

THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

Understanding policy-based energy transition under rapidly growing electricity demand of developing and emerging economies: A case study of Indonesia, the Philippines, and Vietnam

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Gothenburg, Sweden 2025

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Printed by Chalmers Reproservice.
Gothenburg, Sweden 2025

Abstract

Energy transition is a crucial part of global climate change mitigation which needs to happen in both developed and developing countries. Different conditions between the two require a balanced understanding of energy transition in both contexts. However, the current literature on energy transitions does not reflect this requirement as the literature has primarily stemmed from studies of developed countries. Energy transitions in developing and emerging economies have been understudied despite the different sets of challenges they face. One such challenge is the rapidly growing energy demand. It complicates the ability of developing countries to replicate renewable energy transition, such as fossil fuel substitution and coal decline, which mainly occur in developed countries with stabilised demand growth. Simultaneously, cases of energy transition in developing and emerging economies show the critical role of policy in driving the transition, suggesting that policy may provide the key to energy transitions under rapidly growing demand.

This thesis aims to understand the interplay between renewable growth and fossil fuel decline, two key components of the energy transition, as aspired to by national-level policy along with their impacts on the decarbonisation process and carbon emissions. It also seeks to enhance the applicability of existing energy transition frameworks which have predominantly originated from studies in developed countries. This thesis examines the electricity supply of three developing and emerging economies in Southeast Asia—Indonesia, the Philippines, and Vietnam—as a case. These countries are chosen because they share similar socio-economic development, have low renewable penetration and high dependency on coal, and have set similar policies on energy targets and a moratorium on new coal power plants.

This thesis explores the dual aspects of energy transition: the growth of renewable energy and the decline of fossil fuels. For the former, this thesis focuses on the energy targets of the case countries and projects future electricity mixes as aimed by the targets. The decarbonisation pathway framework is then used to analyse the energy transition phases of each country as indicated by the projected electricity mixes. For the latter, this thesis focuses on peak coal, an important step towards coal decline and phase-out which has not been widely investigated in the electricity system context. The peak coal is further distinguished into peak coal capacity and peak coal generation, leading to the development of separate approaches for each. Peak coal capacity is determined by using coal pipeline data. Peak coal generation is determined by considering the growth of coal substitutes through the construction of policy-based and empirical scenarios.

This thesis contributes to the development of the literature on energy transition in developing and emerging economies. In particular, it raises discussion on the link between energy targets and future transition pathways as well as the importance of peak coal electricity in transitioning away from coal. Methodologically, this thesis provides complementary tools to extend the applicability of the decarbonisation pathway framework and proposes distinct methodologies to determine future peak coal capacity and generation. This thesis also provides policy insights on electricity system decarbonization in Indonesia, the Philippines, and Vietnam, which are likely to be applicable also to other developing and emerging economies facing similar challenges of rapidly growing energy demand and high coal dependency.

Appended publications

This thesis is based on the following papers:

- Paper I** M.R. Dzikurrokhim, E. O. Ahlgren, Target-driven energy transition in Southeast Asia: A comparative study of Indonesia, the Philippines, and Vietnam, *Manuscript*
- M.R.D. – Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Visualisation, Writing – original draft, Writing – review and editing. E.A. – Conceptualisation, Resources, Supervision, Writing – review and editing.
- Paper II** M.R. Dzikurrokhim, E. O. Ahlgren, M. Vetier, Peak coal electricity under rapid electricity demand growth conditions: A case study of Indonesia, the Philippines, and Vietnam, *Manuscript*
- M.R.D – Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Visualisation, Writing – original draft, Writing – review and editing. E.A. – Resources, Supervision, Writing – review and editing. M.V. – Conceptualisation, Supervision, Writing – review and editing.

Acknowledgements

In the name of Allah, the best of planners and the best Disposer of affairs. My journey at Chalmers up to this point has been mentally, physically, and academically challenging, and even painful at times. However, I also received a lot of help and support from so many people, to whom I am very grateful.

First, I would like to extend my special thanks to Erik Ahlgren, my supervisor, who has believed in me and my research, even when I did not believe in them myself. Thank you for offering me academic help and support at a time when it seemed impossible to find. Thank you also for letting me lead my own work and for the supervision and engaging discussions along the way.

Another special thank goes to Göran Berndes for agreeing to become my examiner and co-supervisor. I appreciate your regular feedback and your ongoing attention to my progress. I am also grateful to Marta Vetier for your patience when temporarily supervising me after recovering from panic attacks, and for your continuous collaboration in writing my second paper.

I extend my heartfelt gratitude to Matthias Maercker, from the Astronomy and Plasma Physics Division, for being my mentor. Thank you for listening to my story, helping me understand my own worries and confusion, and turning them into valuable lessons. Special thanks also to Pascale-L. Blyth, Chalmers' Doktorandsombud in 2023-2024, and Peter Hellqvist, SACO-S representative at Chalmers, for representing and assisting me throughout the process with the department.

A big thank you to Teresa Berdugo Vilches for warmly welcoming me when I first moved to the Energy Technology Division and for supporting me throughout the process. Thank you also to Anna Borg for finding me a desk in a very short time despite the desk scarcity in the division. Thank you to everyone at the Energy Technology Division for providing me with a neutral working environment which has allowed me to focus on my research.

I would also like to extend my gratitude to Peter Forkman, David Pallares, and Madelene Olsson from the SEE Department management for allowing me to complete my licentiate and for providing me with the time to rebuild myself and recover from my traumatic experiences in the previous division.

A lot of thanks to my colleagues and friends from the FRT division: Avi, Ankit, Caglar, Caroline, Masa, Lola, Ella, the “lunch for scientists” gang (Edvin, Johanna, and Matilda), and other PhDs and postdocs. Thank you for supporting me, and I will always cherish every moment I spent with all of you.

I am also deeply indebted to my Indonesian friends in the “Mossen” family 2023: *mas* Victor, *mas* Faris, *mbak* Nisa, and *mas* Rahmatdi. Thank you for always standing with me during the hardest time of my life and for supporting me when I had to fight for my rights as a PhD. I am 100% certain

that I would not have reached this point without your unwavering support. Special thanks to the Prianto family (*mas* Pandu, *mbak* Ryah, Araz) and Andhika for all the fun and good times which have replaced the painful memory during this journey.

Thank you also to all the people whom I met along this journey and who have given me valuable lessons for both my personal and professional development. I am sure that I will never forget these lessons for the rest of my life.

Finally, I would like to thank my family in Indonesia for their prayers, support, and understanding throughout this journey.

Göteborg,
August 2025

Journey before destination

Brandon Sanderson, *The Way of Kings*

Table of Content

ABSTRACT	I
APPENDED PUBLICATIONS	III
ACKNOWLEDGEMENTS	V
TABLE OF CONTENT	IX
CHAPTER 1 INTRODUCTION	1
CHAPTER 2 BACKGROUND CONDITIONS OF THE CASE COUNTRIES	5
2.1 SOCIO-ECONOMIC DEVELOPMENT	5
2.2 ELECTRICITY SYSTEM CONDITIONS	5
2.3 ENERGY TARGET DEVELOPMENT	6
2.4 COAL POWER DEVELOPMENT	6
CHAPTER 3 METHODOLOGICAL FRAMEWORK	9
3.1 DECARBONISATION PATHWAYS (PAPER I)	9
3.2 PEAK COAL IN THE ELECTRICITY SUPPLY (PAPER II).....	10
3.2.1 <i>Peak coal capacity</i>	11
3.2.2 <i>Peak coal generation</i>	11
3.3 SCENARIO CONSTRUCTION (PAPER I & II)	11
3.3.1 <i>Policy-based scenarios</i>	12
3.3.2 <i>Empirical scenarios</i>	13
3.4 EMISSION CALCULATION (PAPER II)	14
CHAPTER 4 DATA AND ASSUMPTIONS	17
4.1 DATA AND ASSUMPTIONS FOR PAPER I	17
4.2 DATA AND ASSUMPTIONS FOR PAPER II.....	18
CHAPTER 5 RESULTS AND ANALYSIS OF THE CASE STUDY	21
5.1 POLICY-DRIVEN ELECTRICITY MIX DEVELOPMENT.....	21
5.1.1 <i>Energy targets of the case countries envision higher renewable share and growth, but fossil fuels will still dominate in scenarios with higher demand projection (Paper I)</i>	21
5.1.2 <i>Achieving peak coal generation requires a rapid growth of natural gas or variable renewables (Paper II)</i>	22
5.2 DECARBONISATION PATHWAYS AND TOTAL EMISSIONS.....	22
5.2.1 <i>Decarbonising the electricity supply mostly requires renewable growth beyond countries' targets (Paper I)</i>	22
5.2.2 <i>Even if peak coal generation is achieved, total emissions can still increase significantly. Reducing the total emissions requires an absolute decline in fossil fuels. (Paper II)</i>	24

