore direct electrification of vehicles is key to achieving net zero in the region.

3. **Road transport—buses:** Representing 3% of ASEAN's total emissions, public transport is another important sector to decarbonize. Electrification of buses will therefore be key in reducing road transport emissions. Globally, about 4.5% of public buses have been electrified and electric buses represented almost 40% of all bus sales in 2022, predominantly led by China, followed by Europe and the United States. There is an opportunity for ASEAN to benefit from this technology that is becoming dominant in other markets.

4. **Industrial heat:** Heat accounted for half of the world's final energy demand and half of it came from industrial heating. In ASEAN, industrial heat represents ~4% of total emissions. Low (<150 °C) and medium-to-high (150–650 °C) temperature heat present an opportunity for decarbonization through direct electrification as its technology solutions are one of the most technologically ready (i.e., industrial heat pumps for low-temperature heat). Food and beverage, pulp and paper, and textile and garment are three industries in ASEAN requiring low-temperature heat that has an impact on global trade and value chains.

5. **Shipping:** More than 90% of global trade happens through shipping using long-haul vessels, hence the decarbonization of shipping is imperative. ASEAN plays a strategic role in the global shipping/trade as it sits in the middle of several large shipping corridors, contributing to at least 10% of the world's shipping volume. Today, Southeast Asia has five of the top 30 ports in terms of annual throughput. Singapore, in particular, has 20+% share of global bunkering demand today. Altogether, the shipping sector contributed to 3% of ASEAN's total emissions.

6. **Minerals refinery—nickel:** (Critical) minerals refinery is a highly important sub-sector to the global energy transitions and ASEAN has a big role to play. Indonesia and the Philippines, in particular, account for ~25% of global nickel reserves, an important element for electric vehicles and battery development (also for energy storage). Developing clean power and heat solutions for nickel and its related battery value chain manufacturing, therefore, will be crucial to reducing the overall carbon footprint of electric vehicles and battery energy storage deployment.

Although these six prioritized sectors apply to all ASEAN countries, the sectoral analysis is focused on countries where each sector has the greatest relevance and impact. The sectoral country mapping is seen in Figure 7.

Figure 7. Country relevance for each prioritized sector

Sector	Emissions	Most relevant countries
POWER (GROUP 1)	25%	Vietnam, Thailand, Philippines, Malaysia
POWER (GROUP 2)		Indonesia, Myanmar, Laos, Cambodia
TWO-WHEELERS IN ROAD TRANSPORT	4%	Myanmar, Thailand, Laos, Malaysia, Cambodia, Singapore, Vietnam, Indonesia, Brunei, Philippines
BUSES IN ROAD TRANSPORT	2%	Myanmar, Thailand, Laos, Malaysia, Cambodia, Singapore, Vietnam, Indonesia, Brunei, Philippines
INDUSTRIAL HEAT *(Low, <150°C)*	4%	Myanmar, Thailand, Laos, Malaysia, Vietnam, Indonesia, Philippines, Cambodia
INDUSTRIAL HEAT *(Med-high, 150-600°C)*		Myanmar, Thailand, Laos, Malaysia, Vietnam, Indonesia, Philippines, Cambodia
SHIPPING	3%	Singapore, Vietnam, Indonesia, Malaysia
MINERALS REFINERY-NICKEL	1%	Philippines, Vietnam, Indonesia

Legend: High Medium Low Very Low

BOX 3. AGRICULTURE AND LAND USE

This report chose not to include the agriculture and land-use (AFOLU) sector in its analysis. This is because the nature of the AFOLU sector is inherently very complex, meaning there is not one low-carbon solution that alone reaches a tipping point and delivers decarbonization of the majority of the sector. AFOLU's dynamics involve intricate and interconnected factors, meaning it is a confluence of solutions—not one primary solution—that could come together to deliver significant impact. Nevertheless, the report does recognize the critical importance of the AFOLU sector in the context of ASEAN's decarbonization efforts given both the potential and significance of the sector to the region's economy.

1. **Large agricultural sector and exporter of key commodities.** 8 out of 10 countries in ASEAN are dependent on agriculture and its production, with the region being a major producer and exporter of palm oil, crude rubber, rice, sugar, seafood, and fruits.[1]

2. **Emissions contribution.** Land-use alone constitutes 35% of the region's GHG emissions.[2] In 2018, CO_2 emissions from the AFOLU were 965 $MTCO_2e$, accounting for around two-fifths of the total GHG emissions.[3]

3. **High potential for nature-based solutions.** The region is home to 15% of the world's tropical forests,[4] 56% of global tropical peatlands[5] and at least four of the 25 globally important biodiversity hotspots.[6] Additionally, it boasts the highest blue carbon content globally with several countries being home to significant areas of mangrove swamps and seagrass meadows.[7]

In view of these, while not within the immediate scope of the report, the AFOLU sector's importance remains evident on the ASEAN decarbonization landscape and should not be ignored.

Source: 1. ASEAN Regional Guidelines for Sustainable Agriculture in ASEAN, 2022; 2. Systemiq Analysis, 2023; 3. Sixth ASEAN State of the Environment Report, 2023; 4. Stibig, H. J., Achard, F., Carboni, S., Rasi, R. & Miettinen, J. Change in tropical forest cover of Southeast Asia from 1990 to 2010, 2014; 5. Sustainable Use of Peatland and Haze Mitigation in ASEAN (SUPA), 2023 ; 6. Sodhi, N. S. et al. The state and conservation of Southeast Asian biodiversity, 2010; 7. Thorhaug A, Gallagher JB, Kiswara W, et al. Coastal and estuarine blue carbon stocks in the greater Southeast Asia region: Seagrasses and mangroves per nation and sum of total. Mar Pollut Bull. 2020.

SECTION 3

IDENTIFYING ASEAN'S TIPPING POINTS BY SECTOR

This section presents analyses on the six prioritized sectors in ASEAN discussed in Section 2. In each sector analysis, the report seeks to answer the following questions:

Global sector context

- What is the **global context** of how this sector will decarbonize?
- What are the **core low-carbon solutions** that will drive decarbonization?

Geographic sector context

- How is the **sectoral transition progressing** at **ASEAN level**?
- Are there **opportunities or challenges** specific to the region?

Solution status

- What is the **current status** of the core solution being adopted at ASEAN level?
- Is it only **in development**, or being adopted in **niche markets**, or starting to break into **mass market**?

Tipping point status

- How close are we to a **tipping point**, to help the solution break into mass market?
- What are the **key gaps** to be addressed to trigger one?

Tipping point calculation & levers

- What is the **comparison** of the **current** and **potential future costs** of the **low-carbon solution** versus **the incumbent**?

Target conditions progress to trigger tipping point

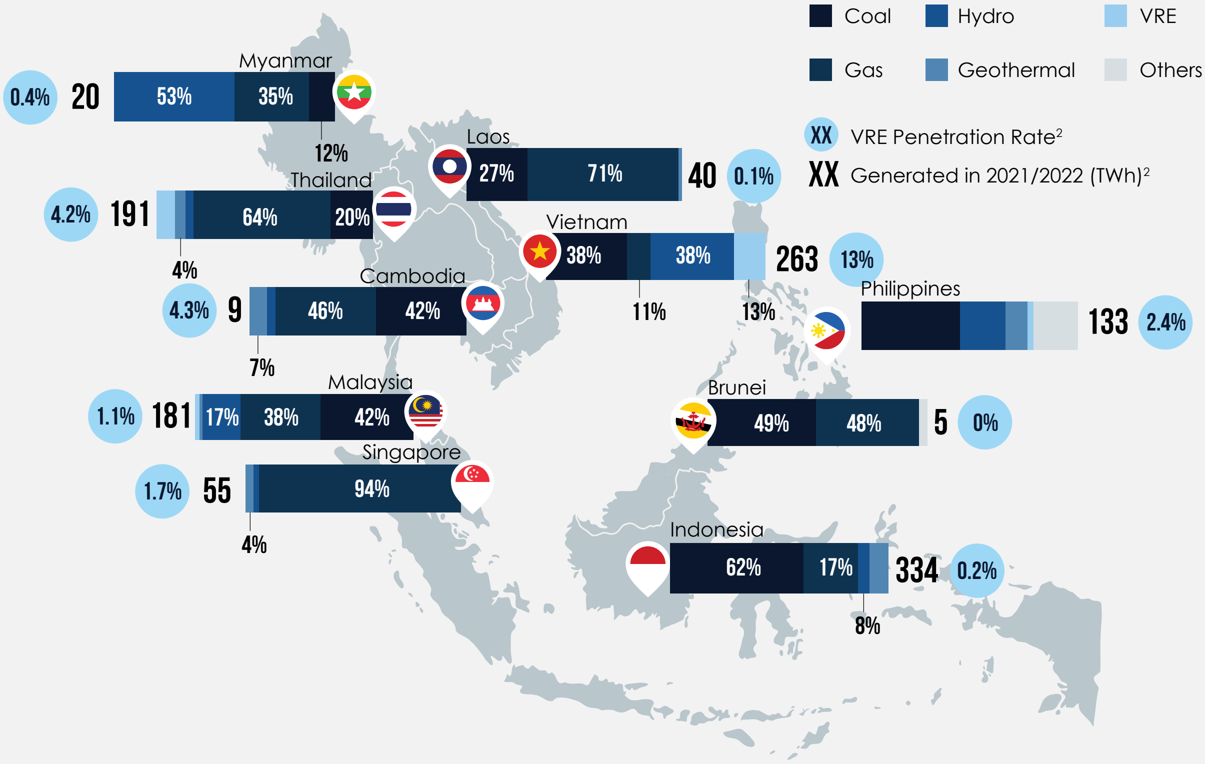
- What is **the current** and **potential future** status of the **tipping point conditions** (affordability, attractiveness, and accessibility)?

POWER: SOLAR & STORAGE

25% OF TOTAL ASEAN GHG EMISSIONS 2020

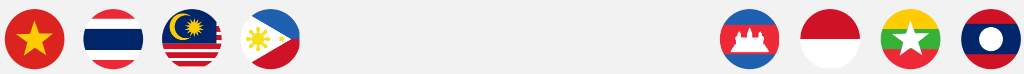
SECTORAL & GEOGRAPHICAL CONTEXT

- **Globally, renewables has experienced a large ramp-up in deployment**. In 2022, solar and wind accounted for 85% of new generation capacity from renewables. Solar and wind together made up 12% of global electricity generation in 2022.[1]
- **ASEAN is still one of the most coal reliant regions in the world**. 45% of power comes from coal, with Vietnam, Indonesia, the Philippines, Malaysia, and Cambodia get 50+% of power from coal. Only 4% of power is served by variable renewable energy (VRE), that is solar and wind, with 3% coming from solar.[2]
- **Growth in ASEAN has not been balanced with renewable energy sources.** Clean electricity, which represents 30-40% of newly installed capacity, is not keeping pace with demand increase (5% annually since 2016).[3]
- **Differing circumstances across grid nodes.** The Philippines and Indonesia have different grid nodes with different situations, making it harder to shift to renewables. Other localized barriers also exist, such as ease of doing business (e.g., Laos & Cambodia).



Our analysis will focus on solar (and solar + storage) as tipping points, considering the lower wind potential in ASEAN overall. Due to differing solar deployment and enabling policy environment, we have classified[4] the ASEAN countries into two groups:

STRONGER ENABLING POLICY ENVIRONMENT	WEAKER ENABLING POLICY ENVIRONMENT
Group 1	Group 2
Countries with higher solar deployment (>1.5 GW), stronger enabling policy environment, more mature market (lower risk), and more ambitious VRE planning in its PDP* (by 2030)	Countries with lower solar deployment (<500 MW), weaker enabling policy environment, less mature market (higher risk), less ambitious VRE planning in its PDP* (by 2030)



Notes: [1] Systemiq (2023), The Breakthrough Effect: How to Trigger a Cascade of Tipping Points to Accelerate the Net Zero Transition. [2] Our World in Data (n.d.), Electricity production by source. [3] ASEAN Centre for Energy (2022), The 7th ASEAN Energy Outlook 2020–2050. [4] Adapted from Asian Development Bank, Bloomberg Philanthropies, ClimateWorks Foundation, Sustainable Energy for All (2023), Renewable Energy Manufacturing: Opportunities for Southeast Asia. *) Power development plan.

SOLUTION STATUS IN ASEAN

Solution status stages: ● *Solution development* › ● *Niche market* › ● *Mass market*

NICHE TO MASS MARKET

Solar

- **Only 3% of power in ASEAN is generated from solar.**[2] Vietnam is leading the charge with 10%, one of the leaders globally. The rest of ASEAN is still lagging: Thailand at 2.6%, the Philippines at 1.6%, and most ASEAN countries at below 1%, compared to leading countries such as China (4.8%), India (5.1%), Australia (13%) and Chile (17.4%).
- **For countries with higher barriers, issues range from technological costs, regulatory processes, and power market structure.** Although there have been several advancements in procurement process and technology cost reduction, more improvements are needed to kickstart solar adoption.

NICHE MARKET

Solar + Storage

- **Energy storage deployment in ASEAN is still in a very early stage** but is expected to reach 1,175 GW in 2050 (1.5°C scenario with 100% RE generation).[5]
- Countries such as Thailand and Vietnam have **incorporated solar + battery storage solutions** into their **long-term electricity plans**, but there has not been any significant progress in project execution. Other countries are looking into system-level storage such as pumped storage (Indonesia, the Philippines).[6]
- **Battery manufacturing is already present and growing** fast in Thailand and Vietnam, with Indonesia and Malaysia also following suit.[7]

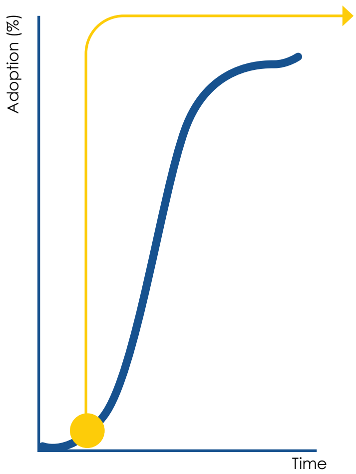
TIPPING POINT AND ADOPTION RATE STATUS

Legend: ⬚ *Focus of tipping points* ✓ *Mostly reached* ○ *Reached in certain cases* – *Not reached*

Tipping point status

	GROUP 1	GROUP 2	INDONESIA*	COMPARISON TO...	STATUS/REASONING
TIPPING POINT 1 LCOE of solar < **new** coal/gas	✓	⬚ ○	⬚ ○	• **New Coal (Group 2)** • **New CCGT (Indonesia)**	• **Has been reached for Group 1 and could already be achieved in Group 2** under certain cases. • **For Indonesia**, since there is already a coal moratorium, **T.P. 1 will be compared to new CCGT**.
TIPPING POINT 2 LCOE solar + storage < **new** coal/gas	○	○	○	• **New Gas (CCGT)**	• **T.P. 2‡ against new CCGT could already be reached** in countries who do not have domestic gas production (or price cap), and when international gas price fluctuation is apparent.
TIPPING POINT 3 LCOE of solar < **existing** coal/gas	⬚ ✓	⬚ ○	⬚ –	• **Existing Coal**	• **T.P. 3 has been reached for Group 1 and could be reached in Group 2** except for Indonesia (domestic coal price cap). T.P.3 can link with **carbon financing for accelerated coal closure.**
TIPPING POINT 4 LCOE solar + storage < **existing** coal/gas	⬚ ○	–	–	• **Existing Gas (CCGT)**	• **T.P. 4 could be reached in certain case, and is currently only relevant for, for Group 1 who has high VRE penetration** (particularly Vietnam, with 13% VRE, and Thailand who has high gas shares).

Current adoption status

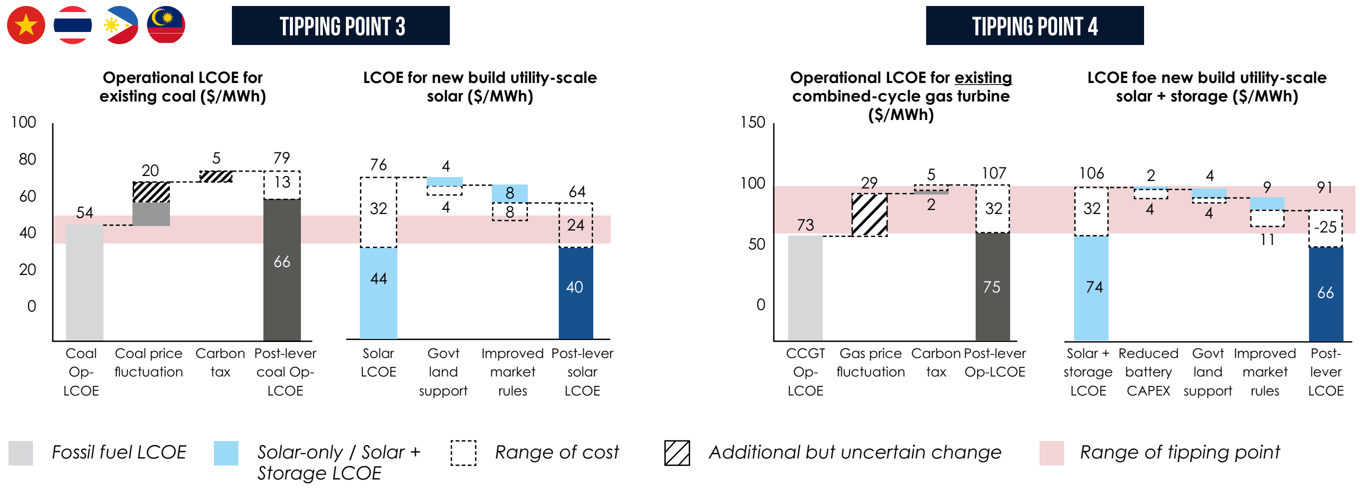


Even though most of the tipping points have been reached, ASEAN's 3% VRE penetration means solar (+storage) is in its early stages of the adoption curve. There are other **key barriers/levers to reach tipping points outside of affordability: attractiveness, and availability, which covers:**

- **Streamlining power purchase agreement (PPA) and procurement process** by using auctions. This can reduce overhead & land costs.
- **Restructuring of existing power generation market structure.** Countries are locked in to long-term/fixed take-or-pay PPAs for legacy coal power plants.
- **Ensuring project proponents receive benefits** from carbon revenue, to enable lower levelized cost of electricity (LCOE).
- **Investing in grid infrastructure** to reduce interconnection costs for new solar + storage.
- **Increasing the price for coal,** either through carbon tax or removing domestic price caps/ subsidies (especially in Indonesia).
- **Implementing strict pollution regulation** for coal plants, increasing their operational costs.
- **Exploring the possibility of direct-PPA and power wheeling**.

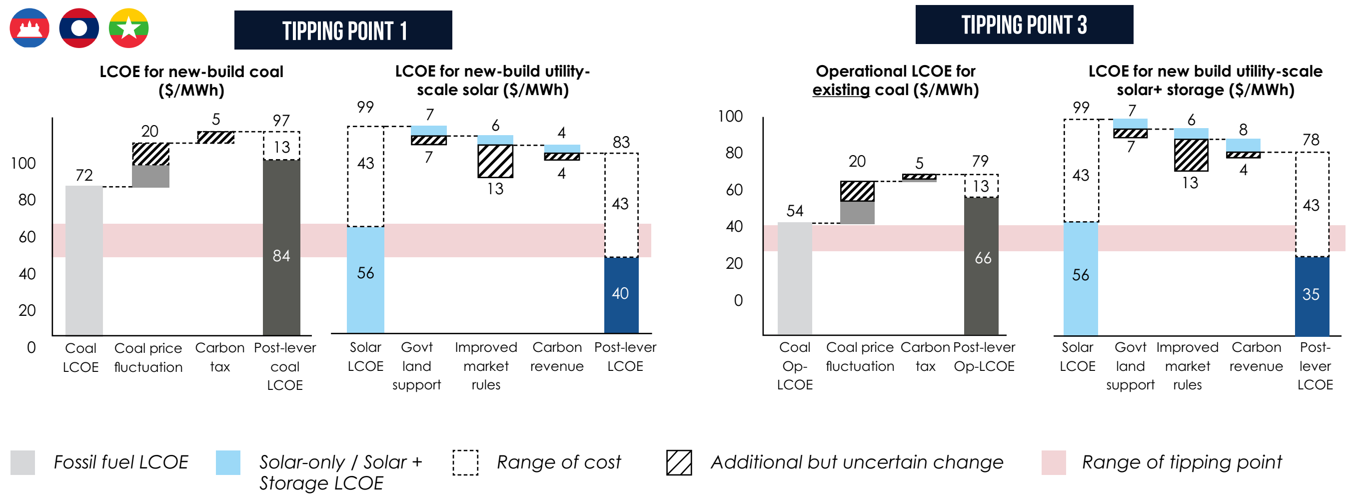
Notes: CCGT = Combined cycle gas turbine power plant. [5] IRENA (2022), Renewable Energy Outlook for ASEAN. [6] Country analysis from respective power development plan, Systemiq analysis. [7] ADB et al. (2023), Renewable Energy Manufacturing: Opportunities for Southeast Asia. *) Country with domestic coal and gas price cap. †) Coal moratorium in place. ‡) Solar + storage (4-hour duration, sized at 40% of solar capacity).

COUNTRY GROUP 1: VIETNAM, THAILAND, PHILIPPINES, MALAYSIA



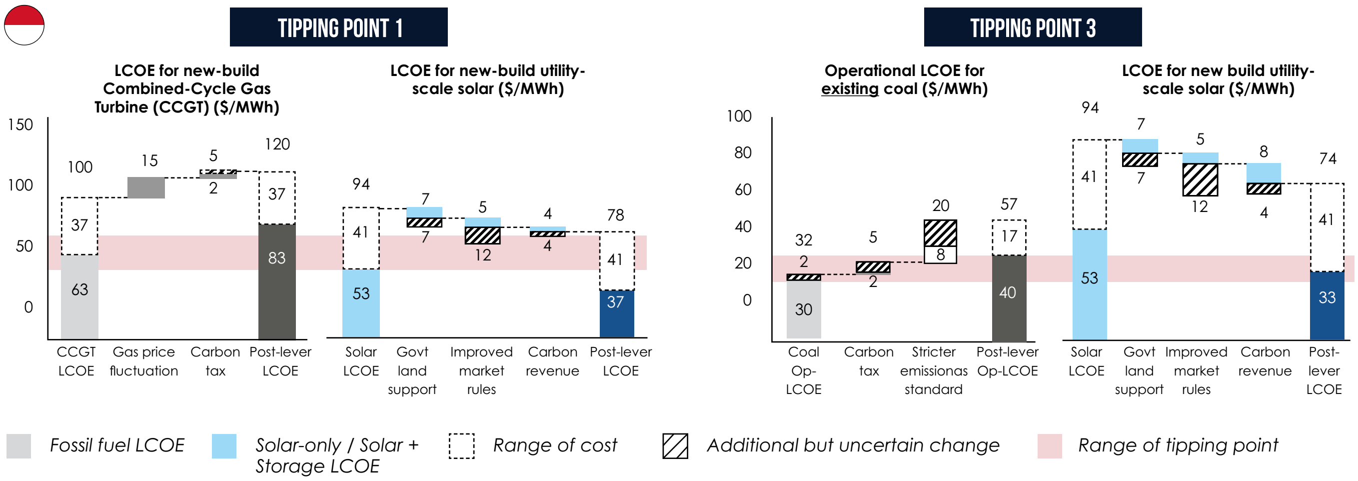
- **Replacing coal would be a priority for Group 1 since new solar LCOE can already undercut the marginal cost of existing coal.** This can be done without the need to couple solar with storage as existing flexibility is typically adequate to provide balancing at <5% VRE penetration (Phase 1 of VRE integration[8]), except for Vietnam (13% VRE penetration).
- **Solar + storage LCOE is already within range of tipping point against existing CCGT.** To push VRE penetration further, countries will need to couple solar with storage to balance the output and provide more system flexibility. However, this will only be relevant at a later stage when VRE penetration has reached >10% (Phase 3).

COUNTRY GROUP 2: CAMBODIA, LAOS, MYANMAR



- **T.P. 1 may have already been reached in Group 2 although not without a range of uncertainty**. This is due to higher market uncertainty, conditions for investment, and inherently lower solar irradiation. That said, solar can already be cost-competitive with support from the government, such as land provision and improved market rules (auction certainty).
- **T.P. 3 can also be brought forward further by accessing carbon financing** from coupling renewable buildout with coal closure,** thus further improving solar's cost-competitiveness.
- **Since most Group 2 countries have a major share of hydropower (~40%) and are still in the Phase 1 of VRE integration[8]**, no additional system flexibility via energy storage is technically required.

COUNTRY GROUP 2 W/ DOMESTIC PRICE CAP: INDONESIA



- **The artificially low domestic price cap for coal ($70/ton) and gas prices (~$6/MMBtu) makes it difficult for solar to compete on a level playing field.** Moreover, Indonesia currently has many barriers for solar deployment, including: overcapacity in some regions, inflexible power system due to rigid PPAs, inefficient procurement, poor market rules and inconsistent regulation.
- **Removing these barriers is therefore imperative to bring forward solar's tipping points in Indonesia.** These could include: gradual removal of implicit subsidies (e.g., from domestic price cap), improving market rules and regulation, supporting land provision, and deploying solar through competitive auctions. Carbon financing** from coupling renewable buildout with coal closure can also bring forward the tipping point faster.

