DECARBONISATION POLICIES FOR VIETNAM

A PLEXOS modelling study on alternative policy scenarios

Master's Thesis

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Abstract

Climate change is a major threat for economic development globally. Mitigation actions are needed to prevent negative effects on the global economy. Positive externalities of decarbonisation include also better air quality and positive economic outcomes. This thesis contributes to the growing research of country-specific decarbonisation pathways. It aims to understand how different policy and market actions affect Vietnam's energy system's carbon dioxide emissions and total costs. Actions are modelled using the PLEXOS energy system optimisation model and compared to the scenario that is based on existing policies.

Vietnam faces a dual challenge: increasing power and electricity demand driven by strong economic growth and national and international pledges to pursue carbon neutrality. Power generation is one of the biggest sources of CO_2 emissions. In its Nationally Determined Contributions (NDC) under the Paris Agreement, Vietnam has committed to reducing total emissions by 9 % (83.9 megatonnes) by 2030 compared to Business-As-Usual (BAU) scenario for the same year. The biggest reductions are aimed at the energy sector.

This study focuses on four mechanisms that Vietnam could implement: 1) carbon taxes or emission trading systems, 2) quotas for coal generation, 3) increase of fossil generation capital expenditures, and 4) feed-in-tariffs for renewable energy generation. It answers the question of how do the policies listed above impact the cost and pace of the decarbonisation of the energy industry in Vietnam.

The results of this thesis indicate that on average the cost of reducing one tonne of CO_2 is ~$24. Secondly, it underlines the difficulty to achieve absolute emission reductions in Vietnam or other countries which face over 5 % annual growth in electricity demand. None of the investigated policies achieved decrease in carbon dioxide emissions compared to current levels. Based on the results, the most efficient policies to reduce carbon dioxide emissions seem to be halting new coal capacity additions, capping coal usage for domestic coal only, and setting a low carbon tax. These actions would decrease carbon dioxide emissions respectively by 120 Mt, 160 Mt and 94 Mt yearly in 2030. Additional yearly investments of $2bn-$4bn per year in 2030 are needed to implement these policy actions. Lastly, the thesis concludes that Vietnam has multiple policy actions available that would achieve carbon emission targets set in NDCs in Paris Agreement.

Keywords Decarbonisation, energy transition, carbon tax, emission trading, coal quotas, feed-in tariffs, decarbonisation pathways, integrated assessment model.
JEL classification: O13, P28, Q47

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Tiivistelmä

Ilmastonmuutos aiheuttaa talouskasvulle merkittävän uhan. Valtioiden on reagoitava nopeasti, jotta ilmastonmuutoksen aiheuttamia negatiivisia vaikutuksia kansantalouteen voidaan lieventää. Nämä toimenpiteet voivat myös kasvattaa bruttokansantuotetta ja lisätä hyvinvointia. Tämä työ tutkii keinoja hiilidioksidipäästöjen vähentämiseksi keskittyen Vietnamin energiteollisuuteen. Pyrkimyksenä on ymmärtää, miten eri poliittiset toimenpiteet vaikuttavat hiilidioksidipäästöjen ja energijärjestelmän kokonaiskustannusten kehitykseen. Poliittiset toimenpiteet on mallinnettu käyttäen PLEXOS optimisointi-mallia.

Vietnam kohtaa samanaikaisesti kaksi ongelmaa: talouden kasvun aiheuttama energian nopea kysyntä on vaikea yhteensovittaa kansainvälisten hiilipäästöjen pienentämiseen pyrkivien tavoitteiden kanssa. Energiantuotanto on yksi suurimmista päästölähteistä. Vietnam on Pariisin sopimuksen mukaisesti luvannut vähentää hiilidioksipäästöjään 9 % (83.9 megatonniin) vuoteen 2030 mennessä verrattuna perusskenaarioon. Suurin osa vähennystavoitteesta on kohdistettu energiantuotantoon.

Hiilidioksidipäästöjen vähentämiseksi on olemassa useita mekanismeja. Tässä työssä keskitytään neljään: 1) hiiliverotukseen ja päästöoikeuskauppaan, 2) hiilen tuotannon ja tuotantokapasiteetin kiintiöihin, 3) hiilivoiman rakennuskustannusten kasvuun ja 4) uusituvan energian syöttötariffeihin. Tutkimus pyrkii vastaamaan kysymykseen siitä, miten eri mekanismit vaikuttavat hiilidioksidipäästöjen kehitykseen ja energiajärjestelmän kustannuksiin Vietnamissa keskipitkällä aikavälillä.

Tulosten mukaan yhden hiilidioksiditonnin vähennys päästöissä lisää järjestelmän kustannuksia keskimäärin $24. Työ korostaa vaikeutta päästöjen absoluuttiseen vähentämiseen maissa, joissa energian kysyntä kasvaa yli 5 % vuosivauhtia. Yksikään tutkituista mekanismeista ei laskenut päästöjä alle vuoden 2021 tason. Tehokkaimmat mekanismit olivat uuden hiilivoimakapasiteetin rakentamisen kieltämisen, hiilen käytön rajoittaminen Vietnamissa tuotetun hiilen määrään ja matalan hiiliveron asettaminen. Näillä saavutettu vuosittainen päästövähenemä vuoteen 2030 mennessä oli mallinnuksen mukaan 120, 160 ja 94 megatonnia. Mekanismit kasvattavat energiajärjestelmän kustannuksia vuosittain $2-$4 miljardilla. Tutkimuksen mukaan Vietnam pystyy saavuttamaan Pariisin sopimuksen mukaiset tavoitteensa vuoteen 2030 useilla vaihtoehtoisilla poliittisilla mekanismeilla.

Avainsanat: Vähähiilinen energiajärjestelmä, energiamurros, hiilivero, päästöoikeuskauppa, syöttötariffit.

JEL koodi: O13, P28, Q47

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1 Background and motivation

Climate change and global warming are threatening modern societies in a way that demands immediate action. According to Intergovernmental Panel on Climate Change (IPCC, 2021) – global warming is increasing extreme weather events and affecting agricultural crops. To tackle climate change greenhouse gas (GHG) emissions need to be decreased drastically. A big challenge is faced by countries that need to scale up their energy systems to meet growing demand but can't do that using the same technologies that were used before by more developed countries. This thesis seeks to answer a question of what the Vietnamese government could do to curb carbon dioxide emissions while addressing growing electricity demand. Furthermore, it investigates how selected key enablers impact the cost and pace of decarbonisation in Vietnam.

International agreements and pledges have been made to reach carbon emission reduction targets (e.g. Paris Agreement, 2015) but they don't cover all countries. More needs to be done to stay within the 1.5 °C temperature increase target. Existing government energy plans and targets are falling short of it and emission reduction has not been as quick it should have been (IRENA, 2021; Marcucci and Fragkos, 2015). Particularly attention should be paid to countries where electricity demand is expected to many-fold in the future and path dependency for fossil fuel-based legacy technologies has not yet been formed.

Decarbonisation requires actions both from the regulatory landscape and private companies. Regulation and legislation can be used to accelerate the adoption of cleaner technologies or decrease the usage of polluting technologies. Paris Agreement in 2015 and the recent United Nation's climate change conference (COP26) in 2021 have listed countries' commitments to decarbonisation – so-called Nationally Determined Contributions (NDCs). Vietnam, amongst others, has pledged to decrease its carbon emissions by 9 % by 2030 from the business-as-usual scenario (BAU) and hinted at achieving carbon neutrality by 2050 (Việt Nam News, 2021).

In many cases pledges to reduce GHG emissions are made nationally before creating a concrete and clear action plan for how the goals are reached. Regulation is needed to keep the decarbonisation development on a wanted trajectory and support transition. When creating new regulations, there is likely to be pressure from private companies to accommodate their interests. Finding a path for economically optimal and just energy transition is more likely to succeed if there is a good understanding between regulators, the private sector and non-governmental organisations. The difficulty lies in balancing altering agendas of different stakeholders.

Energy systems have been changing fast around the world in the past few years. The energy transition towards renewable energy sources has been fuelled by a sharp decrease in the costs of solar photovoltaics (solar PV) and wind generation capacity. Capacity additions of renewable energy surpassed non-renewable capacity for the first time in 2014 globally and have been increasing ever since (figure 1.1.). Currently, around 80 % of capacity additions are renewable energy. However, investments in renewables are divided unevenly – most of the funding goes to the U.S., China and European countries (IRENA, 2021). Therefore, it is relevant to consider what policy actions Vietnam could drive to attract renewable generation additions and what could be the impact of those actions.

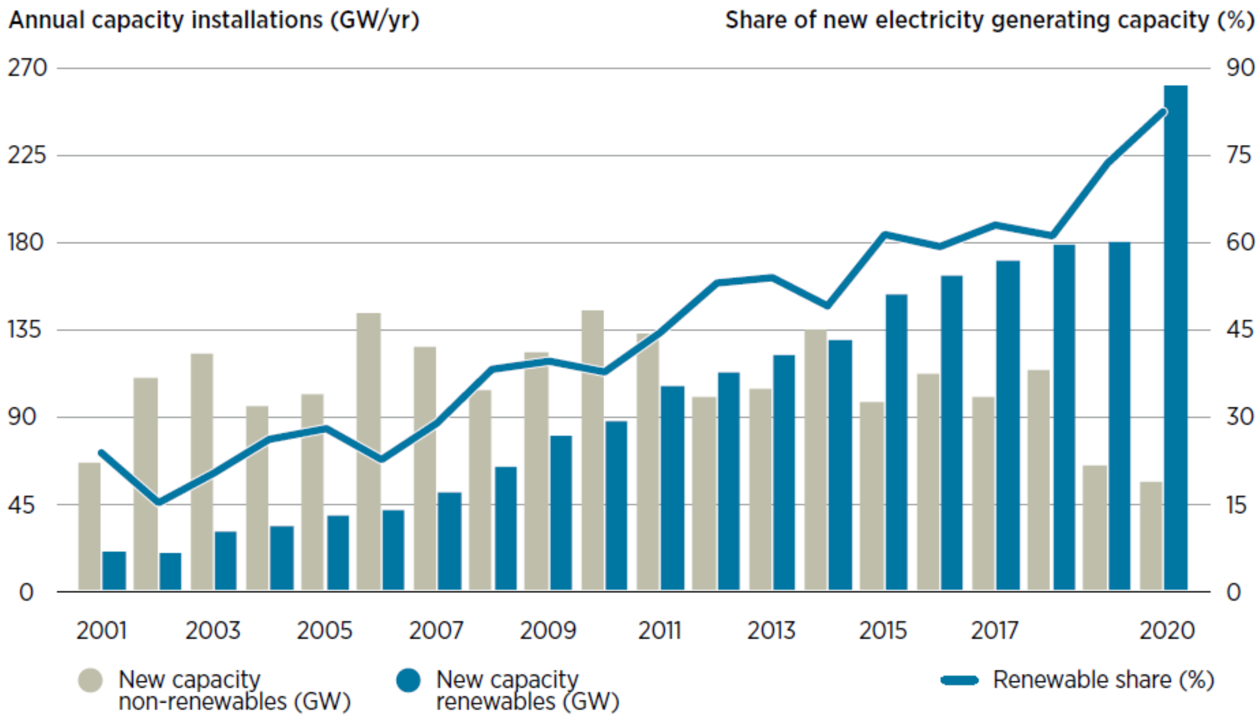

Figure 1.1 Renewables share internationally of new capacity 2001-2020 (IRENA, 2021)

1.1 Global warming scenarios

Existing pledges and plans to reduce carbon emissions are not aligned with a global consensus to limit global warming to 1.5 degrees Celsius (IRENA, 2021; International Energy Agency, 2021). Current Nationally Determined Contributions (NDCs) under the Paris Agreement are leading only to a slight decrease of total carbon emissions (STEPS scenario in Figure 1.2). Limiting temperature increase to 1.5 °C would require drastic changes to gain net negative carbon emissions by 2050 (NZE scenario). International Energy Agency (IEA) describes four different scenarios that are modelled in Figure 1.2. Stated Policies Scenario (STEPS) shows the development based on policies in place in 2021. Announced Pledges Scenario (APS) is showing the development if all pledges were to be implemented. Sustainable Development Scenario (SDS) is a scenario that is aligned with key energy-related United Nations Sustainable Development Goals and reaches global net-zero emissions in 2070. The temperature increase peaks at 1.7 °C in the SDS. Net-zero scenario (NZE) keep global warming within a 1.5 °C limit and reaches net-zero by 2050.

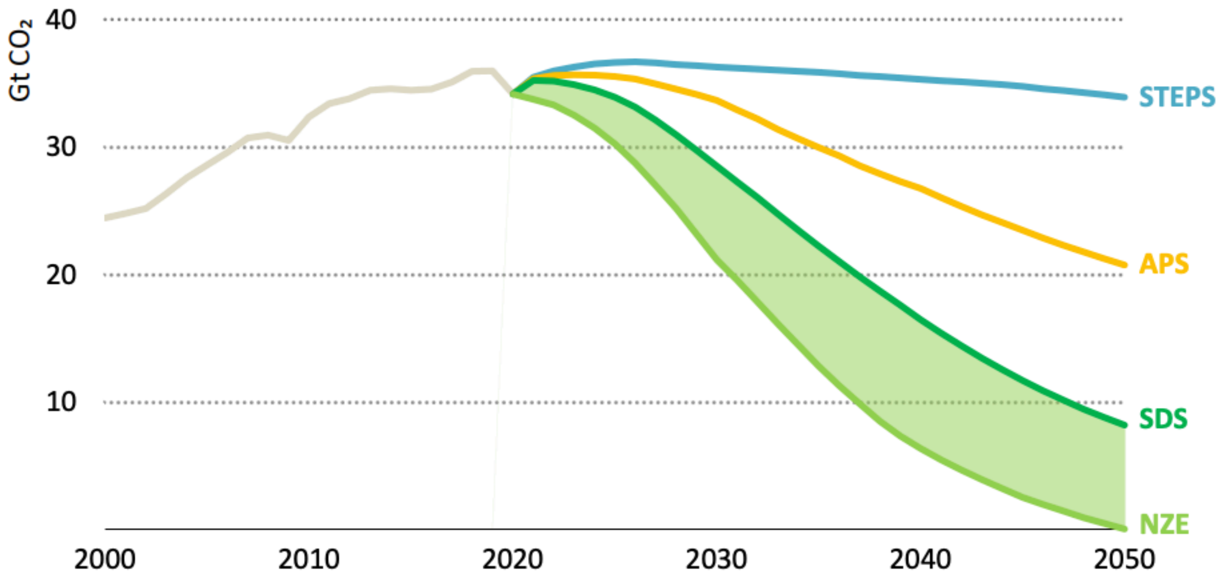

Figure 1.2 Global carbon emission development according to different scenarios (IEA, 2021)

GHG reductions are needed across the field, but especially the energy sector and transportation are often considered the first steps on the decarbonisation pathway (e.g., Lallana et al., 2021). The energy sector is one of the biggest emitters representing over half of global GHG emissions (IRENA, 2021). Existing and emerging technologies offer a possibility to increase the share of renewables in energy systems and decrease industry's GHG emissions. Already by 2030, yearly carbon emissions in energy sectors (power and heat plants) should be reduced by 50 % (IRENA, 2021).

1.2 Limiting global warming to 1.5 °C

As mentioned in the previous chapter, decarbonisation of the energy sector is crucial to limit the temperature increase to 1.5 °C. Figure 1.3 explains from what sources emission abatements should be achieved by 2050. To remain on a 1.5-degree Celsius trajectory, around a 45 % decline in carbon dioxide emissions from 2010 levels are required by 2030. Global net zero emissions should be achieved by 2050 as IPCC's report states. In absolute numbers that would mean almost 37 gigatonnes of CO_2 reduction in 2050. That is achieved through significant improvements in energy efficiency (compared to historical development) as well as new ways to generate, carry and store energy (figure 1.3). Around one-third of emission reductions is expected to originate from new technologies such as carbon capture, hydrogen and bioenergy. (IRENA, 2021)

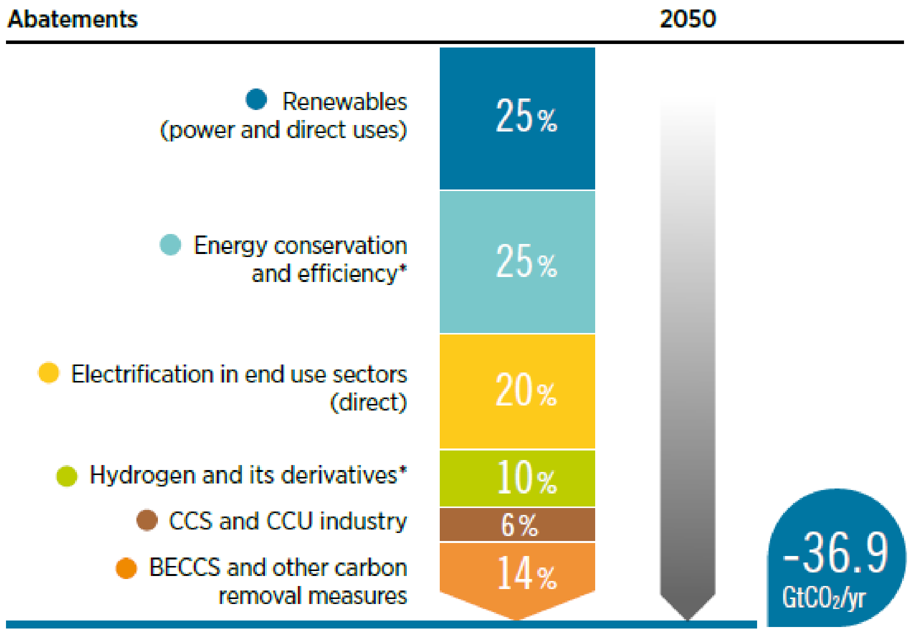

Figure 1.3 Carbon emission abatements for 1.5 °C path (IRENA, 2021)

International pledged such as Paris Agreement and United Nations' climate change conferences are important to create international consensus on limiting emissions. But intention alone is not enough. Implementation and concrete actions are needed to make changes like those suggested in IRENA's report. The change is guided and mediated through regulation and financials.

IRENA (2021, p. 22) has defined some prerequisites or enablers for remaining on a 1.5 °C pathway that is presented in Table 1.1. The role of coal in power generation is remarkable. According to IEA ("Coal - Fuels & Technologies - IEA," n.d.), over a third of global energy generation was produced by coal in 2019 representing over 30 % of global CO_2 emissions. Replacing coal generation with cleaner sources of energy is one of the prerequisites listed by IRENA and should be prioritised to remain on a 1.5 °C pathway.