CHAPTER 6 DISCUSSION ON METHODOLOGICAL DEVELOPMENT	25
<i>6.1 Energy target interpolation and policy-based scenario construction complement the decarbonisation pathway frameworks (Paper I).....</i>	<i>25</i>
<i>6.2 New approaches to determine peak coal are proposed for reaching peak coal under growing electricity demand (Paper II).....</i>	<i>26</i>
CHAPTER 7 CONCLUSION	29
7.1 RETURNING TO THE RESEARCH QUESTIONS.....	29
7.2 CONTRIBUTIONS AND POLICY IMPLICATIONS	30
CHAPTER 8 REFLECTION AND OUTLOOK.....	33
REFERENCES	35
PAPER I	
PAPER II	

Chapter 1 Introduction

Energy transition can simply be defined as “*a change in the state of an energy system*” [1]. In the current context of climate change mitigation, it commonly refers to a change from a fossil fuel-based system to a renewable-based one [2]. The change can be viewed from narrow perspectives, such as changes in fuel sources, technology, or prime mover, or in a broader sense as a holistic system change [3]. Energy transition also entails a decline in the use of established energy sources and a simultaneous expansion of new energy sources [4]. In the context of the electricity system, energy transition brings about changes from a system where electricity is predominantly generated from fossil fuels to one where it is predominantly generated from non-fossil fuel sources.

As the energy transition is also described in terms of energy technologies as much as in terms of energy sources [4], the transition in the electricity system can also be viewed from the perspective of the technology lifecycle [5], starting from the formative phase, followed by growth, mature, and decline phases. This implies that in the energy transition, renewable technologies should shift from their formative phase to the growth phase and, possibly later, to the maturity phase. In contrast, fossil fuel technologies should transition from the growth or maturity phase to the decline phase, and potentially, phase out if there are deliberate interventions such as those from governments [6]. An example of this substitution can be observed in the EU and G7 countries, where renewable and low-carbon technologies have replaced fossil-fuel technologies since the second half of the 2000s [7].

However, unlike in developed countries, renewable energy development in developing¹ and emerging² economies is an addition rather than a transition [8]. This may be attributed to the increase in energy demand, which occurs much more rapidly in developing countries due to economic and population growth [9]. The rapid demand growth also presents different challenges to the energy transition in these countries. One challenge is that expanding the electricity system affects technology diffusion rates, with diffusion occurring more rapidly in a small system than in

¹ The term “developing country” in this thesis refers to the countries under World Bank’s category of low-income, lower-middle-income, and upper-middle-income.

² This thesis uses the term “emerging economies” as defined by Francisco Arizala and Di Yang from IMF through five weighted variables of nominal GDP, GDP per capita, population, the share of world trade, and the share of world external debt [71].

a larger one [1,10,11]. It implies that more efforts will be required to maintain the same rate of renewable energy development as the systems expand, let alone achieve a faster growth rate. At the same time, developing and emerging economies have less access to capital [12] which leads to a high cost of electricity generation from renewables under the constraints of countries' budget [13] while lacking institutional capacity to support rapid energy transition [14].

The transition difference between developed and developing countries is also evident in the technology lifecycle of coal power. Many developed countries have been experiencing a decline in coal power [15] while it is still growing strongly in developing countries, particularly in Asia [16]. As coal power plants need to be phased out globally to achieve the 1.5 °C target [17], it is not surprising that various studies have investigated coal phase-out from different perspectives [18–28]. The different phases also suggest that coal power is being phased out more rapidly in developed countries than in developing countries. Current literature has given less attention to peak coal [15] and coal decline [29] in the electricity system, which precede coal phase-out, even though these topics remain highly relevant to bridge the gap between the current coal growth and the aspired coal phase-out in developing countries.

These differences raise a question about how energy transition can occur in developing and emerging economies that are facing rapid demand growth and thriving coal power development. Following the historical precedents of developed countries, which have undergone earlier transitions, is likely to be difficult because transition processes like fossil fuel substitution [7] and the peaking of coal in electricity systems [15] only occurred under stabilised electricity demand³. The recent success story of rapid solar deployment in Vietnam, which emphasises the role of supportive policies [30], may indicate the importance of policy in inducing energy transition in developing and emerging economies. Furthermore, as energy transition studies have been conducted primarily in developed countries [31,32], there is also a question of whether the currently available energy transition framework can be applied to the different context of developing and emerging economies.

This thesis aims to understand the interplay between renewable growth and fossil fuel decline, two components that encompass the current energy transition, as aimed for by policies in

³ Stabilised electricity demand can refer to electricity demand that does not increase in the last few years or electricity demand that grows but in a relatively slow rate, i.e. not accelerating growth.

developing and emerging economies along with their environmental impacts. One important but currently overlooked policy in the energy transition literature is the energy target, whose importance lies in its role as a regulatory tool to implement regulatory instruments [33] and as a catalyst for common consent regarding the future that is to be achieved [34]. As developing countries have recently set high targets for accelerating renewable energy growth and reducing the share of fossil fuels in their electricity systems to attract financial support from the international community [35], understanding the implications of these targets for electricity systems becomes important in understanding energy transitions of developing and emerging economies. Aside from that, this thesis also aims to enhance the applicability of the existing energy transition framework to developing and emerging economies with rapidly growing electricity demand.

To achieve its aims, this thesis focuses on the supply side of the electricity system and presents case studies of three developing and emerging economies in Southeast Asia: Indonesia, the Philippines, and Vietnam. The countries are chosen because they are located in the same geographical area and have similar socio-economic development. They are also projected to have a rapidly growing electricity demand until 2050 [36–38] but have low renewable energy penetration and high dependence on coal. At the same time, the countries have set targets to increase renewable energy deployment and limit coal power growth and have announced moratoriums on new coal power plants [39,40]. The research questions are formulated as follows.

1. How will the electricity mix develop in Indonesia, the Philippines, and Vietnam if the countries achieve their aspirations as stated in national-level policies on energy targets and moratoriums on new coal power plants?
2. How do these developments affect the decarbonisation pathways and the total emissions of the electricity supply?
3. What are the methodological challenges in applying the existing frameworks to developing and emerging economies with rapidly growing electricity demand, and how can they be overcome?

Paper I focuses on energy targets and addresses the questions by analysing the decarbonisation pathways for future electricity mix development. It also proposes target interpolation and scenario construction as complementary tools to the decarbonisation pathway framework to overcome future uncertainties regarding the supply-demand balance of the electricity mixes. Paper II focuses

on peak coal in the electricity system and answers the three questions by distinguishing peak coal capacity and peak coal generation and analysing the timeline of and conditions enabling peak coal along with emission calculations. It also proposes separate methodologies for determining peak coal capacity and peak coal generation under conditions of growing electricity demand.

The rest of this thesis is structured as follows. Chapter 2 describes the background conditions of the case countries, including socio-economic background and electricity system conditions. Chapter 3 summarises the theoretical framework and general approaches, as used in Papers I and II, to answer the research questions of this thesis. Chapter 4 further specifies the data and assumptions used for each studied country within the approaches. Chapter 5 presents the results of the case study, with the main focus on addressing the first and second research questions. Chapter 6 addresses the third research question and discusses methodological development as a contribution of this thesis. Chapter 7 presents the conclusions of this thesis along with several policy implications. Lastly, Chapter 8 completes this thesis with a reflection and an outlook for future research.