Notes: LCOE of new-build solar and solar + storage are calculated using NREL's 2021 Annual Technology Baseline (ATB), which can be accessed at https://atb.nrel.gov/. LCOE of new-build and operating LCOE (marginal cost) of existing thermal power plants (i.e., ultra super-critical coal-fired power plant, combined-cycle gas turbine, and open-cycle gas turbine) are calculated using IESR's LCOE calculator, https://energycost.id/, with inputs from Lazard's (2023), Levelized Cost of Energy Analysis, Version 16.0, for global comparison and IESR (2023). Making Energy Transition Succeed: A 2023's Update on The Levelized Cost of Electricity and Levelized Cost of Storage in Indonesia, for ASEAN assumption. [8] Based on IEA's six phases of VRE integration [IEA (2018), System Integration of Renewables], where Phase 1: VRE has no noticeable impact on the system (<5% VRE penetration), Phase 2: VRE has a minor to moderate impact on system operation (5-10% VRE penetration), Phase 3: VRE generation determines the operation pattern of the system (10-25% VRE penetration), and Phase 4: The system experiences periods where VRE makes up almost all generation (may begin above 20% VRE penetration for less flexible grids; often above 30% for more developed grids). No countries have reached Phase 5 or 6 as of 2022 yet and hence will not be detailed here (see here for more details); **) Carbon revenue from accelerated coal closure uses $10-$15/tCO2e carbon pricing,, 0.9 tCO2e/MWh coal plant emissions intensity, and 0.3 tCO2e/MWh grid emissions intensity for the avoidance calculation.

FOR OTHER ASEAN COUNTRIES

For Singapore and Brunei: These city states might be better inclined to import VRE or hydro from neighboring countries (e.g., Malaysia/Indonesia), and become the market that triggers the inflection point of solar (+storage) adoption in ASEAN countries.

COUNTRY GROUP 1:

ENABLING CONDITIONS TO TRIGGER TIPPING POINT		PROGRESS
AFFORDABILITY	• **Relevant tipping points at current VRE penetration (in highlight):** *[T.P. 1] LCOE solar < new coal/gas;* *[T.P. 2] LCOE solar + storage < new coal/gas;* **[T.P. 3] LCOE solar < existing coal/gas;** **[T.P. 4] LCOE solar + storage < existing coal/gas.** • **Reduced battery price for solar + storage.** • **Increased cost of running fossil-fuel power plants** (e.g., import tariffs for coal or gas).	✓ **[T.P. 3]: Solar LCOE in Group 1 can already undercut existing coal generation** (at $44-76/MWh vs. $54-79/MWh, respectively). ✓ **[T.P. 4]: Solar + Storage's** (4-h duration, 40% PV capacity) **LCOE** ($74-106/MWh) **in Group 1 is already close to tipping point with existing CCGT** ($73-107/MWh), driven in part by fluctuating natural gas price. It may reach parity by pulling a few levers such as reduced battery energy storage CAPEX, land support, or improved market rules. ✓ **Plans in investments for battery manufacturing has been seen across ASEAN** (e.g., LG, CATL, and REPT in Indonesia; VinES in Vietnam). ✓ **Coal import tariffs**, which is being considered in Vietnam, may accelerate tipping point being reached. **Key actions to accelerate progress:** ❑ **Policy adjustment:** Set ambitious VRE deployment target to make the full use of solar's tipping points to go net zero. ❑ **Procurement adjustment:** Utilize large-scale solar auctions to further bring down the cost of solar/solar+storage.
ATTRACTIVENESS	• **Sufficient flexibility in the system** to manage the intermittency and variability of solar and wind. • **Fossil-fuel PPA lock-in is solved.** Utilities can renegotiate/restructure existing PPA deals. • **Ensured demand from large-scale/-volume projects.** This can be achieved from dedicated renewable auctions or mass procurement from industrial parks/ large private sector players.	✓ **Existing system flexibility** (e.g., gas or hydro) **in Group 1 are capable to provide required balancing** given that VRE integration in ASEAN is mostly still in Phase 1 (<5%), except for Vietnam. Vietnam (13% VRE) is currently facing grid and solar curtailment issues due to the unpredictable growth of solar from its previous feed-in tariff program and extreme drought rendering its hydropower resources low). ✗ **While technical flexibility is often adequate, contractual inflexibility of long-term PPAs caused the system to be 'rigid'.** Renegotiating rigid coal/gas PPAs can unlock more flexibility in the system. However, no progress is seen yet. ✓ **Large solar demand** (in gigawatt-scale) **has generally been available in Group 1, although is declining in Vietnam** (due to grid and curtailment issues). **Malaysia and Philippines have used large-scale reverse auction** for its procurement instead. **Key actions to accelerate progress:** ❑ **Policy adjustments:** Plan for flexibility needs in the power system (toward net zero); Streamline rigid PPA renegotiation to unlock more system flexibility. ❑ **Procurement adjustment:** Take the full benefit of the price discovery effect of reverse auction-based procurement.
ACCESSIBILITY	• **Availability of Direct PPA or Power Wheeling** to increase access to more solar projects to support industrial decarbonization. • **Build-out and improvement of existing electricity networks** to increase renewables penetration to the grid. • **Development of interconnectivity between ASEAN** countries is key to increase accessibility to countries with lower renewable resources.	✓ **Countries like Philippines and Vietnam have explored schemes like direct PPA and power wheeling** for both large-scale and distributed solar deployment. Thailand is exploring similar schemes. ✓ **All four countries have expressed plans to improve their grid infrastructure in their power development plans (PDP).** ✓ **Interconnectivity between neighbouring ASEAN** is still under development, and increasing importance of environmental attributes of renewable energy might become barrier. **Key actions to accelerate progress:** ❑ **Investment for grid:** Foreign direct investments to further develop grid ability for increased renewable penetration. ❑ **Infrastructure advancement:** New technology investment to improve grid connectivity and energy access.

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[8] Phase 4 of IEA's six phases of VRE integration, IEA (2018), System Integration of Renewables.

COUNTRY GROUP 2:

ENABLING CONDITIONS TO TRIGGER TIPPING POINT	PROGRESS

AFFORDABILITY

Enabling conditions to trigger tipping point

- **Relevant tipping points at current VRE penetration (in highlight):**

  [T.P. 1] LCOE solar < new coal/gas;

  [T.P. 2] LCOE solar + storage < new coal/gas;

  [T.P. 3] LCOE solar < existing coal/gas;

  [T.P. 4] LCOE solar + storage < existing coal/gas.
- **Reduced battery price for solar + storage.**
- **Increased cost of running fossil-fuel power plants** (e.g., import tariffs for coal or gas).

Progress

- ✓ **[T.P. 1]: Solar LCOE in Group 2** ($56-99/MWh) **could already undercut the LCOE of new-build coal ($72/MWh),** although not without a wide range of uncertainty.[9] For Indonesia, this has not been reached due to its domestic price cap that in effect is a major subsidy for coal power. Against CCGT, however, it can already tip (also w/ range).
- ✓ **[T.P. 3]: Similarly, solar LCOE has almost reached cost parity with existing coal for Group 2** (except Indonesia).
- ✓ **Investment plans in downstream battery manufacturing are in place in Indonesia** (LG, CATL, RPET).
- ✓ **Increased price for coal/gas due to international market volatility is likely** although does not seem so for Indonesia at least in the mid-term (3 years ahead).

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Plan a gradual phase down of fossil fuel subsidies to create a level playing field for renewables. Accelerated coal phase out financing will also help.
- ❑ **Market design adjustment:** Improve market rules/design by creating market certainty, fair allocation of risks for long-term PPAs (investment), and clear & consistent regulation.

ATTRACTIVENESS

Enabling conditions to trigger tipping point

- **Sufficient flexibility in the system** to manage the intermittency and variability of solar and wind.
- **Fossil-fuel PPA lock-in is solved.** Utilities can renegotiate/restructure existing PPA deals.
- **Addressed system overcapacity** in some countries, such as Indonesia and Laos, to make room for VRE.
- **Ensured demand from large-scale/-volume projects.** This can be achieved from dedicated renewable auctions or mass procurement from industrial parks/large private sector players.

Progress

- ✓ **Existing system flexibility in Group 2 countries are generally capable to provide required balancing** given that VRE penetration in Group 2 is still below 1%, except Cambodia.
- ✗ Despite having technical flexibility, **contractual inflexibility of long-term PPAs often causes the system to be 'rigid'.** No progress to renegotiate/restructure PPA is seen yet.
- ✓ **In Indonesia and Laos, the point above is exacerbated by overcapacity.** Indonesia is currently working on early coal retirement, in part to circumvent its overcapacity.
- ✗ **Current auction method in Group 2 are generally sporadic and one-off** with huge sunk cost risk for project developers.

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Streamlining national coal phase-out strategy to enable VRE-led transition toward net zero (including streamlining rigid coal PPA renegotiation to enable higher system flexibility).
- ❑ **Procurement adjustment:** Develop gigawatt-scale solar pipelines and design large-scale solar auction to bring down 'local' solar LCOEs through economies of scale.

ACCESSIBILITY

Enabling conditions to trigger tipping point

- **Availability of Direct PPA or Power Wheeling** to increase access to project developer.
- **Build out and improvement of existing electricity networks** to increase renewables penetration to the grid.
- **Development of interconnectivity between ASEAN** countries is key to increase accessibility to countries with lower renewable resources.

Progress

- ✗ **Some countries in Group 2 still have not made power wheeling available, nor direct PPA** (due to its electricity law).
- ✓ **Several countries must still prioritize investments in T&D** to improve reliability in certain areas before improving major grids to enable renewable penetration.
- ✓ **Interconnectivity in ASEAN is still under development,** and it is planned that 20 GW to be dedicated for interconnectivity purposes[11]. However, environmental attributes of renewable energy might become barrier.

Key actions to accelerate progress:

- ❑ **Policy adjustments:** Enable power wheeling to increase accessibility to renewable energy.
- ❑ **Transmission infrastructure investment:** Invest in improving transmission lines.
- ❑ **Interconnectivity improvement:** Accelerate interconnection execution to accelerate renewable buildout.

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[9] Myanmar's political landscape are the business barriers. Laos's regulatory framework and planning are still lagging compared to other ASEAN countries. [10] SEADS (2023), Building the ASEAN Power Grid: Opportunities and Challenges.

TRANSPORT: ELECTRIC TWO-WHEELERS (E2W)

4% OF TOTAL ASEAN GHG EMISSIONS 2020

GLOBAL SECTOR CONTEXT

- **Shifting to electric vehicles is required for full decarbonization in road transport.** In parallel, demand reduction and behavioral change are also important, e.g., usage of public transportation and better urban design.
- **Electrification happens faster in two-wheelers than cars.** Sales of E2W already accounted for 44% of new sales of BEVs[1] in 2020, dominated by China which accounted 60% of the global EV sales.[2,3]
- **95% of global 2Ws[4] are in Asia,** and ASEAN is the largest market after China and India.[3]

GEOGRAPHIC SECTOR CONTEXT

Two-wheelers are a prominent mode of transport in ASEAN, accounting for 20% of the world's total two-wheeler fleet.[5]

- **Indonesia (47%), Vietnam (31%), Thailand (9%) are** 2W hotspots, accounting for **90%** of ASEAN 2W fleet.[6] Dominated by **scooters and mopeds,** comprising **90% of fleet.[7]**
- **Adoption rates in ASEAN are still not as high as China or India**, due to sticker price being 1-2x higher vs. ICE 2W8 (~$600–800 vs. $1000–1250 for 1–1.5 kWh battery class),[9] as well as issues with accessibility and attractiveness.
- **Countries are implementing incentives** such as 0% VAT on electric vehicles.[10]

SOLUTION STATUS IN ASEAN

Solution status stages: Solution development 〉 Niche market 〉 Mass market

NICHE TO MASS MARKET

This sector is on the border of niche to mass market with numerous countries implementing purchase subsidies to help close price gap.

Two-wheeler electrification is starting in ASEAN. Total cost of ownership (TCO) is competitive, but only 2% (~42,000) are electrified.[7]

Fleets electrify faster than mass market in ASEAN. Overall growth projected 4-5% p.a., with sales at ~12,000 p.a.,[7] mostly to ride-hailing/logistics.

Charging and battery technology landscape. There is still a differing battery (li-ion vs lead acid[11]), and charging (plug-in vs. swap-based) technology, as well as scarcity of charging stations.

TIPPING POINT AND ADOPTION RATE STATUS

Tipping point status

TIPPING POINT 1 (Reached in certain cases)
TCO of E2W < TCO of ICE[12] 2W

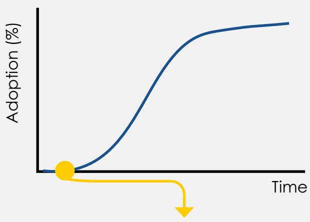
- **This has been reached in major ASEAN countries.** Vietnam, Thailand, Malaysia, and the Philippines have reached this due to lower operational expenses and VAT exemption.[10]
- **This tipping point is aligned with fleets market**, with total cost of ownership being the main driver in decision making.
- Key drivers to this tipping point are **sticker price, price of electricity, and availability of charging stations.**

TIPPING POINT 2 (Not reached)
Sticker price of E2W < Sticker price ICE 2W

- **This has been not reached for similar class vehicles across ASEAN.** Main driver for this tipping point is the battery price.
- **Implementing VAT exemption or direct subsidy** is key to E2W purchases to make these electric vehicles more competitive compared to ICE.
- **This tipping point should be viewed from cashflow perspective, which is an important decision-making factor:** higher sticker price, even with similar financing costs, discourages mass market adoptions.

Legend: ✓ *Mostly reached* ○ *Reached in certain cases* – *Not reached*

Current adoption status



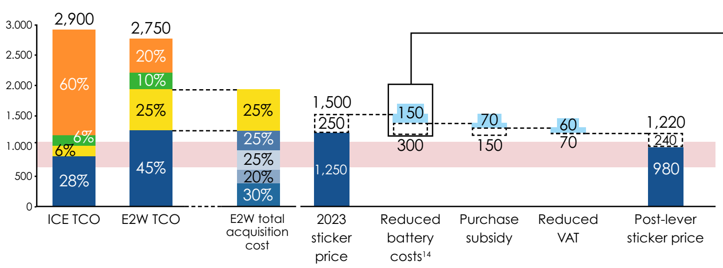
Even though **TCO is competitive, the increase in adoption rate is still very low.** The first-mover markets, fleets and high-end market, are facing issues ranging from accessibility (e.g., charging stations) and attractiveness (e.g., branding, product-market fit, charging time).

Notes: [1] BEVs = Battery Electric Vehicles; [2] BloombergNEF (2022), Electric Vehicle Outlook; [3] IEA (2023), Global EV Outlook 2023; [4] 2Ws = Two-wheelers (including Moped, Scooter, Motorcycle); [5] Data in ASEAN (n.d.); [6] ICCT (2022), Market Analysis of Two- and Three-wheeler Vehicles in Key ASEAN Member States; [7] McKinsey (2023), The real global EV buzz comes on two wheels; [8] ICE = Internal Combustion Engine Two-wheelers; [9] Systemiq analysis, BloombergNEF (2022), Electric Vehicle Outlook; [10] HKTDC Research (2023), Philippines: VAT Zero-rating Rules on Inputs Clarified; Malaysia Budgeting Announcement; [11] ICCT (2023), Total Cost of Ownership Comparison for Electric Two-wheelers in Vietnam.

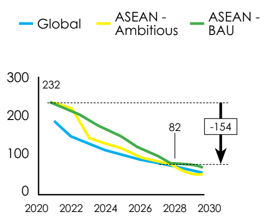
TIPPING POINTS FOR E2W

5-year TCO (in $) for mass market E2W vs ICE for 2W[13]

Mass-market sticker price (in $) E2W reduction levers



Battery cost curve[15], global vs ASEAN (in $/kWh)



Battery cost, which represents 30% of E2W sticker price, could be further reduced following a learning rate of battery deployment and increased R&D in battery manufacturing.

Sticker Price | *Financing Cost* | *VAT* | *Fuel & OM* | *Battery* | *Suspension* | *Chassis* | *Electronics* | *Range of cost* | *Target range for cost parity*

- **TCO tipping point** has been **reached.**
- **Sticker price,** which is a more relevant factor for mass-market adoption **is not close to tipping** unless **reduction in battery price.**
- **Potential solutions:** 1) Investment in battery industry, 2) Incentives (e.g., VAT/subsidy).

ENABLING CONDITIONS TO TRIGGER TIPPING POINT

PROGRESS

AFFORDABILITY

- **Cost parity for sticker prices** (i.e., pre-tax retail prices) for E2W vehicles across the region—primarily dependent on the price of the battery.
- **Reduce cashflow during usage** by availability of lowinterest financing, providing free after-sales service, and better insurance.
- **Adjusted policy to close the price gap** between E2W and ICE 2W and provide direct subsidy on E2W purchase.
- **Operationalized subsidy system** to further reduce the sticker cost.

✓ **Sticker price parity is still an issue.** The sticker price of low-end E2W is 1–2x higher compared to ICE in ASEAN.[7]

✗ **Low-interest financing is being developed by banks,** but interest in product is still lacking.

✓ **Supporting incentives.** Some countries, such as Malaysia, the Philippines and Brunei have already imposed 0% VAT[10] on green transportation, while Indonesia only charged 1%.[15]

✓ **Subsidy systems in ASEAN countries have not been able to materialize.** Indonesia has recently rolled out a purchase incentive subsidy for E2W to boost the uptake.[16]

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Additional policy to incentivize E2W penetration to manufacturer, to further reduce costs.
- ❑ **Investment for battery:** Scaling up battery production to obtain benefit from the economies of scale.
- ❑ **Improved financing costs:** Banks and lenders need to reduce the cost of financing and lease rates.

ATTRACTIVENESS

- **Performance and design fit with target market.** Achieving product market fit that resonates with market characteristics.
- **Comparable brand awareness for E2W and ICE 2W.**
- **Availability of further incentives** outside of TCO and sticker price.
- **Raised awareness of the health benefits** of using E2W due to less emissions emitted.
- **Scaled-up after-sales networks** that is comparable with ICE.

✓ **Businesses are buying, but consumers are not ready.** Only 2% of 2W are electrified,[7] mostly fleet owners as it is still seen as not attractive for mass market consumers.

✓ **Brand awareness for E2W OEMs** are still very low.[14]

✗ **No further incentives implemented** e.g., free parking and access to preferred lanes.

✓ **Low-interest BEV financing is being developed** by banks.[14]

Key actions to accelerate progress:

- ❑ **Support R&D for OEM:** To achieve product-market fit and reduce technology manufacturing costs.
- ❑ **Improved financing costs:** <see above>.
- ❑ **Introduce more incentives:** Identify non-cost incentives to further attract markets.

ACCESSIBILITY

- **Improved electricity reliability** to fulfil the rising demand due to EV penetration.
- **Scaled-up charging public station locations** both in quantity and dispersion to ensure greater coverage and accessibility.

✗ **Still big-city centric.** Around 6,000 charging stations across ASEAN countries, but most are in major cities.[17]

✓ **Need to improve electricity reliability.** Longer charging time (6-8 hours at home vs 4-hours in public), means electricity reliability will be key. Some ASEAN countries are still struggling with a 0.74 and 0.82 SAIDI an SAIFI.[18]

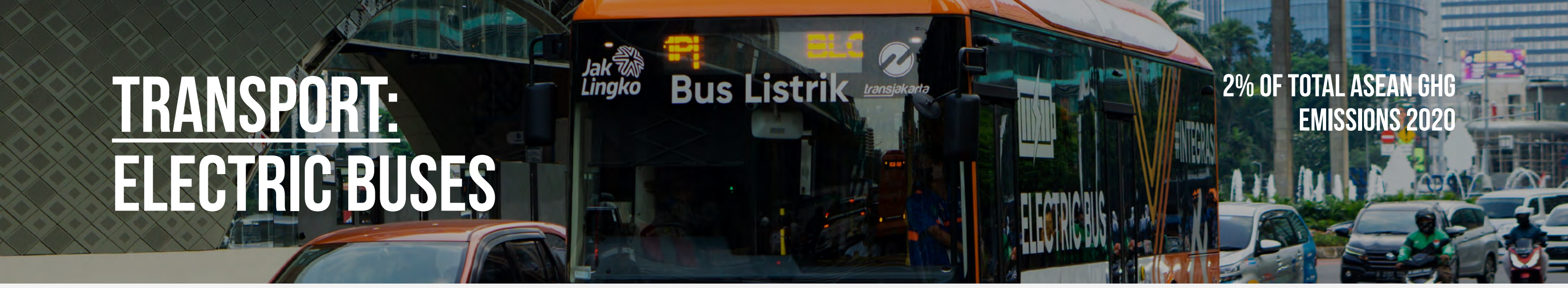
Key actions to accelerate progress:

- ❑ **Infrastructure advancement:** Enhancing public charging infrastructure and electricity reliability.

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[12] TCO is calculated for moped/scooters with battery range of ~1–1.5 kWh; [13] Battery cost are assumed to be at ~250 $/kWh, based on industry interview; [14] BloombergNEF (2022), Electric Vehicle Outlook. Global battery learning curve uses 17 and 18% learning rate. ASEAN battery learning curve is adjusted to have 15% learning rate to reflect developing battery value chain in the region; [15] Kantor Staf Presiden Republik Indonesia (2023), Government's VAT Incentives to Boost Electric Vehicle Ecosystem; [16] Indonesia Investments (2023), Indonesian Government to Offer USD $275 Subsidy to Encourage Electric Motorcycles Sales; [17] Systemiq analysis, Power Technology Research (2022) and government reports; [18] D. Kammen (2019)., ASEAN grid flexibility: Preparedness for grid integration of renewable energy. SAIDI = System Average Interruption Duration Index, SAIFI = System Average Interruption Frequency Index.



TRANSPORT: ELECTRIC BUSES

2% OF TOTAL ASEAN GHG EMISSIONS 2020

GLOBAL SECTOR CONTEXT

- **Electrifying road public transportation is important in reducing 5–7% of global emissions.**[1] Hence, switching to electric buses will help accelerate the decarbonization of road public transportation.
- **E-buses upfront capital are still costly compared to internal combustion engine (ICE) buses, but total cost of ownership (TCO) is comparable.** E-bus upfront cost, which includes vehicle cost and charging systems, can be 2.5-4x higher than ICE bus.[2]
- **Globally, 4.5% of public buses have been electrifie**d and already represented 38% of all bus sales in 2022, anchored by China's electric vehicle (EV) market. Most electrification is happening in Europe, the United States, and China.[3,4]

GEOGRAPHIC SECTOR CONTEXT

Across ASEAN

Shifting to public transportation is a universal decarbonization lever. Electrifying buses for public transportation will be relevant for all ASEAN countries.

- **Singapore is consistently ranked top 10 in sustainable public transportation indexes;**[5] but the rest of ASEAN is still lagging.
- **Thailand (68k), Myanmar (29k), and the Philippines (17k) have the largest bus fleets in ASEAN.**[6,7] These three countries and Singapore also have the biggest bus-to-road vehicle ratio.
- **ASEAN countries have developed electric bus manufacturing capabilities.**[8] This is key to lowering bus costs and accelerating the learning curve.
- **Most major cities in ASEAN have Bus Rapid Transit (BRT) model,**[9] **with operators owning their own (relatively young) assets,**[10] making it more complex to increase the uptake of e-buses.

SOLUTION STATUS IN ASEAN

Solution status stages: *Solution development* ❯ *Niche market* ❯ *Mass market*

NICHE TO MASS MARKET

E-buses are in between niche market and mass market stage. E-buses can easily reach mass market if governments receive financing support for new vehicle acquisition.

Penetration rate in ASEAN is still quite low. E- bus penetration estimated to be under 5%.[11]

Issues span across existing asset fleet age, high start-up/upfront cost, and convenience & reliability. Public authorities or bus operators might have limitations, younger ICE fleet-owners are hesitant to switch, and E-buses need 3-6 hours to charge compared to <1 hour for ICE.

Innovative business/financing models were explored. Some have adopted leasing models and carbon financing (e.g., Thailand with Article 6.2).[12]

TIPPING POINT AND ADOPTION RATE STATUS

Tipping point status

TIPPING POINT 1
TCO of E-Bus < TCO of ICE Bus

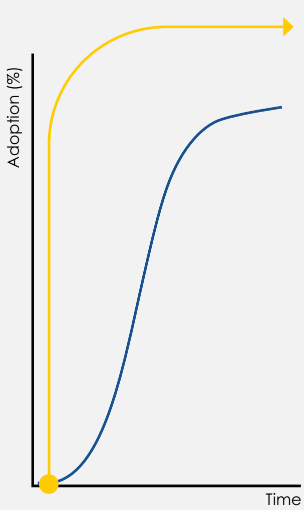
- **The first tipping point has been reached in certain cases/regions,** due to lower fuel cost (electricity vs fossil fuel) and operation & maintenance (O&M) cost.
- **Reliable, affordable, and accessible charging points** (and required power supply) will be key in maintaining TCO and reliability of e-buses.

TIPPING POINT 2
Early retirement of existing ICE Bus fleet

- **Whilst this is not a socio-economic tipping point, younger ICE fleets has been a barrier for increased e-bus adoption.**
- Resolving this issue is an important tipping point for the sector.

Legend: ✓ *Mostly reached* ○ *Reached in certain cases* – *Not reached*

Current adoption status



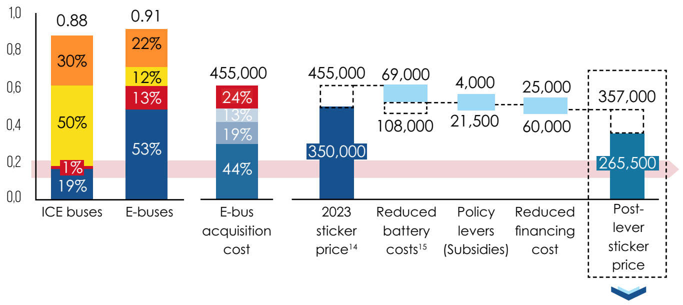
Even though **TCO is competitive, the increase in adoption rate is still very low.**

- **Invest in the battery value chain** to accelerate the learning curve.
- **Targeted policy such as OEM subsidy or mass government procurement.**
- **Retirement mechanism** for younger **ICE fleets.**
- **Introduce innovative business models** to not only reduce cashflow, but also **allow risk-sharing** of vehicle components.