However, thoughts and deeds don't seem fully met. In recent years new coal generation capacity has been installed around the world and between 2000 and 2021 coal power additions have surpassed retirements each year ("Global Energy Monitor," 2021). Planned coal generation additions are located especially in South and South-East Asia where many economies are growing rapidly and fulfilling growing energy needs with other energy sources might be difficult.

Table 1.1 prerequisites for remaining on 1.5-degree Celsius pathway (IRENA, 2021)

Supporting emerging technologies most likely to become competitive in the short-term and most effective in achieving emissions reductions in the long-term.
Limiting investments in oil and gas to facilitating a swift decline and a managed transition.
Reserving carbon capture and storage technologies for economies heavily dependent on oil and gas and as a transitional solution where no other options exist
Phasing out coal and fossil fuel subsidies.
Adapting market structures for the new energy era.
Investing in a set of policies to promote resilience, inclusion, and equity and protect workers and communities affected by the energy transition.
Ensuring all countries and regions have an opportunity to participate in and realise the benefits of the global energy transition.

1.3 Developing countries are a key for global decarbonisation

Decarbonisation is especially difficult in countries where the economy and electricity demand grow rapidly. Developing countries emit the majority of global greenhouse gases and emission growth is the fastest ("Carbon emissions anywhere threaten development everywhere | UNCTAD," 2021) but at the same time, they are difficult to decarbonise. Reasons can vary from lack of funding, instability or lack of political will to decarbonise.

One prominent theory in economics to explain environmental development is called Environmental Kuznets Curve (EKC) phenomenon based on its inventor Simon Kuznets. According to it, there is an inverted U-shaped relationship between pollutants and per capita income (Dinda, 2004). Environmental damage increases up to a certain threshold level when an economy grows. When this threshold is passed pollution levels start to decline. Important questions asked by many economists is if economic growth can be part of a solution for environmental development instead of a problem (Dinda, 2004b). Increasing income might lead more favourable attitude towards environment protection regulation (Dinda, 2004b). Higher involvement in international trade might also lead to external pressure: stricter emission requirements through markets rewarding clean firms and displacement of polluting industry to other countries (Dinda, 2004b; Stern, 2004). However, there seems to be a lack of evidence that EKC would apply to carbon dioxide emissions

(Stern, 2004). Still, it indicates that when an increasing share of the world's population become wealthy, the interest in cleaner societies grows.

Regardless of if the pressure for decarbonisation stems from internal or external pressure, the transformation of energy systems globally will require significant investments and funding. Availability and price of funding might either accelerate or slow down the decarbonisation development. Developing countries, in general, are in a worse position compared to developed countries as are more dependent on direct foreign investments for the development of their energy systems. IRENA's new energy outlook (2021) estimates that funding needs for energy systems to remain on the 1.5 °C pathway will be 131 trillion US dollars over the period to 2050. Also, other scholars highlight the role of funding to accelerate the energy transition in developing countries (e.g. International Energy Agency, 2021; Ouedraogo, 2019). Polzin et al. (2017) have examined how funding for energy technology innovation comes from different sources (figure 1.4) and how funding is difficult to raise for technologies that are in pre-commercial or niche market phases. According to IRENA (2021) government strategies, today predict investments in energy worth $98 trillion by 2050 but most of that funding is expected to be directed to fully commercialised technologies. Allocation of that funding is a crucial part for two reasons: funding for new technologies help reach disruptive innovations and part of the money is still directed or intended to fossil energy sources that won't advance energy transition towards more sustainable energy systems.

Funding sources are both public and private. Government policies should guide private investments to sustainable technologies. Fiscal policies (e.g. tax incentives), carbon pricing instruments (carbon taxes and emission trading systems) and feed-in tariffs attract private foreign investments (Wall et al., 2018). Public funding could be used for early-phase technology development and projects where loans or private equity are not options. However, public funding for renewable projects is not attracting foreign investors perhaps because it is not considered stable in a long run (Wall et al., 2018). Controversially to decarbonisation goals, many governments still stick to subsidising fossil fuel production and consumption directly or indirectly (e.g. Cheon et al., 2015).

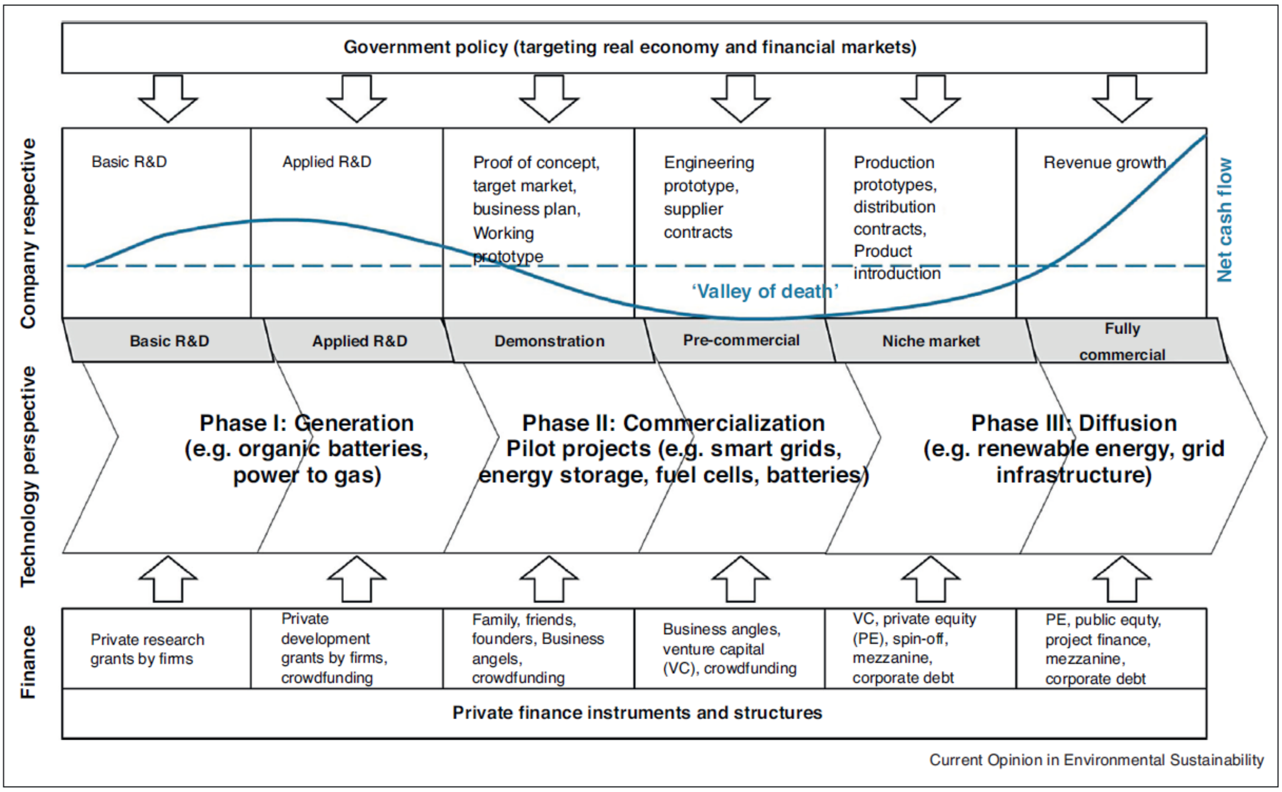

Figure 1.4 Financing energy technology innovation and entrepreneurship (Polzin et al., 2017)

Funding offers a way to pressure single countries to reduce their carbon emissions. Several means have been proposed from carbon border taxes (under discussion in European Union) to blocking funding for new coal projects (e.g. China's announcement in COP26 meeting: ("China's overseas coal power retreat could wipe out $50 billion of investment | Reuters", 2021).

Observing funding of energy transition offers an interesting perspective to justness. Rapidly growing countries like India, Vietnam and China need massive amounts of new energy capacity as the growth of industry, population and electricity coverage increase demand significantly. Fossil fuel sources might be easier to scale up due to their large scale and existing experience from conventional technologies. Even if building renewables would be economically feasible (which, in many cases, it is not), there might be limitations caused by emerging legislation, supply constraints (e.g. battery technology or solar photovoltaics), or simply lack needed land space. What would be best for the climate might not be possible or fast enough for a developing country. Many growing countries might possess fossil energy resources (namely oil, gas and coal). There might exist a strong interest to use those domestic resources to fulfil growing energy demand. The question of justness emerges: why should developing countries compromise their energy systems and not build fossil power generation when developing countries have become rich by burning oil and coal for decades?

Generation capacity's relative growth is substantial, for example, Vietnam's gross domestic product has been growing on average over 6 % annually for the last 10 years (Vietnam Institute of Energy, 2020). Installed power generation capacity has been growing even faster: almost doubling in five years to 59 GW in 2020. The capacity is expected to be over 138 GW in 2030. Current plans of Vietnam's Institute of Energy (2020) which operates under the Ministry of Industry and Trade (MOIT) include around 15 GW of new coal and gas thermal capacity to be built by 2025. Even though plans include also a lot of renewable energy (e.g. 10-30 GW of solar energy by 2030), is the absolute increase in emissions still remarkable if fossil fuels won't be phased out. A closer look at Vietnam's energy system will be taken in the second chapter. (Vietnam Institute of Energy, 2020)

1.4 Vietnam offering a good test platform for energy transition policies

No two countries nor energy systems are alike. Global energy production mix has been analysed widely in reports of intergovernmental organisations (e.g. IEA, 2021; OECD, 2019; IRENA, 2021), for-profit research providers, such as BloombergNEF, and academics (e.g. Barragán-Beaud et al., 2018; Lallana et al., 2021; Staffell et al., 2019)on multiple levels. If a global perspective is adopted, the depth of details remains shallow as fundamentals between countries differ significantly: existing energy production mix, available technologies, existing regulation, infrastructure, and energy price are different in each country. Many publications that focus on a single country either have a narrow perspective to explore the impact of certain policies (e.g. Barragán-Beaud et al., 2018; Brandt et al., 2021) or are ordered by a governmental organisation to support decision-making; EREA & DEA, 2019; USAID, 2020). This research focuses on the decarbonisation pathway of Vietnam by combining holistic evaluation of energy system development with the modelled impact of different policy actions.

Vietnam is an ideal focus country due to a few reasons. First, its relatively small size makes the modelling reasonably simple. Information quality is good as it is provided directly by the governmental organisation responsible for planning Vietnam's energy system development. Second, its energy system is quite similar compared to big emitters like India. According to the energy system classification by Kueppers et al. (2021) Vietnam belongs to archetype 8 together with Botswana, Dominican Republic, India, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam. In 2016 these countries emitted almost 4,000 Mt of CO_2 representing over 11 % of all CO_2 emissions globally (Worldometer, 2021). Typical for archetype 8 countries are high dependency on coal, a large increase of CO_2 emissions and a low share of renewable generation technologies (Kueppers et al. 2021).

Third, Vietnam has made its climate change mitigation targets stricter recently (more in section 2.2) and thus is about to implement a new regulation to guide development. Stringent climate goals are partly linked to international efforts of tackling climate change, but increased income may have led to question and mitigate environmental stress – as proposed in Economic Kuznets Curve -hypothesis. As a country with a fast-growing national income, it offers an interesting object to research how different policies would affect its energy system and which policy tools work most efficiently in Vietnam.

1.5 Economical aspects of climate change

Climate change, global warming and energy transition are not just about environmental protection but also the economy. The economic impacts are already visible today through extreme weather conditions. Social cost includes increased diseases, decreased crops and forced changes in culture and business. Effects on the economy are expected to grow the more the temperature increases (The Socialist Republic of Viet Nam, 2020). Estimating the economic impact of climate change is difficult due to the global scale and ambiguous interpretation of the reasons for climate change. How to define a relationship between an emitted tonne of carbon dioxide and drought more severe than usually?

Some quantifications models have been developed by scholars. The first econometrical approach to the problem was offered by Mendelsohn, Nordhaus and Shaw in 1994. They used the Ricardian cross-sectional approach to estimate how changing weather conditions are going to decrease the value of agricultural land. Dynamic Integrated model of Climate and Economy (DICE) was developed to examine these dynamics. Besides the Ricardian approach, some panel-data research has been made to compare the effect of weather conditions on agricultural output and other factors (e.g. Auffhammer et al., 2006).

Many economists approach decarbonisation and its economic impact through the effect of a specific technology (e.g. Capros et al., 2014), policy (e.g. Aklin and Urpelainen, 2013) or industry (e.g. Aghion et al., 2016). Considering system level approaches, some scholars are observing decarbonisation on the global level (e.g. Kueppers et al., 2021). Such research helps us understand what international regulation is needed for decarbonisation development globally. However, the global approach usually decreases the level of details and therefore policy indications are less accurate. Results vary and there is no clear consensus on the holistic impact of decarbonisation on the economy. The following paragraphs present some insights: first describing the research of potential cost of global warming, and second describing economic upside potential of decarbonisation.

Cost of excessive global warming

Economists agree that the temperature increase will have a negative impact on the global gross domestic product (GDP). The negative impact is channelled through rising temperatures (and how they affect diseases and agriculture), a rise of sea level, ocean acidification, changes in climate and rainfall patterns and extreme events – such as floods, droughts, heatwaves and wildfires (Deryugina et al., 2014). Both destruction of wealth and reduction (and volatility) of income are possible (Krogstrup and Oman, 2019). Vietnam is not immune to the impacts of global warming. Researchers suggest that global warming will reduce annual rice yields by 5.5 – 8.5 % (Kontgis et al., 2018). As rice exports' impact on Vietnam's GDP is over 10 %, the decrease can be considered significant (*Linking the Poor with Rice Value Chains*, n.d.). And other impacts like droughts are likely to increase. Estimates from EREA and DEA (2019) show the external costs from air pollution from the power sector in Vietnam to be around $23 billion per year in 2030. This represents around 2 % of the country's GDP.

Quantitative estimates on the cost of global warming vary and the magnitude of the impact is huge. Hsiang et al., (2017) estimate climate change to decrease United States' GDP on average by 1.2 % per each +1°C increase. Sanderson and O'Neill (2020) estimate that each year postponement of starting climate change mitigation actions to align 2 °C pathway cause discounted damages worth $0.6 trillion per year.

Also, mitigation actions are expensive. Vietnam's government estimate that "the cost of climate change adaptation is estimated to exceed 3-5 % of Viet Nam's GDP in 2030. With 1.5 % of its GDP spent on climate change adaptation in the 2021-2030 period, Viet Nam has to mobilise about USD 3.5 billion each year on average or USD 35 billion for the entire 2021-2030 period in addition to state resources" (The Socialist Republic of Viet Nam, 2020, p. 21).

Climate change mitigation actions boost economies

Besides climate change affecting negatively the economy, some researchers suggest that the global economy could benefit from climate change mitigation. IRENA models the cost and saving of pursuing a 1.5 °C path versus the current "planned energy scenario". According to their report (2021), every dollar spent on energy transition would reduce externalities valued between 2 to 5.5 dollars. The effect for the global GDP would then be 2.4 % annually for the next decade if the world pursues a more ambitious pathway compared to the one that we are now heading. However, there are also differing opinions in the literature stating that the net effect of decarbonisation on GDP would be negative (Capros et al., 2014; Le Treut et al., 2021; Luderer et al., 2011).

The decision of decarbonisation efforts will, nor should, be done solely on an economic basis in a situation where externalities of climate change are not fully understood or are disputed. One part of climate change's impact on the GDP is the employment effect. The energy sector only employed over 58 million employees worldwide in 2019 and the number is expected to by 2050 to 122 million (IRENA, 2021). Tackling climate change can also boost economies.

To sum up, the economic impact of global warming is substantial through increased climate-related damages and significant employment and GDP potential of green tech and energy industries.

1.6 Research question and structure

This research conducts a literature analysis on decarbonisation enablers and roadblocks in Vietnam. Additionally, it models how different policies impact the decarbonisation cost and timeline. The research question of this thesis is:

> **How do selected key policies impact the cost and pace of the decarbonisation of the power industry in Vietnam?**

Some of the decarbonisation enablers are market-based, and some are regulation-based. The first contains carbon emission trading and carbon taxes, the development of coal technology. Regulation-based factors include quotas for coal production and generation, and subsidies for renewables, e.g. feed-in tariffs (FIT) for renewables. Policies are picked from the literature presenting potential actions that Vietnam could implement.

The thesis contributes to the growing research of holistic and country-specific decarbonisation development. It aims to understand how different policy and market actions affect carbon dioxide emissions and the total cost of energy system development in Vietnam. Actions are modelled using the PLEXOS optimisation model. Most relevant policy and market-based enablers for decarbonisation pathways are selected based on existing literature and their impact on price and pace of decarbonisation is modelled through different scenarios.

The structure of this thesis is following. The second chapter explains the theoretical background of the research. It contains also a deep dive into Vietnam's energy system and regulatory landscape. The third chapter focuses on methodology and data. PLEXOS modelling and its use cases and working logic are introduced. The fourth chapter focuses on introducing the results of modelling work. In the fifth chapter results and their implications are discussed, limitations of this thesis and further research topics are presented.

2. Decarbonisation policies and Vietnam's energy system

The theoretical background section is divided into three chapters. The first one explains what different policies there are that could be used to advance decarbonisation. The second chapter focuses on Vietnam and its energy system's special traits. It also presents current decarbonisation targets and policies in place in Vietnam. The third chapter gives an overview of energy system modelling and different model types.

2.1 Energy transition policies

Efficient and perfectly functioning markets would address all hidden and available externalities related to energy systems. If such markets would exist in the global energy sector, climate change and global warming would not be one of the top priorities in international politics. Carbon neutral and carbon negative technologies exist already today. The price of renewables has decreased over years, and now renewables are amongst the cheapest means for energy production (IRENA, 2021). The bottleneck is not in technologies but rather in policies, funding and capabilities to scale up more sustainable technologies to replace old fossil-based energy generation. Energy transition needs to be supported by policies and regulations addressing multiple issues and imperfections. IRENA (2021) lists some of those factors in Table 2.1. This work focuses on modelling energy systems with existing mature technologies. Objectives and technological avenues that are under scrutiny in this work are bolded in the Table below.