Chapter 2 Background conditions of the case countries

This chapter summarises the background conditions of Indonesia, the Philippines, and Vietnam based on papers I and II. The conditions include socio-economic development, electricity system conditions, energy target development, and coal power development.

2.1 Socio-economic development

The socioeconomic development of this thesis focuses on population and economic growth. The population of the three countries have been steadily increasing, and in 2022, it reached 275 million in Indonesia, 115 million in the Philippines, and 98 million in Vietnam [41]. The economic growth is indicated by the GDP per capita, which has also been growing rapidly. The fastest growth is observed in Vietnam with a 4200% growth between 1990 and 2022, followed by Indonesia with 800% growth, and the Philippines with 440% growth. Aside from the population and economic growth, the electricity penetration has also increased significantly: Indonesia and Vietnam reached 100% electricity penetration by 2022 while the Philippines' penetration was above 95%.

2.2 Electricity system conditions

Following the rapid socioeconomic development, electricity demand has grown rapidly: since 1990, it has increased more than tenfold in Indonesia, fivefold in the Philippines, and fortyfold in Vietnam [42]. This, in turn, has led to the expansion of the electricity supply. The expansion has been fueled by fossil fuels, firstly oil until the early 2000s, and then coal and natural gas (refer to Figure 2 of Paper I). In 2022, the case countries generated electricity dominantly from coal, followed by natural gas. The renewable share was much lower than the fossil fuel share and mainly came from non-variable renewable energy (non-VRE) like geothermal in Indonesia and the Philippines, and hydropower in Vietnam (refer to Figure 3 of Paper I). However, Vietnam has recently been able to deploy solar power, which accounted for 10% of the total generation in 2022.

Despite sharing a similar expansion trend in electricity demand and supply, the three countries have different grid systems for transmitting their electricity. As the world's largest archipelago, Indonesia's national grid comprises seven main grids across the islands, and not all grids are connected. The Philippines and Vietnam divide their grid network into three main systems, from north to south, within the countries.

2.3 Energy target development

Indonesia, the Philippines, and Vietnam have updated their energy targets⁴ several times since 2010. The Philippines' energy target has undergone the most revisions as the country updated its energy target in 2018, 2020, and 2023. Vietnam, on the other hand, establishes its targets every ten years, and the last period (2010-2020) saw only one revision in 2016. Indonesia set its energy target in 2014, and a revision has been underway since 2024. The countries set their targets differently, either as electricity capacity or generation that they aim to achieve in each revision. However, each revision tends to increase countries' targets for renewable growth and fossil fuel reduction. A more detailed explanation of these target revisions can be found in Paper I.

The most current energy targets for Indonesia can be found in the proposed draft of the new National Energy Policy [36], in the Philippines Energy Plan 2023-2050 for the Philippines [38], and in the Power Development Plan 8 for Vietnam [37]. Each document establishes targets for both renewable, fossil fuel, and low-carbon sources until 2050, with some targets for specific sources stated within a range of values. Aside from targets, the document also includes projections of electricity demand until 2050, which are provided within a range of values.

2.4 Coal power development

Coal has seen an increasing share in the electricity mixes of Indonesia, the Philippines, and Vietnam since the 1990s. Significant increases occurred in the 2010s when many new coal power plants began their operations. This development is encouraged by concerns over energy security and affordability among policymakers [43–45]. Indonesia has the largest coal power capacity with more than 60 GW, followed by Vietnam with almost 30 GW, and the Philippines with almost 15 GW [46]. Around half of the capacity comes from coal power plants less than 10 years old.

The share of imported coal for electricity generation has risen continuously, especially for the Philippines and Vietnam [42]. In addition, the global trend of moving away from coal has begun to catch up in the three countries, especially after international financial support for coal becomes more limited [35]. The combination of these two factors has likely contributed to the countries announcing their aspirations to achieve net zero [47,48] and sign the Global Coal to Clean Power Transition Statement at COP26 in 2021 [49], marking a milestone on the global stage. At the

⁴ Energy target refers to the target that case countries set for their electricity supply. For more detailed explanation, refer to Paper I.

national level, Indonesia and the Philippines have incorporated their pledges for no new coal power plants into their regulatory documents [39,40] while Vietnam has included a long-term decline and phase-out of coal in its latest energy plan [37].

Chapter 3 Methodological framework

This thesis utilises existing methodological frameworks of the decarbonization pathway by Suzuki et al. [7] (Paper I) and peak coal electricity by Lægreid et al. [15] (Paper II). The first framework places greater emphasis on the renewable growth component of energy transition, whereas the second framework focuses more on the decline of fossil fuels, especially coal, in the energy transition. Despite these different emphases, it should be noted that both frameworks consider both renewables and fossil fuels to some extent. Both frameworks also address the first and second research questions regarding the future electricity mix development and its implications for decarbonization pathways and total emissions in the case countries. At the same time, as both frameworks are derived from empirical studies of primarily developed countries, methodological challenges exist when applying the frameworks to developing and emerging economies. Additional tools or steps are used to overcome these challenges, which also lead to the third research question.

3.1 Decarbonisation pathways (Paper I)

Paper I of this thesis utilises the framework developed by Suzuki et al. [7] to analyse decarbonisation pathways of the case countries. It is applied to energy targets set by each country in its electricity system. Analysing decarbonisation pathways envisioned by energy targets enables a direct link between energy targets and the future transition, which previous studies on energy targets have not established [50–54].

The decarbonization framework aggregates various low-carbon sources, including renewables and nuclear, and fossil-fuel sources each into a separate group and builds decarbonisation pathways based on the growth rate of each resource group. The growth rate of each source is calculated by averaging the annual growth rate during the observed periods. Paper I uses five-year periods to accommodate relatively detailed changes in the growth rate while avoiding extreme values which might occur in some specific years. The growth rate is calculated by using equation (1).

$$GR = \frac{(EG_{YearFinal} - EG_{YearInit}) * 2}{TES_{YearFinal} + TES_{YearInit}} \quad (1)$$

GR is the growth rate, EG is electricity generation, TES is the total electricity system, $YearInit$ is the initial year of a period, and $YearFinal$ is the final year of a period.

The pathways then represent energy transition phases that the case countries undergo (Fig. 1). The transition is classified into four categories: 1) high-carbon substitution with increasing fossil fuel growth and decreasing low-carbon growth, 2) energy additions with increasing fossil fuel and low-carbon growth, 3) low-carbon substitution with decreasing fossil fuel growth and increasing low-carbon growth, and 4) energy reductions with decreasing fossil fuel and low-carbon growth.

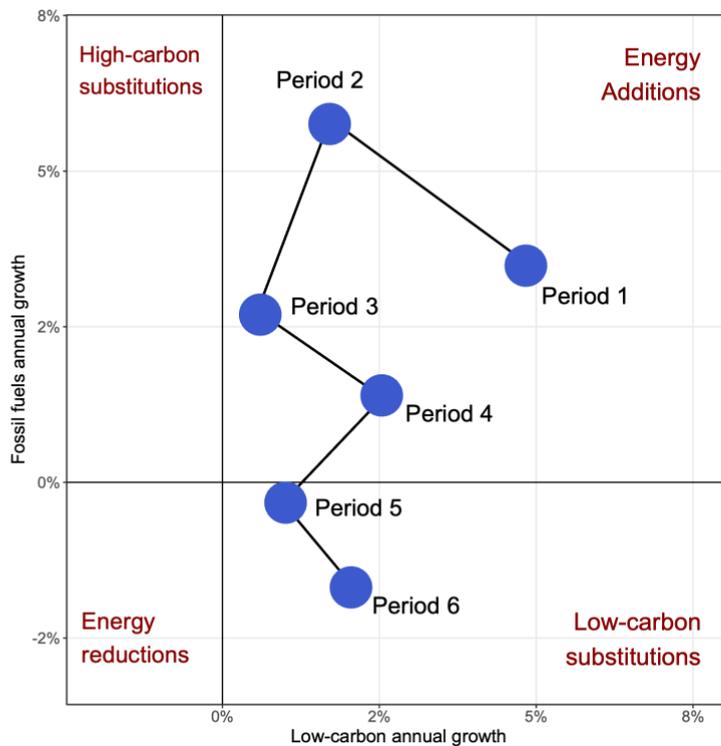


Figure 1 Illustration of decarbonisation pathway framework as utilised in Paper I. The dot represents the total electricity system size. The x-axis represents the average annual growth rate of low-carbon sources during the period and the y-axis represents the average annual growth rate of fossil-fuel sources. Adapted from Suzuki et al. (2023).