Notes: [1] IEA (2019), Transport sector CO2 emissions by mode in the Sustainable Development Scenario, 2000-2030; [2] Arthur D. Little (2020), Electric Buses; [3] IEA (2022), Global EV Outlook 2023; [4] BloombergNEF (2023), Electric Vehicle Outlook 2023; [5] Oliver Wyman (2023), Urban Mobility Readiness Report 2022; [6] ASEANStats (2018), Number of public buses (in thousand); [7] Statista Research Department (2023), Number registered private buses Philippines 2020-2022; [8] BIMP-EAGA (2022), ASEAN Gears Up for a Shift to Electric Vehicles, Systemiq analysis; [9] T. Satiennam et al. (2006), A study on the introduction of bus rapid 24 transit system in Asian developing cities; [10] Expert and industry interviews; [11] ICCT (n.d.), Zero-emissions vehicle deployment statistics; [12] Quantum Commodity Intelligence (2023), Switzerland, Thailand agree e-bus ITMO scheme under Article 6.

Total cost of ownership (TCO) for e-buses vs ICE buses (in $/km)[13]

Upfront cost reduction levers for e-buses (in $)



TCO is close to being reached, but upfront cost for E-Bus is still high.

Reduced upfront costs and policy support can pull us close to even sticker price parity.

Upfront cost | Cost of financing | Fuel | O&M | Battery | Electrical System | Chassis & Suspension | Charging infrastructure | Cost reduction | Range of cost reduction | Target range for cost parity

Increased E-Bus adoption will require the ability to implement innovative business model/ financing, to either transform Capex into Opex (via risk-sharing) or reduce upfront cost directly:

- **Lease and operate.** Non-bus operator entities (e.g., utility companies) procure E-buses & lease to traditional operators.
- **Mobility-as-a-Service.** OEM offer operators vehicles + charging on a pay-to-use basis without asset ownership.
- **Special financing facility.** Offering lower-rate financing for e-bus or financial incentive to retire ICE buses earlier.
- **Carbon financing.** Voluntary market or bilateral schemes to help with upfront capital or improve operational cashflow.

ENABLING CONDITIONS TO TRIGGER TIPPING POINT | PROGRESS

AFFORDABILITY

Enabling conditions:

- **Continued battery learning curve** to lower down upfront cost of electric buses, that currently accounts around 50–60% of total TCO.[13]
- **Lowered TCO from charging infrastructure cost and charging-related cost (electricity price).**
- **Implementation of business models to reduce upfront capital** such as lease and operate, special financing facility, or carbon financing mechanisms.
- **Improved policy/regulatory environment** to enable new entities to enter the bus transport ecosystem, seeing several intangible aspects of the current ecosystem is hindering uptake of business models.

Progress:

- ✓ **Investments in battery and e-bus manufacturing** (incl. critical mineral supply chain) are in progress across ASEAN.
- ✓ **Charging infrastructure and related charging costs may already tip the TCO of e-buses against ICE** in specific routes and charging types, as TCO is highly dependent on route.[13]
- ✓ **Several case studies of lease-and-operate** (e.g., Enel X in Santiago)[16] and **Special Financing Facility** (e.g., IFC) has been implemented for e-buses in Latin America. Thailand has been able to raise innovative e-bus financing through Article 6.2 mechanism, with Swiss as financier.[12]
- ✗ **Barrier to entry remains high,** permitting-wise.

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Regulatory support (e.g., procurement process or permits for non-operators to contract with transport authorities) for innovative business models.
- ❑ **Investment for battery:** Scaling up battery production to obtain benefit from the economies of scale.
- ❑ **Innovative business financing:** Continued efforts to access carbon financing or set-up of financing facilities.

ATTRACTIVENESS

Enabling conditions:

- **Separation/reduction of cost** through either lease-and-operate models or direct reduction through special financing or carbon financing mechanisms.
- **Improved charging mechanism and infrastructure** to further increase accessibility to non-fixed/ longer routes.
- **Higher urgency for better air quality** in metropolitan cities, to influence public push for e-bus procurement.

Progress:

- ✓ **Innovative business models for e-buses** have been used globally but have not become mainstream in ASEAN.
- ✓ **Push for better air quality and awareness has increased post-COVID.** This is apparent with prevalence of social media creating movements on this matter.
- ✗ **Charging infrastructure has not been developed well.**

Key actions to accelerate progress:

- ❑ **Policy adjustments:** Regulatory support for innovative business models to be successfully implemented.
- ❑ **Societal push:** Further strengthen the push for better air quality in metropolitan cities.

ACCESSIBILITY

Enabling conditions:

- **Improved charging mechanism and infrastructure** to further increase accessibility to non-fixed/ longer routes.

Progress:

- ✗ **Charging infrastructure has not been developed well** for non-fixed/longer routes due to the lack of clear deployment plan, although is increasingly improved for BRT routes (mostly via depot charging).

Key actions to accelerate progress:

- ❑ **Policy adjustments:** <see above>.
- ❑ **Innovative business model/financing:** <see above>.

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[13] ICCT (2023), Evaluation of factors that affect total cost of ownership in support of Transjakarta's electric bus adoption plans; [14] Systemiq analysis; [15] Using battery price of 275-300 $/kWh, based on BloombergNEF's 2020 e-bus battery pack numbers in the EU; [16] Morris, C (2020), IEA case study #2: electric buses in Santiago, Chile.

MANUFACTURING: INDUSTRIAL HEAT

4% OF TOTAL ASEAN GHG EMISSIONS 2020

GLOBAL SECTOR CONTEXT

HEAT CONSUMED BY SECTOR[A] (EJ)

Industry	Buildings - space and water	Agri	Total
107	96	6	209

Heat accounted for half (209 EJ) of the world's total final energy consumption in 2019. Half of that came from industrial heating (107 EJ). [A]

INDUSTRIAL HEAT DEMAND BY RANGE[B] (EJ)

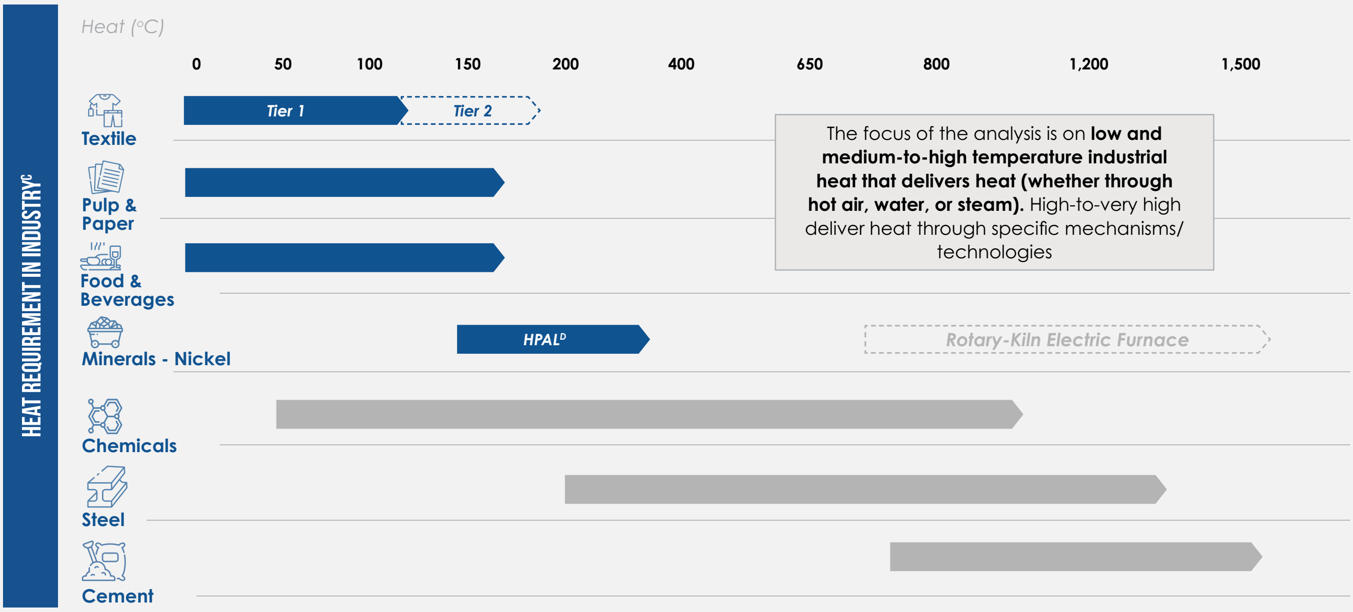
Heat range (°C)

0-60	60-150	150-200	200-400	400-650	>650	Total
15%	12%	17%	6%	8%	41%	108

Low (<150 °C)
- Washing
- Rinsing
- Cooking
- Sterilisation

Medium-to-High (150-650 ° C)
- Drying
- Evaporation
- Distillation
- Activation

High-to-Very high (>650 ° C)
- Steam reforming & naphtha cracking
- Hydrogen heating for DRI steel
- Calcination of limestone for cement
- Melting in glass furnace



INDUSTRIAL HEAT DECARBONISATION PATHWAYS

Currently, there is a range of decarbonisation solutions: direct electrification (e.g., heat pumps, thermal storage), **low-carbon heat** (e.g., concentrated solar), and **low-carbon fuels for specific conditions** (e.g., biomass that is low-cost & sustainable supply):

Existing

Coal-based heat

1. **Biomass/Gas boiler**
Co-firing with byproduct biomass or gas, depending on industry process

Low-carbon solutions

2. **Heat pumps**
Deploy heat pumps (can also be for electrified resistance heating for higher temp and precise control requirements) in regions with relatively inexpensive electricity

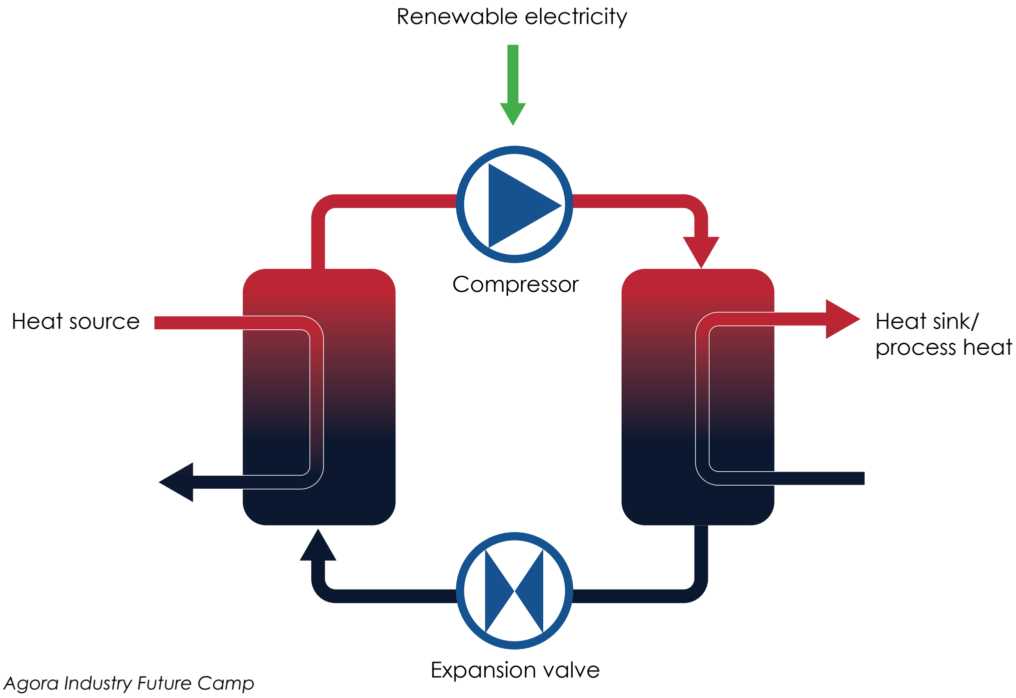
3. **Electric-Thermal Energy Storage**
Deploy in regions with inexpensive intermittent renewable electricity is available

4. **Concentrated Solar Thermal**
Evaluate solar thermal in advantageous areas for solar power

Focus of this analysis is on direct electrification of heat, the end-state solution. Since the use of alternative fuel are either site/industry specific or have supply constraints (e.g., biomass), it is therefore only considered as a niche solution.

Notes: [A] Sourced from IEA (2018); [B] Sourced from IEA, modified by internal calculation; [C] Sourced from Energy Innovation (2022), Decarbonizing Low-Temperature Industrial Heat in the U.S.; [D] HPAL stands for High-Pressure Acid Leaching

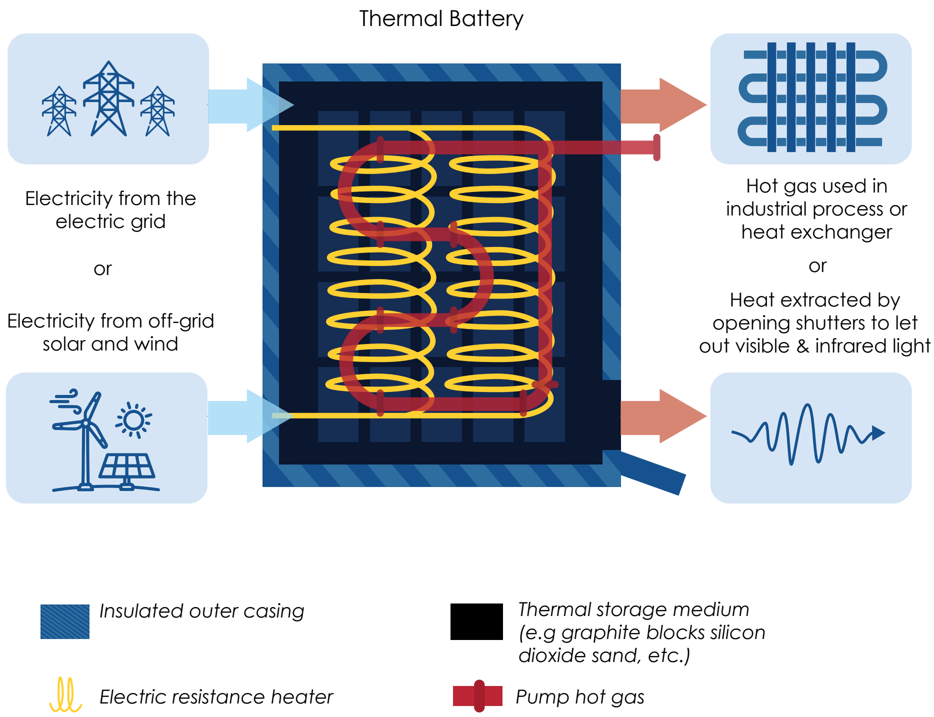
Heat pumps[E]



Agora Industry Future Camp

- **Simple technology. Air-sourced heat pumps** works like air conditioning, only in reverse. It extracts heat from a source (e.g., surrounding air or waste heat), lifts the temperature through compression, and transfers heat to where it is needed.
- **Heat pumps are far more efficient than conventional heating** (e.g., gas steam boilers) because heat is transferred rather than generated. It has the **efficiency of 200–500%** depending on the desired heat output range (up to ~200°C) and source.
- A heat pump typically consists of a compressor, which moves a refrigerant, and heat exchangers. Resulting heat from heat pumps can be delivered via **superheated air, hot water, or steam,** or to directly heat materials.

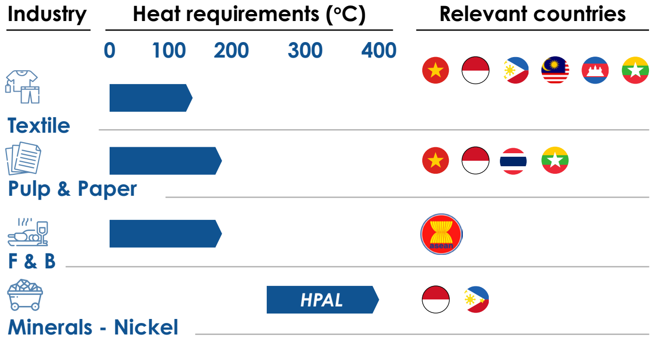
Electric Thermal Energy Storage (ETES)[F]



- **An Electric-Thermal Energy Storage (ETES)** is **a relatively new industrial heating technology** that can store heat at up to 1,800°C (using storage mediums such as volcanic rocks, molten salts, and clay bricks) and deliver heat at temperature up to 1,500-1,700°C.
- **ETES utilizes clean, low-cost, and intermittent power generation** such as wind and solar because its heating cycle does not have to be constant due to having the thermal storage capability.
- **Certain ETES solutions can also be setup to provide combined heat and power on a continuous basis.** Both heat and power can be at low-cost, where solar/wind are available at reasonably low-cost.

Notes: [E] Agora Industry, FutureCamp (2022): Power-2-Heat: Gas savings and emissions reduction in industry. [F] Energy Innovation: Policy and Technology LLC (2023); Industrial Thermal Batteries Decarbonizing U.S. Industry While Supporting a High-Renewables Grid (n.d.)

GEOGRAPHIC SECTOR CONTEXT



- **Industrial heat contributes to 30% of energy demand and ~280 MtCO_2e emissions in ASEAN. Almost 40-50% of industrial heat comes from coal,** with some utilizing gas where available.[1]
- **Heating is crucial for >11% of ASEAN exports sectors.** Textile (5%), mineral refineries (5%), pulp & paper (1%).[2] Market restrictions (e.g., CBAM) are coming, these industries must decarbonize.[3]
- **Electrification must be coupled with grid decarbonisation.** Grid emission factors in ASEAN is 0.56~0.8 tCO_2/MWh.[4] Direct electrification solutions can also use near-site dedicated VRE.

SOLUTION STATUS IN ASEAN

Solution status stages: ● *Solution development* 〉 ● *Niche market* 〉 ● *Mass market*

NICHE MARKET

Heat pumps

For low-temperature heat using heat pumps, this solution is in the **niche market**.

- **Nascent uptake in ASEAN.** Even globally, industrial heat pumps adoption are not yet widespread (98% in buildings).[5]
- Despite its very high efficiency (3-5.5x), conditions like **cheap incumbent fuel**,[6] and **lack of awareness of the technology** provide barriers to adoption.

SOLUTION DEVELOPMENT TO NICHE

Electric-Thermal Energy Storage

ETES is on the edge of **development stage**. Some companies already completing early deployments.[7]

Competitive levelized cost of heat ($/MWh-th) is achievable with low-cost intermittent electricity (e.g., ~6 hrs/day) through[7]:

- **Direct connection to solar/wind farms,** or
- **Buying electricity from a wholesale market that has daily price dips during hours of high solar/wind generation**, i.e., where solar/wind are at high penetration in the grid mix, and there is a wholesale electricity market with hourly pricing.

TIPPING POINT AND ADOPTION RATE STATUS

Tipping point status

Legend: ✓ *Mostly reached* ○ *Reached in certain cases* – *Not yet reached*

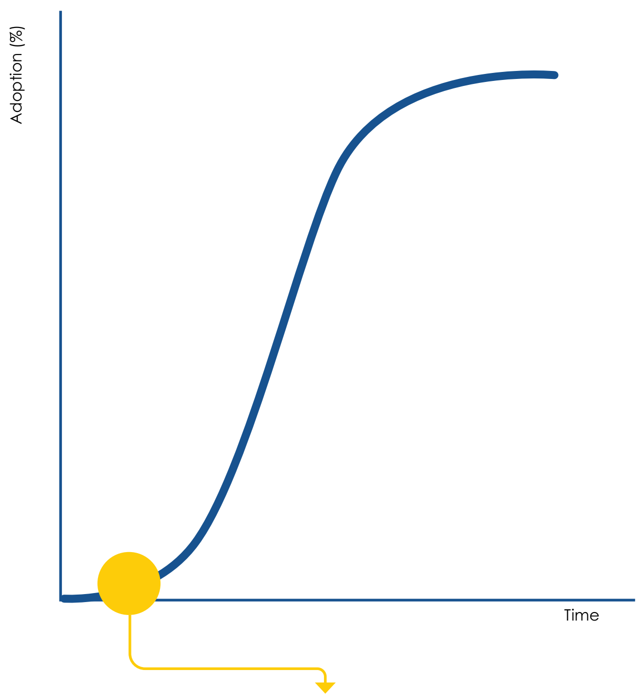
✓ **LOW HEAT TIPPING POINT** — LCOH of Heat Pumps < LCOH Gas

- **Has a closer path to the tipping point.** However, this is determined by market conditions, particularly energy costs (i.e., coal or gas prices vs. electricity prices).
- **Heat pumps can also provide protection against fossil fuel price fluctuations and security of supply for primary energy.**
- **Strong policy to disincentive fossil fuel usage** (e.g., carbon tax) can help accelerate heat pumps uptake.

○ **MED-HIGH HEAT TIPPING POINT** — LCOH of ETES < LCOH Gas

- **Heat provided through ETES has not yet reached a tipping point** due to solutions still being at early commercial deployments stage (e.g., early niche market), and conditions of low-electricity price for ~6 hr/day has not yet been reached.
- **However, ETES can reach an initial tipping point** where conditions are in place for superior economics, e.g.: dedicated (off-grid) VRE as electricity supply, and combined heat and power configuration.

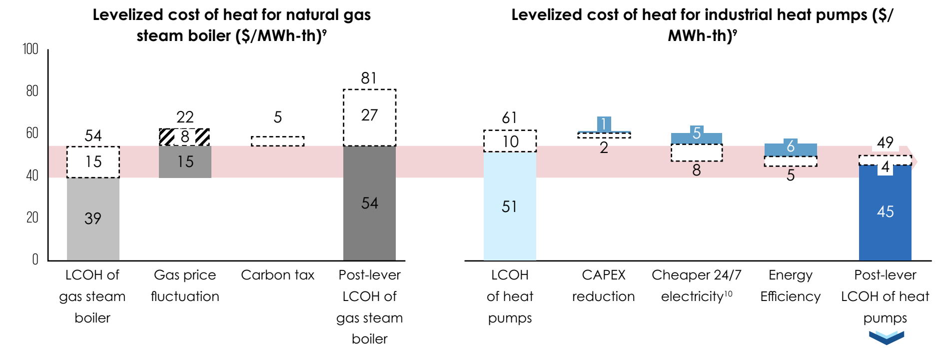
Current adoption status



Inflection point will be **driven by affordability** (LCOH: levelized cost of heat), **attractiveness** (push for lower- carbon products from market) and **accessibility** (availability of tech & engineering capability)

Notes: [1] ASEAN Centre for Energy (2022), 7th ASEAN Energy Outlook, Systemiq analysis. [2] Trade Map, Systemiq analysis. [3] European Commission (n.d.), Carbon Border Adjustment Mechanism, [4] ADB (2017), Guidelines for Estimating GHG Emissions of Asian Development Bank Projects. [5] Energy Innovation (2022), Decarbonizing Low-Temperature Industrial Heat in the U.S. [6] Electricity-to-gas price ratio is usually used to reflect the economics for fuel switching. Because heat pumps are very efficient technology, a ratio between 3–5 is enough for heat pumps to compete economically. In ASEAN, owing to relatively cheap electricity price, this is already within the range of switching (2.5–5.5) depending on whether there is domestic gas price cap and gas infrastructure available at the site. However, grid emissions factor will be another determining factor to switch.
Source: Systemiq analysis, BloombergNEF & WBCSD (2021), Hot Spots for Renewable Heat. [7] Expert and industry interviews.

TIPPING POINTS FOR LOW-TEMPERATURE INDUSTRIAL HEATING



Heat pumps can be cost-competitive due to its ability to deliver efficient (2 to 5.5x) power to heat.

Fossil fuel LCOH | *Heat pumps LCOH* | *Range of cost* | *Additional but uncertain change* | *Range of tipping point*

- **Industrial heat pumps are already close to a tipping point**, in part due to its electricity-to-heat conversion efficiency.
- **The issue on low adoption is more on accessibility** as air-/ground-source heat-pumps, as opposed to waste heat-based, are not well-known in ASEAN.
- **Mainstreaming technology through** collaboration with OEM and **greening the power grid** will be key to further accelerating the uptake of heat pumps.

ENABLING CONDITIONS FOR LOW HEAT TIPPING POINT | PROGRESS

AFFORDABILITY

Enabling conditions

- **Comparable levelized cost of heat for heat pump vs gas boiler.**
- **Disincentivized coal and gas utilization through regulation.**
- **Supportive regulations and collaboration between OEM countries** on new technology adoption.
- **Low-interest financing for energy efficiency projects,** especially related to direct electrification.

Progress

- ✓ **Levelized cost of heat from heat pumps still varies** by geography and electricity price.
- ✗ **Regulation has not incentivized the usage of heat pumps** in place of fossil-fuel based heat.
- ✓ Some customers of major industries in ASEAN are **providing financing mechanisms to facilitate energy efficiency projects.**[7]

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Specific electricity price for heating to support electrified heat source or carbon tax on coal/gas.
- ❑ **Financial support:** Grants, tax incentives, lending mechanism and access to low-cost financing.

ATTRACTIVENESS

Enabling conditions

- **Heat pumps reaching commercial scale Technology Readiness Level** for all temperature requirements (up to 160°C).
- **Opportunity to increase pricing on products with lower emissions intensity** (e.g., EVs with low production emissions in supply chain including battery metals such as nickel).
- **Increased pressure to lower carbon footprint from market requirement on emissions** (e.g., EU's CBAM.[4]
- **Availability of third party "Heat-as-a-Service" business model** (via a long-term Heat Purchase Agreement) **can be considered.**
- **Demand for increased safety and worker's health** in industrial areas due to cleaner and electrified heat generation.

Progress

- ✓ **Industries are pushing for lower-emissions products** in food, textile and critical minerals.
- ✓ **EU's CBAM came into effect on 1 October 2023 for initial sectors** and will only increase its industry coverage.[4]
- ✓ **Mass adoption of industrial heat pumps are limited to low heat, but** reaching commercial stage in >130°C heat requirements.[8]
- ✓ **Concerns for air quality has been increasing** in major cities.