Table 2.1 Policy actions to support energy transition (IRENA, 2021)

Technological avenue	Objective	Recommendations
Renewables (power and direct uses)	Deploy renewable energy in end uses	These policies include regulatory measures that create a market, as well as fiscal and financial incentives to make them more affordable and increase their cost competitiveness compared to fossil-fuel-based solutions
	Deploy renewable energy in the power sector	The choice of instrument and its design should consider the nature of the solution (*e.g.*, utility-scale, distributed, off-grid), the sector's level of development, the power system's organisational structure and broader policy objectives
Energy conservation and efficiency	Increase energy conservation and efficiency in heating and cooling	Energy efficiency policies such as strict building codes, support for building retrofits and appliance standards are critical for the energy transition in buildings and industrial processes.
	Increase energy conservation in transport	Decarbonising the transport sector, among other measures, requires a shift from energy-intensive modes to low-carbon modes.
Electrification of end uses	Electrify heating and cooling	Targets for renewable power should consider the rising demand from the electrification of end uses, in line with long-term decarbonisation objectives. Moreover, policies and power system design are needed to support electrification in achieving its potential for providing system flexibility.
	Electrify transport	
Green Hydrogen	Support the development of green hydrogen	An enabling policy framework should consider four key pillars: a national green hydrogen strategy, priority setting, guarantees of origin and enabling policies.
Sustainable bioenergy	Ensure the sustainable use of bioenergy	Renewable energy is not exempt from sustainability concerns. Some of these concerns include greenhouse gas emissions related to land-use change and impacts on air and water quality and biodiversity.

East-Asian countries have varying decarbonisation ambitions and renewable targets. The starting point differs significantly as well. For example, hydropower capacity is not spread evenly in the area and some countries have implemented stricter decarbonisation policies for a long time. Thus, comparing only Nationally Determined Contributions and renewable energy targets is not showing the whole situation. However, it indicates what policies are implemented to reach certain targets. Table 2.2 lists NDCs, renewable energy targets and decarbonisation policies in place in some East-Asian countries.

The majority of South and South-East Asian countries have an NDC emission reduction target of around 20 %, and almost all have adopted Feed-in tariff systems to reach that goal. Bangladesh has very low ambition NDCs. Bangladesh is planning to reduce its greenhouse gas emissions by only 5 % compared to the BAU scenario by 2030. Decarbonisation policies are non-existent. Other policy actions taken into use are coal tax (in India), financing for renewable development (Thailand, Pakistan), value-added tax exemptions for clean energy (Philippines), net metering (Pakistan and Philippines) renewable energy auctions (India and Pakistan) and net metering (Philippines and Pakistan). Compared to other countries in the area, Vietnam's unconditional NDC target is relatively low and actions in place, mainly FITs, are also below average.

Table 2.2 NDCs, renewable targets and used policies in East-Asian countries (Combined from Climate Analytics 2019a-g)

Country	NDCs and GHG emission targets compared to the BAU scenario	RE Targets	Decarbonisation policies	Other
Vietnam	Unconditional 9 % emissions reduction by 2030, a 20 % reduction in emissions intensity per GDP unit. Conditionally, 27 % emissions reduction with a 30 % reduction in emissions intensity per GDP unit could be achieved.	Aiming at increasing renewables share and use to 31 % in 2020, 32 % in 2030, 44 % in 2050.	FITs guarantee a fixed income per kWh generated for 20 years for solar PV and wind. The system ended in 2021.	Sustainable Renewable Energy Fund: public funding for e.g. increasing the share of households using solar heat equipment.
India	Reduction of GHG emissions intensity by 33-35 % by 2030 from 2005 levels.	Non-fossil capacity 49.3 % by 2022, and 57.4 % by 2026. Power generated from renewables 24 % by 2027, incl. hydro.	Coal tax is $3.2 per tonne. Periodical renewable energy auctions.	High coal capacity additions are still planned in the National electricity plan
Thailand	An unconditional 20 % reduction in GHG by 2030, as well as a conditional reduction of 25 %. The country also pledges to investigate and promote market mechanisms at various multilateral levels.	15-20 % of electricity generation in 2036, and heat to 30-35 %, overall: 30 %.	Feed-in Tariffs for renewable energy for 25 years. Green bonds for the development of renewable energy projects.	
Philippines	70 % reduction in comparison to BAU by 2030. This would result in emissions 32-40 % below 2010 levels.	35 % of generation capacity by 2030. 50 % by 2040.	VAT exemptions for the sale of power or fuel generated by renewable sources. Feed-in Tariffs for solar, wind, biomass, and run-of-river hydropower.	Net metering allowed. The carbon tax is too low to help shift away from fossil fuels.
Pakistan	20 % reduction by 2030, conditional on financial support in the range of $40 billion necessary to finance the costs of achieving this target.		Net metering Financing scheme for renewables. Auctions for wind and solar that was replaced with FITs in 2016.	
Indonesia	Emission reduction targets 29 % unconditionally and 41 % conditionally by 2030.	23 % renewables by 2025. The renewable energy target for electricity generation is 25 % in 2030.	FITs for renewable energy in place. Blending requirements for biofuels and bioethanol.	
Bangladesh	Unconditional 5 % GHG emissions reductions by 2030, with a conditional target of 15 %.	REN generation growing from 5 % in 2015 to 35 % in 2041 (excl. hydropower).		Massive coal generation additions planned

Policy decisions

There are several regulative options to curb carbon emissions. Some literature exists that compare different policies (e.g. Goldblatt, 2010), but as all energy systems and countries differ, it is difficult to know which policy would be the most efficient in given circumstances. According to Tagliapietra et al. (2019, p. 950), "*decarbonisation policies should be carefully crafted because without extensive consideration of their distributional consequences there is a risk of social backlash*". Aghion et al. (2016) take the idea even further suggesting that all climate policy decisions impact future decisions *"Environmentalist governments strategically lock-in decarbonisation efforts by overregulating, while antiregulation governments offer even less support to clean energy than they would do without strategic concern"* (p. 565). To be effective, policy actions need to be realistic in the target country: there might be limitations in the infrastructure or system that prevent the adoption of some policies.

The next paragraphs list different decarbonisation policies or enablers. Starting from policies to increase renewable energy generation, implementing carbon emission trading or carbon tax, improving energy efficiency and lastly describing long-term energy transition enablers.

Increase of renewables

Key technologies for decarbonisation are renewable energy assets: solar photovoltaic and wind turbines. The cost of renewable energy generation assets has been decreasing rapidly in the past few years. In many countries, they are already the cheapest means for energy generation (IRENA, 2021). The question is how to scale the share of renewables quickly enough and in a way that keeps the energy system in balance. Investments in legacy technologies have been massive and thus it might not be socially acceptable to prohibit coal and oil power plants leading them to become stranded assets.

Deregulated energy markets have been designed for a system where the majority of production is based on steady baseload sources where so-called scarcity pricing, production serving peak demand, defines the price of electricity and makes demand and supply meet (OECD, 2019). Increasing share of variable renewable energy sources increase price volatility increasing also investors' risks. As renewable energy variable cost in a short term is close to zero, the price mechanism won't work similarly with fossil fuel generation. Political incentives are needed to attract investors, but the risk is that such actions lead to sub-optimal production mixes (OECD, 2019). Some policies that have worked to introduce higher penetration of renewable generation are listed below.

Fiscal policies

Feed-in tariffs (FIT) are fiscal policies that guarantee certain payments for the owner of a renewable asset when electricity is "fed" into a power grid (Kim and Lee, 2012). Such tariffs are widely used in many countries to speed up the adoption of new technology. There are different pricing techniques used for FITs proposed by Kim and Lee (2012). The amount of FIT can be e.g. fixed (= price guarantee), increasing after a certain price (= minimum price guarantee) or increasing so that the premium is fixed. According to Wall et al. (2018), feed-in tariffs are the most significant policy instrument to attract foreign direct investment into renewables. Vietnam, besides many other countries, has achieved rapid renewable penetration using fixed-price feed-in tariff, as can be seen from Figure 2.1. (Guild, 2019). Following the implementation of FIT in Vietnam in 2019 the solar PV capacity has exploded growing over 4.5 GW in the year 2019 only.

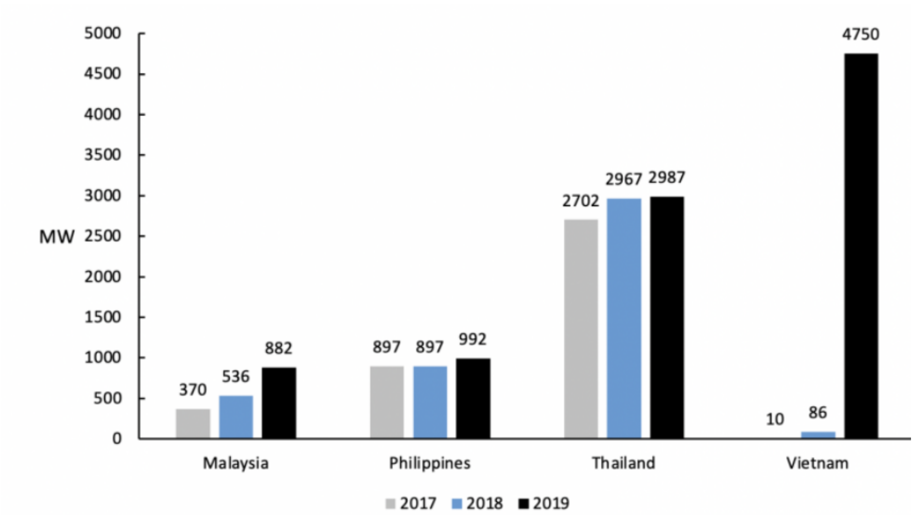

Figure 2.1 Solar PV penetration in South East Asia (Guild, 2019)

Other fiscal measures, such as reduced taxation for renewable generation assets and financing support (one-time governmental funding for covering part of the renewable investments) are available (Wall et al., 2018). OECD (2019) lists also feed-in premiums, production tax credits and zero-emission credits to be opportunities to increase the share of renewables in energy systems.

Regulatory and public policies

Renewable Portfolio Standards are obligations for power generation companies to produce a certain percentage of electricity from renewable energy sources. Also, Net Metering, allowing a two-way flow of electricity between energy grid and local producer (that might use rooftop solar panels) increases incentives to more distributed generation with renewable energy generation assets. (Wall et al., 2018)

Public options for increasing renewables include tendering and direct public investments. However, public investments have been observed to have reduced foreign investments in renewables. (Wall et al., 2018)

Carbon trading and carbon tax

According to OECD (2019), carbon pricing would be the best policy instrument for cost-effective carbon emission reductions. This is implemented by levying a tax or having markets for emission rights. If carbon would be priced equal to its social cost, it would automatically lead to an economically optimal situation and natural development of low-carbon alternatives (OECD, 2019). At least when assuming that no out-of-market support would be given for renewable energy sources. However, direct carbon pricing would lead to a question of distributional impacts and the long-term credibility of the carbon pricing system. Currently, companies have been allowed to seek economical rent by emitting carbon into the atmosphere for free. Setting prices to those emissions would transfer wealth from companies to governments or instances that could abate emissions with the lowest cost.

Emission trading systems (ETS) are used to allocate emission reductions to industries where the marginal cost of avoided emission is the lowest. ETS have been proposed as one carbon emission mitigation action already in Kyoto protocol in the United Nations Framework Convention on Climate Change in 1997. The system works so that the regulator sets a cap level for emission, and companies obligated to participate in the system either reduce their emissions or trade ETS units to cover their expenses. Emission allowances can either be given away based on historic emissions of certain actors (so-called *grandfathering)* or auctioned off by governments without allowances.

The price is set on markets depending on the demand and supply: companies reduce their emissions up to that point where buying an emission allowance from the ETS is cheaper. If a company exceeds its carbon allowance, it is obligated to pay a penalty that is higher than the price for an emission right unit. Carbon units under the ETS can be traded between companies or transferred to the ETS system through 1) removal of CO_2 through land use, land-use change and forestry activities, 2) joint implementation projects and 3) certified emission reductions from clean development mechanism projects. Emission trading systems are in use in European Union (since 2005) and China (since 2021). (Villoria-Sáez et al., 2016).

Carbon taxes are taxes set for carbon emissions. Different taxes can be applied directly to the CO_2 emissions but also indirectly through fuels or energy consumption. The idea is that a regulator sets a fixed price for an emission unit. When facing a carbon tax, an emitter will conceptually reduce its emission until a point where the marginal cost of emission reduction exceeds the carbon tax. Setting the tax to the optimal level requires defining the externalities of an emission unit. (Goldblatt, 2010) According to OECD (2016), 90 % of developed countries have set carbon tax on too low levels. Conservative estimate from OECD gives an external cost of EUR 30 per tonne for carbon dioxide emissions. There might be political concerns about how high tax levels would impact national economies.

Both carbon taxes and emission trading schemes should lead to relatively similar outcomes funnelling the external cost of emissions to the emitters. A carbon tax is a ´price instrument´ where optimal emission levels are selected through pricing. Emission trading is a 'quantity instrument' where an optimal cap is first defined, and trading defines the final price for the emission unit. (Goldblatt, 2010) Both systems are described in Figure 2.2. Before any regulation economic rent for an emitter is the whole area A+B+C. After a carbon price is implemented, the economic rent reduces to area A. Area B is the government's income from levying the tax or selling emission allowances. In ETS that are based on *grandfathering,* area B is returned to emitters. Area C is lost economic activity in all cases, but when the social cost of emissions is considered, benefits outweigh losses.

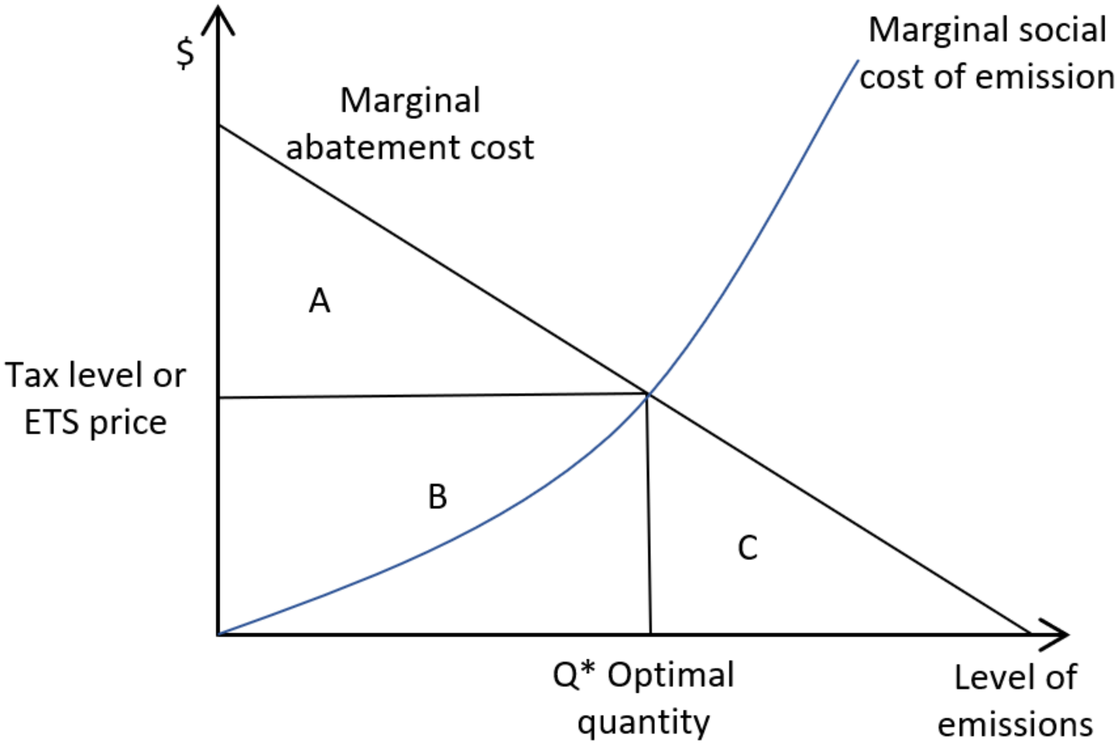

Figure 2.2 Optimal emission quantity and carbon price (OECD, 2019)

Even though carbon tax and emission trading should, in theory, lead to the same result, there is disagreement amongst economists on which system yields a better outcome. OECD (2016) suggests using market-based carbon pricing mechanisms but admit that taxes might be the simplest option administratively. Barragán-Beaud et al. (2018) argue that in Mexico ETS is the most appropriate instrument due to higher cost-efficiency and lower distributional effects when compared to the carbon tax. Contrary Hájek et al. (2019), Andersson (2019) and Nordhaus (2017) suggest that carbon tax that has been in operation for a long time is more efficient than the emission trading systems. Funds from carbon pricing should be flown back to the economy through increased government spending or reduced general taxes.

Energy efficiency

One of the most relevant decarbonisation policy channels for Vietnam is improving energy efficiency through regulation (EREA & DEA, 2019). Energy efficiency is measured as the energy intensity of GDP. According to Marcucci and Fragkos (2015), energy efficiency improvement alone won’t be able to achieve climate targets but can support the development. EREA and DEA (2019) argue that energy efficiency saving outweighs the costs and investments needed for it. They suggest that the most relevant sectors for energy efficiency improvements are the industry, transport and residential sectors.

Possible regulative measures for improving energy efficiency are for example making utility companies co-responsible for efficiency improvements, defining and maintaining standards and removing barriers that prevent investments for technologies improving energy efficiency.

Long-term decarbonisation technologies

This thesis focuses on the period until 2030. Thus, technologies and enablers that are available only after that are not included in the modelling. Net-zero targets are not relevant before 2030 but once societies need to do the final push towards full carbon neutrality, or even negative carbon emissions, new technologies are needed. Such technologies addressed by many scholars (e.g. Rajbhandari and Limmeechokchai, 2021) are bioenergy combined with carbon capture (BECCS), carbon capture and storage (CCS) or carbon capture, utilisation and storage (CCUS). Also, small modular nuclear reactors (SMR) are provided for a solution.

2.2 Vietnam's energy system

Vietnam has a socialist one-party system. Electricity coverage reaches almost the whole of Vietnam's population (Vietnam Electricity Group, 2021). Energy markets are heavily regulated: new capacity is planned periodically through power system development programs (PDP) that are conducted by the Ministry of Industry and Trade and the Institute of Energy. A key player in the power industry is the state-owned Vietnam Electricity Group which, through its subsidiaries, owns the majority of power generation capacity. Vietnam Electricity Group also owns the country's transmission infrastructure and five companies operating in the national electricity business. Energy companies are divided per region and the biggest cities Ho Chi min City and Hanoi have their own energy companies.

The backbones of the current energy production mix are coal (22 GW), hydropower (22 GW) and solar generation (17 GW) as Figure 2.3 states. Also, the share of gas turbines (7 GW) and wind (6 GW) is notable. The development of solar generation has been extraordinary fast: Vietnam implemented a feed-in tariff system creating a strong incentive for households and companies to build rooftop solar panels. That led to an over 9 GW increase in installed solar capacity in under a year (World Economic Forum, 2021). The rapid development of renewable energy sources causes an occasional local overload of distribution as transmission capacity has not been developed synchronously (Vietnam Institute of Energy, 2020a).