3.2 Peak coal in the electricity supply (Paper II)

Peak coal in the electricity supply marks the transition between the maturity and decline phase of coal power [5]. Laegreid et al. [15] found that historically, the peak of coal capacity (peak coal capacity) and the peak of coal-powered generation (peak coal generation) in the electricity system do not always coincide. The latter could occur before, around the same time, or after the former, and there are cases where it did not happen at all even after a country peaks its coal capacity. Therefore, it is essential to distinguish approaches when analysing the two peaks. Paper II of this thesis proposes new analysis methodologies which separate peak coal capacity and generation. The

new methods are also deemed necessary to address the different conditions of the past and future peak coal, in which the past peak coal occurred exclusively when countries' electricity demand stabilised [15].

3.2.1 Peak coal capacity

Peak coal capacity is determined using coal power plant projects data obtained from S&P Global [55] and Global Energy Monitor (GEM) [46]. The data provides details up to the power plant unit level and distinguishes power plants based on their operating statuses, which include planned, under construction, deferred, delayed, in operation, retired, and cancelled. A manual check is conducted for coal power plants with a capacity above 50 MW that are in the planned and under-construction statuses and lack data on the start of the operating year. A manual check is also conducted on the power plants with the statuses of deferred and delayed to ensure they have not changed statuses. Three assumptions are used for power plant lifetime: the age of the oldest operating coal power plants in the case countries (61 years), the average lifetime of global coal power plants (38 years) [46], and the lifetime compatible with the 1.5-degree scenario of the Paris Agreement (20 years) [56].

3.2.2 Peak coal generation

Peak coal generation is determined based on the electricity demand growth and the growth of alternatives to coal. These include renewable sources, both VRE and non-VRE, natural gas, and low-carbon technologies, including nuclear power and hydrogen. To limit coal power development under rapid electricity demand growth, there needs to be other energy sources which can generate enough electricity to fill the gap that might be left by coal. Because the growth dynamics of energy sources are explored through scenarios, peak coal generation is presented along with the scenarios.

3.3 Scenario construction (Paper I & II)

Two types of scenarios are developed in this thesis: policy-based and empirical scenarios. Policy-based scenarios aim to understand and assess what the case countries envision for their energy transitions, while empirical scenarios function to explore alternatives to the pathways set in the policies of the case countries. As such, policy-based scenarios are designed primarily based on countries' policies, with slight differences in the developed scenarios in Papers I and II. Empirical scenarios are constructed based on historical data of the "reference countries", which is a borrowed concept from the feasibility space construction [57], and is solely used in Paper II. Each scenario

is explained in more detail below while the summary of scenario construction can be found in Figure 2.

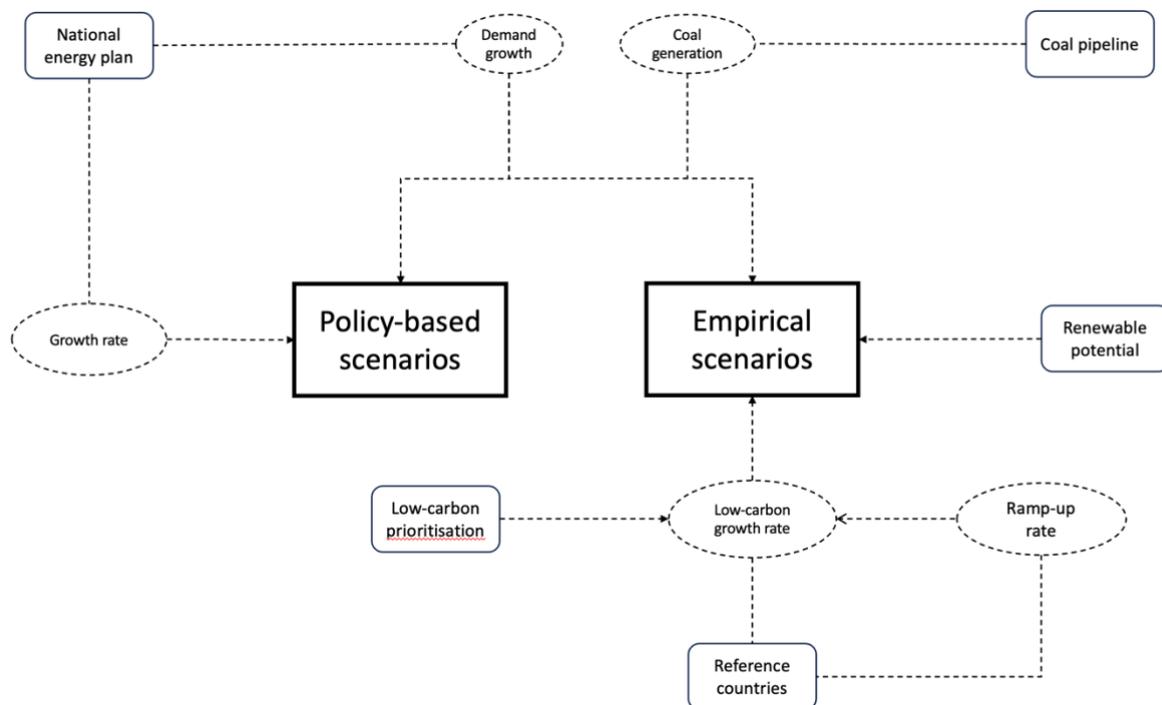


Figure 2 A summary of scenario construction process for policy-based and empirical scenarios. The squares with solid lines represent data sources, and the ovals with dashed lines represent variables taken from the data sources. The dashed lines connect the data sources, the variables taken from the data sources, and the scenarios in which the variables are used. Adapted from Paper II.

3.3.1 Policy-based scenarios

Policy-based scenarios are constructed based on policy documents, specifically energy or electricity plans that include electricity supply targets. The scenarios acknowledge the assumptions used by the policymakers to establish the targets and explore future electricity mix development if one, several, or all components of the targets are achieved. The assumptions include growth rates of electricity generation/supply and electricity demand. The scenarios also consider targets for all energy sources regarded by the policy documents. These include renewable sources (such as biomass, hydropower, geothermal, solar, and wind), fossil fuels (primarily coal and natural gas), and low-carbon sources (mainly nuclear). Although Papers I and II both utilise policy-based scenarios, a slight change is made in Paper II where target-based coal power growth is constrained by coal power generation derived from the pipeline capacity of coal power. The names and more detailed information about policy-based scenarios used in Papers I and II are described in Chapter 4.

3.3.2 Empirical scenarios

Empirical scenarios aim to explore different future developments of the electricity mix. They take optimistic assumptions where the case countries can replicate the fastest historical growth rates of coal-substitute sources from relevant reference countries, which are chosen based on (a) shared characteristic(s) with the case countries. Because there is a trade-off between the number of criteria and the number of countries that qualify as reference countries [57], Paper II establishes a total electricity system (TES) of at least 100 TWh/year for a minimum of five consecutive years as the primary criterion for selecting reference countries. This criterion accounts for the effect of system size on technology diffusion rate [1,10,11] and the five-year observation period.