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Enabling power wheeling access to lower-cost PPAs from renewables developers.
- ❑ **Energy efficiency or emissions standard:** Mandate to raise industry energy efficiency standards.
- ❑ **Market advocation:** Key end- markets that are buyers of products from ASEAN (e.g., fashion brands buying textiles) should signal the need for low-carbon products.

ACCESSIBILITY

Enabling conditions

- **The existence of reliable power grid** to consistently power heat pumps.
- **The existence of heat grid** in some industrial parks **to enable "Heat-as-a-Service" model delivery.**
- **Availability of technology (OEM) and services (EPC) to install customized heat pump systems** that can be integrated/retrofitted with existing heating system.
- **Industrial park entities play a supportive role** in heat electrification.

Progress

- ✓ **Electricity reliability is acceptable.** Apart from questionable reliability (e.g., Cambodia, Laos), electricity is reliable.
- ✗ **Technology introduction from OEMs is not at the same pace** as European or USA industry.

Key actions to accelerate progress:

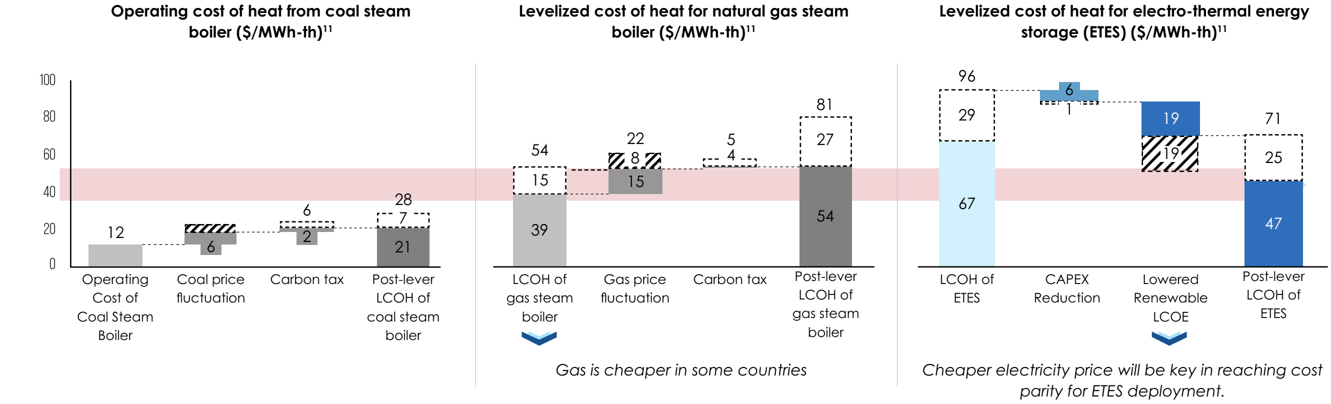
- ❑ **Increase reliability of grid:** To increase accessibility of heat pumps even in remote industrial locations.
- ❑ **Accelerate technology introduction:** Soliciting OEMs should be courted to introduce tech in ASEAN.
- ❑ **Industrial park electrification mandate:** Increasing uptake in electrification through industrial park managing entities.

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[8] Levelized cost of heat (LCOH) of gas steam boiler and heat pumps are calculated using Power-2-Heat transformation cost calculator developed by Agora Industry, FutureCamp, and Wuppertal Institute, accessible here: https://www.agora-energiewende.de/en/publications/transformationskostenrechner-power-2-heat/. Agora Industry, FutureCamp (2022): Power-2-Heat: Gas savings and emissions reduction in industry; and Energy Innovation (2022), Decarbonizing Low-Temperature Industrial Heat in the U.S. are used as primary reference for key cost and performance assumptions; [9] Heat pumps need 24/7 electricity, and on-site renewables are not able to provide that any reasonable cost.

TIPPING POINTS FOR MEDIUM-TO-HIGH TEMPERATURE INDUSTRIAL HEATING



- **ETES technology is still in the early stages of commercialization.**
- **Moving forward, further cost reduction** for ETES will come predominantly through even lower cost of electricity for the ~6 hours per day, e.g., from dedicated solar/wind either on-site or delivered through the grid with PPA and power wheeling.

Fossil fuel LCOH *ETES LCOH* *Range of cost* *Additional but uncertain change* *Range of tipping point*

ENABLING CONDITIONS FOR MED-HIGH HEAT TIPPING POINT

PROGRESS

AFFORDABILITY

Enabling conditions:

- **Comparable levelized cost of heat for** Electric Thermal Energy Storage (ETES) vs Gas Boiler.
- **Local / regional cost of solar reduced** (e.g., through enabling policies, economies of scale), to provide lower-cost electricity supply either off-grid with private or via PPA with power wheeling through the network. Combined with **streamlined permitting for building dedicated on-site or near-site power plant.**
- **Supportive regulations and incentives on new technology adoption,** e.g., CapEx subsidy, contract for difference on price of heat. Combined with **disincentives on use of coal and gas for heat.**

Progress:

- ✓ **LCOH of electrified heat generation varies measurably across ASEAN,** due to different electricity prices from dedicated renewables (e.g., solar PV).
- ✓ **Historical learning curve has made Solar PV LCOE decline significantly in the last decade** and should further decline both driven by global tech cost declines and any supportive policies enacted locally/regionally (e.g., lowered import tariffs).
- ✗ **Specific regulations and subsidies are not yet present as ETES is a new technology.**
- ✓ **Captive power development is less bureaucratic** than on-grid power project development across ASEAN countries.

Key actions to accelerate progress:

- ❑ **Policy adjustment:** capex subsidy, grants, tax and fiscal incentives, and policies to enable off-grid or power wheeling to support low-cost PPAs.
- ❑ **Commercial pilot project in ASEAN countries.**

ATTRACTIVENESS

Enabling conditions:

- **Supportive regulations and incentives** on new technology adoption, particularly on its combined (clean) heat and power (CHP) capability.
- **Demand and green premium for products with lower emissions intensity.**
- **Increased pressure to lower carbon footprint from market requirement on emissions** (e.g., EU's CBAM).[4]
- **Demand for air quality and worker's health** in industrial areas due to cleaner heat generation.

Progress:

- ✗ **Specific regulations and subsidies are not present** due to ETES technology still being developed.
- ✓ **Industries are pushing for lower-emissions products** in food, textile and critical minerals.[8]
- ✓ **Concerns for air quality has been increasing** in major cities.
- ✓ **EU's CBAM came into effect on 1 October 2023 for initial sectors** and will only increase its industry coverage to other sectors.[3]

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Regulations on reduced air pollution which will drive industrials to clean alternatives to coal and natural gas.

ACCESSIBILITY

Enabling conditions:

- **Availability of technology (OEM) and services (EPC)** to install ETES solutions.
- **Streamlined permitting for building dedicated captive VRE power** in nearby industrial parks.

Progress:

- ✓ **ETES solutions are still at the stage of early deployment** and will take a few years before broad industry application.
- ✓ **Captive power development is already less bureaucratic.**

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Streamlined permitting process for captive power that is designated for electrified industrial heat, including allowing private wires to connect near-site generation to industrial sites in proximity (e.g., <20 kms).

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

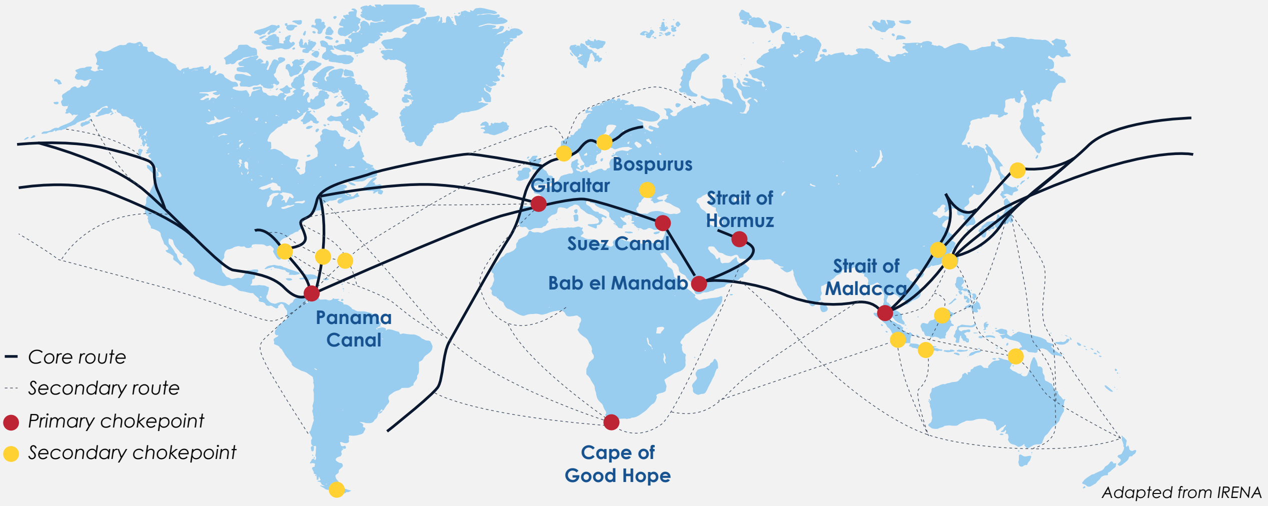
Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[3] Same as previous page. [10] LCOH of gas steam boiler and electric-thermal energy storage (ETES) are calculated using Power-2-Heat transformation cost calculator developed by Agora Industry, FutureCamp, and Wuppertal Institute, accessible here: https://www.agora-energiewende.de/en/publications/transformationskostenrechner-power-2-heat/. For ETES, electric boiler function is used and adjusted. Agora Industry, FutureCamp (2022): Power-2-Heat: Gas savings and emissions reduction in industry; and Energy Innovation (2023), Industrial Thermal Batteries are used as primary references for key cost and performance assumptions. See Technical Appendix for more details.

SHIPPING: GREEN AMMONIA FOR SHIPPING FUEL

3% OF TOTAL ASEAN GHG EMISSIONS 2020

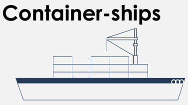
GLOBAL SECTOR CONTEXT



Adapted from IRENA

- **~90% of global trade is done through shipping, mostly by long-haul vessels. These vessel types are responsible for ~85% of emissions.**[A]
- **Decarbonizing shipping can be done through alternative energy sources** to complement operational and energy efficiency.
- **Port location determines importance and influence in shipping industry**, including for decarbonization efforts. The top 30 ports global are responsible for 60% of the global container trade.[B]
- **Leading solutions for clean fuel are green ammonia and methanol**, given energy density limits for electric engines or hydrogen fuel, as well as constraints on sustainable biomass availability. **Green ammonia is the solution in focus in this analysis, due to challenges expected in sourcing sustainable CO_2 cost effectively for green methanol.**

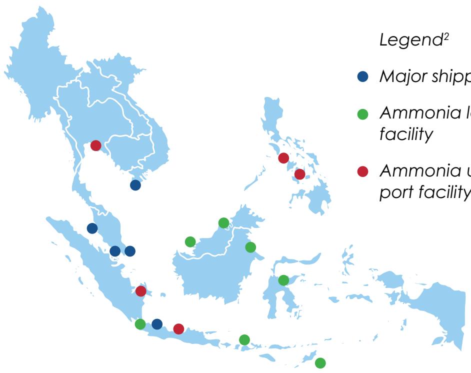
Important long-haul global shipping routes[C]

Vessel type	Goods	Route	Volume (m tonnes, 2019)
Container-ships 	Diversified-mainline	Transpacific mainline	202
		Asia-Europe mainline	235
		Translatlantic mainline	58
Dry bulk 	Diversified - non- mainline	Non-mainline East-West	193
		North-South	89
		South-South	144
		Intra-regional	405
	Iron ore	Australia-China	689
		Brazil-China	212
		Australia-Japan	62
		Australia-South Korea	53
		Brazil-Malaysia	29
		South Africa-China	17
		Brazil-Japan	13
		Brazil Netherlands	11
	Soyabeans	Brazil-China	58
		United States-China	23
	Bauxite	Guinea-China	38
		Australia-China	31
	Manganese	South Africa-China	11
	Nickel ore	Philipines-China	25
		Indonesia-China	18

ASEAN is in the intersection between major large/very-large shipping routes that account for at least 10% of global shipping volume. This means ASEAN is in a strategic position to influence global shipping decarbonization efforts.

Notes: [A] Systemiq (2023), The Breakthrough Effect: How to Trigger a Cascade of Tipping Points to Accelerate the Net Zero Transition; World Shipping Council (n.d.); IRENA (2022), A Pathway to Decarbonize the Shipping Sector by 2050; B) Global Maritime Forum (2023) Fuelling the decarbonisation of iron ore shipping between Western Australia and East Asia with clean ammonia; C) Getting to Zero Coalition (2021), The Next Wave Green Corridors.

GEOGRAPHIC SECTOR CONTEXT



- **Southeast Asia has 5 of the top 30 ports in terms of throughput.** (Singapore, Klang, Tanjung Pelepas, Tanjung Priok, and Ho Chi Minh has >5 million TEU annual throughput[3].
- **Singapore has a 20+% share of global bunkering demand[4]**, making their bunkering strategy significant for global shipping.
- **ASEAN as green corridors beneficiaries[5].** Maritime green corridors are likely to play a role as enablers of the niche markets phase in green ammonia for shipping fuel uptake, and ASEAN sits in the middle of several corridors (e.g., Australia-East Asia, Inter-continental Container corridors).
- **ASEAN has existing ammonia infrastructure to build from.** There are currently 12 ammonia loading/unloading ports in ASEAN, even though there is still a lot of development to be made to reach bunkering capability, including the vessels procurement.

GLOBAL SOLUTION STATUS

Solution status stages: *Solution development* ❯ *Niche market* ❯ *Mass market*

SOLUTION DEVELOPMENT

Green ammonia for shipping fuel solution is still in further development.

- **Green ammonia for shipping requires 4 aspects to be fulfilled:**
  1) **Bunkering infrastructure:** Ammonia handling safety and impact analysis are required. *Still in development[6]*
  2) **Green ammonia production:** Green ammonia projects underway but still at pilot scale. *In niche market[6]*
  3) **Ship engine development:** No ammonia-engine ships are in deployment right now. *Still in development[6]*
  4) **Handling safety:** Required for mass market, leading ports (e.g., Singapore) have done studies. *Still in development[6]*
- **Technology development is progressing quickly.** Up to Q1 2022, 30% of new ship projects and 25% of bunkering & infrastructure projects globally are for ammonia[7].

Only cheapest green hydrogen/ammonia (+carbon tax or equivalent subsidy) will reach cost parity with HFO, and ASEAN's projected cost of production does not reach this. Add to the fact that 90% of global ships are being built in East Asia[8], **it is expected that ASEAN's contribution to green ammonia for shipping fuel will be bunkering, not production.**

TIPPING POINT AND ADOPTION RATE STATUS

Tipping point status

Legend: ✓ *Mostly reached* ○ *Reached in certain cases* – *Not yet reached*

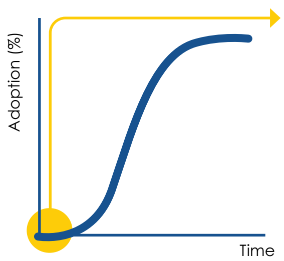
–

TIPPING POINT 1

Cost of Green Ammonia ($/ton) vs Heavy Fuel Oil

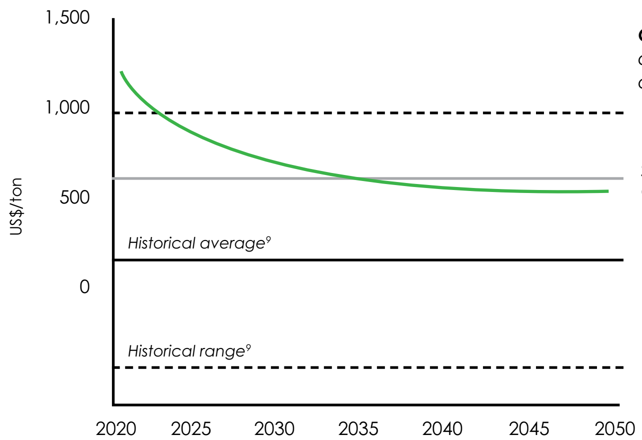
- **Tipping point will be focused on the cost of green ammonia** vs the incumbent fuel, Heavy Fuel Oil.
- Since solution is in development stage, **the tipping point has not been reached.**

Current adoption status



Utilization of green ammonia as shipping fuel is still at a nascent stage. Further development and synchronization of each aspect (infrastructure, ship engine, fuel production) is required for accelerated adoption.

TIPPING POINTS FOR GLOBAL SHIPPING



Cost Parity: *requires green hydrogen price of $1.6kg + $100/ton carbon price or equivalent subsidy.1 Government subsidies such as the IRA can further accelerate this tipping point.*

HFO + Equivalent Subsidy

Green Ammonia (HFO equivalent)[10]

Heavy Fuel Oil (HFO)[9]

Even though fuel cost parity will require time and support from governments, **TCO of ammonia ships are competitive for several routes with the help of subsidies (e.g., IRA),** as per studies done by Global Maritime Forum.

Notes: [1] IRENA (2022), A Pathway to Decarbonize the shipping sector by 2050. [2] World Shipping Council (n.d.), The Top 50 Container Ports. [3] SeaTrade Maritime, Minerva (n.d.);. [4] Global Maritime Forum (2021), The Next Wave: Green Corridors. [5] Systemiq analysis; [6] Getting to Zero Coalition (2022) Mapping of Zero Emission Pilots and Demonstration Projects; [7] United Nations Conference on Trade and Development (UNCTAD) (2022), Ships built by country data; [8] Systemiq (2023), The Breakthrough Effect: How to Trigger a Cascade of Tipping Points to Accelerate the Net Zero Transition; [9] Making Mission Possible (2022), Making 1.5-Aligned Ammonia Possible; [10] INSEE Data (n.d).

ENABLING CONDITIONS TO TRIGGER TIPPING POINT		PROGRESS
AFFORDABILITY	• **Cost parity for green ammonia as shipping fuel vs. HFO,** with the help of subsidies. This cost parity challenge is mostly due to 2 tonnes of NH³ is equivalent to 1 tonne of HFO in terms of energy volume. • **Development of major green corridor that goes across the ASEAN region.** (e.g., Asia-Europe Mainline).	✗ **Total cost of ownership** of green-ammonia powered vessel expected to be ~70% higher than HFO in 2030[11], but several routes can reach cost competitiveness, as outlined by recent GMF studies. ✗ **Cost parity is possible by 2035** as green hydrogen cost falls (~$1.6/kg), but only in favourable locations and coupled with CO2 price/equivalent subsidy of ~$100/tCO21. EU ETS will tax 50% of emissions for ships docking in EU ports.[12] ✗ **No indication of ASEAN governments to provide subsidy** on the development of green corridors. **Key actions to accelerate progress:** ❑ **Policy adjustments:** Carbon tax for HFO usage in shipping. ❑ **Green ammonia development.** Incentive for green corridor development, including ammonia bunkering and other technology investments.
ATTRACTIVENESS	• **Market incentives and market push to provide low-carbon shipping.** As companies using shipping lines aim to reduce Scope 3 emissions, decarbonization of shipping is imminent. • **Updated international safety & regulation** to address handling and safety concerns around ammonia. • **Proven positive net impact of ammonia.** Concerns over Ammonia usage to natural nitrogen cycle need to be addressed. • **Enforcement on low-carbon shipping,** both by ports and regional or country carbon regulations.	✓ **IMO is starting to operationalize their decarbonization efforts** through Carbon Intensity Indicator program.[12] ✓ **Companies are starting to ask shipping lines to provide ship carbon emission reports** as part of vendor selection.[12] ✓ **Several international ports have increased pollution standards** requirement for ships to dock, and EU ETS will tax 50% of emissions for ships that dock in European ports.[12] ✓ Several coalitions have been developed e.g., Cargo Owners for Zero Emissions Vessels (COZEV) or Zero-Emissions Maritime Buyers Alliance (ZEMBA) **Key actions to accelerate progress:** ❑ **Policy and regulation adjustments.** Stricter regulation in ports related to pollution and emissions. ❑ **Market incentive.** Green premium for ships using low-carbon or alternative fuel. ❑ **Facilitate market coalitions for green shipping.**
ACCESSIBILITY	• **Availability of multiple large ports with bunkering infrastructure,** focused on major and secondary hubs in ASEAN (e.g., Port of Singapore, Vietnam, Indonesia). • **Shipyards developing capacity to build or retrofit ships** to run safely and efficiently on ammonia. • **Updated international safety & regulation** to address handling and safety concerns around ammonia.	✓ **Plans and studies are in place for import/bunkering terminals** at major ports (Rotterdam, Hamburg, and Singapore).[12] ✗ **Pipeline for shipyards** still a major hurdle with overdemand. ✓ **First models expected to be available in** 2026 (e.g. Eastern Pacific Shipping placed order for ammonia ships).[7] ✗ **Safety regulations and re-training the workforce for ammonia handling** has not been issued or commenced. **Key actions to accelerate progress:** ❑ **Improve bunkering capabilities.** ❑ **Accelerating manufacturing capabilities.** ❑ **Including ammonia handling/usage in global safety standards and regulations.**

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

ASEAN FOCUS FOR GREEN AMMONIA

- **Improving bunkering infrastructure to also provide low-carbon fuels.** Strategic geographic positioning that is well aligned with existing major shipping routes and improved ability to provide bunkering activities in Singapore or Indonesia.
- **Developing ship-building capabilities for low-carbon shipping engines.** Specifically, Vietnam, since there is overdemand in Japanese and Korean shipyards.
- **Forging strategic relationships with countries/private sector that has low green hydrogen/ammonia production.** Strategic off-take agreements with first-mover private sectors that can provide low-cost ammonia producers, such as Australia.

To bring the 3 focus opportunities together, ASEAN countries should look into developing green industrial parks (e.g., for nickel in Philippines and Indonesia) to trigger new large-scale strategic green corridors to China or other battery manufacturing regions, in which these green corridors should also integrate shipping decarbonization in their planning. With the increase in interest for low-carbon battery value chains, this is a strategic approach that should be explored in unison by governments across ASEAN.

[11] Maersk- McKinney Moller Center for Zero Carbon Shipping (October 2021), Industry Transition Strategy; [12] Expert and industry interview; [13] Ammonia Energy Association (August 2022).

SECTION 4

TIPPING CASCADES AND SUPER-LEVERAGE POINTS

"The Breakthrough Effect in ASEAN identifies two super-leverage points to help trigger a cascade of tipping points across a total of eight sectors representing 50% of ASEAN's emissions."

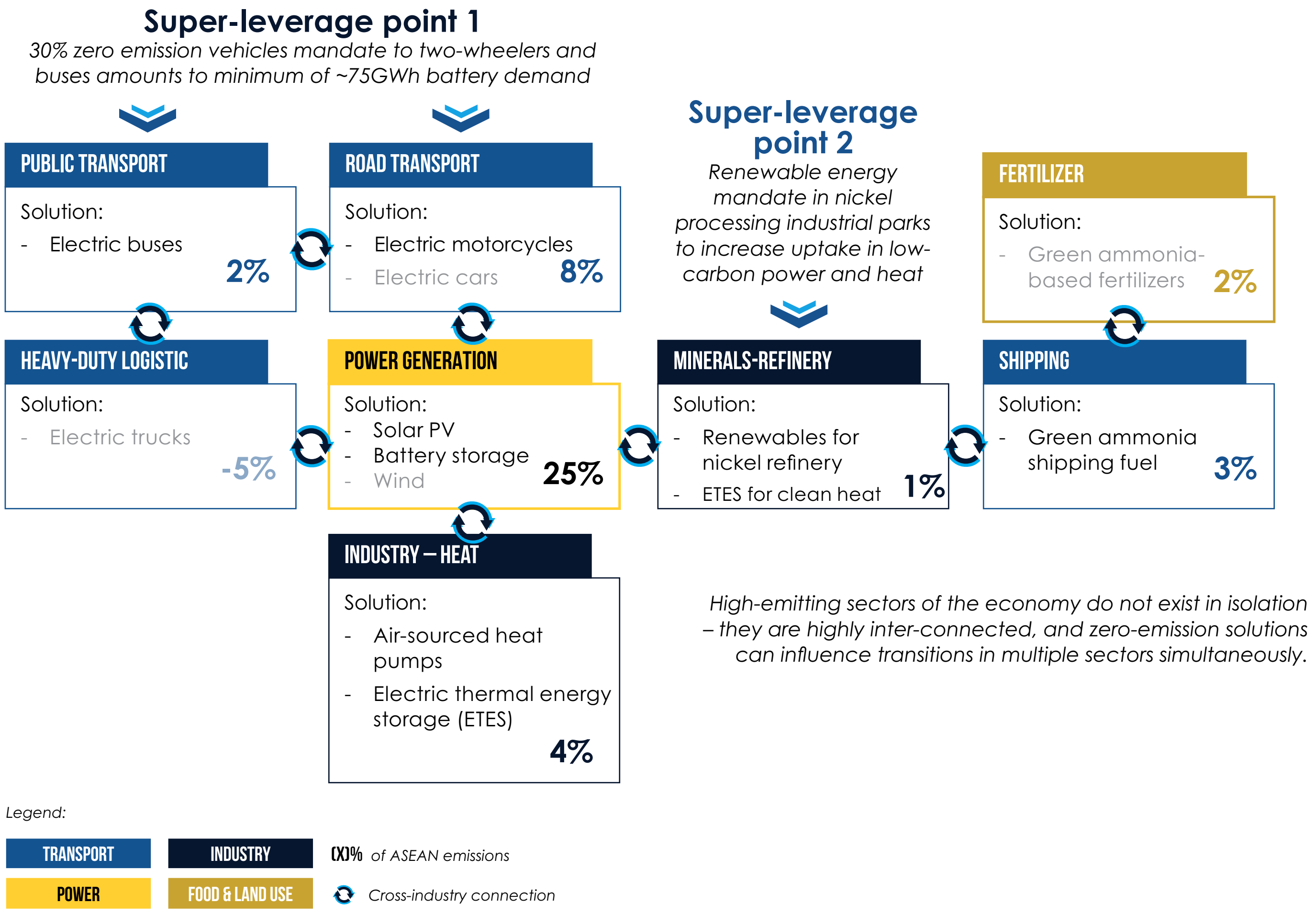
Many low-carbon solutions can support transitions in multiple different sectors. For example, low-cost renewable power combined with cheaper and longer-duration battery storage is now making direct electrification more feasible across many sectors of the economy (e.g., road transport, industrial heating). Globally, advancements in compact, durable, and longer-lasting lithium-ion batteries are being witnessed. These batteries, driven by the demand for EVs, are also benefiting the power sector by enabling the adoption of renewable energy on a larger scale. This progress is constantly pushing the boundaries of the energy transition. In 2021, the estimated scale of investment of decarbonizing 70% of global emissions was 40% lower than two years earlier ($3.2 trillion per year vs. $5.3 trillion per year in 2019), thanks to technologies that are making it easier to reduce emissions in sectors that were once considered difficult to decarbonize.[33]

These connections can lead to tipping cascades, where reaching a tipping point in one sector speeds up progress in other sectors. For example, increased adoption of EVs pushes deployment—and hence cost decline—of batteries, this benefits the power sector as low-cost electricity storage helps expand intermittent renewable electricity generation from wind and solar.