Vietnam is almost self-sufficient in its energy production. The majority of coal and gas used for energy production is domestic, but in the future, if fossil capacity increases as planned, both gas and coal imports are expected to grow. Besides fuel imports, there is an interconnection capacity of 2 GW to neighbouring countries, Laos and China. Actual imports and exports, however, are on relatively low levels. (Vietnam Institute of Energy, 2020a)

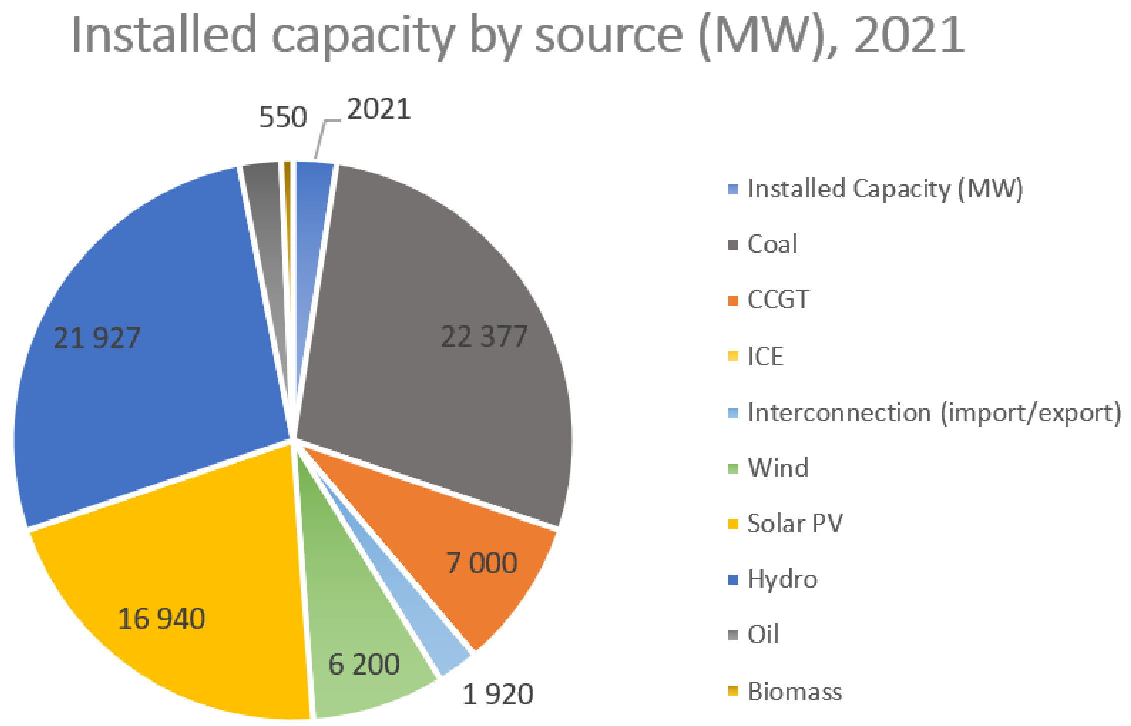

Figure 2.3 Forecast of installed capacity in Vietnam's energy system in 2021. (Vietnam Institute of Energy, 2020a)

Installed power generation capacity has grown fast. It has almost doubled in five years to 78 GW in 2021. The drivers for that growth have been growing demand from industry and households (Vietnam Institute of Energy, 2020a). The current electricity production lies above 250 TWh per year. The rapid growth of production has been mainly fuelled by an increase in coal and gas capacity as Figure 2.4 describes. Rapid growth started around 1990, and since then the electricity generation has thirty-folded from 9 TWh to last year's 267 TWh. Also, hydropower has played a significant role and is currently producing approximately 25 % of electricity.

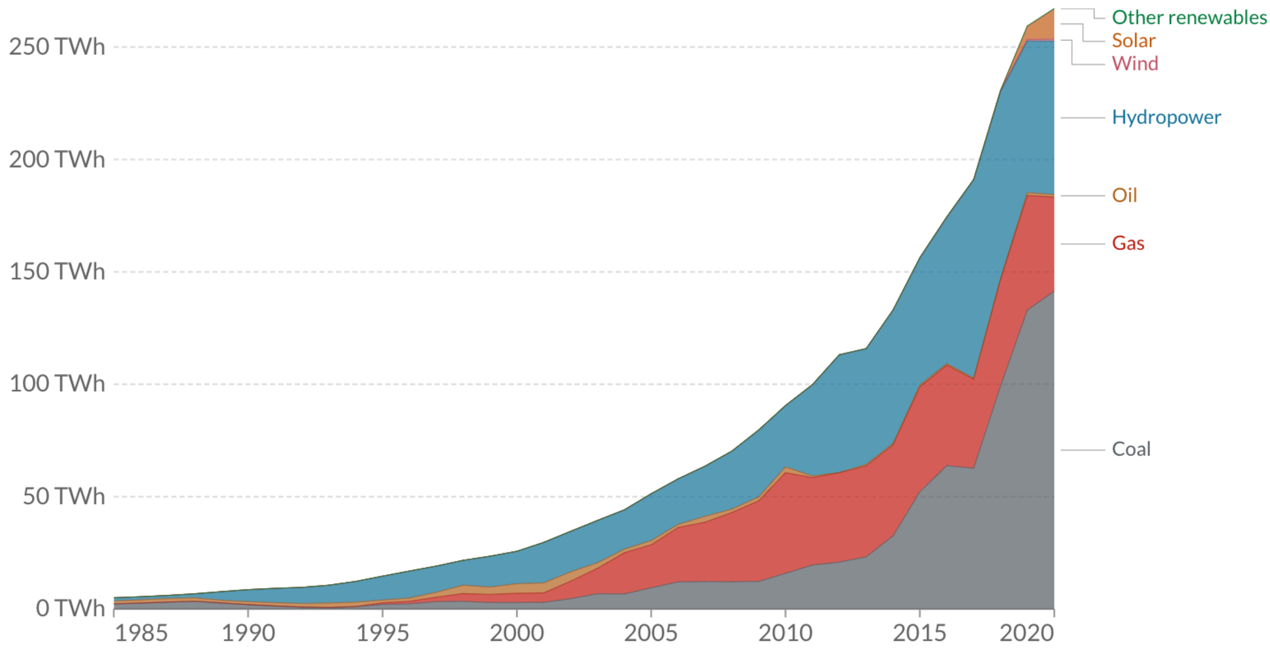

Figure 2.4 Power mix development in Vietnam 1985-2020 (Richie and Roser, 2020)

Three interconnected energy regions

Vietnam's energy system consists of three interconnected regions: Northern, Southern, and Central. Generation mix and constraints in each region are different and thus they need to be addressed individually when planning or modelling the overall energy system. Differences occur especially in the amount of hydropower. North region energy production is based mostly on coal and hydropower, Central region production is mainly hydro – there is no coal at all. The South region is the most diverse with one-third of coal, one-third of gas and rapidly increasing amounts of solar energy. In size-wise, the Central region is much smaller totalling around 10 GW capacity where both North and South regions were almost 25 GW each in 2019 (Vietnam Institute of Energy, 2020). An increase in solar production capacity has focused on the Central and South regions.

Regions generate the majority of their demand independently, but inter-regional transmission is needed to balance supply and demand. South Region has been the biggest importer of energy, the transmission from Central region has peaked in 2019 being almost 20 TWh. Stable energy sources (coal and hydro) in the North region are used to feed power to the Central region where peak demand exceeds occasionally the supply of mostly hydropower-based capacity. This represents a challenge of seasonality in a hydropower-heavy generation. During rain seasons Central region affords to export big amounts of power to the South, but in other parts of the year, it needs to import 5-10 TWh of energy from the North. (Vietnam Institute of Energy, 2020a)

The future energy system of Vietnam

Currently, Vietnam's Ministry of Industry and Trade is preparing a new power system development program. That PDP will be 8^{th} in the order. Drafts of the PDP 8 will cover high-level planning for the years 2021-2030 and a vision to 2045. Orders and public authorisations for new power plants are done in ministry based on this long-term planning. The plan is indicative and guides the construction of the energy system: for example, in the previous planning period (2011-2019) thermal sources reached only 58 % of the planned capacity and renewable sources exceeded it by 105 %. (Vietnam Institute of Energy, 2020b)

PDP 8 is conducted using several models. Power source planning is done by combining outputs from the Balmorel equilibrium model and Integrated asset energy model PLEXOS that optimises the composition of the energy system on a single generation asset level. Besides internal work done in the Institute of Energy, modelling is supported by the United States Agency for International Development (USAID) and Danish Energy Agency (DEA). As an outcome from Balmorel and PLEXOS modelling, national power and electricity balances yearly are formed.

Ongoing planning work is targeted to address the huge growth in energy and electricity demand. Current modelling estimates that the capacity would exceed 130 GW in 2030 and 250 GW in 2050. Current electricity production was about 250 TWh in 2020 and that also is expected to double to >500 TWh by 2030. The growth will continue after 2030 but slower than before. Institute of Energy (2020a) estimates electricity need to be over 900 TWh in 2045. (Vietnam Institute of Energy, 2020a)

Figure 2.5 describes planned capacity additions until the year 2045 according to PDP 8. Current plans of Vietnam's Institute of Energy (2020a) include around 20 GW of new coal and gas thermal capacity to be built by 2025. However, it is worth mentioning that the current power system development plan (PDP 8) is postponing or delaying over 17 GW of coal power that was approved in the PDP7. The planned increase of renewable energy generation capacity is 10-30 GW for solar by 2030 and 10-40 GW for wind by 2030. Also, an addition of a few gigawatt hydropower is planned but the total potential is limited due to geography as feasible sites are soon utilised.

An increase in renewable energy sources will require investments in the transmission grid. As the renewable generation is concentrated in the South region, there will be increased demand for transmission to the North from 2025 especial transmission from Central South to North. Vietnam Institute of Energy (2020a) predicts an increased need for flexible sources after 2025. Battery energy storage and internal combustion engines (ICE) are mentioned to be possible flexibility providers in the long term.

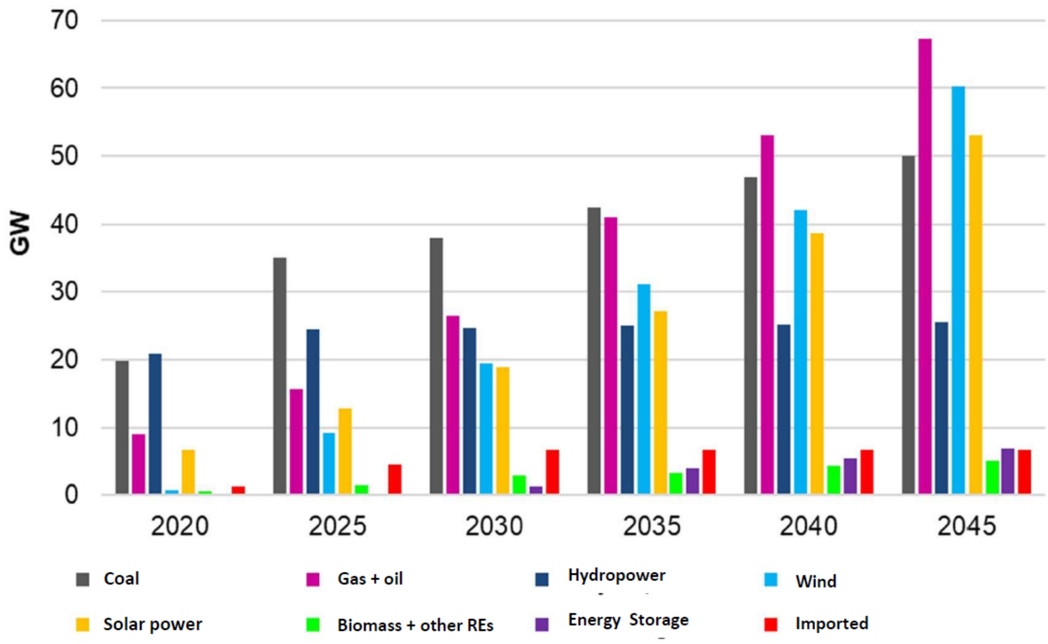

Figure 2.5 Power sources proposed in the development plan (Vietnam Institute of Energy, 2020a)

2.2.1 Natural resources of Vietnam

This chapter defines the current situation and limitations of natural resource reserves and potential in Vietnam. All figures are based on Vietnam's Institute of Energy (2020a) report that works as an input for the national power system development program (PDP 8).

Coal

Vietnam has large domestic coal resources of over 2.2 billion tonnes. Most of the reserve is located in the northeast, and with today's consumption, it could be consumed for roughly 40 years. Current production is 35 megatonnes, and it is expected to grow modestly (~10 %) by 2030. On top of that, around 17 megatonnes are imported for power generation.

Domestic coal costs are estimated to vary between 55 and 75 $/tonne (EREA & DEA, 2019). Using that to estimate the existing coal resources of Vietnam leads to a valuation of $121 – $165 billion. The total energy value of domestic coal production is around 300 TWh per year. The current efficiency rate of coal plants is around 35 % (Vietnam Institute of Energy, 2020a) leading to a total domestic coal output potential of ~100-120TWh in energy production. In 2030 that represents only ~15 % of the energy sector's annual demand.

Gas

The current gas turbine and gas engine capacity is relatively small in Vietnam (~7 GW in 2021). However, gas generation might have an important role in replacing coal generation and shifting towards lower CO_2 intensity. Vietnam has domestic gas reserves of approximately 871 billion cubic meters. Base supply is expected to two-fold by 2025 but decreases after that to current levels of 11 billion cubic metres per year. That equals around 116 TWh and 20 % of annual energy sector generation. The computational value of gas reserve (using price estimates for 2030) is ~$300 billion. Gas reserves are located unevenly, and thus gas needs to be transported especially to the South region. (Vietnam Institute of Energy, 2020b)

Hydropower

From a global perspective, Vietnam is lucky to have a high hydropower potential relative to its energy demand. The total capacity of built hydropower by 2021 is ~22 GW. Additional ~3 GW and 2,5 GW can be developed between 2020-2025, and 2025-2030, respectively. Hydropower is a stable source of energy seasonally. Historical output has shown a utilisation rate of 45 %. However, global warming might increase severe droughts that diminish production significantly. This underlines the importance of increasing flexible energy generation. Around 110 TWh or 18 % of annual energy need is expected to be covered by hydropower in 2030. (Vietnam Institute of Energy, 2020b)

Wind power

The total technical potential for on-shore wind is 217 GW and for off-shore wind 160 GW – mostly located in the South and North regions. However, the current cost level of wind power is not economically feasible for areas where wind speeds are low. Today's feasible potential for wind generation in high or medium wind areas (>5,5 m/s) is around 54 GW. Out of this capacity, a bit over 6 GW was in use in 2021. There are investment plans for several projects that would aim to build over 20 GW new wind capacity. (Vietnam Institute of Energy, 2020a)

Vietnam has a feed-in tariff system for wind power in place compensating wind generation by $0.08 and $0.1 per kWh. The tariffs are offered for projects that are commercially commissioned before December 2023. After that Vietnam plans to move to an auction-based system. ("Vietnam will extend FiTs for wind projects until December 2023 | Enerdata," n.d.)

Solar power

Vietnam implemented a successful feed-in tariff system in 2017 that helped to scale up its solar energy generation (see Figure 2.1). By the end of 2021, there is estimated to be around 17 GW of solar generation capacity. The feed-in tariff system for solar installation has been between $0.07 and $0.085 per kWh produced and it ended in November 2021 ("Vietnam to cut rooftop solar feed-in tariff in bid to ease grid pressure | Reuters," 2021).

Even more capacity is to come. Due to the geographical location of Vietnam, there is huge potential for solar. The Institute of Energy estimates the capacity potential for ground solar, floating solar and rooftop solar to be 309 GW, 77 GW, and 48 GW, respectively. The biggest potential is in the South and Central regions which are sunnier. However, land-use fees are defined to be higher in those regions favouring rooftop and floating solar installations wherever it is possible.

Other renewables, batteries and nuclear

According to the Institute of Energy (2020), biomass, waste-to-power, geothermal energy, tidal generation and biogas would each have a potential between 1 to 5 GW of capacity. Those technologies could balance the volatility of other renewable sources but are rather small compared to solar and wind capacity estimates.

Batteries could also work as a solution for short-term balancing. The cost has come down rapidly and is expected to decrease in the future as well. Still, batteries are rather expensive, and Vietnam's Institute of Energy don't consider them to be feasible before 2030 (Vietnam Institute of Energy, 2020a).

Nuclear generation has been considered but according to the Vietnam Institute of Energy (2020a), it won't be economically feasible if carbon emission prices remain low levels. They suggest adding nuclear generation to be deployed earliest in 2035 if the CO_2 price is to exceed $40/tonne. High investment costs, low flexibility and risk of high-impact incidents are disadvantages in nuclear power. The benefits of nuclear power include carbon neutrality, long lifetime and energy security through the stable generation and low dependency on fuel markets.

2.2.2 Difficulties and special traits of Vietnam's energy system

Vietnam's energy system development faces several challenges. Some of them are common for other developing countries as well; others are specific to Vietnam.

One of the biggest challenges of the energy system of Vietnam is the question of how green technologies are combined with the massive growth that the country is facing. How to integrate renewable energy sources into the energy system in a reliable and cost-competitive way? Adding big amounts of renewables will increase the volatility of the grid, and thus require balancing both seasonally and in the short term.

Volatility of renewables

Weather conditions play a big role. As almost one-third of capacity comes from hydropower, seasonal changes in rain call for flexibility to the power system (Vietnam Institute of Energy, 2020b). Global warming might increase extreme weather conditions including droughts (Deryugina et al., 2014). During rain seasons, heavy rainfall might cause flooding of either reservoirs or downstream from hydropower plants. Also, La Nina and El Nino phenomena cause fluctuation in yearly rainfall and wind conditions. During them, it is more difficult to predict hydro generation.

Tagliapietra et al. (2019) highlight the convergence between decentralisation and digitalisation and encourage to transform the energy distribution grid "*into an open platform where the various decisions of the multiple players are made coherently interacting in an 'open source' sharing economy coupled with a guaranteed physical delivery loop*" (p. 953).