Empirical scenarios primarily consider renewable sources and natural gas as substitutes for coal. Their growth rates, referred to as low-carbon growth rates in Figure 2, are calculated based on the historical growth rates of each reference country over five-year periods by using equation (1). The scenarios then use the 95th percentile value⁵ for each coal substitute to consider possible technological advancements during the observed periods while avoiding extreme outliers that might be difficult to replicate. This value is supplemented by a ramp-up rate, which is an annual growth rate derived from the historical annual growth of each coal substitute in the reference countries. The idea of ramp-up rate originates from the S-curve growth model [58] and represents the phase in which power supply technologies accelerate after transitioning from the formative phase to the growth phase. It is expressed mathematically in equation (2).

$$\text{Ramp-up rate} = \frac{EG_{YearFinal} - EG_{YearInit}}{EG_{YearInit}} \quad (2)$$

EG denotes electricity generation, *YearInit* denotes the first year, and *YearFinal* denotes the second year. The ramp-up rate of each source is selected through graphical observation (Figure 4 of Paper II) from the reference countries that have a higher penetration of related energy technology than the case countries and have experienced rapid growth in a relatively short period. A steep slope reflects the latter on the graph.

⁵ The calculation of low-carbon growth rates from the reference countries results in a large dataset of five-year growth rates. For every coal substitute, the 95th percentile of this dataset is used as the growth rate in the empirical scenarios.

Three constraints are introduced to low-carbon growth rates. The first constraint is electricity demand growth, which, similar to policy-based scenarios, is taken from energy plan documents of the case countries. The second constraint is the renewable potential and the natural gas limit. Paper II uses the technical potential of renewable sources as available in the literature. The natural gas limit is based on the highest value of electricity generation from the source as aimed for by the case countries in their energy plans. The limit represents the maximum capacity of the case countries to deploy natural gas power along with its supporting infrastructure. The last constraint is low-carbon prioritisation, which accounts for competition among coal substitutes as no reference country has been able to deploy all supply technologies at rapid rates simultaneously. The prioritisation leads to the development of three scenario groups within empirical scenarios: policy-priority scenarios, which take the priority from energy plans of the case countries, non-VRE scenarios, which prioritise electricity generation from hydropower, geothermal, and biomass in the respective order, and VRE scenarios, which prioritise electricity generation from solar and wind.

Coal generation is converted from the coal pipeline capacity by assuming the maximum utilisation rate. It is calculated using the capacity factor derived from historical coal capacity and generation in each of the case countries. The calculated coal generation from the pipeline is then constrained by electricity generation from other sources because coal is always considered the least prioritised source in every empirical scenario. Yet, it is assumed that fossil fuel deployment, encompassing coal and natural gas, will not decline over the observed period in the scenarios. Therefore, electricity generation from coal and natural gas will at least amount to the generation from the previous year. The generation can only decrease if electricity generation from renewable sources grows rapidly enough to replace that from coal and natural gas.

3.4 Emission calculation (Paper II)

I calculate the carbon emissions of the electricity mixes in both policy-based and empirical scenarios. The emissions consist of direct and lifecycle emissions. The data for direct and lifecycle emissions are mainly sourced from the Fifth Assessment Report of the IPCC [60]. Because the report does not consider the carbon storage effect of biomass vegetation, this thesis also omits this effect. Direct emissions consider only carbon emissions during the operation of power plants. In contrast, lifecycle emissions encompass three different sources of emissions: 1) direct emissions from power plants, 2) methane emissions from fuel production and delivery systems, and 3)

emissions from infrastructure, including the power plant itself, and supplies [59]. The lifecycle emissions also consider albedo effects when applicable. The calculated emissions are also compared with historical emissions. However, due to the unavailability of historical data, lifecycle emissions are calculated using the same methodology as the projected emissions. The values of direct and lifecycle emissions for each source are presented in Table 4 of Paper II.

To summarise this methodology chapter, Paper I employs the decarbonization pathway framework proposed by Suzuki et al. [7], and Paper II utilises the concept of peak coal electricity introduced by Lægreid et al. [15]. Yet, the characteristic of emerging economies, where electricity demand grows rapidly, requires an additional tool of scenario construction to apply the frameworks. In Paper I, scenario construction facilitates consideration of uncertainties arising from the demand-generation projection imbalance. In Paper II, scenario construction allows determination of the peak of coal-powered electricity despite the historical precedence that requires stable demand growth conditions. Carbon emissions are then calculated for each scenario to understand further the impacts of energy transitions on climate change mitigation.

Chapter 4 Data and assumptions

This chapter summarises country-specific data and assumptions from Papers I and II, which are utilised within the methodological framework to obtain the results and address the research questions. More detailed information on the data and assumptions can be found in the data section of Papers I and II.

4.1 Data and assumptions for Paper I

The targets and electricity demand projections established by Indonesia, the Philippines, and Vietnam have three characteristics which need to be considered when applying the decarbonisation pathway framework. First, the given targets and demand projections extend until 2050 with the values only provided for certain years before 2050. Yet, the current framework requires continuous data to create decarbonisation pathways. To solve the problem, the energy target and demand projection are interpolated. Between two available data points, it is assumed that the energy target or demand will grow linearly, meaning that the growth rate remains constant for each year between the data points.

Second, the targets and demand projections are given in a range of values for each data point. Third, the projected demand and the total supply derived from the targets do not always match, especially for the data points after 2040. To account for the different development possibilities that these two characteristics can lead to, four scenario groups are constructed: no adjustment of demand-supply balance, proportionate adjustment of demand-supply balance, countries achieving only lower values of renewable targets, and countries achieving higher values of renewable targets (Table 1). Combined with the demand projection values, eight scenarios, which also constitute the policy-based scenarios, are constructed. For LDLRE, HDLRE, LDHRE, and HDHRE scenarios, the remaining electricity demand is assumed to come from fossil-fuel sources, both natural gas and coal, with the proportion of each source for each year taken from the original targets.

Table 1 Summary of the eight scenarios derived from the demand projection and energy targets of Indonesia, the Philippines, and Vietnam. The ↑ sign represents a higher range, ↓ represents a lower range, CV represents generation values respective to the demand projection, NA represents no adjustment, PA represents proportional adjustment, and FF represents fossil fuels. The table is copied from Paper I.

Scenario group	Scenarios	Abbreviation	Demand projection	Generation value
No adjustment (as stated in the policy documents)	LDNA	Lower demand, no (generation) adjustment	↓	CV, NA
	HDNA	Higher demand, no (generation) adjustment	↑	CV, NA
Proportional adjustment (generation is made to match demand)	LDPA	Lower demand, proportional (generation) adjustment	↓	CV, PA
	HDPA	Higher demand, proportional (generation) adjustment	↑	CV, PA
Fossil-fuels development	LDLRE	Lower demand, lower renewable energy	↓	Renewables: ↓, remaining demand: FF
	HDLRE	Higher demand, lower renewable energy	↑	Renewables: ↓, remaining demand: FF
Low-carbon development	LDHRE	Lower demand, higher renewable energy	↓	Renewables: ↑, remaining demand: FF
	HDHRE	Higher demand, higher renewable energy	↑	Renewables: ↑, remaining demand: FF

4.2 Data and assumptions for Paper II

The data and assumptions for Paper II primarily concern the construction of policy-based and empirical scenarios. The policy-based scenarios of Paper II only use the LDPA, HDPA, LDLRE, HDLRE, LDHRE, and HDHRE scenarios from Paper I. The LDNA and HDNA scenarios are omitted because of the imbalance between total supply and demand. It means that the policy-based scenarios of Paper II assume that the total supply will always meet the projected demand.

For the empirical scenarios, the data and assumptions cover the reference countries, low-carbon growth rates, ramp-up rates, renewable potential, and low-carbon prioritisation. After

applying the TES criteria to countries worldwide, 31 reference countries are identified: United Arab Emirates (UAE), Argentina, Australia, Brazil, Canada, China, Egypt, France, Germany, India, Iran, Italy, Japan, Mexico, Malaysia, the Netherlands, Norway, Pakistan, Poland, Russia, Saudi Arabia, South Africa, South Korea, Spain, Sweden, Thailand, Türkiye, Taiwan, Ukraine, the United Kingdom (UK), the United States (USA), and Venezuela. The growth rate is determined from the 95th percentile value of the historical five-year growth rates of these countries (Table 2). The ramp-up rates are also selected from reference countries, with the rate for solar power coming from the Netherlands, wind power from the UK, biomass and renewable waste (BWR) from Thailand, and hydropower from Argentina. It is only for geothermal power that the ramp-up rate comes from one of the case countries, the Philippines, because the country has a higher penetration than the reference countries and the other case countries. Low-carbon sources of nuclear and hydrogen are not considered because the case countries lack a history of previous deployment, resulting in very high uncertainty in the scenarios.