Figure 8 below highlights some of the key interactions between sectors and their low-carbon solutions.

[33] Goldman Sachs (2021), The Dual Action of Capital Markets Transforms the Net-Zero Cost Curve.

Figure 8. Super-leverage points in ASEAN's prioritized sectors



Notes: Greyed out technologies are not included in the analysis

Leverage points

In dynamic systems, cause and effect can be disproportionate and much-expended effort may at times have little to no effect. A leverage point is a place where a small intervention can achieve a large effect.[34]

In the context of low-carbon transitions, a leverage point can be seen as a policy or action that has a relatively manageable cost or difficulty and a relatively large effect on the development or deployment of zero-emission solutions. In any emitting sector, many enabling policies are needed to support a transition. Nevertheless, at any given moment in time, there may be one policy that stands out for its unusual degree of leverage.

As an example, in the current phase of transition in the ASEAN power sector, feed-in tariffs (FIT)—ideally with prices determined through auction to drive cost declines—can be very useful for boosting the initial use of VRE. Countries have demonstrated that a sustained pipeline of auctions can drive down local prices rapidly. For example, a renewable energy auction program in South Africa has demonstrated a rapid and massive solar PV price decline of about 83% between 2011–2014 through its four bid windows.[35]

In addition, a smart way to continue integrating renewables is to consider using enhanced procurement methods such as auctions with land subsidies or reverse auctions, after the initial FIT phase.

[34] D. Meadows (1997), "Leverage Points: Places to Intervene in a System," Whole Earth.
[35] Meridian Economics (2020), A Vital Ambition: Addressing South Africa's electricity crisis and getting ready for the next decade.

Super-leverage points

The potential for tipping cascades between sectors suggests the existence of what could be called "super-leverage points"—opportunities for actions that have a relatively manageable cost or difficulty, and a relatively high chance of catalyzing a tipping point in one sector, where that tipping point can then help to trigger a tipping point in another sector, hence a tipping cascade. Here we define super-leverage points as having the following attributes:

- Being the highest-leverage action within their own sector, based on combining manageable cost or difficulty with large effect on the development or deployment of zero-emission solutions;
- The sector impacted has an influence on at least one other major-emitting sector that: a) is positive in direction, i.e. it supports the transition; b) is high in impact; c) is reasonably high in probability; d) makes the solution in the impacted sector easier to implement/gives it a higher success potential.

While the economy-wide transition to net-zero emissions will require countless interventions, it may be useful to identify and focus on super-leverage points to increase the chances of rapid progress.

The actions of just one country acting alone within the ASEAN region, however well targeted, are unlikely to catalyze a tipping cascade in the region. If ASEAN countries act together and jointly focus efforts on a super-leverage point, they may well be able to do so. This would be crucial to the global economy, as ASEAN already accounts for ~3.4 percent of the global GDP and contributes 10 percent to global economic growth.[36,37] The world's fifth-largest economy is set to take an increased role in global markets and the green economy transition, meaning the success of crossing tipping points in the region will have great impact on an international scale.

WE SUGGEST HERE TWO CANDIDATE SUPER-LEVERAGE POINTS THAT COULD POTENTIALLY ACCELERATE TIPPING CASCADES ACROSS A TOTAL OF EIGHT SECTORS REPRESENTING 50% OF ASEAN'S EMISSIONS:

Super-leverage point 1: Zero-emission vehicles mandate to two-wheelers and buses

Within the road transport transition, there is evidence that zero-emission vehicle (ZEV) mandates are a strong leverage point. By requiring manufacturers to ensure ZEVs account for increasing proportion of their car sales in the short- to medium-term period, they overcome a constraint on supply, push manufacturers to stimulate the market with marketing and products fit for the market, and ultimately achieve increasing volumes of production—which in turn leads to falling costs and rising demand.

Versions of this policy have proved highly effective in California, China, and the Canadian provinces of Quebec and British Columbia.[38] The ZEV mandate involves no government expenditure, but instead relies on the reallocation of industrial capital to drive investment and innovation toward the new solution. The ZEV mandate is insufficient alone—charging infrastructure investment and many other policies are important—but it has particularly high leverage for accelerating the transition to EVs in light road transport.

This can help to accelerate low-carbon transitions in at least two other sectors, in significant ways:

1. **Power:** Considerable demand for batteries can be attributed from the sheer volume of two-wheelers and high battery demand per bus. Implementing a 30% ZEV mandate to new two-wheelers and buses could amount to minimum of ~75 GWh battery demand. Given the projected battery manufacturing investment plans, reaching this mandate will create the conditions where demand for batteries outstrip production capacity—driving additional investments to the industry and decreasing the cost of batteries over time. Lower cost batteries in turn help the power sector to decarbonize by lowering the cost of solar/wind + storage solutions.
2. **Heavy-road transport—cars and trucks:** Cheaper and better-performing batteries achieved through the scale-up of electric two-wheelers and buses would also increase the competitiveness of battery-electric cars and trucks, bringing forward the point where they outcompete petrol or diesel cars and trucks. There are also likely to be advances in electric drivetrain technology that is transferable from buses to trucks, not to mention the increased learning rate for ultra-fast charging technology that is key for non-fixed route heavy road transport.

[36] K. Georgieva (2023), ASEAN Matters: Cooperation for A Stronger and More Resilient Global Economy.
[37] S&P Global (2022), The ascent of APAC in the global economy.
[38] ICCT (2019), Overview of Global Zero-Emission Vehicle Mandate Programs.

Just as with tipping cascades, confidence in the existence and effectiveness of super leverage points varies across sectors. Evidence of ZEV mandates proving effective in bringing forward EV tipping points mentioned above, combined with the importance of battery costs in bringing forward power and heavy road transport tipping points, means there is high confidence in this super-leverage point. However, it should be noted that it might not be as easily replicable in ASEAN due to varying policy and market context. For instance, the relatively young age of existing bus fleets makes it more challenging to implement ZEV mandates for buses in the region. Therefore, a continuous stakeholder engagement from all sectors (government, private, and third sector) will be required to enable effective implementation.

Super-leverage point 2: Renewable energy mandate in nickel processing industrial parks to increase uptake in low-carbon power and heat

The second super-leverage point is to mandate Variable Renewable Energy (VRE) for critical mineral refineries. Tipping this sector is estimated to add 1.7 to 2.8 GW of VRE demand, a volume that could enable scale economies and thus help drive cheaper costs of VRE in the region.

With the growth of battery and manufacturing demand, both Grade I & II nickel production in Indonesia and the Philippines will have to increase in volume significantly. Current Grade I nickel processing in Indonesia is very energy and emissions intensive. The two main methods of nickel production, the rotary kiln electric furnace (RKEF) and nickel pig iron (NPI) method, are emissions intensive due to reliance on coal for both heat and electricity production.

Indonesia alone is projected to have 4.5 million metric tons of nickel production by 2030. This production spike will be covered by 50+ smelters that would by default use coal as their main source of power and heat. Using projected nickel production routes of 50% RKEF, 25% NPI, and 25% HPAL (high-pressure acid leaching), mandating renewables for processing can open ~1.7 to 2.8 GW of demand for low-carbon solutions for power.

In addition, achieving low-carbon nickel production will also attract new markets and create green corridors for battery-production regions (e.g., the European Union (EU))—creating cascading effects on the power, industrial heating, and shipping sectors. As Global North trade policies increasingly favor low-carbon products, the need to reduce carbon emissions in the supply chain can be a key factor driving the creation of a low-carbon nickel shipping corridor from Asia to the EU or the United States. One of the examples is the EU's Batteries Regulation, a policy that pushes the agenda for sustainable sourcing of raw materials, including considering the carbon footprint throughout the process.

1. **Power:** As the demand for low-carbon nickel production is set to rise, decarbonization of the industrial supply chain can be accelerated. The energy-intensive process of refining nickel means sources of alternative energy will need to be integrated into the power supply. Carbon pricing mechanisms may also provide additional incentives for the uptake of renewable energy, and with the advent of better-performing batteries, technological advances in storage capacities can be integrated as well.

2. **Industrial heat:** Increased usage of VRE within the power supplies of critical minerals refineries might generate the demand of energy storage systems to accommodate the energy-intensive and constant heat requirement in smelting processes. The adoption of technologies such as electric-thermal energy storage (ETES) to generate medium-to-high heat in the refinery industry might provide a learning curve for other industries. Key value points such as flexibility of load to time-match intermittent VRE-based power, high temperature discharges, and low-carbon emissions will prove attractive to other industrial processes leading to further application and economies of scale.

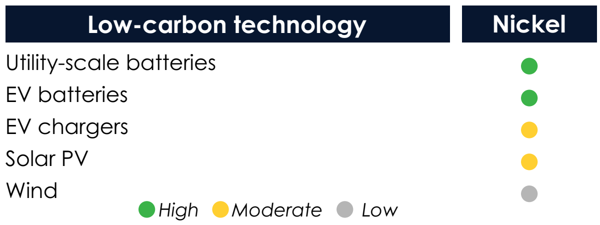
3. **Shipping:** In the shipping industry, one of the key enablers to reach the tipping point for green ammonia for shipping fuel is to develop green shipping corridors. As the demand for low-carbon nickel production is set to rise, ASEAN's refined minerals to major importers such as the EU and the United States will most likely be scrutinized in the future—including the emissions associated with transporting the refined nickel. Establishing a low-carbon nickel production in ASEAN, with the refined nickel moved on ships running on green ammonia, can kickstart new green corridors.

The evidence supporting the potential for rapid cost reductions in power and industrial heating is relatively high/strong, but this remains a nascent industry with limited historical data across its use cases, giving us moderate confidence in the existence of this super-leverage point.

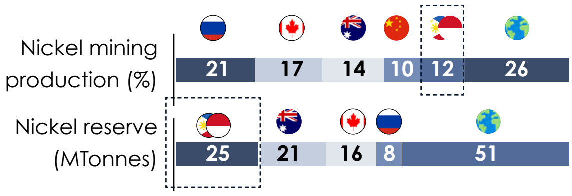
Figure 9 below shows the selected super-leverage points and the tipping cascades that would follow.

ASEAN has world-leading nickel reserve and is focusing on downstreaming the nickel industry

1. **Nickel will be an important mineral for energy transition.** Low-carbon technologies, especially batteries that use CAM technology, need Grade I Nickel[1]

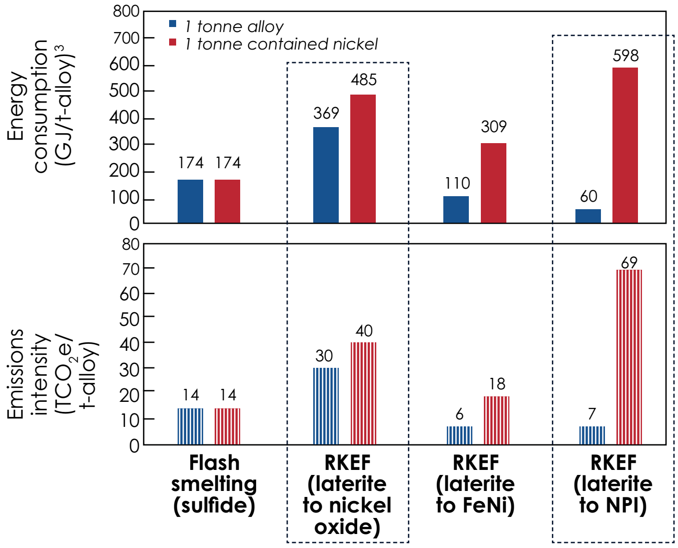


2. **Indonesia and the Philippines are key producers of nickel.** These two countries have ~10% of nickel mining and possess ~25% of global reserve.[2] **~$50bn has been invested** on nickel value chain in ASEAN over the **past five years**



Other than high-pressure acid leaching method, existing nickel production is energy intensive, due to high electricity and heat consumption

1. **Current Grade I nickel processing in Indonesia is very energy and emissions intensive.** Rotary Kiln Electric Furnace (RKEF) and Nickel Pig Iron (NPI) method, both of which are emissions intensive due to reliance on coal, are main methods for production.



Integrating VRE in nickel processing can create up to 2.8 GW demand of VRE (solar/wind)

Using projected nickel production routes, mandating **renewables use in nickel-related industrial parks** can create **~1.7 to 2.8 GW** demand for **low-carbon solutions for power[4], depending on scenario.**

With the right timing, Indonesia can further **unlock enabling conditions for power and medium-to-high industrial heat, creating a cascading effect** into the low-carbon solution ecosystem.

Achieving low-carbon nickel production will also attract new markets, thus adding the potential of **establishing green corridors to battery production regions** (e.g., EU), creating **cascading effect to the shipping sector.**

Notes: 1) IFC (2022), Net Zero Roadmap for Copper and Nickel; 2) McKinsey (2020), How clean can the nickel industry become? and BloombergNEF; 3) Wei et al (2020), Energy Consumption and Greenhouse Gas Emissions of Nickel Products; 4) Systemiq analysis using assumptions: Class I nickel production achieved through 50% RKEF-NiO and 25% RKEF-FeNi, at 23 MWh/tonne Ni. See Appendix A for more details.

SECTION 5

KEY ACTIONS TO BRING FORWARD TIPPING POINTS IN ASEAN

For new solutions to reach tipping points, many actors in the system need to adapt and coordinate to support the new solution.

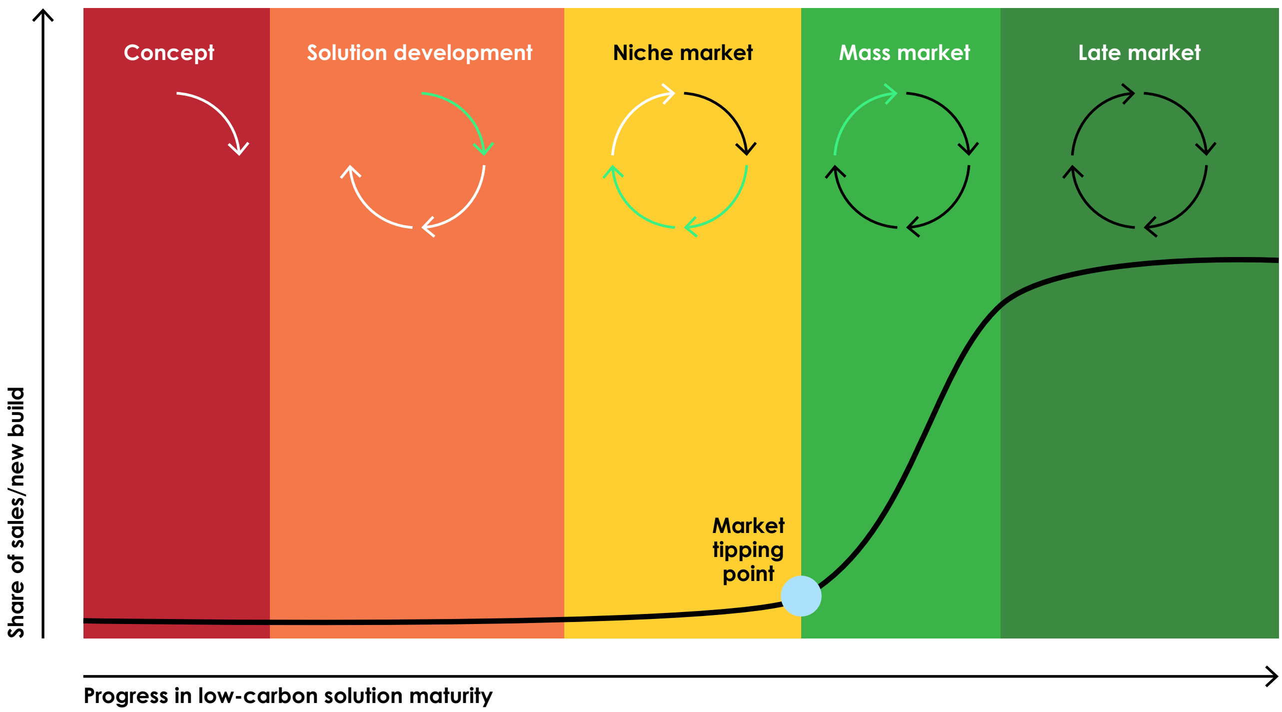
When new technologies or practices emerge, they often face strong initial resistance from incumbents who favor the status quo. In road transport, for example, the use of ICE vehicles is embedded within larger structures that make rapid change difficult, such as co-dependent industries across the supply chain (e.g., component parts manufacturers, car maintenance/repair firms, dealerships etc.), existing physical assets (e.g., refueling networks and stations), or legal and regulatory frameworks (e.g., revenues from fuel taxes). Another example of this can be found in the challenges to transform the power sector across ASEAN: high dependence on relatively young coal-fired power plant assets to serve the growing demand from economic development, lagging grid infrastructure to accommodate accelerated renewable build-out, and non-supportive policies on renewables adoption. However, once the advantage of the new solution becomes apparent, actors increasingly shift to support it and drive its adoption.[39] In practice, this means that there is often a long lead-in period for new solutions when overall market share remains small, before rapid growth kicks in.

[39] Brookings Institution (2019), Accelerating the Low Carbon Transition: The Case for Stronger, More Targeted and Coordinated International Action.

DIFFERENT TYPES OF ACTIONS ARE REQUIRED ACROSS DIFFERENT STAGES OF ADOPTION.

As new technologies and practices develop, they go through a series of transition phases which call for different interventions and strategies from policymakers, corporates, consumers, and financiers. These can broadly be categorized as per the S-Curve adoption stage, as follows[40]:

Figure 10. Examples of the five stages of technology adoption



Stages of technology adoption and example actions to accelerate through the stage

Concept: US CHIPS and Science Act supports nuclear fusion and bio-technology research and development.

Solution development: First mover coalition supporting development of green ammonia in shipping corridors.

Niche market: US Inflation Reduction Act (IRA) provides green hydrogen credit of \$3/kg H^2 making green steel cost competitive in the United States.[41]

Mass market: Carbon pricing programs, zero-emission solution mandates, bans on fossil-fuel boilers or ICE vehicles, adjust power procurement process or market structure to support solar/wind integration.

Late market: Early retirement of coal plants (Europe, the United States).

[40] RMI (2022), Harnessing the Power of S-Curves.
[41] RMI (2022), Green Hydrogen on an S-curve: Fast, Beneficial, and Inevitable.

In the ASEAN context, we have identified specific action points for both the government and the private sector across the prioritized sectors to bring forward the tipping points. This section covers:

- Actions governments can take in bringing forward solutions' tipping points by creating an enabling policy and regulatory environment, providing financial support and incentives, and investing in shared infrastructure.

- Actions the private sector can take in triggering tipping points through driving technology innovation and adoption, investing in local manufacturing of net-zero solutions, developing market coalitions for low-carbon products, and bringing low-cost finance.

1. Power sector

As electricity markets in ASEAN are largely regulated, policy and regulatory support are required to enable accelerated uptake of variable renewable energy. At the same time, the private sector can help realize the deployment by investing in local solar PV and battery supply chains to reduce supply chain risk and prices, and developing market coalitions to ensure there is a strong clean power demand.

Key actions to trigger tipping points in the power sector:

For governments:

- **Set ambitious VRE deployment target** (toward achieving net-zero emissions by mid-century or earlier).
- **Streamline national coal phase-out strategy** to open up capacity for renewable energy supply.
- **Improve market rules/design by removing barriers and providing support to VRE deployment.** This includes improving market certainty and fair allocation of risks in power purchase agreements by providing clear, consistent, and supportive regulations. Two specific key actions to make it happen:
  - ► **Remove barriers to VRE deployment**, including navigating coal overcapacity (in few countries), streamlining rigid coal PPA renegotiation to unlock more system flexibility, planning a gradual phase-down of fossil fuel subsidies (e.g., domestic price cap) to create a level playing field for renewables.
  - ► **Support the development of gigawatt-scale solar** (and solar + storage) project pipeline—including land provision support—and utilize reverse auctions to take the full benefit of solar + storage's cost decline and the auctions' economies of scale. For example, governments can explore the potential of floating solar, particularly on hydropower reservoirs, as it can be a quick win for countries to develop large-scale solar with low-to-no land-associated cost and without the need for significant investment for the transmission.[42]
- **Invest in grid infrastructure** to further advance the ability to take on renewable buildouts, including cross-border transmission. This will also increase the reliability of the grid to reduce operational concerns.
- **Enable power wheeling** to increase the accessibility of renewable energy for captive markets. Beyond the regulated utility market, enabling power wheeling can help accelerate variable renewable energy deployment from the distributed generation side.

For the private sector:

- **Continue investments in local solar PV and battery manufacturing** to secure local supply chains and push local prices further down.[43]
- **Develop market coalitions** for products using low-carbon electricity.

[42] Indonesia, for example, is currently developing the largest (~200 MWp) floating solar project in ASEAN and recently signed development plans to triple its capacity. Masdar (2023), "Agreement to triple size of ASEANs floating solar plant.
[43] Vietnam, Malaysia, and Thailand produce ~10% of the world's PV cells and modules, although their manufacturing are predominantly owned by Chinese manufacturers and are net-exporters of solar PV products (lower domestic demand). ADB et al. (2023), Renewable Energy Manufacturing: Opportunities for Southeast Asia.

2. Road transport: two-wheelers

For electric two-wheelers, which are already close to a sticker price parity, both the government and the private sector can work together at further improving sticker price competitiveness through targeted subsidies, continued investment in the local battery and E2W manufacturing, and improved financing rates and options to enable broader market adoption. Investment in public charging infrastructure will also enable wider accessibility to E2W adoption.

Key actions to trigger tipping points in electric two-wheelers:

For governments:

- **Deploy targeted subsidies** to support research and development and manufacturing for OEMs to tip sticker price competitiveness.
- **Invest in charging infrastructure** for electric vehicles to increase accessibility and reduce range anxiety.

For the private sector:

- **Continue investing in local battery and E2W manufacturing** to further reduce the sticker price.
- **Provide low-cost financing** for electric two-wheelers.

3. Road transport: buses

Bringing forward e-buses tipping points will hinge on further reducing the high upfront cost that is largely driven by the battery cost. Innovative business models that separates asset-ownership to reduce the technological/operational risk, and upfront cost requirements are some of the potential solutions to accelerate the adoption of e-buses. For this, governments could create the regulatory conditions to make these adoption model feasible. Businesses and investors can continue exploring and piloting innovative financing models, and investing in local battery and e-bus manufacturing to further reduce the sticker price.

Key actions to trigger tipping points in electric buses:

For governments:

- **Create regulatory framework to enable innovative business models** (e.g., lease and operate, Mobility-as-a-Service model). For example, supporting the procurement process or permitting extension for non-operators to contract with transport authorities to involve more market participants.
- **Deploy targeted subsidies** to support research and development and manufacturing for OEMs to tip sticker price competitiveness.
- **Invest in charging infrastructure** for electric vehicles to increase accessibility and reduce range anxiety.

For the private sector:

- **Continue investing in local battery and e-bus manufacturing** to further reduce the sticker price
- **Explore innovative financing** for e-buses, such as the carbon financing scheme in Thailand with Switzerland under Article 6.2 of the Paris Agreement.

4. Industrial heat

To accelerate the adoption of direct electrification of heat technologies, governments can provide an enabling environment and strong regulatory support to incentivize the transition to the technology. Raising awareness of heat pumps and electric-thermal energy storage will also be key as these technologies are currently at a nascent stage in the region.

Key actions to trigger tipping points in industrial heat:

For governments:

- **Provide regulatory and financial support for direct electrification of heat** (e.g., preferential electricity tariff, carbon taxation to incumbent fuel).
- **Increase energy efficiency, air quality, and/or emissions standards** in the industrial heat sector to increase the attractiveness of (shifting to) clean heating.
- **Set a mandate** for industrial parks for electrification of heat.
- **(Specific to ETES) Streamline permitting for captive power**, including enabling private wire for near-site VRE generation and power wheeling for delivering through the grid from a dedicated VRE site to the industrial site.

For the private sector:

- **Advance technology introduction** especially for air-source heat pumps and ETES.
- **Develop market coalitions** for products using low-carbon heat.
- **Provide low-cost financing support** for direct electrification (e.g., by principal off-takers).

5. Shipping

Although ASEAN's contribution to green ammonia production for shipping fuel is expected to be limited (see section 3), ASEAN is still positioned to play a strategic role as a beneficiary of green shipping corridors. To capitalize on this opportunity, ASEAN Member States could create the right conditions to accelerate the progress and prepare themselves for the transition. This include putting in place more ambitious regulations on ports decarbonization, and supporting studies on ammonia handling and safety to address concerns around it. Similarly, the private sector in ASEAN can start developing market coalitions for low-carbon shipping to create a demand pull for the technology and its enabling infrastructures.