Decentralisation and digitalisation, and increasing renewable in the first place, will require significant investments. State resources can meet only one-third of the financial need of the energy system (The Socialist Republic of Viet Nam, 2020). The problem is that the electricity price is not attractive to foreign investors (Vietnam Institute of Energy, 2020a). The Ministry of Industry and Trade in Vietnam plans to adopt two-component pricing so that electricity purchase prices between different regions could vary. Also, a bidding mechanism to let markets define the most competitive means of energy generation could increase the amount of foreign investment capital flowing to Vietnam's energy system (Vietnam Institute of Energy, 2020B).

Regional differences

Renewable energy generation potential has been divided unevenly between different regions. Most of the country's hydropower capacity is in the North region. The highest potential for wind and solar generation is in the South and Central regions. Hydropower is a seasonal generation asset and wind and solar are volatile depending on weather conditions. Transmission grids have been built in the last years and more is still needed to offer flexibility between regions. Other sources of flexibility might be needed.

Politics

Finally, domestic and international politics should be considered when planning for the energy system development in Vietnam. Limited availability of domestic natural resources, mostly gas and coal, might be a constraint for building more fossil fuel capacity. The current exploitation rate of domestic fuels can barely be increased (Vietnam Institute of Energy, 2020a). Changes in international politics may lead to a situation that importing fossil fuels from other countries would not be possible.

Already now trade politics have been causing distress in Vietnam. A huge deficit of US-Vietnam trade has raised concerns in the United States. U.S. Treasury's included Vietnam in its trade manipulators list ("Vietnam put on US Treasury list of currency manipulators - Nikkei Asia," 2020) after the trade deficit exceeded $69 billion in 2020 (US Census Bureau, 2020). Energy system development doesn't happen in a vacuum from other politics, and thus such external pressure might lead to decisions and investments that support or are aligned with the overall political landscape. Vietnam is a socialist single-party state. More radical legislative changes might be feasible to conduct faster compared to parliamentary systems.

2.2.3 Pledges of Vietnam to mitigate climate change

Vietnam has made several pledges concerning decarbonisation and mitigating climate change – either to the international community or domestically. This chapter introduces the most important of those pledges. Major targets are described in Table 2.3.

Table 2.3 Vietnam's policy targets mentioned in current energy and climate policy (EREA & DEA, 2019)

Target	2020	2025	2030	2050
Renewable energy				
RE share in primary energy supply	31 %		32 %	44 %
RE share in total electricity generation (*excluding hydro)	38 % / 4 %*		32 % / 15 %*	43 % / 33 %*
Energy efficiency as compared to BAU				
Final energy demand saving (VNEEP3)		5-7 %	8-10 %	

GHG emission reductions as compared to BAU				
Green growth strategy (VGGS)	10-20 %		20-30 %	
Intended nationally determined contribution			8 % unconditional 27 % conditional	
REDs (Energy sector)	5 %		25 %	45 %

Carbon emission reduction under NDC

At the 21st Conference of the Parties (COP21) in 2015, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement. Aligned with the Paris Agreement, Vietnam has pledged to reduce its total GHG emissions by 7.3 % by 2025 and by 9 % by 2030 compared to the business-as-usual scenario. The reduction is equivalent to 52.9 million and 83.9 tonnes of CO_{2eq} respectively. The business-as-usual scenario is developed based on the year 2010 and provides a projection for 20 years. Vietnamese government updated the NDC in 2020 increasing the level of ambition and including also industrial processes under the emission reduction scope. (The Socialist Republic of Viet Nam, 2020)

The updated NDC also states that Vietnam can raise the reduction commitment up to 27 % with international support and add also the industrial processes sector under the NDC which previously was excluded (The Socialist Republic of Viet Nam, 2020).

Share of renewables

Renewable Energy Development Strategy (REDS) is setting national renewable generation targets in the energy and power sectors. The current share of renewables is 38 % of total electricity generation or 4 % if hydro is excluded. The target for the year 2030 is 32 % increasing the amount of non-hydro production to 15 % of total electricity generation. The lower renewable target addresses the rapid growth of energy demand which is not expected to be fulfilled with renewable energy sources. However, the REDS target for 2050 is 43 %. In this target, only 10 % of total electricity generation is expected to be produced with hydropower. (EREA & DEA, 2019)

Energy Efficiency

National Program on Energy Efficiency and Conservation for the period 2019-2030 (VNEEP3) states to improve energy efficiency by reducing final energy demand by 5-7 % by 2025 and 8-10 % by 2030 compared to business-as-usual scenario (Ministry of Industry and Trade, 2019).

Coal reduction

In COP26 Vietnam pledged to reduce new coal power generation. This included not building or investing in coal-fuelled power generation and new coal plants from 2040 onwards. Vietnam's representatives suggested further that coal will be gradually decreased by 30 % by 2030 and be replaced by gas and renewable energy sources. ("Vietnam Coal Pledge at COP26 - A New PDP8 and Net-Zero by 2050," Energy Tracker, 2021)

Carbon neutrality by 2050

Vietnam's prime minister Phạm Minh Chính announced in the COP26 that Vietnam will "build and implement strong measures to reduce greenhouse gas emissions by using its resources coupled with the cooperation and support of the international community, especially from developed countries, in terms of finance and technology transfer, including implementation of mechanisms under the Paris Agreement, to achieve zero emissions by 2050" ("Việt Nam strives to achieve 'net zero' by 2050, with international support: PM," n.d.). This is not a binding pledge but indicates a political will to accelerate decarbonisation efforts.

2.3 Models for climate and power system modelling

Models and scenarios have been widely utilised to plan legislation and strategies for governments and companies. Vietnam is also using different modelling to support its national power system development activities, e.g. USAID (2020), Vietnam Institute of Energy (2020b). Models and scenarios are descriptions of real energy systems. By sophisticated modelling different options to reduce GHG emissions can be modelled the best possible development path identified. At best models and scenarios accommodate all current information available to forecast the future. Remote events are more difficult to forecast as the number of variables increases and there are uncertainties beyond measuring (unknown unknowns). Therefore, accuracy for forecasts might be bad and prone to errors caused by unexpected events. Also, the assumptions behind the country-specific features might change. Decarbonisation pledged, for example, might be changed either direction when the political landscape changes.

In this chapter, some modelling approaches are introduced that are used for energy system modelling. Multiple different models might be needed to get a holistic view of energy system development. Vietnam and other instances (e.g. USAID, 2020) use both the Balmorel and PLEXOS models as inputs in their reports.

Least-cost optimisation models

Least-cost optimisation models are used in energy planning to define optimal capacity expansion and dispatch under a set of constraints and requirements. Some widely used modelling tools for that are the TIMES (The Integrated MARKAL-EFOM System) and PLEXOS. The starting point of least-cost modelling is to describe the current state of the system: list all existing generation assets and primary energy resources. Also forecasted demand or needed dispatch is included or approximated based on certain factors such as GDP or population. The model then calculates the cost-optimal development of the system that fulfils the demand in theory.

Least-cost optimisation models can be used short, medium or long-term planning as models are considered to have “perfect foresight”. This means that the net present values of each generation asset are known for the modelling period. Good results have been achieved by combining granular models that can address the variability of a single energy generation asset to long-term energy models that predict future energy demand (Welsch et al., 2014).

Balmorel model

Balmorel model is an open-source model that is used for a wide variety of use cases related to electricity and combined power and heat production modelling. The model emphasises open communications and transparency so that data and the model itself are transparent for all enabling comparable results. The partial equilibrium model enables to optimise and analyse energy generation, transmission and consumption of electricity and heat (Wiese et al., 2018). In other words, it gives an estimation of power consumption on a country or international level. Balmorel model has been used for example defining external costs of air pollution at a local level (Zvingilaite, 2011) and calculating changes in socio-economic system costs when certain technologies are added to an energy system (Jensen and Skovsgaard, 2017).

Integrated Assessment Modelling (IAM)

Integrated assessment models are also widely been used to define the impacts of climate change. They are computable general equilibrium models. One of the most well-known IAM is the Dynamic

Integrated Climate-Economy model (DICE) that was developed by William Nordhaus. Other models include e.g. Climate Framework for Uncertainty, Negotiation and Distribution model (FUND) that was developed by David Anthoff and Richard Tol, Long-range Energy Alternative Planning by Stockholm Environment Institute (LEAP), and Policy Analysis of the Greenhouse Effect model (PAGE) that was developed by Chris hope.

Integrated assessment models are used to capture externalities and mechanisms that are typically not considered in traditional modelling approaches. The basic working logic of the DICE model is described in Figure 2.6. Maybe the most common use case is estimating the social cost of carbon emission to define externalities. Without knowing external costs competitive markets won't lead to optimal production quantities and policy actions are not optimally set. As one example, William Nordhaus (2017) estimates the social cost of carbon to be around $31 per tonne of CO_2 in 2010 US$ and growing 3 % each year. According to Brandt's et all. (2021) research specifying Vietnam's situation, the total external cost of emission in 2010 (from a domestic and foreign source) is estimated to be approximately 43 billion euros which represent around 8 % of Vietnam's GDP (in 2016 prices). Even though the calculation is based on assumptions and values, the ballpark size of external costs of emissions from such research indicates the magnitude of the phenomenon.

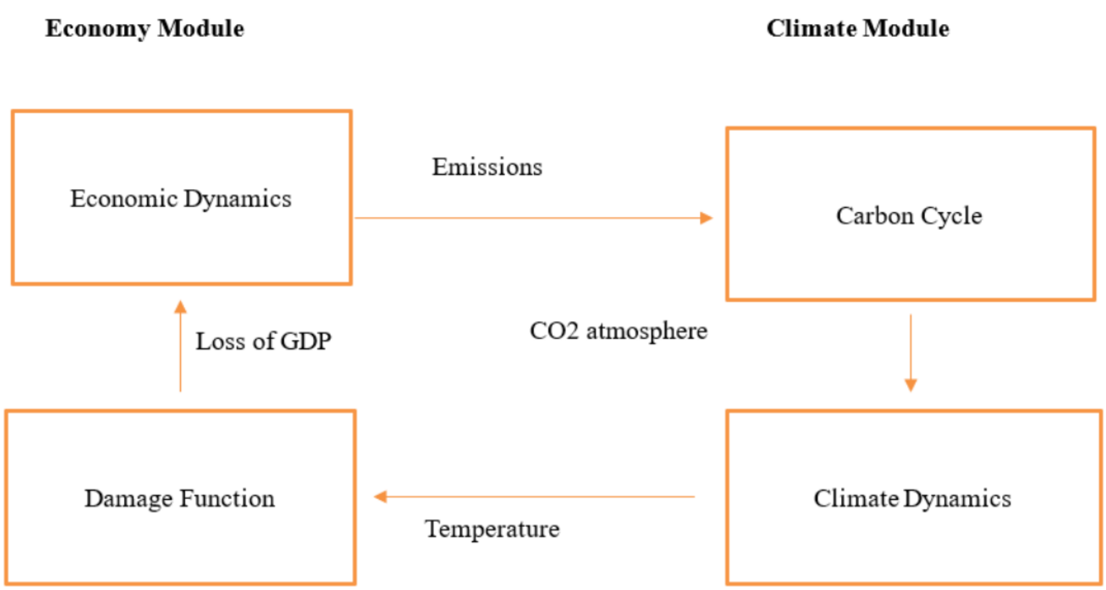

Figure 2.6 DICE model structure based on I2AMPARIS

However, some critique has been raised recently to question the biases and shortcomings of IAMs. For example, Keppo et al. (2021) suggest these models lack understanding of actors' heterogeneity, technology diffusion, representation of capital markets and energy-economy feedback: assuming markets to be perfectly functioning and omitting possible frictions. "*IAMs that are based on neoclassical economic growth and general equilibrium models, in which limited savings are allocated to borrowers by banks and capital markets, face a problem that is known as the Lucas Paradox (Lucas 1990)—the observation that capital does not flow from developed to developing countries as the standard economic theory of perfect capital markets would suggest*" (Keppo et al., 2021, p. 8).

Integrated Assessment Models are widely used for climate change research (e.g. by IPCC) and offer a modelling approach that can capture effects other models don't address, it is reasonable to expect such modelling approach to be continued and further developed.

3. Data and methodology

This chapter explains the research setup. It starts by introducing data used for modelling, then explains the methodology used for selecting scenarios for quantitative analysis and explaining the working logic of the PLEXOS modelling tool.

3.1 Data

The research has been done using integrated energy modelling, and the study combines data from different sources. The main data types are 1) future energy demand estimates, 2) description of the current generation and transmission assets and their performance and, 3) techno-economic parameters of technologies, 4) meteorology data to feed into the defined output of solar, wind and hydro generation. To align the research with a regulator, we have used as much as possible the same data and assumptions as Vietnam's Institute of Energy which is responsible for power system development planning.

Future energy demand estimates

Demand data used in this research is provided by the Institute of Energy under Vietnam's Ministry of Industry and Trade. It contains an hourly demand forecast for the future (and historical) power demand in Vietnam. The power demand forecast is based on previous power development plans and economic development forecasts have been used to extrapolate future energy demand.

Current generation and transmission assets and their performance

The data originates directly from power generation asset owners and is used for national planning purposes. Thus, it can be considered the most reliable source of data for this field. The load profile data is from existing power plants for 8,760 hours per year for the period of 2017 – 2019. Data from individual generation units (power plants) is collected by the Ministry of Industry and Trade directly from power and transmission companies. Data contains hour by hour history of when generation units have been producing electricity to the national transmission grid.

Techno-economic parameters of different technologies

Ministry of Industry and Trade in Vietnam has been cooperating with the Danish Energy Agency through a joint Energy Partnership Program. Together those instances have completed the Vietnam Technology Catalogue which describes the complete set of new power generation technologies that would be applicable for Vietnam in future (EREA & DEA, 2019). Besides technological and cost estimates for different generation technologies, the data addresses investment costs for transmission grid, cost of land use, fuel price forecasts, operations and maintenance costs, and external costs of certain emissions. The emission externalities are adapted from International Monetary Fund. Key techno-economic parameters for modelling are listed in appendix 1.

Meteorology data

Electricity generation of renewable energy sources is volatile and depends on weather conditions. As the share of renewables grows it is increasingly important to understand the hourly production potential of solar, wind and hydropower. DEA has helped put together an hourly profile for onshore and offshore wind, and together with external partners monthly hydrological data for hydropower and hourly generation capacity for solar and hydropower are defined.

3.2 Methodology

The study was conducted as quantitative research where the literature review on decarbonisation and quantitative approach to the decarbonisation pathway options of a single country are combined. The quantitative part of the research is done using PLEXOS modelling with the support of Wärtsilä Oyj, a publicly listed technology company that manufactures and constructs engine power plants and battery storage globally. The PLEXOS modelling utilises the outcome of Balmorel modelling from USAID (2020) and Vietnam Institute of Energy (2020a) to define the cost-optimal energy production mix for Vietnam under the different assumptions.

Scenarios

Scenarios for modelling were selected based on existing literature (e.g. Lallana et al., 2021; Zhou et al., 2020) defining possible policy actions. The purpose is not to capture all possible policy actions but rather to consider how different regulations would impact the cost and carbon emissions of Vietnam's energy system. Scenario assumptions are then loaded into the PLEXOS modelling tool and computable general equilibrium for future energy system's composition, cost and emissions are defined.

In this research, I developed four different regulative scenarios for Vietnam's energy industry on top of the first base case scenario. Each scenario investigates the impacts of single policy action. The first scenario examines the adoption of a carbon tax with different tax levels. The second is about setting national quotas for coal-generated power or coal capacity starting in 2025. The third one focuses on the increase of construction costs of new coal generation capacity through decreased competition or government regulation. The fourth investigates the effect of implementing a feed-in-tariff system with a fixed price for renewable energy sources in Vietnam. All scenarios use the same assumptions on technology development, technology costs and fuel prices. The only changing factor is the policy action that is added on top of the base scenario. All scenarios are listed in Table 3.2.

Table 3.1 Descriptions of policy actions modelled in this research

	Descriptions
Scenario 0 – Base case	The base case scenario describes the current situation of Vietnam's energy system. The only constraints for the model are provided by Vietnam's officials (e.g. RES potential, land availability, etc.).
Scenario 1.1 – Carbon tax – Low	Carbon tax implemented for carbon emissions. 0.4 \$/tonne of CO_2 in 2021, 10 \$/tonne in 2025 and 20 \$/tonne in 2030.
Scenario 1.2 – Carbon tax – Medium	Carbon tax implemented for carbon emissions. 0.4 \$/tonne of CO_2 in 2021, 30 \$/tonne in 2025 and 40 \$/tonne in 2030.
Scenario 1.3 – Carbon tax – High	Carbon tax implemented for carbon emissions. 0.4 \$/tonne of CO_2 in 2021, 50 \$/tonne in 2025 and 90 \$/tonne in 2030.
Scenario 2.1 – Coal capacity quota	No new coal generation capacity is allowed after 2021.
Scenario 2.2 – Coal usage quota	Coal usage for energy production is limited to domestic coal production.
Scenario 3 – High construction costs	The construction cost of new coal capacity increased by 30 % through additional taxes or permitting costs.
Scenario 4.1 – Low FITs for renewables	Feed-in tariffs subsidise solar and wind production by 35.5 and 42.5 \$/MWh respectively.
Scenario 4.2 – High FITs for renewables	Feed-in tariffs subsidise solar and wind production by 71 and 85 \$/MWh respectively.

0. Base case scenario

The baseline scenario is simply based on least-cost optimisation and existing regulation. The modelling software uses inputs and assumptions on technology and fuel prices to "build" new generation capacity so that the energy supply meets the demand. This is not the expected future state of the energy system but a scenario where the system is based on current assumptions and costs and without further political or market guidance. All assumptions on fuel prices, technologies, weather etc. are the same in all scenarios if not otherwise stated.

It is important to understand that the baseline scenario as such is not a prediction on what will happen in the future (if no new policies are implemented), but a least-cost solution to fill energy demand in today's assumptions. According to Strachan (2011, p. 159) baselines are "*generally recognised as a key input assumption into energy modelling exercises of CO_2 mitigation, energy resilience or other mid and long-term energy policy initiatives*". However, as Strachan (2011) points out, existing energy policies are not sunk effort but something that can be reversed. Thus, the baseline scenario won't be representative in a situation where policies, that have impacted our assumptions, are revised.