Table 2 The growth rate for each low-carbon source, which is used as the low-carbon growth rate in empirical scenarios. The equivalent country means the reference country with the closest growth rate to the 95th percentile, which occurred during the period denoted as the equivalent period. The table is copied from Paper II.

Fuel	Five-year growth rate (% of TES)	Equivalent country	Equivalent period
Gas	23%	UAE	2012-2017
Hydropower	16%	Canada	1975-1980
Geothermal	0.8%	Mexico	2002-2007
Solar	3.7%	Mexico	2017-2022
Wind	6.1%	Brazil	2012-2017
BWR	2.7%	Germany	2010-2015

The combination of low-carbon growth rates and ramp-up rates is then constrained by the renewable potential and low-carbon prioritisation. The technical potential for various renewable sources in Indonesia, the Philippines, and Vietnam is presented in Table 3 and expressed in TWh of electricity generation. The low-carbon prioritisation for policy-priority scenarios is determined based on the share of energy sources in the electricity mixes that the case countries aim to achieve

in their energy plan. The most prioritised source for Indonesia is solar, followed by BWR, geothermal, hydropower, and wind. For the Philippines and Vietnam, solar and wind power are their first priorities, followed by hydropower, geothermal (for the Philippines only, due to resource availability), and BWR.

Table 3 Technical generation potential (in TWh) from the renewable sources in Indonesia, the Philippines, and Vietnam. Adapted from Paper II.

Energy sources	Indonesia	The Philippines	Vietnam
Biomass (BWR)	247	0.5	3
Geothermal	205	22	-
Hydropower	314	34	154
Solar	915	2504	1662
Wind	152	534	612

Chapter 5 Results and Analysis of the Case Study

This chapter presents selected results and analysis from Papers I and II, with a primary focus on addressing research questions 1 and 2 of this thesis. Research question 3 is discussed in Chapter 6 to facilitate a more critical examination of the methodological development and contribution of this thesis. More detailed results and analysis can be found in each paper in the Appended Papers at the end of this thesis.

5.1 Policy-based electricity mix development

5.1.1 Energy targets of the case countries envision higher renewable share and growth, but fossil fuels will still dominate in scenarios with higher demand projections (Paper I)

The electricity mix results of the policy-based scenarios indicate that Indonesia, the Philippines, and Vietnam envision significantly higher renewable energy growth than the current level (Fig. 3 of Paper I). This growth is primarily driven by solar power in Indonesia as well as by solar and wind power in the Philippines and Vietnam. Interestingly, unlike the Philippines and Vietnam, Indonesia does not plan to deploy significant wind power until 2050, as the projected wind share is very low. This may be due to the country's more limited wind power potential and its geographical distribution, although the exact reasons require further investigation.

Despite the plan for a higher deployment of renewables than the historical level, fossil fuels are still projected to dominate countries' electricity mixes (Fig. 4 of Paper I). This is more apparent in Indonesia, where all policy-based scenarios consistently show that at least half of the total supply will come from fossil fuel sources. The share is the highest in the scenarios with higher demand projection (HDP, HDLRE, HDHRE). The Philippines and Vietnam also exhibit a similar trend of a high fossil-fuel share in these scenarios. The highest fossil-fuel share and growth in all countries occurs in the HDLRE scenario, where higher demand is combined with achieving a lower renewable target. As countries envision a decline in coal power generation by some point before 2050, most of the fossil fuel share is expected to come from natural gas, which appears to be used as a transition fuel [61] by these countries.

Other scenarios of the Philippines and Vietnam, however, show more optimistic features. The Philippines is projected to have stabilised its fossil fuel share in LDHRE and HDHRE

scenarios, while Vietnam can undergo a significant decline in its fossil fuel share in LDPA, HDPA, and LDHRE scenarios. Yet, to achieve the decline, Vietnam needs a tremendous amount of electricity generated from other low-carbon sources like nuclear and hydrogen, which have no history of previous deployment in the country.

5.1.2 Achieving peak coal generation requires a rapid growth of natural gas or variable renewables (Paper II)

All policy-based scenarios for Indonesia, the Philippines, and Vietnam indicate a peak in coal generation by 2030 (Fig. 7A of Paper II), which aligns with the projected timeline for peak coal capacity. However, to achieve it, many scenarios require a significant growth of electricity generated from natural gas. In correlation with the results in Section 5.1.1, the highest growth of natural gas is observed in scenarios with higher projected demand, particularly for HDLRE and HDHRE in Indonesia and Vietnam, and for HDLRE in the Philippines. Yet, this rapid growth of natural gas share can lead to other problems, including gas lock-in and stranded assets in the long-term energy transition.

Different alternatives for achieving peak coal generation are presented in the empirical scenarios. Despite peak coal generation being observed at a much later year than in the policy-based scenarios, the empirical scenarios show more limited growth of electricity from both coal and natural gas (Fig. 7B of Paper II). This is evident in the policy priority and VRE scenarios, where natural gas share will still increase, but the increase is not as sharp as in the policy-based scenarios. In these scenarios, renewable sources partially substitute for natural gas to generate electricity and meet the growing demand. However, non-VRE scenarios of Indonesia and the Philippines project a higher natural gas share than policy-based scenarios. This is due to the potential limitations of non-VRE sources in these countries, while the deployment of VRE sources, which have greater potential, is too slow to meet the demand. This result also suggests that the development of VRE sources is crucial for the energy transition in the three countries.

5.2 Decarbonisation pathways and total emissions

5.2.1 Decarbonising the electricity supply mostly requires renewable growth beyond countries' targets (Paper I)

Indonesia, the Philippines, and Vietnam exhibit a similar trend of increasing renewable and low-carbon energy growth alongside a decline in fossil fuel growth across all scenarios. However,

when analysed under the decarbonisation pathway framework, the countries exhibit different transition trends. Indonesia's LDNA, HDNA, LDPA, LDLRE, and HDLRE scenarios indicate that the country will still be in the energy addition phase until 2050, while the HDPA, LDHRE, and HDHRE scenarios result in a low-carbon substitution phase around 2040. Yet, the HDPA scenario requires renewable growth beyond the current target while the LDHRE and HDHRE scenarios require the development of nuclear power, which is currently non-existent in the country. This means that Indonesia's current renewable energy target is insufficient to lead to the decarbonization of its electricity supply.

On the opposite side is Vietnam, whose LDNA, HDNA, LDPA, HDPA, LDHRE, and HDHRE scenarios suggest that the country will transition to low-carbon substitution after 2030. This trend primarily stems from the country's aspiration to phase out both coal and natural gas from its electricity supply starting from 2030. However, this requires a significant increase in the share of low-carbon technologies, specifically nuclear power and hydrogen technologies, which are currently absent in the country. If Vietnam cannot achieve the targets for low-carbon technologies, as it did with nuclear between 2010 and 2020, the country will need significantly higher renewable deployment than what is currently aimed for. This is partially reflected in HDLRE and LDLRE scenarios, where the country will still be in energy addition because it can only achieve the lower range of its renewable targets.

The Philippines shares similar trends with Indonesia as all of its scenarios ultimately lead to energy addition by 2050. This also means that decarbonising the country's electricity supply requires renewable energy growth beyond the current targets. However, the LDPA, LDLRE, HDHRE, LDHRE, and HDHRE scenarios indicate that the country will remain in the low-carbon substitution phase until 2030 before shifting towards energy addition. This suggests that the Philippines may not need to expand its fossil fuel share to meet the growing demand until 2030. Although fossil fuel sources may still be required afterwards, replacing fossil fuels with renewable sources, even in the short term, can increase the country's confidence in energy transition, which, as shown by Vietnam, may lead to more ambitious renewable targets in the long term.