Key actions to trigger tipping points in green ammonia for shipping fuel:

For governments:

- **Impose stricter environmental regulations** for international ports or carbon taxation for incumbent fuel to incentivize the shift to low-carbon shipping.
- **Provide incentive for green corridor development,** including ammonia bunkering.
- **Support international study and standard adjustments on ammonia handling and safety** to address safety concerns around ammonia and better prepare the workforce.
- **Start identifying potential Special Economic Zones** to develop green corridors in the region.

For the private sector:

- **Develop market coalitions** for products using low-carbon shipping.

6. Minerals refinery

As the demand for critical minerals (i.e., nickel and rare earths) in the region increases, there is a significant opportunity to decarbonize the supply chain by ensuring that these critical minerals are processed using low-carbon energy. To do this, governments can impose a mandate for the use of clean electricity and heat for critical minerals. In parallel, mineral refinery owners can start identifying potential sites to implement low-carbon minerals refinery using VRE and ETES.

Key actions to trigger tipping points in mineral refineries:

For governments:

- **Impose a mandate** to use clean electricity and heat for critical minerals refinery.

For the private sector:

- **Identify potential sites** to implement low-carbon technology (i.e., VRE + ETES).

Figure 11 further summarizes the key actions across sectors and the identified super-leverage points. The key actions were identified as either strategic or cross-cutting:

- **Strategic actions** refer to key actions that can help a certain sector-geography category to reach its tipping point in the near future. These key actions provide the biggest impact toward tipping points and have been proven to work in other economies or sectors that have reached mass adoption of low-carbon technology.

- **Cross-cutting** actions refer to key actions that are relevant and applicable across multiple prioritized sectors. These actions can help multiple sectors reach their tipping points and are designed to address overarching issues or challenges that are not limited to a single specific sector. Similar challenges and feedback loops across sectors exist and acting on these cross-cutting key actions ensures greater efficiency in resource allocation in their journey to reach these tipping points. ASEAN governments and industry practitioners should align their overarching goals and objectives when tackling these cross-cutting actions.

Figure 11. Key actions and cross-cutting actions across six prioritized sectors in ASEAN

Super-leverage Point 1

Zero-emission vehicles mandate to two-wheelers and buses (30% ZEV mandate amounts to minimum of ~75 GWh battery demand

ROAD TRANSPORT SECTOR

Heavy-duty logistics (5%)

Not assessed

Road public transport (2%)

- **Deploy targeted subsidy and innovative procurement** from government to lower the total cost of ownership (TCO)
- **Adjust policy and regulation** to enable Innovative business models/financing to address technology risk-sharing

2W road transport (4%)

- **Deploy targeted subsidy** to support research and development related to product-market fit and to further lowering TCO
- **Continue charging infrastructure build-out** to increase accessibility and reduce range anxiety

4W road transport (4%)

Not assessed

POWER GENERATION (25%)

- **Set ambitious VRE target** (toward net zero), including **streamlining coal phase-out strategy**
- **Remove barriers** for VRE uptake, e.g., **navigate coal overcapacity, restructure rigid coal/gas PPA**, and **plan gradual phase down of fossil fuel subsidies** (e.g., domestic price cap).
- **Support project pipeline development**, including **land provision support**, and **utilize reverse auctions**
- **Enable power wheeling** to increase the accessibility of renewable energy for captive markets
- **Invest in grid infrastructure** to further advance ability to take on renewable buildouts, including cross-border transmission

INDUSTRY – HEAT (4%)

- **Provide regulatory support** (e.g., special electricity tariff or carbon tax) or **innovative financing** (e.g., special financing program) **for heat electrification**
- **Increase energy efficiency, air quality, or emissions standard in the sector**
- **Advance technology introduction,** especially for air-sourced heat pumps
- **Develop market coalitions for coal-free products,** which can lead to green premium or supplier financing programs
- **Increase reliability of grid** to reduce operational concerns
- **Streamline permitting for captive power** (for ETES)

MINERALS REFINERY (1%)

- **Impose mandate to use clean electricity and heat for critical minerals refinery**
- **Identify potential sites** to implement low-carbon technology

Super-leverage Point 2

RE mandate in critical minerals industrial parks to increase uptake of low-carbon power & heat

CROSS-CUTTING KEY ACTIONS:

1. **Continue investments & development of battery industry**
2. **Develop local manufacturing capability for solar PV**
3. **Incentivize industrial park to push for clean electricity and direct electrification of heat**
4. **Identify potential Special Economic Zones to implement low-carbon technology**

SHIPPING (3%)

- **Adjust environmental regulations** related to pollution and emissions in international ports
- **Support international study and standard adjustments** on ammonia handling & safety
- **Facilitate market coalitions** for green shipping
- **Identify potential Special Economic Zones** to develop green corridors in the region

FERTILIZER (2%)

Not assessed

Legend:

TRANSPORT | INDUSTRY | POWER | FOOD & LAND USE

(X)% *of ASEAN emissions*

Cross-cutting action

Cross-industry connection

Key opportunities and risk

Opportunities:

The transition to a low-carbon economy has the potential to create a more prosperous and just global economy on multiple fronts:

Value chain development: A low-carbon economy provides the opportunity for countries to transition to new "green" economic sectors given the newfound or increased demand in low-carbon technologies. The shift toward these sectors means new value chains will be needed and countries will be provided with the opportunity to receive capital gains from the transition. ASEAN itself stands to possibly profit by around $1 billion and enable access to ~$2 trillion of financing by establishing a low-carbon economy.[44,45] Some ASEAN economies are already capitalizing from this transition, as Indonesia and the Philippines are developing upstream supply chain processes to increase the value of their nickel products, which are vital to the global EV supply chain.

New jobs: A green transition offers the opportunity to expand the number of jobs along the supply chain and create opportunities for many households. The IEA projects that the transition to clean energy alone would generate over 4x more new jobs by 2030 than would be lost in fossil-fuel sectors.[46] In ASEAN, the transition to a green economy is expected to create 5–6 million new jobs in the ASEAN region which would boost economic growth and address the continued high unemployment rate in the region.[47,48] The interconnectivity of clean energy with other corresponding sectors means more indirect jobs may also be created and fuel growth in other industries.

Public health: The shift away from a high-carbon economy can also reduce other harms to the environment and public health, including air pollution and biodiversity loss. This has the added benefit of reducing the impacts of burning fossil fuels, which is responsible for one in every five deaths globally and disproportionally impacts lower-income communities.[49,50] Maximizing the potential benefits of the transition calls for a focus on scaling low-carbon industries responsibly, for example by developing low-impact mining solutions, significantly increasing material circularity, and investing to enable employees of fossil industries a route into new jobs.

Risks:

Energy security and infrastructure readiness: With the shift to renewables in the power system, there is a risk of grid reliability if the transition is not managed properly. Current grid infrastructures across ASEAN were originally designed to support fossil-fuel–based energy production, which allows for dispatch generation in power output to match fluctuations in demand. It was not initially intended to accommodate the variable power generation from wind and solar installations, which can lead to system instability. To note, many countries have already pushed variable renewables (solar/wind) to 30% of total generation, and are finding solutions to manage grid reliability and continue to deploy at pace. Certain countries are even well beyond this (e.g., Denmark at ~55% solar/wind penetration already).

Infrastructure reach is also a key factor, as existing grids are designed to cater for the transmission of electricity from a few large power plants with grid-forming capability and is struggling to keep pace with the build-outs of dispersed, intermittent renewables projects. As a result, newer transmission lines that cover long distances, cross difficult-to-access terrain, and comply with various environmental and regulatory requirements would be required to connect renewable projects to the new demand. Risks related to land space and way of rights requirements need to be mitigated appropriately since the best renewable generation sites are often located remotely from the existing grid infrastructure.

Critical mineral supply chain risk: As the energy transition accelerates, the production of renewables, batteries, electrolyzers, and power grids will lead to a substantial rise in demand for critical minerals, e.g. demand of lithium-ion is set to increase ~7x by 2030.[51] However, reserves are often located in ecologically and socially sensitive areas (e.g., nickel is highly concentrated in Indonesia and the Philippines), meaning that potential exploitation in these sites requires considered assessment and mitigation of potential negative impacts. In addition, long project timescales (e.g., 7–10 years for nickel mines) mean that expanding supply at the pace required for the transition could be a challenge without efforts to reduce these or other innovations.[52] This must be carefully managed to avoid bottlenecks in the deployment of many zero-carbon energy solutions, as well as the adverse impact of extracting these minerals.

44 Bain & Company (2020), Southeast Asia's Green Economy: Pathway to Full Potential.
45 Bain & Company (2023), Southeast Asia's Green Economy 2023 Report: Cracking the Code.
46 IEA (2021), World Energy Outlook: People-Centred Transition.
47 Bain & Company (2023), Southeast Asia's Green Economy 2023 Report: Cracking the Code.
48 ASEAN Secretariat (2023), ASEAN Employment Outlook: The Quest for Decent Work in Platform Economy: Issues, Opportunities and Ways Forward.
49 HSPH T.H. Chan School of Public Health (2021), "Fossil fuel air pollution responsible for 1 in 5 deaths worldwide."
50 PNAS (2019), "Inequity in Consumption of Goods and Services Adds to Racial-Ethnic Disparities in Air Pollution Exposure."
51 BloombergNEF (2022), 1H Battery Metals Outlook.

Improving material recovery and recycling systems will be crucial to ensure that supply keeps pace with rising demand and to manage resource intensity of the transition over the long-term. Creating a more effective recovery and recycling system is crucial to reducing virgin material demand growth as clean energy technology stock reaches end-of-life. This can be achieved with the right system of policies and incentives, and a build-out of logistics and infrastructure. If these are successfully introduced, this could lead to falling primary demand requirements by 2040s, mitigating many of the impacts from mining over the mid-to-long term.[53]

Just transition: It will also be crucial to retrain the workforce for new jobs in the low-carbon transition to ensure skills shortages do not become a bottleneck and to ensure a just transition. Growth in sectors such as renewable power, energy-efficient buildings, local food economies, and land restoration will likely happen in ASEAN and the region stands to create new job opportunities from green growth. While new jobs generated by the transition to a zero-carbon economy considerably outnumber those that will be displaced as old industries decline, thousands of jobs will still be affected.

In Indonesia's coal industry alone, it is estimated around 250,000 jobs will need to be transitioned while 35,000 employees in Malaysia's petroleum and natural gas sector will also be affected. It will be crucial to support workers to move into growing industries to ensure the transition delivers on its opportunity to reduce inequality as well as emissions. Governments are beginning to demonstrate how a just transition can be assured. These strategies center on investment in the development of new industries in regions where the economy has been most dependent on fossil-fuel industries, workforce retraining and relocation support, and the provision of social safety nets.

[52] BloombergNEF (2022), Global Copper Outlook 2022.
[53] WWF (2022), The Future is Circular: Circular Economy and Critical Minerals for the Green Transition.

APPENDIX A: CASE STUDIES LIBRARY

Electric two-wheeler in road transport

Name	Summary
China's E2W Industrialization and Technological Advancements	China's exponential sales growth of electric two wheelers due to product market fit, production economies of scale, and technology advancements
India's Subsidies And Regulatory Easing for Electric two-wheelers	India's national electrification policy provides subsidy and regulatory easing to accelerate adoption of electric two wheelers

E-bus in road transport

Name	Summary
Santiago's Accelerated E-buses Adoption	Government electrification policy and public private partnerships lead to bus fleet electrification in City of Santiago, Chile
Oslo, Norway's Mass E-bus Procurement	Mass procurement enables Oslo to become world's first city with all-electric public transport
India's National E-mobility Subsidies for E-bus OEMS	India's national e-mobility subsidies give opportunity for OEMs to kickstart adoption of E-Buses
Shenzen, China's Public Bus Fleet Electrification	China's zero emission policy provides incentives and enabling infrastructure to accelerate e-buses adoption in Shenzhen, China

Solar & storage in power

Name	Summary
Malaysia's Accelerated Solar Uptake from Better Auctioning	National solar PV auction addresses Malaysia's triple threat in power sector
Philippines's Annual Auction Programme Leads To Accelerated Adoption of Solar	Philippines's annual auction programme gives opportunity for country to loosen dependency on coal/oil and volatility of international markets
Vietnam's Feed in Tariff Scheme	National Feed-in Tariff scheme boosts Vietnam's solar PV uptake

Direct electrification of heat in industrial heat

Name	Summary
EU's Subsidies and Policy Support to Drive Industrial Heat Pump Growth	Policy push and financial incentives drive market growth of industrial heat pumps in Europe
USA's Inflation Reduction Act's support for Industrial Heat Pumps	IRA's financial incentives and technical assistance programme provides opportunity to catalyze and decarbonization of US industrial heat

Green ammonia for fuel in shipping

Name	Summary
Yara's Green Ammonia Devlopment for Shipping	Yara capitalizing the shipping industry's decarbonisation pathway by developing green ammonia infrastructure and networks
South Africa's Development of World's Largest Plant	Global demand for green ammonia fuels South Africa's development of world's largest green ammonia plant
The Netherland's ACE Terminal	Netherland's green ammonia terminal to catalyze green ammonia's adoption in the shipping's industry

CHINA'S E2W INDUSTRIALIZATION AND TECHNOLOGICAL ADVANCEMENTS

Context

Historical sales trend between E2W and ICE two-wheelers. In 1998, annual sales of electric two-wheelers (E2W) in China barely reached 100,000 units/year while internal combustion engine (ICE) 2-wheeler sales were nearing 9 million units/year[1]. By 2006, E2Ws were on par with ICE 2W annual sales. Today, China accounts for the largest share of E2W ownership and of E2W sales globally[1].

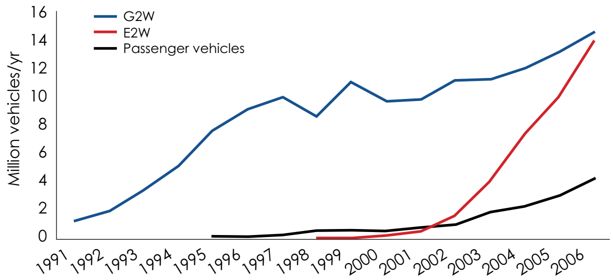


Figure 1.1 Motorized Vehicles Sales in China

Levers to Trigger Tipping Points

This exponential update of E2Ws in China can be attributed to technological advancements of motor efficiency and significant reduction of sticker price of E2Ws that enhance the attractiveness from a product-market fit point of view and affordability of the technology.

- **Attractiveness**. In terms of attractiveness, E2W motors saw significant technological advances most notably in motor efficiency. Between 1995 and 2000, improved E2W efficiency resulted in a 60% increase in range, a key consideration to consumers at the time. The government's decision to eliminate emissions-heavy gasoline-powered scooters made E2Ws even more attractive compared to ICE two-wheelers[1].
- **Affordability**. In 1999, an E2W cost about $310 on average. By late 2003, the price had dropped to $188. This significant price reduction in just four years was driven by substantial industrial growth which led to economies of scale. For example, both E2Ws and their components saw increased production after national e-bike standards were passed in 1999 and e-bike manufacturing licenses were granted in several cities.

INDIA'S SUBSIDIES AND REGULATORY EASING FOR ELECTRIC 2-WHEELERS

Context

India's exponential adoption in electric two-wheelers (E2W). Rising environmental concerns, fossil fuels import dependency and government commitments to reducing greenhouse gas (GHG) emissions intensity by 33-35% by 2030 drove the government to accelerate the decarbonization of the transportation sector, the 4th largest emitting sector in the nation[2,3]. Now, India is the second-largest market for E2W, lagging only behind China[4]. In 2021, the E2W market experienced a year-over-year sales growth of 305% and is expected to continuously grow by 29% to reach USD ~1 billion by 2028[5,6].

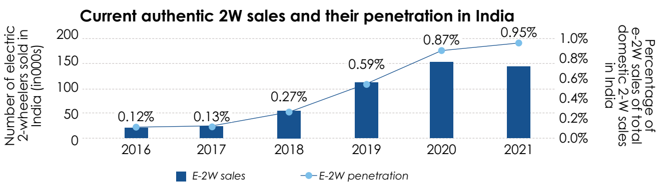


Figure 1. Current electric 2W sales and their penetration in India.
Sources: Society of Manufacturers of Electric Vehicles (EV).

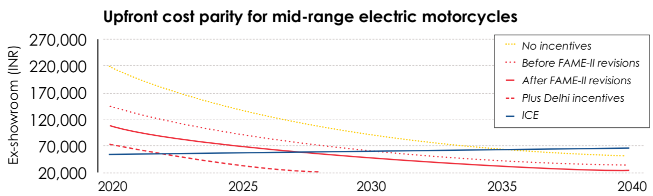


Figure 1. Impact of incentives on upfront cost-parity for mid-range electric motorcycles.

Levers to Trigger Tipping Points

Increased affordability and attractiveness from India's Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme has driven the adoption of India's E2W uptake. FAME is an incentive programme that aims to encourage electric and hybrid vehicle purchase by providing subsidies to original equipment manufacturer (OEMs) to incentivize the uptake of EVs, including electric two-wheelers (E2W). The programme began in 2015 and has supported E2W uptake in the following levers.

- **Affordability**. FAME provided original equipment manufacturers (OEMs) with subsidies of up to USD 240 for E2Ws with specific specifications. As a result, the number of OEMs for E2Ws increased significantly and there are now 58 OEMs for E2Ws as of 2020, the largest number of OEMs for E2Ws in the world[9].
- **Attractiveness**. Under the programme, regulatory easing was also conducted and registration and licenses for E2Ws with speeds less than 25 km/h were no longer required. This reduced transaction costs for consumers to purchase the electric vehicles, further incentivizing the adoption of E2W.

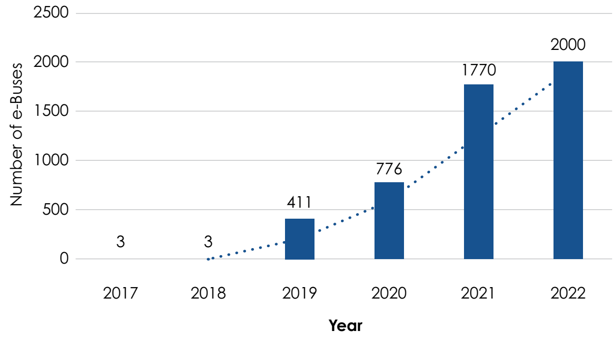
Notes: [1] W. X. Jonathan. (2007). The Rise of Electric Two-wheelers in China: Factors for their Success and Implications for the Future Notes: [2] Government of India. (2017). Nationally Determined Contribution. [3]] Tiseo, I. (2023). Distribution of GHG emissions in India 2020, by sector; [4] Mckinsey & Co. (2022). Capturing growth in Asia's emerging EV ecosystem; [5] Autocar India. (2023). Electric two-wheeler sales up 305 percent in 2022; [6] Businesswire. (2022). India Electric Two-Wheeler Market Report 2022-2028F: Government Initiatives and Environmental Consciousness, A Shift Towards Advanced Technology, & Reduction in Cost of Ownership; [7] Kumar, P & Singh, A. Complete Decarbonization of 2-Wheeler Segment in India by 2030: Expected e-2Ws Sales and Battery capacity Requirement. WRI India; [8] Rokadiya, S. (2021). FAME-II revisions spark hopes for a jump in electric two-wheelers sales in India; [9] E-Vehicle Info. (2022). List of Electric Two-Wheeler Manufacturers in India

SANTIAGO'S ACCELERATED E-BUSES ADOPTION

Context

E-buses adoption to tackle Santiago's city air pollution. By the early 1990s, Santiago was one of the most polluted cities in Latin America. Approximately 1,300 - 2,900 premature deaths was caused by air pollution every year between 1989 – 1991[1,2]. One of the government strategies to address this is to reduce emissions from the transport sector, Chile's largest emitting sector. The city aims to electrify their buses as public buses accounted for more than 25% of public transport use. Today, Chile is the owner of the world's second-largest electric bus fleet, a result of strategic public-private partnerships and a government focus shift to e-Buses[3].

Total number of e-Buses in Santiago, Chile



Levers to Trigger Tipping Points

Santiago's strategy to electrifying their buses was to develop a strategy for the electrification of its public bus fleet and partner with the private sector for mass procurement. The strategy enveloped development projects and supported the uptake of e-buses on two fronts:

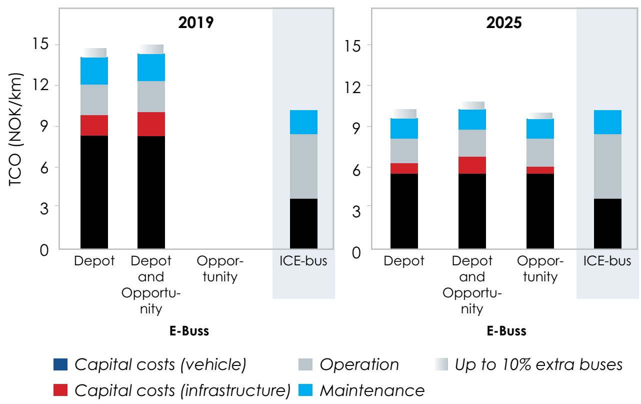
- **Attractiveness**. Early pilot projects in 2011 and 2013 brought two buses to operate under regular service and after a year of operations, they covered 105,981 km, moved 350,000 passengers, and showed that operating costs were 75% lower compared to diesel buses. The high reliability and lower costs made e-buses attractive for the local government.
- **Accessibility**. A partnership agreement between Santiago's government, BYD, and Enel X was struck in 2017 and resulted in a 10-year charging infrastructure build-out programme starting from 2019. This greatly enhanced accessibility in the long run with 100 charging stations built within only 2 years. They also created Latin America's first electric bus route which runs along a major public transportation axis in Santiago and covers 11% of the city's public transportation users[4,5].

OSLO NORWAY'S MASS E-BUS PROCUREMENT

Context

High-emitting transport sector catalyses Norway to fully electrify their public bus fleet. The transport sector contributes to 25% of greenhouse gas (GHG) emissions in Europe[6]. While there have been vehicle efficiency improvements in recent years, transport has not seen the gradual emission decline achieved in many other sectors due to equivalent increases in transport demand. In an effort to curb emissions, mass procurement contracts has enabled Oslo to possess more than 200 e-buses, and the city plans to full electrify its remaining 450 buses in the city by the end of 2023[7]. This will enable Oslo to become the world's first city with a fully electric public transit system[8].

TCO of e-Buses in 2019 vs 2025



Levers to Trigger Tipping Points

Oslo's transition can be attributed to several interventions that enabled affordability and accessibility levers to be pulled.

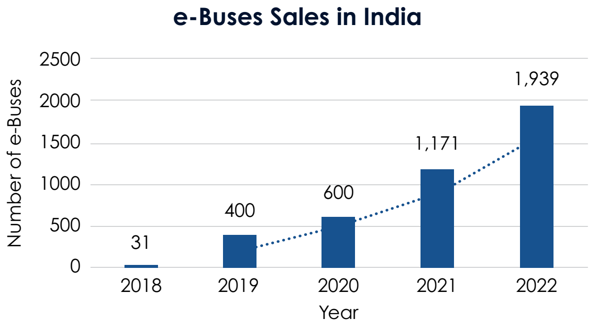
- **Affordability**. The local government's decided to mass procure e-buses in the late 2010's and this has enabled economies of scale, improved efficiency, and lower expected total cost of ownership (TCOs). Operational costs of the e-buses have also been reported as cheaper, and price parity is expected by 20251. This has provided incentive for the country to expand its e-bus fleet.
- **Accessibility**. Norway's nation-wide charging infrastructure build-out programme in the early 2010s enabled easier implementation of e-bus in Oslo, providing accessibility for charging its new e-bus fleet.

Notes: [1] Bloomberg Business News. (2019, March 5). Air pollution problem in Santiago, Chile, is critical. Los Angeles Times; [2] Eskeland, G.S. (1997). Air Pollution Requires Multipollutant Analysis: The Case of Santiago, Chile; [3] Bnamericas. (2023). Santiago's electric bus fleet exceeds 2,000 units; [4] Galarza, S. 2020. Zero Emission Bus Rapid Deployment Accelerator: From pilots to scale. CMM Chile; [5] BYD. (n.d.). BYD helps to launch latin America's first 100% electric bus corridor; [6] Thorne, R. J., et al. (2021). Facilitating adoption of electric buses through policy: Learnings from a trial in Norway. Energy Policy; [7] Winge, L. (2023). Norway gets fully electric public transport system; [8] [5] Klesty, V. (2022). E-bus deal puts Oslo on track for zero-emissions public transport goal. Reuters;

INDIA'S NATIONAL E-MOBILITY SUBSIDIES FOR E-BUS OEMS

Context

Electric buses (E-bus) was seen as a solution to decarbonize the transport sector. However, the relatively high total cost of ownership (TCO) of e-buses compared to its diesel counterparts were a major financial barrier given India's price-sensitive market. Accessibility was also an issue, as charging infrastructure for electric vehicles (EV)'s were not widespread at the time. Today, India has managed to overcome these barriers and accelerate the adoption of e-buses. E-buses sales have seen a 62x increase between 2018 to 2022[1,2]. There are now a total of approximately 4,141 buses, accounting for 16% of India's total buses in operation, and the government expects to deploy 3,000 year-by-year and 7,090 by 2024[3,4].



Levers to Trigger Tipping Points

The success in e-bus uptake can be attributed to India's Faster Adoption and Manufacturing of Electric Vehicles (FAME) program which successfully tackled the barriers for mass procurement of e-buses. The programme provided financial incentives for e-buses as well as charging buildout to support operations.