1. Carbon tax scenarios

Vietnam is already addressing the externalities of CO_2 and some other exhaust emissions. The value used for the external cost of CO_2 was only $0.4 per tonne (Vietnam Institute of Energy, 2020a), where some research estimates the actual social cost globally to be over 100-fold, EUR 45 per tonne (Nordhaus, 2017; OECD, 2016). As introduced in chapter 2.1, the optimal tax level for a carbon tax would equal its external cost. However, defining actual external costs is impossible and political nuances impact what elements are weighted. Carbon pricing could be organised ´quantity based´: letting markets define the price through an emission trading system (ETS). Equilibrium should be the same regardless of policy is implemented through carbon emission trading or carbon tax. Now a policymaker faces a challenge to set the cap to the right level so that the equilibrium price of emission right equals the external costs of carbon emissions. Defining external costs depends of course on how different aspects of externalities are valued and thus it can change over time and politics.

In PLEXOS modelling the carbon tax is defined based on direct CO_2 emissions. Fixed tax per emitted tonne is applied to generation costs. To define a feasible tax level, I have benchmarked the price setting of two different emission trading systems: one in the European Union and another in China. China's carbon trading system is relatively new (started in 2021) but as a neighbouring country same assumption will apply to Vietnam that is included in the price of China's carbon emission right. European Union's carbon trading system is older. The price of an emission right in EU ETS has been increasing rapidly and is currently significantly higher than China's. EU's carbon price can be considered as an upper limit of carbon pricing due to the EU's strong thought leadership in climate policies.

Modelling was done with different carbon tax levels described in Table 3.1. In scenario 1.1 carbon emission price is set to be \$10/tonne in 2025 and doubling to \$20/tonne in 2030. Scenario 1.2 starts more rapidly setting the price to \$30/tonne already in 2025 with a modest increase to \$40/tonne in 2030. The high-scenario 1.3 starts with a price of \$50/tonne in 2025 and increase it to \$90/tonne in 2030 – that is the level in EU's ETS in December 2021. Predicting future prices is practically impossible as emerging technologies, political changes and public opinion might fluctuate the sense of urgency for decarbonisation. Some estimates on the optimal carbon tax and ETS price development have been used to base numbers used in these scenarios (e.g. Barragán-Beaud et al., 2018). However, running these different carbon tax scenarios help us to understand the effects of different tax levels on the overall system.

Table 3.2 Carbon tax scenario assumptions

	CO_2 tax (\$/tonne of CO_2)	
	2025	2030
Scenario 1.1 – Low	10	20
Scenario 1.2 – Medium	30	40
Scenario 1.3 – High	50	90

To estimate system costs in a way that is comparable to other scenarios, carbon taxes were considered to be income for the society. To address inefficiencies related to collecting and reallocating taxes, I have used an assumption that 80 % of the original tax amount levied can be returned to the system through public spending or tax reductions(Jha et al., 2000; Kowal and Przekota, 2021). The equation for the total cost (C_{Total}) for scenarios 1.1 – 1.3 is following:

$$C_{Total} = C_{Fuel} + C_{O\&M} + C_{Building} + 0.2 \times T_{Carbon}$$

Where C_x stands for fuel costs, $C_{O\&M}$ for operations and maintenance costs and $C_{Building}$ for annualised building costs. T_{Carbon} stands for the amount of carbon tax paid by companies.

2. Coal Quota Scenarios

The second policy scenario focuses on observing a situation where government restricts coal generation either through cap capacity or cap generation. Such a scenario could realize either through internal or external pressure to curb carbon emissions. As power plants and power generation are heavily regulated in Vietnam, the government can simply decide to stop permitting new coal capacity. In scenario 2.1 a constraint is set to stop coal capacity additions. International pressure or agreements could lead to a situation where building new capacity wouldn't be feasible anymore.

As mentioned in chapter 2.2, Vietnam is not self-sufficient in coal. The second coal quota scenario (2.2) limits the usage of coal in power generation so that only domestic coal is allowed. The constraint of the amount of energy produced is 812,465 TJ in 2025, and 879,136 TJ in 2030. Those numbers are estimates of coal production capacity provided by the Ministry of Industry and Trade (2020). Such a situation could happen if international agreements would seize coal imports or heavy carbon customs would be taken into use.

3. High construction cost for coal power scenario

The third policy scenario is about an increase in the construction cost of new coal power generation capacity. High construction cost scenario would be more likely to occur after market-based changes, not through national or international regulation.

Vietnam doesn't have coal power plant technology and capabilities to construct plants without the help of foreign companies. Recent headwinds for coal power may lead to a situation where some companies stop selling and delivering coal power plant technology. Decreased demand might decrease equilibrium price, but additional regulation and decreased competition could also lead to higher technology prices. Also, the development of technology could fluctuate from predicted leading lower efficiency development.

Another factor affecting construction costs is the cost of capital. Vietnam's energy system development depends on foreign investors (EREA & DEA, 2019). According to Polzin and Sanders (2020), the majority of energy system investments come from private companies: insurers, pension funds and climate bonds. Increasing opposition to coal power could lead to a situation where capital would be difficult to raise or would come with a higher price.

Scenario 3 assumes that the construction costs of coal power plants would increase 30 % by the figures defined in the base case scenario. The increase is applied to all different types of coal generation for each year predicted price.

4. Feed-in tariffs and renewables subvention

In the past two years, Vietnam has succeeded many-fold in its solar generation capacity ("Vietnam to cut rooftop solar feed-in tariff in bid to ease grid pressure | Reuters," 2021) and that is large because of the successful implementation of the feed-in tariff system. Feed-in tariffs are governmental guarantees to pay the differential between tariff-level and market price of electricity. Scenario 4 investigates what impact feed-in tariffs would play if they were to be continued. Two different levels are modelled: one which was used until 2021 (scenario 4.2), and one where tariffs are 50 % lower (scenario 4.1). The original levels of feed-in tariffs were 8.38 US cents/kilowatt hour (kWh) for rooftop solar power projects, 7.69 US cents/kWh for floating solar power projects and 7.09 US cents/kWh for the ground-mounted solar power project.

From the modelling point of view, feed-in tariffs are direct support to be paid for each unit of energy produced. Thus, the equation for approximating the total cost (C_{Total}) for scenarios 4.1 and 4.2 is following:

$$C_{Total} = C_{Fuel} + C_{O\&M} + C_{Building} + F_{Tariff}$$

Where C_x stands for fuel costs, $C_{O\&M}$ for operations and maintenance costs and $C_{Building}$ for annualised building costs. F_{Tariff} stands for the feed-in tariff paid by the government to an energy company to support renewables. Therefore, the total cost of feed-in tariff system is higher than the amount spent on constructing and operating energy system.

3.3 PLEXOS modelling

PLEXOS is a private energy market simulation software for large and complex energy systems, developed by Energy Exemplar. It is globally offered for private and public users for power market modelling and simulation. Primary use cases are planning capacity expansions, modelling and predicting energy prices, planning generation dispatch and predicting demand and dispatch of power plants or technologies on a plant-level or system-level. The first version of the software was published in 2000 and to date, they claim that by 1000 installations PLEXOS is the most widely used energy market software in the world – users include policymakers, regulators, operators, power generator companies, transmission system operator companies, manufacturer and construction companies, consultants, analysts and researchers ("About Us | Energy Exemplar," 2021).

The starting point of a PLEXOS model is accurate data on the current situation of the energy system. On top of that is built assumptions on the development of factors such as fuel prices, investment costs of new production capacity, carbon pricing etc. With the model, we can understand constraints in energy systems and understand the production mix of an optimal power system. The energy dispatch need is calculated with 10-minute slots for the wanted period and frequency. Then the system approximates net present values for each power plant and its production. For defining the value, the model can be seen having a *perfect foresight* – all costs and other inputs are known for the future. Based on that the model builds an optimal generation mix. It "builds" more generation capacity to fulfil all forecasted energy demand assuming the cost of generation is less than the cost of unserved energy. Function logic of PLEXOS modelling in this thesis is described in Figure 3.1.

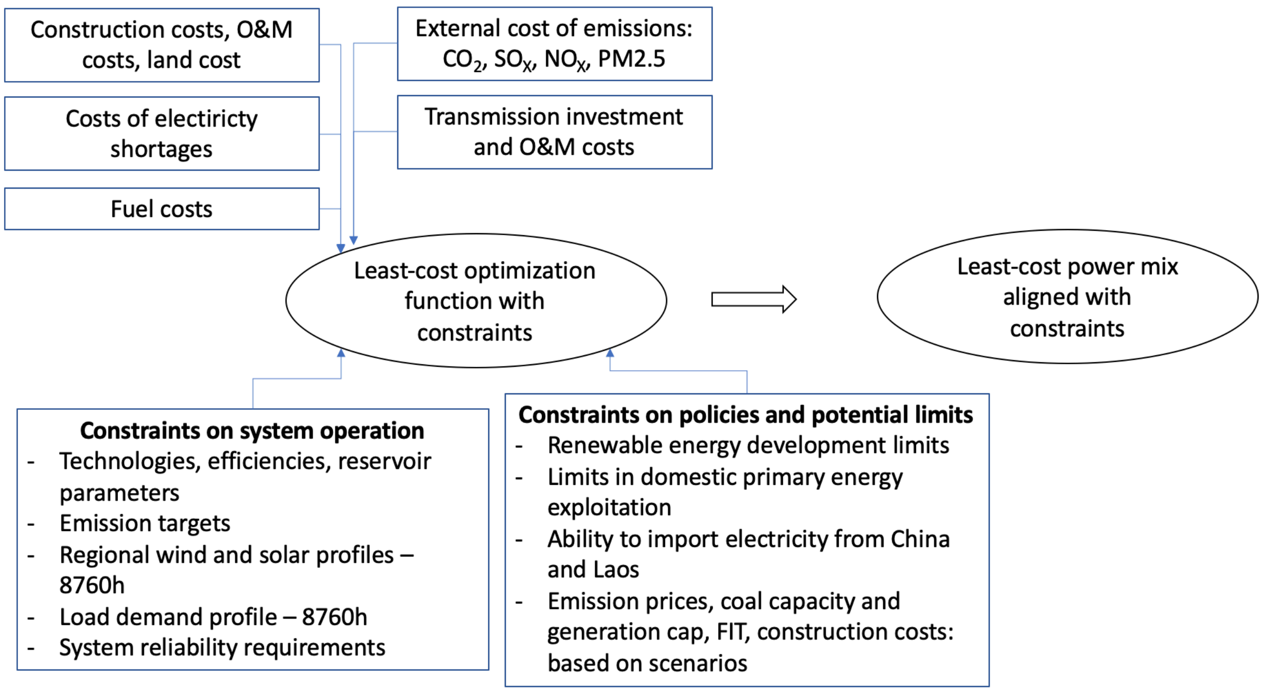

Figure 3.1 PLEXOS modelling approach

The system estimates the optimal capacity expansion for the power system to fulfil future electricity demand. The optimisation is done within given constraints and assumptions such as technology and fuel prices, political decisions and others. The optimal energy system is defined by the lowest total cost over the studied period. Total costs are calculated from three different elements. They include capital expenditures, fixed operations and maintenance costs and operations costs.

The software chooses from multiple technologies. Input parameters for those are provided by the Ministry of Industry and Trade and the Danish Energy Agency. The selection of technologies is based on detailed information e.g. data of heat rates, start-up costs and times, duration and costs of forced outages etc. are included. The flexibility of different generation assets is based on characteristics of technologies and solar, wind and rainfall predictions with 1-hour resolution. The prediction is based on real measurements from Vietnam and predictions used by the Ministry of Industry and Trade. Understanding both seasonal and intra-daily variation is a prerequisite for a reliable energy system.

Some system-level constraints are built into the model. Vietnam is modelled through three regions with interconnectors between them. Transmission lines to neighbouring China and Laos are also modelled. However, interconnector capacity is constrained according to assumptions on potential provided by the Ministry of Industry and Trade. Also, system reserves are included to accommodate balancing needs due to the volatility of renewables.

Energy system modelling is done for three periods: years 2021, 2025 and 2030. Even though only three periods are observed, PLEXOS has considered the cost of capital (with 10 % discount factor), construction times and requirements for each year individually between years 2021 and 2030. For example, if energy demand in the year 2028 would be higher than in 2030, the software builds extra capacity for the year 2028 even if it wouldn't be needed anymore in 2030.

After each scenario is modelled, main outputs were collected to Excel where graphs and analysis is conducted. The used PLEXOS version will be 8.2. Major output elements are economically optimal simulation on energy production mix: needed generation capacity and electricity generation per asset type, fixed and variable costs, construction costs and CO_2 intensity.

Benefits of PLEXOS modelling

PLEXOS models, or private and non-transparent tools overall, are not the most typical tool for economic analysis, but there are several reasons why it brings additional value to topics under scrutiny. First, it helps us define the optimal generation mix with high accuracy. Second, with simple regression models, we could be able to understand the cheapest energy sources, but PLEXOS offers an additional layer bringing understanding of the need for flexibility in the energy system. It can calculate the needed total capacity based on hourly generation estimates of each power plant. Third, it gives a deep level of details in energy system modelling including start-up times and variable costs related to each technology.

4. Results

In this chapter introduces decarbonisation policies under scrutiny from different angles. Energy system composition, carbon emission development and total costs of energy systems are described for each scenario in their own chapters.

4.1 Generation capacity

Generation capacity increases to address increased power demand. As power demand is expected to over double by 2030 a lot of new capacity will be needed. Figure 4.1 describes the base case energy production mix. The growth is mainly addressed through increased coal capacity that grows from 22 GW to 47 GW by 2030. A slight increase is visible also in gas turbines, solar and hydro generation. Over half of energy demand in 2030 would be produced using coal in the base case.

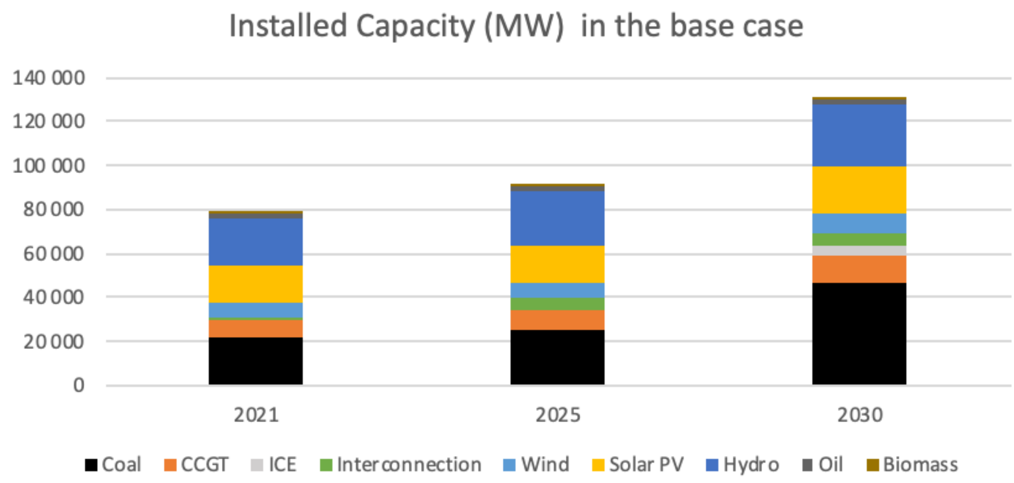

Figure 4.1 Capacity development 2021-2030 in the base case

The total system capacity varies between base case's 92 GW and 131 GW in 2025 and 2030 respectively, to high feed-in tariff scenario's 134 GW and 228 GW (Fig. 4.2). The relative increase happens mostly after 2025. In high FIT scenario (4.2) capacity increases by 50 GW already by 2025 but the majority of additions still happen after 2025. The biggest energy system capacities in 2030 are in scenarios 1.3 Carbon tax – High and 4.2. high FIT. Coal usage or capacity cap (scenarios 2.1 and 2.2) and increase of construction costs for coal (scenario 3) seem to lead to only a slight increase in system total capacity.

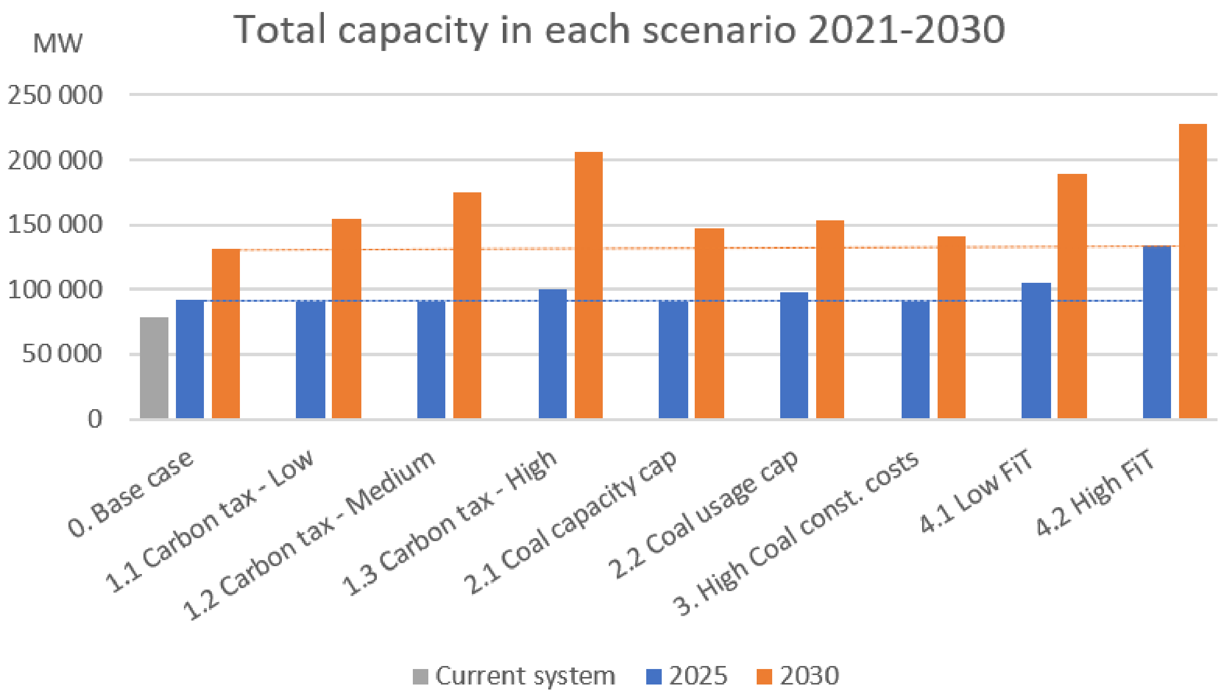

Figure 4.2 Total system capacity in different scenarios. The Blue dotted line shows the year 2025 capacity level, and the orange line year 2030 capacity level in the base case. Interconnection, oil and biomass have been removed from the figure as their relative share is little and changes between scenarios are very small.