5.2.2 Even if peak coal generation is achieved, total emissions can still increase significantly. Reducing the total emissions requires an absolute decline in fossil fuels. (Paper II)

Emission calculations of the electricity mixes in Indonesia, the Philippines, and Vietnam reveal that the majority of policy-based and empirical scenarios project an increase in both direct and lifecycle emissions (Fig. 9, Paper II) compared to the historical emissions. This increase is more pronounced in scenarios with higher demand or lower renewable deployment, and more observable in lifecycle emissions than in direct emissions. This seemingly unavoidable trend stems from the projected rapid and continuous growth in electricity demand until 2050. The direct emissions may follow the lower estimates of emissions, which can lead to lower total direct emissions, as seen in the Philippines' policy-based LRE scenarios, or to a less significant increase, as observed in Indonesia's empirical VRE scenarios. The lower estimates of lifecycle emissions, on the other hand, still result in higher emissions than the historical level. However, the increase will not be as drastic as the upper estimates.

The only way to reduce both direct and lifecycle emissions in the electricity supply of the three countries is to reduce the absolute electricity generation coming from fossil fuel sources. This alternative is demonstrated by Vietnam's policy-based scenarios in which the country aims to reduce electricity generation from both coal and natural gas after 2030. The lower and upper estimates of direct emissions as well as the lower estimate of lifecycle emissions in these scenarios indicate that total emissions will decrease starting from 2030 and reach levels below the historical emissions. Yet, the upper estimates of lifecycle emissions in the scenarios can still lead to significantly higher emissions, particularly driven by hydropower plant construction which has a very wide range of emissions.

Chapter 6 Discussion on Methodological Development

The existing energy transition frameworks used in this thesis are applied differently from how they were originally developed in the studies where these frameworks were established. As such, methodological challenges arise along the process. These challenges come from two main differences between this thesis and the original studies. First, the original studies mainly investigate historical energy transition while this thesis aims to investigate future transition as particularly evident in the decarbonisation pathways framework [7]. Second, the existing frameworks have been devised in the context of developed economies with stabilised demand growth: the decarbonisation pathways framework for G7 countries while peak coal electricity [15] has only been observed in developed countries with stable electricity demand. In contrast, this thesis focuses on energy transition in the context of developing and emerging economies with rapidly growing electricity demands. The remainder of this chapter addresses the challenges coming from these differences, the methodological development necessary to overcome them, and the limitations of this approach.

6.1 Energy target interpolation and policy-based scenario construction complement the decarbonisation pathway frameworks (Paper I)

The different timeline and countries in the application of the decarbonisation pathways framework in Paper I leads to different characteristics and quality of the available data for constructing decarbonisation pathways. The energy targets of the case countries only provide capacity or generation values for specific years between 2022 and 2050, whereas the decarbonisation framework requires continuous data availability. The targets are also mostly stated in a range of values. Besides these characteristics, the target and demand projections do not exactly match each other although they are obtained from the same document. Various factors, including high uncertainty due to rapid demand growth, technical capacity, or even the choice of interpolation method, can cause this target-demand discrepancy. However, the exact reasons may need further investigation. If the discrepancy is mainly due to technical capacity, it also raises questions about whether this challenge happens more commonly for developing than developed countries.

To overcome these challenges, target interpolation and scenario construction are put to complement the framework. Target interpolation ensures the availability of continuous data until 2050, while scenario construction provides an approach to explore different possibilities that may

arise from setting targets within a range of values and from target-demand discrepancies. Aside from expanding the application of the framework in developing and emerging economies, these complementary tools also facilitate the application of the framework to future decarbonisation pathways, not limited to historical decarbonisation. A more detailed discussion on the expanding application of the framework is available in Paper I.

The complementary tools also have limitations. The target interpolation may contribute to the uncertainties surrounding the imbalance between projected demand and generation in the case countries. The policy documents stating energy targets and demand projections do not specify the projection method and attempts to fit growth models from the existing literature to the targets do not yield a sufficient match between the targets and the models (Section 3.1 of Paper I). The demand-generation adjustment explored in the policy-based scenarios raises concerns about robustness, as it yields significantly different trends across scenarios within the countries. This limitation implies that the scenarios should be used and treated within the context of country target development.

6.2 New approaches to determine peak coal are proposed for reaching peak coal under growing electricity demand (Paper II)

The main challenge in determining peak coal electricity in developing and emerging economies is the absence of precedented cases of achieving peak coal under growing electricity demand. Laegreid et al. [15] observed that stable demand growth is one of the main factors affecting countries' ability to reach at least peak coal capacity, with peak coal generation varying depending on the country's conditions. As such, different approaches are necessary to determine peak coal electricity in developing and emerging economies with a clear distinction for peak coal capacity and generation.

Determining peak coal capacity can be done by looking at the coal power plant projects in the pipeline of the case countries. A similar method has been used by Clark et al. [62] and Chen & Mauzerall [63], even though these studies do not explicitly focus on peak coal capacity. Paper II adds a policy component as one of the assumptions, considering the three case countries have announced their pledges and plans to not build new coal power plants other than those already being considered.

On the other hand, determining peak coal generation comes with a higher level of complexity. The electricity demand of the case countries is projected to grow rapidly, making it impossible for them to transition solely through coal substitution. Scenario construction helps explore the necessary growth of various energy sources to replace coal while meeting the growing demand. This eventually leads to a further understanding of whether peak coal generation can be reached under such growth, and if not, under what electricity supply conditions peak coal generation may be achieved. In addition, policy-based scenarios provide insights into the feasibility of the case countries' current electricity plans to reach peak coal, while empirical scenarios offer insights into the alternative electricity supply conditions that other countries have previously achieved.

Despite providing a way to determine peak coal electricity under growing demand conditions, the developed approaches also have several limitations. First, the approaches only consider techno-economic conditions of electricity systems even though political factors also play a significant role in coal power development in developing and emerging economies [23,64]. Second, empirical scenarios adopt very optimistic assumptions of replicating the 95th percentile growth rates of several coal substitutes over a long period. However, empirical evidence does not entirely support the feasibility of such rapid growth. The prioritisation is also introduced to avoid developing several energy sources rapidly at the same time, a condition that has no historical precedent. Still, the prioritisation does not consider cost, so the energy source that the case countries choose to develop in the future may differ from what the scenarios present. Third, coal generation in both policy-based and empirical scenarios is derived from pipeline capacity, assuming coal power plants in the case countries will be retired after they reach the global average age. Yet, the case countries still operate coal power plants which are more than 50 years old [46]. This implies that such a lifetime assumption may need policy intervention, despite the effort to avoid it in the policy construction process due to the absence of such intervention in the case countries.

7.1 Returning to the research questions

Developing and emerging economies face different challenges in energy transition compared to developed countries. One of the challenges is the rapidly growing energy demand [9], which makes it difficult for developing countries to replicate renewable energy transition processes which mainly occur in countries with stabilised demand growth [7,15]. At the same time, current energy transition studies, which give more attention towards developed than developing countries [31,32], result in analytical frameworks primarily designed for understanding energy transition in those countries. Focusing on the electricity sector of three developing and emerging economies in Southeast Asia — Indonesia, the Philippines, and Vietnam — this thesis addresses three research questions as follows.

The first question inquires about the electricity mix conditions of the three countries based on their policies on energy targets and coal power plant moratoriums. To answer this question, countries' electricity targets are interpolated, and electricity mix scenarios are constructed based on these targets and the empirical growth rates of reference countries. The results show that future electricity mixes indicate a significantly higher share of renewables than the current level in the three countries; however, fossil fuels, particularly natural gas, will still dominate the electricity supply. A significant increase in the natural gas share is also required if countries are to achieve peak coal generation, aside from peak coal capacity, through their moratorium policies. The lower carbon options require fast deployment of hydrogen and nuclear power technologies, which the countries have no history of previous development, or a much higher share of VRE sources.