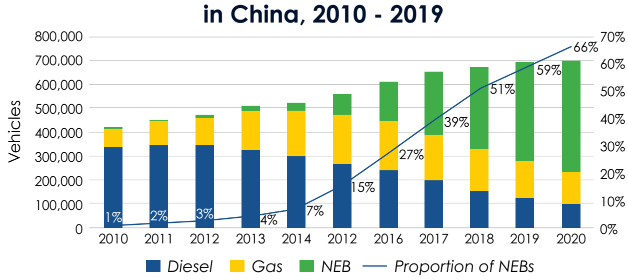
- **Affordability**. Under the FAME Initiative, subsidies of up to USD 242/kWh for operational costs was provided under gross cost contracts to operators. This brought down the TCO/km of e-buses to be lower than the TCO/km of diesel buses[5].
- **Accessibility**. FAME also enabled the construction of charging infrastructure in India, and led to the installment of 427 charging stations spread across the country, a significant buildout given the limited amount of charging stations available at the time[6].

SHENZEN'S PUBLIC BUS FLEET ELECTRIFICATION

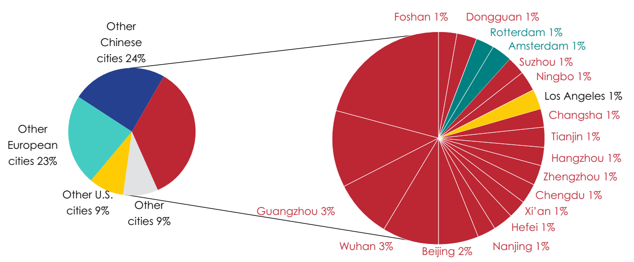
Context

China's Shenzhen pilot led them to be the world leader for e-buses adoption. Air quality as a major environmental issue in early 2000s China. 99% of the 560 million urban population was breathing air deemed unsafe and it was estimated that 350,000 – 400,000 residents died prematurely due to air pollution[7]. As a result, China recognized the need to convert diesel-powered vehicles to electric buses (e-buses) to reduce emissions from the transportation sector. The city became the world's first to have an all-electric public bus fleet by 2018. China scaled-up Shenzen's pilot at the national level and has since made China the world leader in e-bus adoption. In 2017, China owned about 99% of the world's 385,000 existing electric buses and were adding about 9,500 new zero-emission buses every five weeks[8].

Development of New Energy Buses (NEB) Proportion in China, 2010 - 2019



Share of global public EVSE stock in cities by the end of 2021 with a specific focus on the top 20 cities (right)



Levers to Trigger Tipping Points

Shenzen's exponential e-Bus growth can be traced to the central government's zero-emissions programme, which supported decarbonization in high-emitting sectors. Shenzen was chosen to participate in this program and the program's incentives enabled total cost of ownership (TCO) of e-buses to be less than TCO of internal combustion engine (ICE) buses[9].

- **Affordability**. The government provided support for e-buses in the following form[8]:
  - Subsidies from central government provided directly to the bus original equipment manufacturer (OEM) of about USD 68,000 – 140,000 on certain requirements;
  - Subsidies from provincial government that covered nearly half of the total capital expenditure (CAPEX) per unit;
- **Accessibility**. The zero-emissions programme also supported charging buildout through financing and installed 500 charging stations in Shenzen, catalysing growth and making the city the first in terms of number of charging stations[8].

Notes: [1] JMK. (2020). Electric Buses: India Market Analysis; [2] Sustainable Bus. (2023). The e-bus market in India has grown 65% in 2022; [3] Business Insider India. (2023). India needs over 600,000 buses for 25 million commuters daily to follow social distancing norms, according to a study; [4] Rudra, T. (2023). Centre Pushing States To Place Orders For More Ebuses To Meet FAME-II Goals. Inc42 Media. [5] WRI India. Ross Center. (2021). Procurement of Electric Buses: Insights from Total Cost of Ownership (TCO) Analysis; [6] India Times. (2023). Explained: What is FAME-India Scheme; [7] US-China Institute. (n.d.). Air quality at the 2008 Beijing Olympics; [8] The success of Chinese electric buses. (n.d.). Frotcom; [9] Berlin, A., Zhang, X., Chen, Y. (2020). Case Study: Electric buses in Shenzhen, China; [10] Kahn, J., & Yardley, J. (2007). China - pollution - Environment. The New York Times; [11] Yiyang, C. & Fremery, V. (2022). E-Bus Development in China: From Fleet Electrification to Refined Management; [12] EV Market Reports. (2023). China leads in EV charging infrastructure development

MALAYSIA'S ACCELERATED SOLAR UPTAKE FROM BETTER AUCTIONING

Context

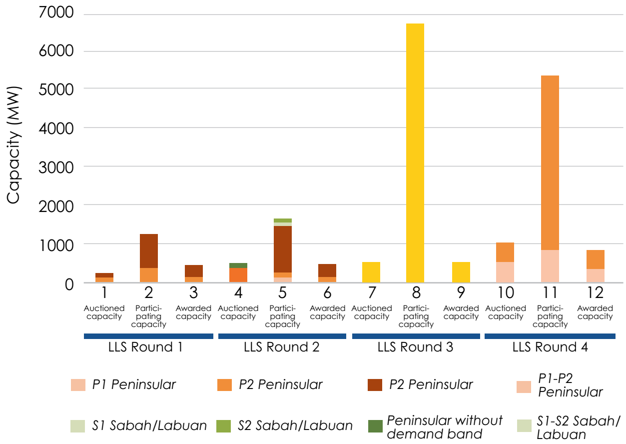
Malaysia's accelerated uptake in solar from better auctioning. In 2015, the Malaysian energy sector was under threat from economic shortage, dependency on imports, and negative externalities. Increasing electricity consumption was met with stagnant supply, which posed a threat to energy security. Heavy dependence on imports and the instability of global fuel markets was also an issue on top of the high greenhouse gas (GHG) emissions generated from burning fossil fuels for energy[2]. To address these issues the government needed alternative sources of energy that would provide stability to the energy sector while also reduce negative externalities such as GHG emissions. Between 2016 – 2020, Malaysia acquired 2.26 GW of Solar PV generation through national auction processes, equivalent to 10x's Malaysia's 2015 variable renewable energy (VRE) capacity, and is now one of ASEAN's leading countries in solar uptake[1,2].

Levers to Trigger Tipping Points

Malaysia's nation-first auctions for solar PV enabled the country to provide stable and sustainable Notes of energy while also reducing emissions intensity. Four auctions were launched as the Large-Scale Solar (LSS) programme in 2016 and enabled the procurement of considerable solar capacity at competitive prices. The programme also revealed market supply readiness for solar PV, as the four rounds were oversubscribed from developers, causing a larger overall awarded volume than that initially allocated by 0.07 GW1.

- **Affordability**. Bid prices from prequalified participants reached as low as USD 42.9/MWh, lower than the administratively set feed-in tariff, leading to economic gains for Malaysia and enabling the uptake of solar into the electricity grid[1].

Auctioned participated and awarded capacity in Malaysian LSS

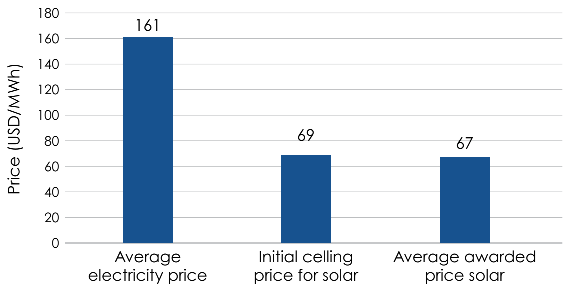


PHILIPPINES'S ANNUAL AUCTION PROGRAMME LEADS TO ACCELERATED ADOPTION OF SOLAR

Context

Philippines accelerated adoption of solar through better auctioning. High dependence on imported coal made the Philippines possess the second most expensive electricity tariff in Southeast Asia at an average USD 161/MWh[3]. To drive down the country's dependency on coal imports and provide lower-costs options to the grid, the Supreme Court ordered distribution utilities to contract electricity using a least-cost approach through a competitive selection. Through auction processes, the Philippines was able to acquire newly installed solar capacity, equivalent to a 93.5% increase in variable renewable energy (VRE) from the year before[3]. From 2022 statistics, the auctioned capacity was also the third largest in the region, lagging only behind Malaysia and Myanmar[3].

Comparison of Electricity prices in Philippines



Levers to Trigger Tipping Points

The auction processes were held by the Department of Energy under the Green Energy Tariff programme (GETP) and provided the Philippines the opportunity to diversify its energy mix. The programme was supported by the newly established Green Energy Auction Committee (GEAC) to undertake all key related activities and resulted in 1.49 GW of solar acquired at competitive prices[3].

- **Affordability**. The awarded capacity was priced at an average of USD 67/MWh, significantly lower than the Philippines average retail rate of electricity and lower than the originally set ceiling price of USD 69/MWh[3].

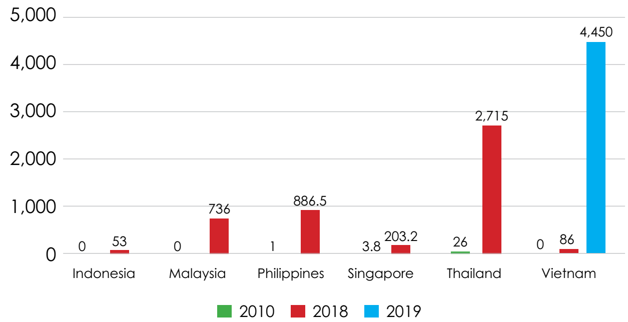
Notes: [1] IRENA. (2022). Renewable energy auction: Southeast Asia, International Renewable Energy Agency, Abu Dhabi; [2] Vaka, M., Walvekar, R., Rasheed, A. K., & Khalid, M. (2020). A review on Malaysia's solar energy pathway towards carbon-neutral Malaysia beyond Covid'19 pandemic. Journal of Cleaner Production; [3] IRENA. (2022). Renewable energy auction: Southeast Asia, International Renewable Energy Agency, Abu Dhabi

VIETNAM'S FEED-IN-TARIFF SCHEME ENABLES EXPONENTIAL GROWTH OF SOLAR PV

Context

Vietnam's leading role in solar uptake in ASEAN. The Vietnamese government's commitment to energy security and strong public support for clean energy made the premise of solar PV popular in the country. Given technological progress in the late 2010s in terms of price and availability of technology, solar was made attractive for the country and Vietnam was keen to capitalise on the energy transition by becoming a first mover in the region. By 2017, 82 solar PV plants were connected to the national grid and the country possessed 17.6 GW of solar capacity in 2021, accounting for 13% of the total energy supply[1,2]. This means the country is well on its way to achieve its Power Development Plan (PDP) VIII goal of 18.6 GW solar capacity by 2030[3].*

Solar installation progress in ASEAN (2010-2019)



Levers to Trigger Tipping Points

- **A key enabling factor that allowed exponential growth in solar PV was a Feed-in-tariff (FiT)** policy. The government introduced this policy in 2017 and offered generous incentives to households and businesses. Through this process, and additional 4.45 GW of solar PV capacity was added to the grid within one year, the highest ever achieved in the ASEAN region[1]. A key lever was attractiveness in terms of pricing.
- **Attractiveness**. A government decree was released in 2017 and offered new solar power developers a rate of USD 0.09/kWh[2]. The tariff was provided under the condition that the project had to achieve commercial operation before the end of the FiT period in 2019, which made developers rush to reap in the potential benefits. The tariff made solar PV projects attractive to consumers and developers as a fixed price for electricity sales would be guaranteed for 20 years.

EU'S SUBSIDIES AND POLICY SUPPORT TO DRIVE INDUSTRIAL HEAT PUMP GROWTH

Context

EU's push in increasing the uptake of heat pumps. Volatility of global oil markets forced the European Union (EU) to reduce its dependence on fossil fuels and fast forward the green transition. With heating and cooling accounting for half of the EU's final energy use, decarbonizing the sector is seen as crucial to meet the EU's emissions reduction targets. Heat is still fueled by fossil fuels, however, with the total share fossil-fuel sourced heating estimated to be around 79%[7]. Heat pumps now account for approximately 16% of Europe's heating and this share is expected to continue its growth for the years to come given it's ability to reduce energy demand an CO_2 emissions[9,10].

Levers to Trigger Tipping Points

Region-wide and national supporting policies enables growth of the industry in the region, with several companies integrating heat pumps into their industrial processes. Fertigungstechnik NORD, an industry leader in the manufacturing of mechanical equipment, and Kiilto, a Finnish company manufacturing chemicals, are some companies that have begun integrating heat pumps into their manufacturing processes and have reported considerable savings in energy costs[8].

- **At EU level: Affordability.** The EU launched REPowerEU, its 2022 plan for saving energy, producing clean energy, and diversifying energy supplies[11]. Accompanied with higher efficiencies and lower total cost of ownership (TCOs) compared to gas heating from lower operational costs, the plan has enabled an uptake of industrial heat pumps in Europe.
- **In Finland and Germany: Affordability.** Germany provides subsidies through its federal funding programme for energy and resource efficiency which can cover up to 50% of the initial cost of the heat pump. Finland also introduced a cut in industrial electricity taxes, creating a favorable financial environment for heat pumps and encouraging electrification in the sector[12,13].

Notes: *Insufficient grid infrastructure is still an issue and has led to imbalances between supply and output. [1] The ASEAN Post. (2020). Vietnam Leading ASEAN's Solar PV Market. [2] Vietnam Briefing. (2023). Feed-in tariffs for solar and wind power projects in Vietnam; [3] EQ International. (2021). Vietnam's Latest Power Development Plan Focuses on Expanding Renewable Notes. [4] D, Kumar. (2021). Southeast Asia's big PV plans – 27 GW by 2025; [5] Innolab Asia. (2022). The Development of Solar Energy in Vietnam – Innovation Lab; [6] Tran, N. (n.d.). Vietnam Solar Power Sector. International Trade Administration; Jiang, W. (2023). 2021 Solar statistics in the country of Vietnam. SolarFeeds Magazine; [7] Bioenergy International. (2020). Fossil fuels still dominate the European heat and cooling sector; [8] European Heat Pump Association (EHPA). (2020). Large scale heat pumps in Europe Vol. 2: Real examples of heat pump applications in several industrial sectors; [9] European Heat Pump Association (EHPA). (2023). Heat Pumps in Europe: Key Facts and Figures; [10] Zefelippo, A. & Ranghino F. (2023). Electrifying Industrial Heat: A trillion Euro Opportunity Hiding in Plain Sight; [11] European Commission. (2023). REPowerEU. [12] De.fi Group. (2022). Federal funding for energy and resource efficiency in the economy; [13] EU Monitor. (2022). Explanatory Memorandum to COM(2022)219;

USA'S INFLATION REDUCTION ACT TO CATALYZE ADOPTION OF INDUSTRIAL LEVEL HEAT PUMPS

Context

Heat pumps as a solution to meeting US decarbonization. Thermal processes in US manufacturing is responsible for ~66% of the total industrial final energy demand, with 60-70% being served by fossil fuel[1]. To ensure the US meets its climate change goals, decarbonization of industrial heat through electrification would be critical and Industrial-level heat pumps (IHPs) can cater to this while also improving overall energy efficiency. If widely deployed in several target sectors, IHPs could reduce GHG emissions by 30 - 43 million tonnes per year - equivalent to 3 - 4% of total national carbon emissions[2].

Levers to Trigger Tipping Points

Despite its potential, however, IHP deployment in the US has been limited. Among the key barriers to widespread IHP deployment in the US are the economic feasibility of IHP integration, the lack of awareness of IHP technology and the lack of knowledge about IHP integration. To address these challenges, the US's 2022 Inflation Reduction Act (IRA), a nationwide policy to curb inflation and support clean energy uptake, provides a variety of support for IHPs.

- **Affordability**. The IRA's support towards IHPs include:
    - Manufacturing tax credits for specified clean energy projects, such as IHPs, by up to 30% of the cost of purchase[3]; and
    - Grants and loans for agricultural IHP applications through the Rural Energy Savings programme (REAP) which include loan guarantees on loans up to 75% of total eligible project costs and grants for up to 50% of total eligible project costs[2].
- **Attractiveness**. The IRA also provided Technical Assistance Partnerships that would allow knowledge transfer and expertise sharing to help industrial facilities install and implement IHPs[2].

YARA'S GREEN AMMONIA DEVELOPMENT FOR SHIPPING

Context

- **Yara's leading role in global green ammonia adoption. Bulk carriers are a notable source of greenhouse gas emissions.** Given its relevance in GHG emissions, the industry has been pushing to raise its climate ambitions and align itself with science-based climate targets with the International Maritime Organization (IMO) aiming to halve shipping emissions by 2050[4].
- **Norwegian chemical company Yara, who is also the world's largest distributor of ammonia, is leading the charge.** In this early-stage adoption wave, Yara is developing initiatives along the supply chain to create and supply green ammonia for global shipping. As the company pushes forward, it will be uniquely positioned as an early adopter and a frontrunner in the green ammonia market which is expected to grow by 60% over the next two decades[5].

Levers to Trigger Tipping Points

To enable the uptake of green ammonia in shipping, Yara is focusing its efforts on the production of the fuel as well as setting up global networks for its use, enhancing the following enabling conditions to trigger the sector's tipping point:

- **Accessibility**. The company has announced a Memorandum of Understanding (MoU) with marine fuel suppliers Bunker Holding to develop ammonia for use as shipping fuel. They have already signed a deal with Azane Fuel Solutions to setup a network of 15 ammonia bunker terminals for deployment across Scandinavia to refuel ships[6,7]. Yara Clean Ammonia has also teamed up with several international clean energy companies to enable the production of clean ammonia on a global scale.
- **Attractiveness**. Financial incentives are helping Yara push forward too, as the company is setting up production in the US to benefit from tax credits of up to USD 85 per tonnes of CO_2 stored under the Inflation Reduction Act (IRA)[8].

Notes: [1] Zuberi, M. J., et al. (2022). Electrification of U.S. Manufacturing With Industrial Heat Pumps; [2] ACEEE. (2023). New federal funds can help companies invest in industrial heat pumps; [3] Greenbiz. (n.d..) 1 year later: Benefits of the IRA; [4] World Economic Forum. (2022). These economies are set to lead shipping's green transition; [5] Yara. (2022). Enabling the hydrogen economy; [6] Yara. (2022). Yara International and Azane Fuel Solutions to launch world's first carbon-free bunkering network, delivering green ammonia fuel to the shipping industry; [7] Reuters. (2022). Yara to set up Scandinavian green ammonia shipping fuel network. Reuters; [8] Donaldson, A. (2023). Yara Clean Ammonia announces MoU for shipping fuel development. Power Technology

SOUTH AFRICA'S DEVELOPMENT OF WORLD'S LARGEST GREEN AMMONIA PLANT

Context

Green ammonia key in shipping decarbonization. Green ammonia set for further adoption as maritime shipping industry seeks to decarbonize and transition to cleaner sources of energy. The alternative fuel is seen as an essential component in net zero scenarios and accounts for 45% of the global energy demand for shipping in 2050, an industry that made up nearly 3% of global CO_2 emissions in 2018[1].

Africa gearing up for transition. African countries which possess substantial renewable energy resources are gearing up to attract investment in green ammonia production to supply to world markets. With historically significant trading routes and agreements, a strategic geographic position, high standard of local skills, and its renewable energy potential, South Africa is well placed to produce and export green ammonia for fuel. South Africa aims to become a green ammonia hub for shipping and has set a production target of 500,000 tons/year by 2030 as well as supply 10% of the global green ammonia market by 2050[2].

Levers to Trigger Tipping Points

In line with South Africa's targets, the country has initiated the development of the world's largest green ammonia plant. The proposed project will become a key lever to enhance accessibility of green ammonia for shipping.

- **Accessibility (Fuel availability).** Hive Energy and Built Africa have announced the establishment of a USD 4.6 billion green ammonia plant in Nelson Mandela Bay, South Africa[3]. The plant, which is also supported by InvestSA, a branch of the South African Department of Trade, Industry, and Competition, will have a production capacity of 800,000 tonnes/year[4,5]. Full operation of the plant is planned to commence by the end of 2026 and will create 20,000 jobs over the lifespan of the project. Given the scale of the HIVE project and its strategic geographic location, the plant will play a key part in the adoption of green ammonia as transiting ships on the European-Asian sea route will be able to bunker the alternative fuel[3].

NETHERLAND'S TERMINAL TO CATALYZE GREEN AMMONIA'S ADOPTION IN THE SHIPPING INDUSTRY

Context

- **Green ammonia growth in Europe.** Europe's green ammonia market anticipated to grow appreciably with the EU targeting production of 10 million tonnes of renewable hydrogen by 2030[7]. The product plays a crucial role in the region's decarbonization as well as the shipping industry, which the sector will use in its efforts to reduce GHG emissions. Given its importance in both the EU's and the shipping industry's plans, ports in Europe are gearing up to become hubs for the sustainable fuel.
- **Port of Rotterdam key in region's transition plans.** The port, which is the largest seaport in Europe and the world's largest outside of East Asia, is preparing for the uptake in green ammonia for shipping and industrial uses. The port will be part of the proposed Delta Corridor, connecting supplies of green hydrogen to industrial plants in Germany and is planned to bunker ships with the sustainable fuel, placing the port as a strategic piece in green ammonia adoption moving forward[8]. The port is also in plan to establish the region's largest green ammonia import terminal, named the ACE terminal.

Levers to Trigger Tipping Points

The ACE Terminal will play a key part in increasing accessibility of green ammonia in the region, further catalysing the adoption of the fuel for the shipping industry. The lever this project will pull are:

- **Accessibility (Infrastructure).** The ACE terminal, developed by Gasunie, HES International, and Vopak, is set to be online by early 2026[9]. Several key developments have been made as of 2023. The port has signed supply deals with Cepsa and Hyphen, been established as part of the first clean hydrogen maritime corridor, and has been recognized as pivotal in the EU's proposed Delta Corridor project[10,11]. Once operational, the ACE terminal is projected to import 4.6 million tonnes of green ammonia by 2030[12].

Notes: [1] Prisco, J. (2023). $4.6 billion plant in South Africa will make 'the fuel of the future'; [2] Boucetta, M. (2023). The Green Hydrogen Market: The Industrial Equation of the Energy Transition; [3] Hive Energy. (2023). Hive Green Ammonia - Hive Energy. [4] Rai-Roche, S. (2022). World's largest green ammonia plant' planned for South Africa, set to go live in 2025. PV Tech; [5] RenewAfrica.Biz. (2022). Hive Hydrogen to set up a $4.6bn Green Ammonia Plant in South Africa. Renew Africa. [6] Redactoramexico. (2021). Hive Hydrogen, Built Africa, and Linde teamed up to establish a green ammonia export plant in Nelson Mandela Bay. Hydrogen Central; [7] European Commission. (2023). Energy Systems Integration. [8] Hydrogen Insight. (2023). Cepsa launches €1bn Spanish green ammonia plant, eyes exports to Port of Rotterdam this decade; [9] Gasunie. (2023). ACE Terminal; [10] Ship & Buker. (n.d.) CEPSA strikes green ammonia supply deal in Rotterdam; [11] Petrova, V. (n.d.). Hyphen agrees European green ammonia imports via Port of Rotterdam. [12] Njovu, G. (n.d.). Port of Rotterdam – Ammonia Energy Association; [13] Port of Rotterdam. (n.d.). OCI expands import terminal for (green) ammonia; [14] Team, P. T. (2022). Port of Rotterdam to establish green ammonia import terminal. Port Technology International; [15] Yara International. (2023). Yara Clean Ammonia and Cepsa seal an alliance to connect southern and northern Europe with clean hydrogen

APPENDIX B: TECHNICAL APPENDIX ON TIPPING POINT ANALYSES

1. Power sector: Solar & storage vs. fossil fuel power plants

In the power sector, the levelized cost of electricity (LCOE) of utility-scale solar power plant, whether standalone or coupled with battery energy storage, were compared against coal and combined cycle gas power plants.

LCOE is a techno-economic measure that calculates the average cost of electricity generation from a power plant over its lifetime. It is also typically used to represent the average revenue per unit of electricity that would be required to recoup the investment to meet a certain investment hurdle rate.

LCOE calculation typically includes key technology costs (e.g., capital expenditure (CAPEX), operational expense (OPEX) such as fixed and variable operations & maintenance costs, and fuel cost), technology performance parameters (e.g., efficiency, capacity factor), and financing assumptions (e.g., cost of capital, discount rate, IRR hurdle rate).

This study used NREL's 2021 Annual Technology Baseline (ATB) workbook (https://atb.nrel.gov/) to calculate solar and solar + storage's LCOE, as was used in the global 'Breakthrough Effect' report. For coal and gas power plants' LCOE, since NREL's ATB does not include calculation of LCOE for fossil-fuelled technologies, another tool, IESR's 2023 LCOE Calculator (https://energycost.id/), was used. To produce an ASEAN-level relevant analyses, key assumptions are taken from institutions who work in the region (e.g., ASEAN Centre for Energy, IRENA, IEA, etc.).

Key assumptions

Grouping of the ASEAN countries was done to showcase regional differences between countries with stronger enabling policy environment and weaker ones. The grouping following with the assumptions are summarized as follows:

- Group 1: Vietnam, Thailand, Malaysia, the Philippines
- Group 2: Cambodia, Indonesia, Myanmar, Laos

Table A-1. Key assumptions for solar and solar + storage's LCOE

<table>
<tr><th rowspan="2">Country Group</th><th colspan="2">PV CAPEX[a] ($/kWdc)</th><th colspan="2">Storage CAPEX[b] ($/kWh)</th><th colspan="2">Fixed O&M[c] (%CAPEX/year)</th><th colspan="2">Cost of capital[d] (%)</th><th colspan="2">Capacity factor[e] (%)</th><th colspan="2">Capital recovery factor (Years)</th></tr>
<tr><th>Min</th><th>Max</th><th>Min</th><th>Max</th><th>Min</th><th>Max</th><th>Min</th><th>Max</th><th>Min</th><th>Max</th><th>Min</th><th>Max</th></tr>
<tr><td>Group 1</td><td>760</td><td>870</td><td>300</td><td>330</td><td>1 (2)</td><td>1 (2)</td><td>5 (7)</td><td>8</td><td>19</td><td>16</td><td rowspan="2" colspan="2">20</td></tr>
<tr><td>Group 2</td><td>800</td><td>940</td><td>315</td><td>356</td><td>1 (2)</td><td>1 (2)</td><td>6 (7)</td><td>10</td><td>18</td><td>16</td></tr>
</table>

Notes: LCOE for solar PV + storage refers to a single-axis tracking PV system of 130 MWp capacity and 4-hour duration lithium-ion battery storage system with 50 MWac of capacity. Values in parentheses are values for solar + storage.