The biggest differences in energy mix between scenarios are in the capacity of renewables. Figure 4.3 shows capacity growth per generation type. Solar photovoltaic capacity has the biggest variation between scenarios. Wind power grows significantly to almost 40 GW in high taxation scenario (1.2) and feed-in tariff scenarios (4.1 and 4.2) versus 20 GW in the base case. Coal generation is also much lower in all scenarios compared to the base case, but decreased coal needs to be replaced by volatile renewables and gas turbines or engines that bring stability to the system. Some system constraints limit capacity additions of renewable, especially hydropower. All scenarios have the maximum amount of hydro in both periods allowed by the constraints. Also, interconnection capacity is capped by constraints given by Vietnamese officials.

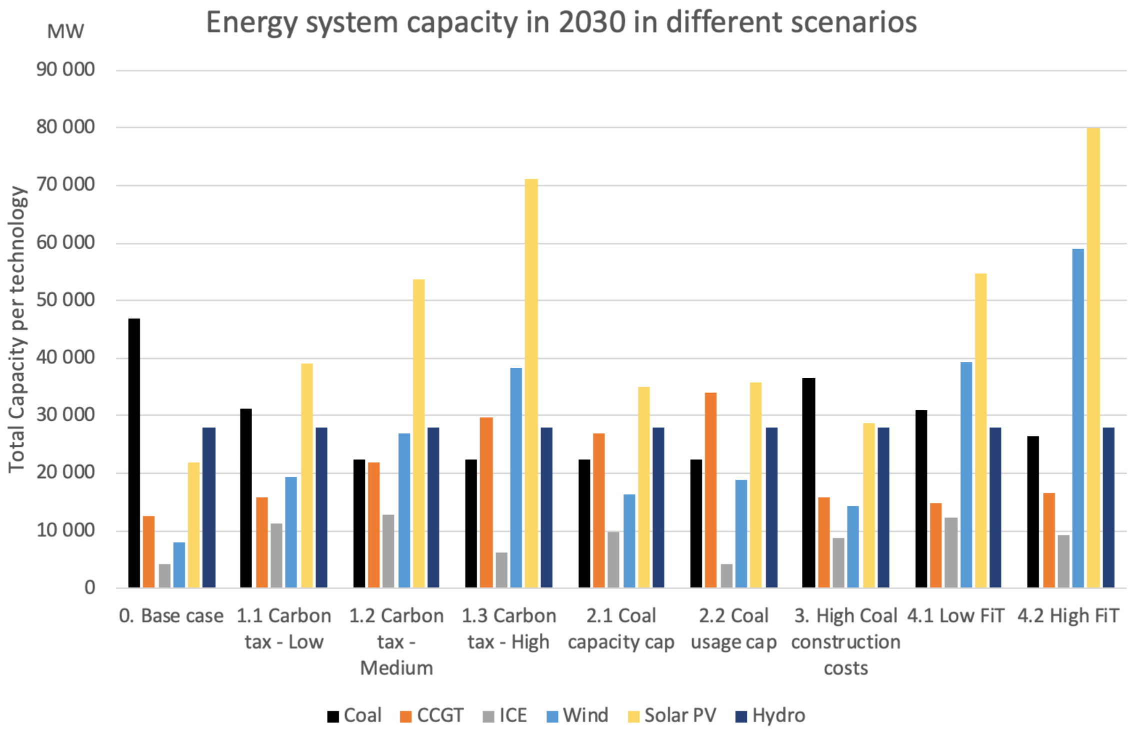

Figure 4.3 Generation mix in 2030 in different scenarios

Generation capacity is an enabler for actual production. PLEXOS model keeps the existing power plants in the system even though their running hours would be extremely low. Therefore, it is important to review how the energy is produced, not just the generation capacity available. Figure 4.4 describes power generation in each scenario by most relevant generation types. Generation types that have under 5 % share of total production for excluded from Figure 4.4. Those were interconnection, combustion engines, oil, and biomass.

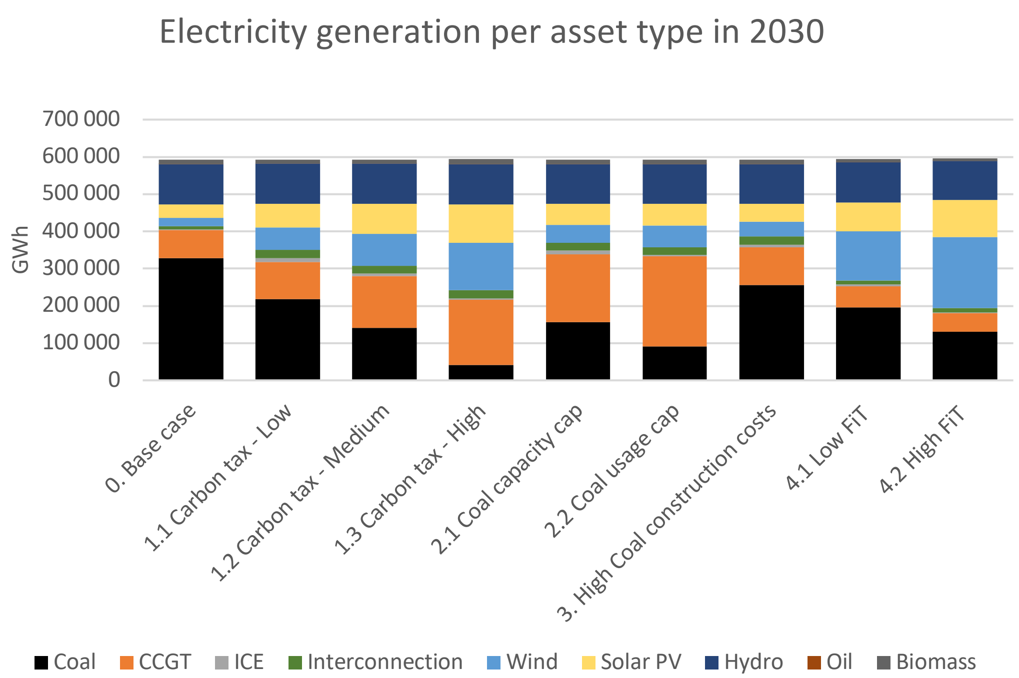

Figure 4.4 Generation by source in 2030

Modelling results show that coal generation in the base case is almost 330 TWh, and over 20 % lower in all other scenarios. Gas turbines become the biggest generation type if coal usage or generation is capped, or when high carbon taxes are in place. The wind was the biggest energy source in scenario 4.2 where renewables are highly compensated. All policy actions also diversify the energy generation mix so that it is not that dependent on a single source of energy, namely coal.

Capacity additions of major generation assets for each scenario and the share of coal in power generation is described in Table 4.1. It shows that all policy actions decrease coal drastically. The strongest effect is in scenario 1.3 where a high carbon tax is taken into use – that would lead to only a 7 % share for coal generation. Also moving to use only domestic coal (scenario 2.2) would decrease coal's share from base case's 56 % to 15 %. An increase in coal power construction costs will decrease the usage of coal by only 13 percentage points compared to the base case: as construction and capital costs are already embodied in the existing capacity, the change won't be as strong for electricity generation as it is for generation capacity.

Table 4.1 Cumulative capacity additions by 2030 and share of coal. Colour coding indicates the relative capacity addition of each technology compared to other scenarios. Darker colour equals higher increase.

		Cumulative capacity additions (GW) relative to 2021					Share of coal in generation (GWh)
		Coal	CCGT	ICE	Wind	Solar PV	
0.	Base Case	25	6	4	2	5	56 %
1.1.	Carbon tax – Low	9	9	11	13	22	37 %
1.2.	Carbon tax – Med	0	15	13	21	37	24 %
1.3.	Carbon tax – High	0	23	6	32	54	7 %
2.1.	Coal capacity cap	0	20	10	10	18	26 %
2.2.	Coal usage cap	0	27	4	13	19	15 %
3.	High coal constr.	14	9	9	8	12	43 %
4.1.	Low FIT	9	8	12	33	38	33 %
4.2.	High FIT	4	10	9	53	63	22 %

The table above (4.1) describes also how gas turbines are increased by large quantities in scenarios where there is no subvention mechanism for renewables. Similarly, wind and solar are increasing heavily in feed-in tariff scenarios and when a high carbon tax is implemented. When the share of coal generation decreases and renewables increase additional sources of flexibility are needed. Internal combustion engines (ICEs) are thus needed to balance the energy system. Their usage is estimated to increase more than in the base case in all other scenarios than scenario 2.2 where coal usage is capped.

4.2 Carbon emission development

All scenarios decreased the carbon emissions of Vietnam's energy system. As Figure 4.5 describes, emission development is relatively stable across scenarios to 2025 and widens between 2025 and 2030. The base case system that relied heavily on coal production yielded almost 350 Mt of CO_2 emissions per year in 2030. The lowest emitting high carbon tax scenario (scenario 1.3) ends up with 113 Mt of CO_2 emissions in 2030. However, high feed-in tariffs (scenario 4.2) enable even lower emissions in short term. In 2025 it yields over 10 Mt lower emissions than a high carbon tax. That is caused by the fast penetration of renewables in the feed-in tariff scenario compared to the higher dependency of gas turbines in the carbon tax scenario.

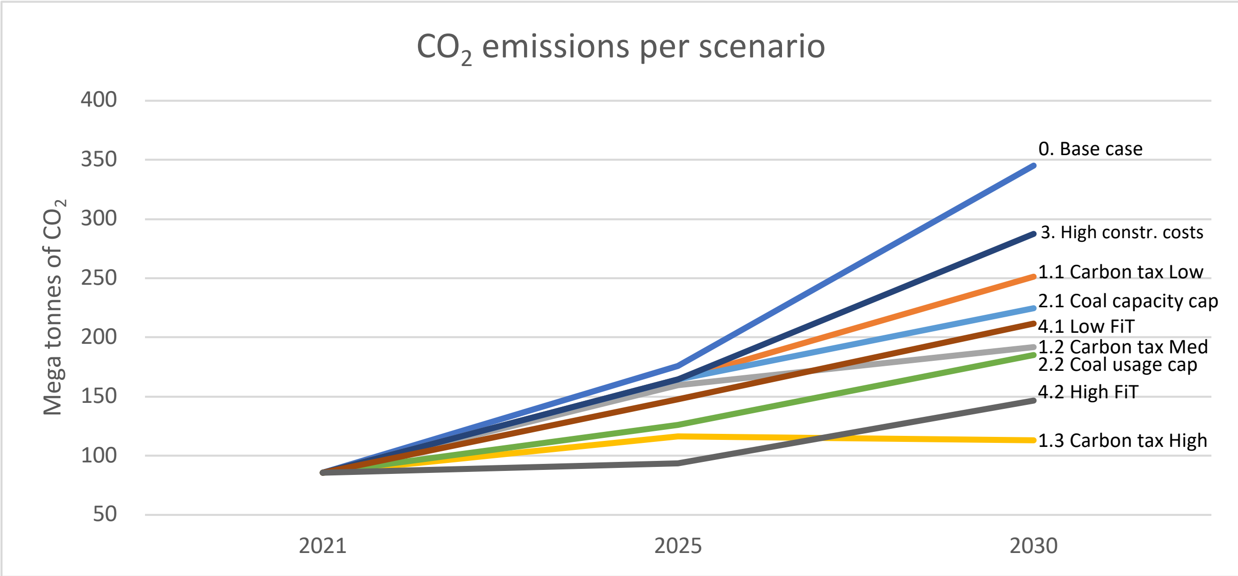

Figure 4.5 Emission development 2021-2030

Even if the share of renewables (including hydro) increases to 67 % and 59 %, the absolute emissions increase over 71 % and 31 % in high FIT and high carbon tax scenarios respectively compared to today's emissions. And much more in all other scenarios.

Results show that the amount of carbon tax leads to big changes in emissions. The difference in emissions between low and medium tax in 2025 (10 and 30 $/tonne in 2025, 20 and 40 $/tonne in 2030) led to a difference of only 4 Mt of carbon emissions in 2025 even though the medium tax level is double the low tax. However, in the longer term, the impact of the tax increases heavily leading to an emission difference of 60 Mt in 2030 when tax is changed from 30 $/tonne to 40 $/tonne.

Similar to the generation mix composition, higher construction costs lead to moderate emission savings (287 Mt vs. 345 Mt in a base case in 2030). The coal generation cap reduces emissions far more (approx. 40 Mt) than just limiting the increase of generation capacity.

4.3 Energy system total costs

Changes in energy system total costs compared to the base case are described in Figure 4.6. Costs in the figure are yearly and include fuel costs, variable and fixed operations and maintenance costs, and annualised building costs.

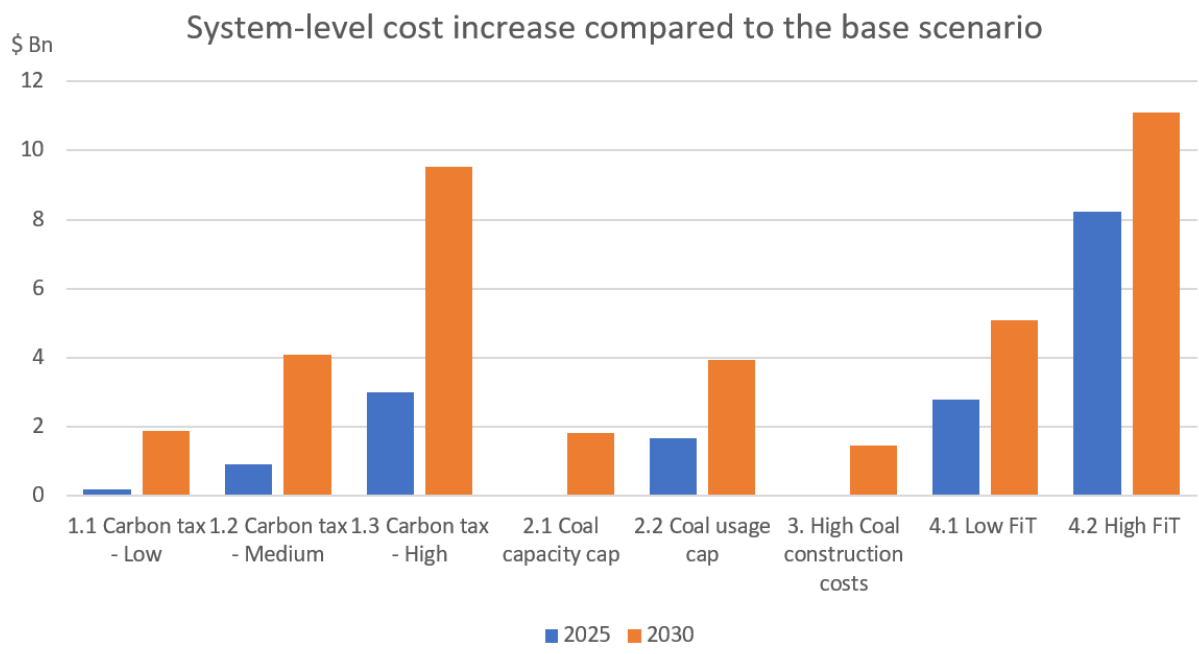

Figure 4.6 System-level cost increase compared to the base case

The most expensive energy systems are those with the lowest CO_2 emissions and highest capacity. A high feed-in tariff system would cost over 8 billion dollars in 2025 and 11 billion dollars in 2030 more than the base case annually. Base case scenario yearly costs are $17bn in 2025 and $36bn in 2030. The cost increase in scenarios 2.1, 2.2 and 3. arises mostly from increased fuel costs and building costs. Especially with scenarios 2.1 and 3. the system cost won't increase at all by 2025 and after that the increase is modest. In scenario 2.2 where coal usage is capped, fuel costs and building costs increase moderately when more expensive gas is used as the main fuel and more gas turbines are built. Carbon tax scenarios and feed-in tariff scenarios require significantly less money for fuel costs and variable operations and maintenance costs, but capital costs to address increased generation capacity needs are significant.

In carbon tax scenarios the tax amount is considered as income for the government, and 80 % of the tax amount is then reduced from the total costs. That is based on assumption that part of the tax is spent for collecting it and other inefficiencies. In feed-in tariff scenarios, the amount of tariff is added on top of yearly costs representing the total cost of the energy system for the country.

4.4 Cost optimal decarbonisation policies

Based on PLEXOS modelling there are several efficient decarbonisation policies that Vietnam could pursue. Figure 4.7 shows the emission saving potential and cost addition compared to the base case in the year 2030. Policy actions that have the biggest impact on emissions are also the most expensive, and vice versa, actions with the lowest cost-saving potential are increasing costs the least. On average in all scenarios saving one tonne of CO_2 per year costs $61.6 in 2025 and $33.9 in 2030.

These results show some scenarios to be more efficient than others. With scenarios with lower emission saving potential (<125 Mt/year), the coal capacity cap scenario (2.1) yields the best outcome with the highest emission reduction with a similar cost structure compared to scenarios 1.1 and 3. Feed-in tariffs seem to be sub-optimal as there are scenarios where total costs are lower but emission saving potential higher. Scenario 2.2 where coal usage is capped to only domestic coal has around $4 billion higher costs per year, but yearly emission savings are over 150 Mt in 2030 compared to the base case. High carbon tax and high feed-in tariff scenarios are by far the most expensive ones even though emission reduction is the biggest. Compared to the coal usage cap scenario (2.2), the cost increase in those is $5.5-$7 billion, and that money saves 40-70 Mt of CO_2. Thus, the theoretical marginal cost of emission reductions for quantities above 160 Mt (moving from the scenario 2.2 to scenarios 1.3 and 4.2) is around $80/tonne.