The second research question, “How do these developments affect the decarbonisation pathways and the total emissions of the electricity supply?”, is addressed by constructing decarbonisation pathways and calculating direct and lifecycle emissions from the constructed scenarios. The results on decarbonisation pathways indicate different stages of future energy transitions in the case countries. Indonesia and the Philippines will remain primarily in the energy addition phase until 2050, suggesting that they need to develop renewable energy beyond the target to decarbonise their electricity supply. In contrast, Vietnam will enter low-carbon substitution by 2050 if it can achieve the upper range of its target. Yet, under the higher demand projection, the

country also needs to deploy renewable energy beyond its target to decarbonise the electricity supply. The emission calculation also reflects the decarbonisation pathways as significant increases in total emissions, particularly lifecycle emissions, are projected for most scenarios, even with a dominant share of renewable energy sources in the electricity supply and peak coal generation. The only alternative for emission reduction is if the absolute electricity generation from fossil fuel sources is in decline.

The third question addresses the methodological challenges of applying the existing energy transition frameworks to developing countries with growing electricity demand, and how to overcome these challenges. In both papers, the methodological challenges mainly stem from applying the frameworks in the context of developing and emerging economies with rapidly growing demand. In Paper I, this leads to uncertainties that affect the characteristics and quality of the energy target data. These, in turn, become the challenges of applying the decarbonisation pathway framework. It addresses the challenges by complementing the framework with energy target interpolation and scenario construction. In Paper II, rapid demand growth creates a condition different from that of countries that have historically reached peak coal electricity. Hence, a new analytical approach is necessary to understand how and when the case countries can reach peak coal electricity. Paper II distinguishes peak coal electricity into peak coal capacity and peak coal generation, and proposes two separate methods for determining each of them. Peak coal capacity is determined by using coal pipeline data while peak coal generation is determined by considering the growth of coal substitutes through policy-based and empirical scenarios.

7.2 Contributions and policy implications

The thesis makes contributions to the literature on energy transition in developing and emerging economies, while also providing valuable policy implications to developing countries, particularly the three countries studied: Indonesia, the Philippines, and Vietnam.

Methodologically, this thesis provides complementary tools to expand the applicability of existing analytical frameworks on energy transition. Energy target interpolation and policy-based scenario construction, as demonstrated in Paper I, have been shown to expand the application of the decarbonisation pathway framework [7] to different types of data, i.e. targets instead of historical data, and different timelines, i.e. future instead of past transitions. The distinct methodologies to determine peak coal capacity and generation of Paper II have been shown to

provide new approaches in analysing peak coal electricity under unprecedented conditions of growing electricity demand. These methodologies further advance the current study on peak coal electricity [15] by applying the concept to countries which still have growing coal power.

Conceptually, this thesis offers insights into the energy transition in the electricity supply system within the context of developing and emerging economies from two perspectives: the growth of renewable energy and the decline of fossil fuels. The emphasis on energy targets in Paper I presents a different perspective, linking energy targets directly to the energy transition, an approach that has not been previously explored. The focus on peak coal electricity pulls back the discourse on coal transition from concentrating solely on coal phase-out to also seriously considering the necessary steps leading up to the phase-out, which remain relevant in many countries. Moreover, the focus on developing and emerging economies positions this thesis as a valuable contribution to addressing the imbalance of case studies on the energy transition topic.

This thesis also provides three policy insights for Indonesia, the Philippines, and Vietnam. Although these policy insights are specific to the three countries, they are likely to be relevant for other developing and emerging economies facing low renewable growth and high coal dependency. First, the current energy targets established by the countries are insufficient to decarbonise their electricity supply, especially if the countries follow higher demand projections as shown in HDPA, HDLRE, and HDHRE scenarios. More ambitious renewable targets, along with limitations on demand growth, are necessary to shift countries from the energy addition phase to the low-carbon substitution phase of the energy transition. Second, VRE sources of solar and wind are vital in achieving peak coal generation and further decarbonising the electricity supply. This insight is in response to Indonesia's current plan which seems to neglect wind power development. All policy-based and empirical scenarios for the Philippines and Vietnam show the importance of increasing the share of both wind and solar power to fill the gap left by coal. Third, the countries need to design policies that focus on fossil fuel decline, including both coal and natural gas, to reduce total emissions of the electricity supply. This is shown in Vietnam's LDNA, HDNA, LDPA, and HDPA scenarios. Current policies of Indonesia and the Philippines which position natural gas as a transition fuel [61], if achieved, will only lead to a significant increase in direct and lifecycle emissions despite the rapid growth of renewables and the peaking of coal-powered generation.

Chapter 8 Reflection and Outlook

This thesis tries to bring up the discourse on energy transition in the context of developing and emerging economies. It particularly highlights rapidly growing electricity demand as a challenge that distinguishes between energy transition in developed and developing countries. However, the approaches and results of this thesis also raise uncertainties and questions which may inspire a future research agenda.

Paper I tries to establish a direct link between energy targets and energy transition. Yet, a more fundamental question remains unanswered: whether and in what ways energy targets have shaped energy transitions. Previous studies [33,34,65] argue about the importance of targets in energy transition and climate change mitigation from legal and theoretical perspectives, but they do not provide further empirical evidence. Additionally, the research for this thesis revealed that further studies are necessary to understand how policymakers perceive and implement energy targets. The lack of studies on the more fundamental issues of energy targets raises questions about the relevance of Paper I. In particular, because energy targets may only be seen as merely political rhetoric that can change significantly with shifts in the political climate, studies centred on targets in energy transition can lose their relevance quickly. Still, the role of energy targets as a regulatory tool cannot be denied, and rather than dismissing them from the discussion, it is more helpful to address the questions regarding the credibility and implementation of energy targets, particularly in countries where policy may become a key component in energy transitions.

Paper II identifies the need for a new approach to investigate peak coal electricity under rapidly growing demand conditions, as this condition is not observable in the countries that have previously reached peak coal [15]. Again, this highlights the significance of rapid demand growth in energy transitions, a finding consistent with previous studies that have identified electricity demand growth as a challenge in the energy transition both in developing countries [66] and in relation to electrification efforts in developed countries [67]. Yet, Paper II and the previous studies have not shown the scale of impact of rapidly growing demand on the energy transition. It would be interesting to investigate this further, as electricity demand growth should have different implications when demand increases tenfold, as in the three case countries, compared to when it only doubles, as in Sweden [68]. Understanding the impact of different electricity demand growth rates on energy transition may encourage further discussions on context differences between

transitions in developed and developing countries. It can eventually help pave suitable paths towards energy transition for developing and emerging economies.

The results on decarbonisation pathways suggest that the case countries need to deploy renewable technologies very rapidly to decarbonise the electricity supply. This might not be easy to achieve, considering the specific socio-economic and political barriers faced by developing countries [69]. As such, there is a need to seriously consider the deployment of carbon capture and storage (CCS) technologies alongside carbon-neutral technologies in developing and emerging economies. Although some developing countries, such as Indonesia, have incorporated CCS technologies into their NDCs and developed a policy framework for CCS [70], it remains unclear how quickly deployment can occur and what conditions may facilitate it. Furthermore, as with energy technologies, the deployment of negative-carbon technologies may also need to be adjusted to the context of developing and emerging economies, which have different characteristics from those of developed countries.

The results on the carbon emissions imply the importance of technology choice in decarbonising the electricity supply of the case countries. Energy technologies like hydropower, which have zero direct emissions, may have larger lifecycle emissions than coal power [60], depending on the location of the power plants. Relying on such technologies may instead raise the emission level of the electricity system, which contradicts what electricity supply decarbonisation should achieve. The possible increase in emissions in the decarbonisation pathways of the case countries can also serve as a cautionary tale in international cooperation for energy transition such as the Just Energy Transition Partnership (JETP) with Indonesia and Vietnam. Sufficient funds and efforts should also be allocated within the partnership framework to understand the lifecycle emissions of energy technologies, particularly those with high levels of uncertainty, within the local context. Otherwise, such a partnership may help decarbonise electricity supply in developing countries without actually resulting in a lower level of emissions.

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