Source: [a]) IRENA & ACE (2022), ASEAN RE Outlook, [b]) BloombergNEF (2023), Top 10 Energy Storage Trends in 2023, adjusted for ASEAN region by +10% for Group 1 and +15% for Group 2 countries. [c]) IESR (2023), Making Energy Transition Succeed: A 2023's Update on The Levelized Cost of Electricity and Levelized Cost of Storage in Indonesia, [d]) IEA & Imperial College London (2023), ASEAN Renewables: Opportunities and Challenges, [e]) Same as source 'a'.

Table A-2. Key assumptions for coal and gas power plants' LCOE

Country Group	CAPEX[a] ($/kW)		Fixed O&M[a] (%CAPEX/ year)		Var O&M[a] ($/MWh)		Capacity factor[a] (%)		Fuel cost[a] ($/ton or $/ MMBtu)		Lifetime[a] (Years)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Group USC	1140	1520	3.7	0.11	74	70	45	42	150 (70)	200 (90)		30
Group CCGT	650	1000	3.4	0.23	50	35	61	56	10 (6)	13 (8)		25-30

Notes: Coal USC refers to ultra-supercritical coal power plant, whereas Gas CCGT refers to combined-cycle gas turbine/power plant. **LCOE for both Group 1 and Group 2 used** the same cost and technical parameters taken from technology data for Indonesia's power sector developed by the Danish Energy Agency except for the fuel cost. Since there is no domestic price cap for primary energy in other ASEAN countries, market prices in 2022 are used. Fuel cost's values in parentheses refer to domestic primary energy price cap in Indonesia ($70/ton for coal and $6/MMBtu for natural gas). Power plant sizes are assumed to be 1,000 and 600 MW for coal USC and gas CCGT, respectively. A default 10% weighted average cost of capital is used.

Source: [a]) IESR (2023), Making Energy Transition Succeed: A 2023's Update on The Levelized Cost of Electricity and Levelized Cost of Storage in Indonesia.

Lever assumptions

Levers, whether through policy or market levers, to showcase how the tipping points can be triggered faster were considered in the analyses. This comes through either disincentivisation of coal/gas power plants or incentivisation for solar and storage deployment. Table A-3 summarises all assumptions used in the analysis.

Table A-3. Key assumptions for levers

Levers	Group 1	Group 2	Group 2 (Indonesia)
I. Coal and gas power plants			
Coal price fluctuation	$150-200/tonne		N/A
Gas price fluctuation	$10-13/MMBtu		$9-10/MMBtu
Stricter air pollutant control (for coal)	N/A	N/A	Retrofit for best available technology[a] Capex: $148/kW O&M: $1.98/MWh
II. Solar & Solar + Storage			
Land support	Capex reduction by 5-10%	Capex reduction by 8-15%	
Improved market rules[b]	Reduced WACC: 5-6.5%	Reduced WACC: 6-8%	
Carbon revenue	N/A	Carbon price x avoided emissions Coal closure-linked carbon price: $10-15/tCO2e Avoided emissions: coal-fired power plants emissions (0.9-1.1tCO2e/MWh) – grid emissions to cover the loss of delivered power (0.3-0.8tCO2/MWh)	
Battery cost learning rate	5-10% Capex reduction	N/A	

Notes: [a]) CREA & IESR (2023), Health Benefits of Just Energy Transition and Coal Phase-out in Indonesia. [b]) IEA & Imperial College London (2023), ASEAN Renewables: Opportunities and Challenges

Fossil fuel disincentivisation:

- **Coal/gas price fluctuation:** Market price fluctuation of coal or gas can tip the economics better for solar rather straightforwardly as it increases the operation cost of building (or even operating) a coal or gas power plant. In countries where there is no protective policy (i.e., domestic price cap), this lever may be viewed as a market condition than a lever per se.
- **Carbon tax:** The implementation of a carbon tax can increase the cost of operating coal/gas power plants. While it has not been set up in many ASEAN countries (except Singapore and Indonesia), it is expected to be implemented by other ASEAN countries.
- **Stricter air pollution control (APC):** Stricter emissions regulations may require operators to retrofit their power plants, leading to higher cost of generation.

Solar and storage incentivization:

- **Land support:** Government support for site development and land acquisition can reduce cost and uncertainty, thereby reducing the overall market risk.
- **Improved market rules:** Clear regulations and auction mechanisms that provide market stability and increased demand assurance can reduce market risks associated with developing solar and solar + storage projects, leading to lower interest rates and lower cost of capital.
- **Carbon revenue:** Additional revenue from carbon reduction tied to coal-closure and VRE-building can improve the economics of solar project.
- **Reduced battery capex:** Lowered battery capex from battery learning curves may further decrease the LCOE of solar + storage.

2. Road transport: Electric two-wheelers

In the two-wheeler road transport sector, total cost of ownership (TCO) of electric two-wheelers (E2Ws) and internal combustion engine (ICE) two-wheelers (ICE 2Ws) were compared.

TCO is a financial estimate of owning a 2W vehicle over a specific period (i.e., years) or distance travelled (i.e., kilometre) basis. TCO typically consists of upfront cost, operating cost (e.g., fuel and maintenance costs), and cost of financing as shown in the following equation.

$$TCO = Upfront\ cost + Operating\ cost + Financing\ cost$$

where, upfront cost includes base/sticker price, VAT, registration fee, license plate fee, insurance fee, battery replacement cost; Operating cost includes fuel consumption and operations & maintenance costs; and cost of financing, that is, the loan amount.

Key assumptions

TCOs for ICE 2W and E2W were calculated for a duration of five years with key cost assumptions listed in Table A-4 below:

Table A-4. Key cost parameters for ICE 2Ws and E2Ws TCOs

ICE Motorcycle TCO

Cost components (USD)	Brunei	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Thailand	Vietnam	ASEAN Average
Upfront cost	**804**	**1,171**	**1,081**	**1,218**	**1,084**	**964**	**1,108**	**536**	**867**	**992**
Sticker price	750	1,000	871	1,014	880	816	900	435	700	818
VAT & other fees	54	171	210	204	204	148	208	101	167	174
VAT	-	*100*	*96*	*71*	*88*	*41*	*90*	*44*	*75*	*67*
Registration fee	*40*	*53*	*47*	*54*	*47*	*44*	*48*	*23*	*37*	*44*
License plate fee			*52*	*61*	*53*	*49*	*54*	*26*	*42*	*48*
Insurance fee	*14*	*18*	*16*	*18*	*16*	*15*	*16*	*8*	*13*	*15*
Operations cost (5 years)	**618**	**2,245**	**1,625**	**2,482**	**933**	**2,073**	**2,137**	**2,288**	**1,833**	**1,804**
Fuel consumption	450	2,020	1,429	2,253	735	1,889	1,934	2,190	1,675	1,620
Maintenance cost	169	225	196	228	198	184	203	98	158	184
Financing cost	**150**	**200**	**174**	**203**	**176**	**163**	**180**	**87**	**140**	**164**
TCO	**1,572**	**3,617**	**2,880**	**3,903**	**2,193**	**3,200**	**3,425**	**2,911**	**2,839**	**2,949**

Li-ion electric two-wheelers

Cost components (USD)	Brunei	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Thailand	Vietnam	ASEAN Average
Upfront cost	**1,646**	**1,790**	**1,509**	**1,747**	**1,402**	**1,718**	**1,646**	**1,618**	**2,189**	**1,525**
Sticker price	1,438	1,438	1,307	1,438	1,225	1,438	1,438	1,389	1,875	1,250
VAT & other fees	208	352	202	309	177	280	208	229	314	275
VAT	-	*144*	*13*	*101*	-	*72*	-	*28*	*208*	*68*
Registration fee	*58*	*58*	*52*	*58*	*49*	*58*	*58*	*56*	*11*	*55*
License plate fee	*64*	*64*	*59*	*64*	*55*	*64*	*64*	*62*	*84*	*70*
Insurance fee	*86*	*86*	*78*	*86*	*73*	*86*	*86*	*83*	*12*	*82*
Operations cost (5 years)	**407**	**792**	**437**	**280**	**517**	**271**	**937**	**446**	**545**	**550**
Fuel consumption	263	648	307	136	394	127	793	307	482	411
Maintenance cost	144	144	131	144	122	144	144	139	63	139
Cost of financing	**581**	**581**	**528**	**581**	**495**	**581**	**581**	**561**	**757**	**675**
TCO	**2,634**	**3,163**	**2,474**	**2,608**	**2,413**	**2,570**	**3,164**	**2,625**	**3,492**	**2,750**

Source: Multiple sources, Systemiq analysis.

Notes: Singapore is excluded due to the low adoption of 2Ws.

For fuel consumption, the following assumptions were used:

Table A-5. Assumptions for fuel consumption

ICE 2Ws – fuel consumption		
Fuel tank capacity	13.5	L
# of full refuelling per month	2	times/month
# of years	5	years
Fuel consumption per year	324	L
E2Ws – electricity consumption		
Distance per day	40	km
Distance per year	14,600	km
Efficiency	0.06	kWh/km
Electricity needs per year	876	kWh

Source: Systemiq analysis

Table A-6. Fuel and electricity price across ASEAN countries

Country	Fuel Price (USD/L)	Electricity Price (USD/kWh)
Vietnam	1.03	0.11
Indonesia	0.88	0.07
Thailand	1.35	0.07
Philippines	1.19	0.18
Malaysia	0.45	0.09
Brunei	0.28	0.06
Cambodia	1.25	0.15
Laos	1.39	0.03
Myanmar	1.17	0.03
Singapore	2.05	0.24
ASEAN Average	1.105	0.103

Source: Global Petrol Prices, Systemiq analysis

Lever assumptions

Levers to trigger E2Ws' 2nd tipping point (i.e., sticker price parity) are as follows:

- **Reduced battery cost (15-17% learning rate):** Reduction in battery capex from battery learning curves may decrease the sticker price of E2Ws.
- **Subsidies (5-10%):** Policies providing subsidies either for the purchase of E2Ws or directly to OEMs will directly affect the sticker price of the vehicle.
- **Reduced VAT (-5%):** Policies that aim to reduce the VAT of E2Ws can lower the sticker price, also affecting the vehicle's sticker price.

3. Road transport: Electric buses

In the road public transport sector, total cost of ownership (TCO) of electric buses and internal combustion engine (diesel) buses were also compared. However, a TCO per distance-travelled ($/km) basis was used rather than pure cost TCO ($) as were used for two-wheelers, so that the equation is as follows:

$$TCO\ per\ km = \frac{Ann.\ \ total\ cost\ of\ vehicle\ (Upfront+Operating\ +Financing\ costs)}{Annual\ distance\ traveled\ (km)}$$

where, *annualised total cost of vehicle* is the total of upfront, operating, and financing costs over an assumed period of lifetime. *Upfront* cost includes vehicle/sticker price and charger cost (in case of e-bus). Operating cost includes fuel consumption and operations & maintenance (O&M) costs, and financing cost refers to the cost of financing (loan amount).

Key assumptions

Key cost assumptions for buses TCO are as follows:

1) Operational assumptions

Table A-7. Operational assumptions for buses TCO calculation

Operational assumptions	Value
General	
Years of operations	12
Distance per year (km)	60,000
ICE bus	
Fuel economy (km/L)	3
Fuel price per litre	1.32
E-bus	
Fuel economy (kWh/km)	1.1
Electricity price ($/kWh)	0.10

2) Charging assumption

Table A-8. Charging assumption for electric bus TCO calculation

Type of charging	Price/unit ($)	Vehicle: charging ratio	Price ($)
Depot	75,000	2	37,500
Route	100,000	4	25,000
	Total		62,500

3) Financing cost assumption

Table A-9. Financing cost assumption

Bus type	Financing cost
ICE (diesel)	6% vehicle price
Electric	24% vehicle price

Resulting TCO calculation

Table A-10. Resulting cost variables for ICE bus and e-bus TCO

Cost variable	ICE bus	E-bus
Upfront cost ($)	120,600	350,000
Vehicle price ($)	120,600	287,500
Charger cost ($)	N/A	62,500
Financing cost ($)	7,236	84,495
Total cost of vehicle ($)	**127,836**	**434,495**
Annualized total cost of vehicle ($)	10,653	36,208
Fuel cost per year ($)	26,400	6,600
O&M cost ($)	15,000	12,000
Annualized TCO ($)	**52,053**	**54,808**
TCO per km ($/km)	**0.87**	**0.91**

Notes: Annualised total cost of vehicle is the total cost of vehicle divided by total years of operations (12 years).
TCO per km is Annualised TCO, which totals annualised total cost of vehicle, fuel cost, and O&M cost, divided by the total distance per year (60,000 km).

Lever assumptions

Levers to further reduce e-buses sticker price were considered in the analysis.

- **Reduced battery cost:** Lowered battery cost from battery learning curves may decrease the sticker price of e-buses. In the base scenario, battery contributes to 50% of electric bus's sticker price. Assuming a 15% learning rate of battery, a range of battery cost reduction is assumed as follows:

Table A-11. Battery cost reduction assumptions

Battery cost reduction	Value
Battery pack price ($/kWh)	289
Battery capacity (kWh)	300
Battery price per bus ($)	86,657
% battery price to upfront cost	25%
Min-max range	0.8-1.25

- **Policy lever (subsidy):** policies providing subsidies for the purchase of e-buses or directly to OEMs will directly affect the sticker price of the vehicle, leading to lower TCOs. A conservative 5-6.25% sticker price reduction was applied to this lever.
- **Reduced financing cost:** As the market grows, it is expected that more and more financing institutions will provide cheaper and longer-term financing options to procure e-buses. Key assumptions used were as follows:

Table A-12. Reduced financing cost assumptions

Variable	Base scenario	Min	Max
Sticker price ($)	350,000	350,000	350,000
%Financed by loan	50%	50%	50%
Interest rate	12%	8%	5%
Tenor (months)	84	96	120
Resulting %financing cost relative to sticker price	24%	17.8%	13.6%

4. Industrial heat

In the industrial heat sector, the **levelized cost of heat (LCOH)** of both industrial heat pumps and electro-thermal energy storage (ETES) were compared against gas and coal steam boiler.

Like other levelized cost, LCOH is a measure of the average unit cost of heating. The inputs of LCOH are technology cost (CAPEX), fixed O&M (OPEX), and fuel cost (gas/coal price or electricity price in the case of the heat pump and ETES). LCOH is represented by the unit $/MWh-th, that is, a dollar unit cost to produce one unit of thermal energy (heat).

The LCOH of coal/gas steam boiler, heat pumps, and ETES were calculated using Power-2-Heat transformation cost calculator developed by Agora Industry, FutureCamp, and Wuppertal Institute, accessible here: https://www.agora-energiewende.de/en/publications/transformationskostenrechner-power-2-heat/.

Key assumptions

LCOH for gas/coal steam boiler, heat pump, and ETES were calculated using key assumptions in Table A-13 below:

Table A-13. Key assumptions for LCOH calculation

Technology	CAPEX ($/kW)		Fixed O&M ($/MWh-th)		OPEX – Fuel cost Coal/gas price ($/ton or $/MMBtu)		OPEX – Fuel cost Electricity price-equivalent ($/MWh)	
	Min	Max	Min	Max	Min	Max	Min	Max
Coal steam boiler	-	-	1.6	3.3	70	100	9.5	13.6
Gas steam boiler	225	250	1.6	3.3	8	12	27	40
Heat pumps	765	957	1.6	2.5	-	-	110	130
ETES	525	700	3	5	-	-	50	73

Notes: MWh-th (megawatt-hour thermal) refers to the energy unit to produce one unit of heat (thermal energy). The specific demand of natural gas steam boiler to produce one unit of heat was 1.05 MWh/MWh-th (95% efficiency) and 1.12 MWh/MWh-th for coal steam boiler (89% efficiency).

*ETES' CAPEX assumptions are drawn from Energy Innovation's 2023 Industrial Thermal Batteries report. There are three main cost components to ETES: electricity input equipment (wires, switches, transformers, etc.), heat delivery equipment (i.e., heat exchanger), and the thermal storage medium. The cost of assumption of each component is assumed to be $100/kW-in, $300/kW-out, and $5/kWh, respectively – figures drawn from the Energy Innovation report.

The configuration of the ETES is assumed to be an off-grid, generation-following type (using only solar PV) -- as opposed to the price-hunting configuration in grid-connected system with wholesale electricity market (in liberalized electricity market). It is assumed that the ETES must provide 24/7 heat. To cover 24 hours of, for example, 1 kW-out of heating demand, it is assumed that there needs to be at least three times (3x) the electricity input capacity (kW-in) to cover both 6-8 hours of direct heating output (while solar is generating) and to charge the thermal storage enough to provide the remaining 16-18 hours of heating demand not covered by solar PV (when the sun is down). The thermal storage is sized accordingly to provide the 16-18 hours of heating demand not covered by solar PV directly. Note that optimization through more rigorous modelling is certainly possible but was not done here for the sake of simplicity of providing high-level LCOH value for ETES.

Levers assumption

Coal/Natural Gas Steam Boiler

- **Natural gas price fluctuation:** Fluctuations in the price of natural gas given market instability might add additional operational costs for heating. In the calculation, a price fluctuation of 1.5-2.25x from the minimum price ($6/MMBtu) was applied ($12-18/MMBtu) to reflect this fluctuation. In 2022, the fluctuation from LNG spot market went above $20/MMBtu[1].

[1]IEEFA (2022). Global LNG Outlook 2023-2027.

- **Carbon Tax:** Implementation of a carbon tax can lead to higher CO_2 costs for natural gas steam boiler. A rather conservative carbon emission allowances of $10-25/EUA price (because the tool was made for the EU context) was applied to reflect a carbon tax impact of $1-5/MWh-th to the LCOH.

Heat Pumps

- **CAPEX reduction**: A 5-10% capex reduction was applied to heat pumps' CAPEX. This is assumed to be resulted in from learning curve from heat pumps installations by the end of this decade[2].
- **Cheaper grid electricity price**: The availability of cheaper grid electricity price may further decrease the LCOH of heat pumps. Here, a 20-40% reduction from the base value ($110/MWh), which is ASEAN's average electricity price, was applied. The basis for this assumption is that in some ASEAN countries electricity prices for the industry were much lower than $110/MWh (e.g., $70/MWh and $63/MWh for medium and high-voltage group, respectively, in Indonesia). In other cases, it is also sometimes sourced from a dedicated captive hydropower.
- **Improvement on heat pumps' coefficient of performance (COP)**: Improvement in heat pumps' coefficient of performance, or efficiency, can further reduce the operational cost (i.e., electricity consumption) of heating using heat pumps. Here, a 10-33% efficiency gain was applied to reflect the improvement on COP.

Electro-thermal energy storage

- **Capex reduction:** A 10-20% capex reduction was applied to ETES' LCOH calculation. The basis for this is that ETES is still in a solution development stage and that capex reduction can be achieved from learning in installations and/or grant support from the government to support industrial heat decarbonization.
- **Lowered VRE LCOE:** Further reduction in VRE's LCOE can also reduce the LCOH of ETES. Here, a VRE electricity price of $30-40/MWh from solar PV was considered assuming it was installed in the best sites. Policies and direct PPA arrangement to enable this deployment can also help realize this low VRE electricity price.

5. Shipping: Green ammonia for shipping fuel

In the shipping sector, **the levelized production cost of green ammonia (LCOA)** for shipping fuel is compared against the incumbent fuel heavy fuel oil (HFO).

The tipping point analysis in this report used the same calculation used in the global Breakthrough Effect report, which uses calculation from **Mission Possible Partnership (MPP)'s *2022 Making Net-Zero 1.5°C-Aligned Ammonia Possible*** report. The calculation assumed an electrolysis-based ammonia production route with dedicated on-site renewables (variable renewable energy with storage) and pipeline H2 storage to balance the intermittency and ensure a stable supply of H2 to the Haber-Bosch (ammonia synthesis) process.

Like other levelized cost, LCOA has several variables, namely CAPEX, fixed OPEX, variable OPEX (which depends on energy and feedstock prices that may vary across region), a weighted average cost of capital (WACC), capacity utilization factor (CUF) and a technology lifetime (T); and is calculated given the equation below. Simply put, LCOA describes the annual cost of investment per unit of production (one tonne of ammonia).

$$LCOA = \frac{CAPEX + \sum_{t=0}^{T} \dfrac{OPEX_{fixed,t} + CUF * OPEX_{variable,t}}{(1 + WACC)^t}}{CUF* \mid \sum_{t=0}^{T} \dfrac{1 \text{ tonne per annum}}{(1 + WACC)^t}}$$

[2]IEA (2020). Energy Technology Perspectives: Special Report on Clean Energy Innovation.

Key assumptions

The original model[3] calculated all 15 possible production routes ranging from steam reforming, gasification, electrolysis, and methane pyrolysis and covered 10 different regional variations with differing energy and feedstock prices. For the calculation of the global report and this report, however, only the minimum LCOA value was used.

The calculated LCOA from the global report is presented in Table A-14. Several LCOAs from regions close to Southeast Asia are also presented in the table to highlight the comparison of green ammonia production in ASEAN compared to other regions.

Table A-14. Levelized cost of green ammonia from selected modelled regions

LCOA ($/t$NH_3$)	2020	2030	2050
Australia	709	493	427
China	645	540	508
Rest of Asia	862	595	501
Saudi Arabia	710	533	469
Min	624	447	397
Median	763	545	477
Max	921	673	588

To convert the LCOA from its cost per ton ammonia ($/t$NH_3$) to cost per HFO-equivalent unit ($/tHFO-equivalent), a conversion factor of 2.07 (tNH_3/tHFO) was used. Other conversion factors used are presented in Table A-15.

Table A-15. Conversion factors

Conversion Factors	Value
Carbon Price USD/tCO_2	100
tCO_2/tHFO	3.15
tNH_3/tHFO	2.07

Prices for HFO were taken from the National Institute of Statistics and Economic Studies (INSEE), which is taken from the global Breakthrough Effect report, and is presented in Table A-16.

Table A-16. Historic average and range price of HFO

Variable	Units	Region	2020
HFO 10-Year Min	$/tHFO	Global	145
HFO 10-Year Max	$/tHFO	Global	1125
HFO Average Price	$/tHFO	Global	550
HFO Average + Carbon Price ($100/t$CO_2$)	$/tHFO	Global	865

Source: National Institute of Statistics and Economic Studies (INSEE).

[3] *Ammonia Sector Transition Strategy Model.* For more details on the key input assumptions of the model, please refer to the Technical Appendix of the MPP Ammonia report.

6. Critical minerals: Nickel refinery

In the critical minerals: nickel refinery sector/super-leverage point, **additional solar PV capacity demand** for nickel refinery in Indonesia was calculated.

The additional PV capacity demand was estimated using the following equation:

$$\textit{Nickel demand x Electricity demand (per tonne } Ni_{eq}\textit{) x \%VRE (\%RKEF (NiO) + \% RKEF (FeNi))}$$

where:

- Nickel demand for batteries was assumed to be 40% of projected smelter capacity in 2024
- Electricity demand (kW) per tonne Ni-equivalent was estimated using assumptions below
- %VRE penetration was assumed using three scenarios: 25, 40, 60% (all from solar)
- %RKEF(NiO) refers to how many % of total nickel smelting came from NiO ore/production route. Here, 50% was assumed.
- Likewise, %RKEF(FeNi) refers to how many % of the total nickel smelting came from FeNi ore/production route. Here, 25% was assumed.

Key assumptions:

a. Nickel demand

Projected nickel demand for batteries in 2024 was estimated using a smelting production capacity forecast in Figure A-17. It is assumed that only 40% of this smelter production capacity goes into the production Li-ion batteries.

Table A-17. Global Nickel smelter production capacity (kt)

	2018	2019	2020	2021	2022F	2023F	2024F
Indonesia	364	470	710	988	1,327	1,512	1,650

b. Electricity demand

Electricity demand per tonne of Nickel-equivalent is estimated by production pathway and type of ore alloys (NiO or FeNi). In this case only rotary kiln electric furnace (RKEF) is considered because it is the production route that requires electricity.

Table A-18. Electricity consumption for smelting Nickel alloys by RKEF

Process	NiO (per tonne alloy)	FeNi (per tonne alloy)
Purity	76%	36%
Electricity consumption (kWh):		
Calcination		104
Smelting	18,187	7,237
Refining		1,081
Total (kWh)	18,187	8,422
Total for 100% Ni-eq (kWh)—[1/purity]	23,930	23,394

Source: Wei et al., (2020), Energy Consumption and Greenhouse Gas Emissions of Nickel Products, Energies, Systemiq analysis.

Electricity demand per tonne Nickel equivalent is then calculated assuming a 20% capacity factor of solar PV. Hence, the equation becomes:

$$Electricity\ per\ tonne\ Ni_{eq} = \frac{Total\ electricity\ needs\ for\ 100\%\ Nickel_{eq}}{8760 \text{ x } Solar\ PV\ capacity\ factor\ (20\%)} = 13.66\ kW/tonne$$

c. VRE penetration scenarios

This calculation considers three different VRE penetration scenarios: 25, 40, and 60% VRE (solely from solar power). These resulted in, respectively, 1.8, 2.9, and 4.3 GW of additional solar PV capacity demand in 2024 for Nickel refinery specific for Lithium-ion batteries in Indonesia.

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