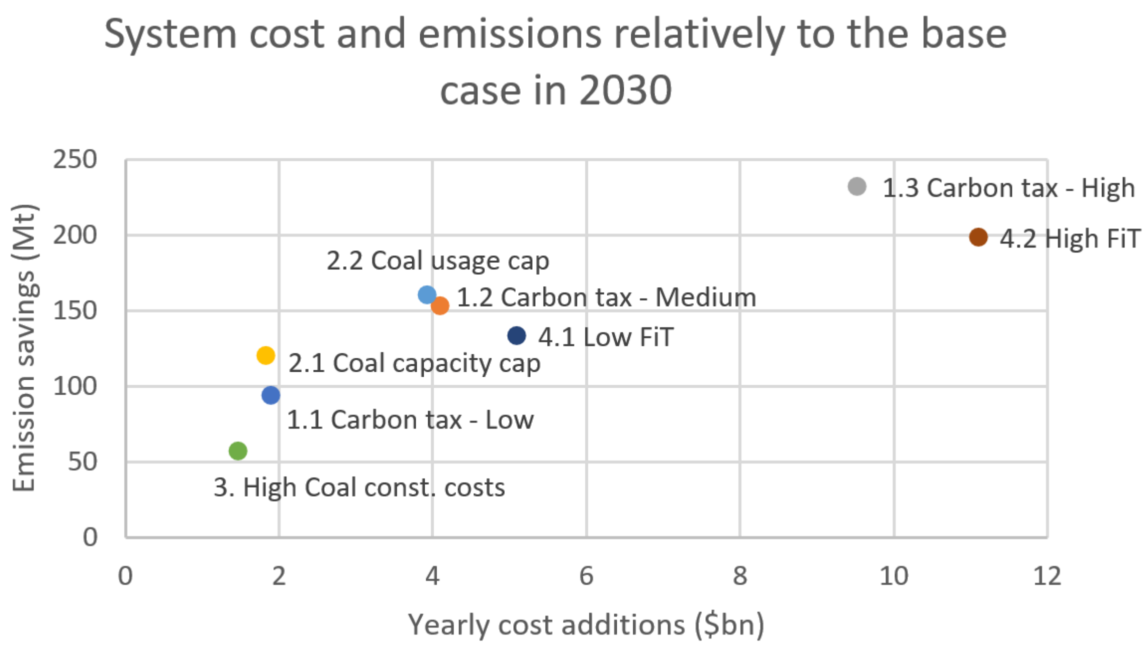

Figure 4.7 Relationship of emission savings and system cost in different scenarios in 2030

One interesting observation is how emission saving and cost in each mechanism develops at a different pace. In 2025 only policies yielding over 30 Mt emission savings are coal usage cap (~50

Mt), high carbon tax (~60 Mt) and high FIT (~80 Mt) yield over 50 Mt emission savings. Emission reductions of other policies are relatively small. Cost of emission reduction per tonne in each scenario is presented in the figure 4.8. Results are similar compared to those where quantities of cost reductions are included. Both feed-in tariff scenarios have relatively high cost per avoided tonne of carbon dioxide – especially in 2025. Those scenarios, together with high carbon tax (scenario 1.3), have highest capacity addition of renewables in the short term. As renewable energy generation has very low operations and maintenance cost, the majority of costs are allocated to the building phase. Therefore, some of scenarios have higher costs for year 2025 compared to year 2030 (figure 4.8).

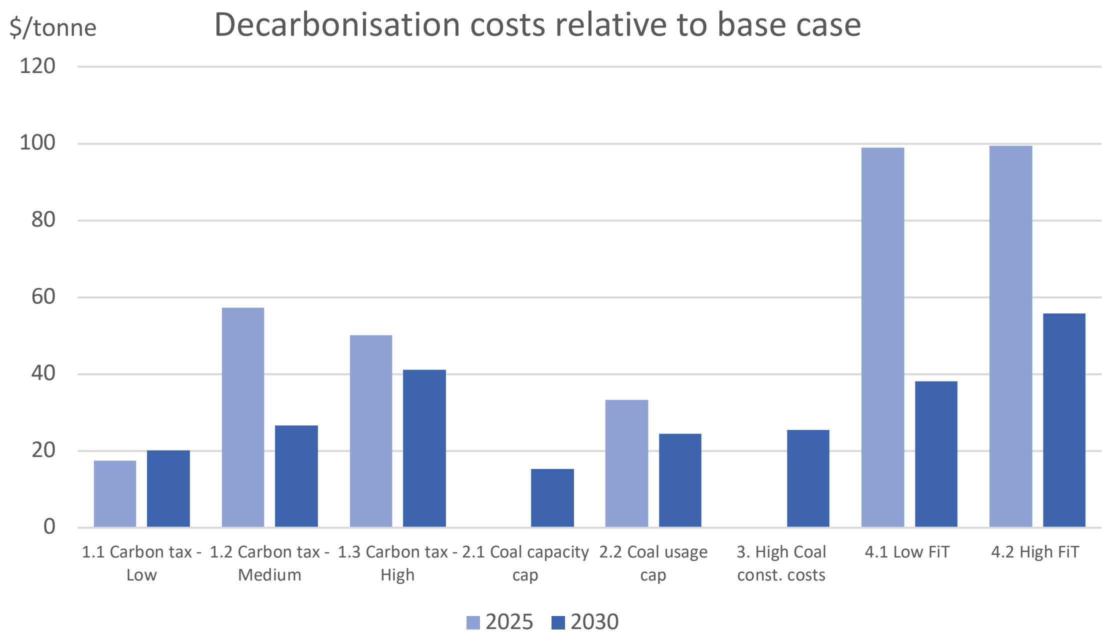

Figure 4.8 Decarbonisation costs of each scenarios relative to the base case in years 2025 and 2030

5. Discussion

The results were somewhat expected in the sense that the bigger emission savings are more expensive to achieve. All policy actions in each scenario decrease coal production remarkably. However, some policy actions seemed to be more efficient than others. Limiting coal generation capacity (scenario 2.1) or usage (scenario 2.2) seem to be relatively most efficient when the observation period is in 2030. Feed-in tariff scenarios (4.1 and 4.2) seem to be less efficient compared to other options. However, if a conservative estimate for the social cost of carbon, $30 / tonne, by OECD (OECD, 2016) is used, all scenarios but high carbon tax and both feed-in tariff scenarios seem to be economically feasible. Achieved benefits would outweigh needed investments. The comparison doesn't include savings from other emissions (e.g. NO_X, SO_2 and CO) and employment effects which would increase the benefits even more.

All policy actions diversify the energy generation mix compared to the base case. A diverse energy mix can reduce risks related to fuel price development and thus lead to more predictable energy production costs in the future. However, this comes with a cost. Additional investments are needed to add the total capacity and the share of renewables in the system to make sure peak demand can be served even if wind and solar generation are low. In competitive energy markets, this could lead to an increase in price volatility. In Vietnam's price-regulated system such events should then be addressed in advance.

5.1 Implementation environment for each policy action

On top of the efficiency of each policy action, other factors need to be considered as well. Implementing policy actions require will and political capital from regulators and politicians (Aklin and Urpelainen, 2013). International politics and trade can also play a role when national policy actions are selected.

Carbon tax or emission trading systems

Carbon tax or emission trading system implementation can be seen as purely fiscal policy action but has also a political dimension. Implementation of a carbon tax could lead to opposition and turn public opinion against the ruling government. A carbon tax should be implemented in phases so that the industry would have time to adapt to increasing power prices. Implementation could be easier if international consensus could be reached and multiple countries would adopt a similar system at the same time. A single country could be hesitant to implement higher taxes than its neighbours to avoid a decrease in local industries' competitiveness.

Some studies (e.g. OECD, 2016) suggest that a market-based approach (like emission trading) would be more efficient for carbon pricing. However, implementing such a system and enabling a competitive and well-functioning ETS system can be more difficult compared to carbon taxing.

European Union and China have their emission trading system that channels emission reduction to industries where the abatement is the easiest. Adoption of the existing ETS system could be faster and help to avoid structural errors. On the other hand, joining an existing ETS could decrease national control of the legislation and be a real option for only united countries.

Coal capacity and generation caps

Capping new coal capacity or limiting the generation to domestic coal only might require political capital as it might be seen as a forced price increase. Even though the cost implication for the total energy system is relatively limited (5-10 % increase compared to the base case) options where increased costs are targeted for the biggest polluters (like a carbon tax) might be considered more legitimate. Of course, external pressure to halt international coal trade (or sales of coal power plants) would lead similar outcome without political actions from Vietnam, but such restrictions are unlikely to happen by 2030.

Implementation of a coal generation cap would be simple as Vietnam's government already now permits all new power plants. Capping coal usage could also be possible if it would be done before additional coal capacity would be built. Giving a strong message of limiting coal usage would scrap any new coal capacity additions and force national power companies to invest in cleaner technologies. However, coal is not imported only for power generation purposes. Even though most power companies are state-owned, it could be difficult to supervise coal usage cap.

Before implementing such regulation, Vietnam should make sure planned new capacity would satisfy the increasing demand. Some flexible power sources will also be supported as modelling shows. Gas turbine and internal combustion engine capacity would over double compared to the base case by 2030. Natural gas infrastructure should be developed and imports increased as the usage and fuel consumption would manifold. In the base case gas capacity (turbines and engines together) is 16.7 GW, in scenario 2.1 it is 36.7 GW and scenario 2.2 38.4 GW.

Construction costs

The high construction cost scenario was the cheapest policy action in the long term, but also yielded the lowest emission reductions. An increase in construction costs could be channelled either through external reasons or internal decisions. An example of external reason could be cost increases related to increased cost for capital or reduced competition when less coal generation is built globally. Also, the decline in new coal generation could lead to lowering economies of scale. The actions of other countries might affect construction costs and this is something that Vietnam could decide alone. Also, Vietnam is quite dependent on direct foreign investments and funding from organizations such as IMF and World Bank. If international funding for new coal capacity would stop, Vietnam might not afford to build coal power with its domestic capital resources.

Internal action leading to increased construction costs could be done through energy taxing for coal power. However, here lies a similar problem than in all other actions: can a single country afford doing a decision of this kind in a situation where electricity demand grows almost two-digit pace?

Feed-in tariffs

In the short term (until 2025) FITs turned out to be the fastest way to have fast emission reductions. Implementation of feed-in tariffs should be quite straightforward and fast. Vietnam has already experienced tariffs and practicalities are in place. Even though money for the FiT system is collected from taxpayers, a FIT system might be easier to justify compared to additional taxing. However, the main question for implementation is if the government is willing to support renewables through feed-in tariffs in the long term and are FITs seen most efficient option to increase renewables. This is related to the critique that FITs adapt to market changes and price signals too slowly. Some scholars argue that e.g. tradable green certificates, proofs that show that electricity is produced from renewable sources, yield a better outcome (Ciarreta et al., 2017). Different ways to implement should be considered as Kim and Lee (2012) propose and that is presented in chapter 2.1.

One reason for the relatively low efficiency of feed-in tariffs could be the way how total costs were defined. Funds for feed-in tariffs are partly gathered from consumers or energy producers through taxes and increased prices. Thus, the full amount of feed-in tariffs is not paid from the public sector as the research setting was showing. Depending on the price elasticity, the total energy demand could be lower in the system where electricity price would be addressed. Then less extra capacity would be needed, feed-in tariff spend would be lower and emissions would decrease more compared to the base case.

5.2 Long way for net-zero emissions in the high-growth countries

Selected policy mechanisms are not enough to reduce absolute emissions in the short term. That indicates that reaching net-zero with the existing technology mix would require very much funding. The high FIT scenario that yielded the highest emission reduction results cost over $11 billion more in the year 2030 compared to the base case scenario. Vietnam's GDP in 2020 was $271 billion, so an additional cost increase on top of base case's costs in 2030 ($36 billion) would be a big burden for Vietnam's economy.

Energy system's costs are increasing manifold in any case as energy demand is expected to grow from 2021 270 TWh to 590 TWh in 2030. Each additional decarbonisation policy is expected to increase power system costs even more. According to Vietnam's power development plan for the period 2021-2030 that is conducted by the Ministry of Energy and Trade, investments for new electricity generation capacity will be around $95.4 billion. Results from this work's modelling indicate that the base case annualised building costs would be ~$1 bn in 2025, and ~$7 bn in 2030. However, the lifecycle of a new coal plant can last 20-30 years, and thus the actual investment needs are much higher as the model annualises construction costs for the whole lifecycle. Ballpark of official forecasts and results of this work is the same.

In some scenarios, annualised building costs are much higher than in the base case. In the high FIT scenario (4.2) annualised building costs in 2030 were over $26 bn. This indicates that such a scenario would require much higher funding needs than Vietnam is currently prepared for. In other scenarios annualised construction costs varied between $19 billion (high carbon tax scenario) and ~ $8 billion (coal capacity cap scenario).

In Vietnam's current NDC (2020) it has pledged to reduce emissions by 9-27 % by 2030 compared to business as usual scenario (928 Mt of CO_{2eq}). The energy sector, which is expected to emit 678 Mt in 2030, is estimated to reduce its emissions by 51.5 Mt domestically, and up to 155.8 Mt with international help compared to the BAU scenario from the NDC.

However, comparing these figures to the results of this research is challenging. Vietnam's NDC defined the energy sector to include also emissions from industrial processes, transportation and household appliances, agriculture and commercial services. If we assume that electricity and power generation address 50 % of the energy sector's emissions, the BAU scenario defined in the NDC would be 339 Mt in 2030. Results from the PLEXOS modelling base case is 345 Mt – well aligned with the NDC. Nationally determined contributions guide yearly emissions in 2030 to be between 250 and 310 Mt of CO_{2eq} per year. All scenarios of this work are aligned with the higher boundary. Furthermore, all scenarios but 1.1 Low carbon tax (251 Mt) and 3. High construction costs (287 Mt) are aligned also with the lower boundary of the NDC even if energy efficiency improvements for existing generation capacity are not addressed.

Carbon intensity in Vietnam scenarios in 2030 varied between 246 g/kWh in a high Feed-in tariff scenario (4.2) to 583 g/kWh in the base case. According to the OECD study *Cost of decarbonisation*

(2019), developed countries should reduce their carbon intensity from today's average 430 g/kWh to only 50 g/kWh by 2050 to reach the 2 °C global warming goal. Results from these scenarios are still far from such numbers. To reach its goal of net-zero society by 2050, new carbon-neutral technologies such as hydrogen and synthetic fuels need to be considered. Also, carbon-negative technologies like carbon capture and storage will likely be needed to reach full carbon neutrality.

5.3 Relationship to other studies

Previous research as well as Vietnam's own PLEXOS modelling for PDP-8 have similar results. EREA and DEA (2019, p. 7) suggested that "*departing from new coal investments and increasing the consumption of LNG can save 53 million tonnes of CO_2 in 2030, while the total system costs increase by approximately 1 billion USD.*" The results of this thesis are aligned with the statement. Stopping new coal capacity additions after 2021 would save over 100 million tonnes of CO_2 and cost approximately $2 billion more than the base case scenario. The difference might arise fast halt of new coal production of this work, while in reality there are ongoing projects that are going to be finished in few coming years.

Other forecasts show a similar direction. USAID (2020) suggests a heavy increase in renewable generation capacity. Wind power would be the preferred type of renewable generation, but they predict solar additions will exceed wind due to its lower financing costs. EREA and DEA (2019) suggest wind capacity additions of ~1GW / year and 1-2 GW/year for solar from 2021 to 2030. Results of this study are very similar, but in some scenarios, estimates of the increase of solar and wind are even bigger. Also, both EREA & DEA and USAID conclude that expansion of renewables needs to be coupled with sources of flexibility, such as internal combustion engines.

EREA and DEA (2019) suggest taxation and limiting new coal-based power generation for policies accelerating decarbonisation. Also, the removal of market barriers in electricity and power generation markets is identified to be an important enabler for balancing the energy grid. EREA and DEA also highlight the urgency of actions. Coal plants built today will be operating decades from now. Due to the path dependency of energy systems, it should be a priority to develop them coherently towards a favourable state in the long term.

Some differences apply in the results of this thesis compared to previous studies. The key difference between this thesis and many other studies was that sensitivity of fuel prices and different technology key metrics was not done. Even though fuel price and technology cost estimates are based on the best available information, some unexpected variation is likely. Also, USAID (2019) modelling showed that lowering the cost of renewable energy sources can reduce overall system costs. In this work and under given assumptions such applies only in 2025 for low and medium carbon tax scenarios if we assume that the amount of tax is fully returned to the system. Total system costs decrease also if the money spent for feed-in tariffs is not taken into account.

Also, this thesis lacked some potential technologies included in other studies. Nuclear generation and battery energy storage were excluded from this research due to Vietnamese officials' insights that it won't be feasible before the year 2030 (Vietnam Institute of Energy, 2020a). However, USAID (2020) report suggests that nuclear energy generation will be built when CO_2 prices exceed $30/tonne.

5.4 Limitations and further research

Modelling different scenarios help us to understand alternative futures. Due to the lack of modelling capacity and wide scope of the study, policy actions were explored ceteris paribus only through a single or few standalone scenarios. More detailed sensitivity modelling should be conducted for carbon tax level, feed-in tariff amount and construction cost increase to get a better insight on their impact on decarbonisation cost and pace. This also excluded potential combined effects if several policy actions are to be implemented at the same time. Also, sensitivity to different fuel prices and technology costs should be observed in each scenario to get a more thorough understanding of which environment they would work the best.

The excess burden of taxation and increased electricity price were not addressed. It was assumed that the power demand is fixed and won't be affected if additional taxes, subventions or regulations are introduced. Thus, scenarios, where regulation would increase electricity prices, were not optimally modelled from an economic point of view. The deadweight loss was then not included for any of the scenarios.

As this study focused on quantitative modelling, an interesting research path related to power market competitiveness remained untouched. Vietnam states in its NDC that it pursues to "*improve the financial mechanisms and mobilise capital for investments in developing the power sector; accelerate the roadmap for implementing a competitive electricity market*" (The Socialist Republic of Viet Nam, 2020, p. 28). It would be interesting to understand how altering from current fixed and pre-determined electricity pricing would affect the total cost of Vietnam's energy system or if auctions would be utilised in capacity addition development.

Some potential policy mechanisms remained also unobserved. Green bonds, energy efficiency improvements and other mechanisms that are used in some countries could offer the potential to reduce emissions with competitive costs. Also, the research did not address electricity price or elasticity of the demand. From an economics point of view, it would be a good further research topic to understand how each policy would impact the electricity markets and deadweight loss caused by increased regulation. Furthermore, how efficiently power markets work in Vietnam under a socialistic regime and if improving market dynamics could lead more efficient power system.

6. Conclusions

Research *summary*

This research was conducted as a PLEXOS modelling study. On top of the base case scenario, four different policy mechanisms were modelled focusing on the power system's emissions and total costs in Vietnam in the years 2021, 2025 and 2030. Main input parameters and assumptions can be found in appendix 1.

Practical implications

Decreasing emissions of rapidly growing economies (like Vietnam) in the short-term doesn't seem feasible with policy actions under scrutiny. PLEXOS modelling done for this research showed that even a very high tax on carbon emissions or generous support for renewable energy sources won't be enough to achieve carbon-neutral growth of the energy system in Vietnam. Also, the marginal cost of emission reductions (compared to the base case) beyond 150 Mt a year seems to be quite high for developing country: around $80 per tonne. Reaching net-zero emissions would require much stronger regulation, a lot of capital and new affordable carbon-negative technologies like CCS.

Secondly, based on modelling results, the economically best option for decarbonisation seems to be halting new coal capacity additions for its current level (~22GW), capping coal usage for domestic coal only (~90GWh / year) and setting low carbon tax for emissions (10 $/tonne in 2025 and 20 $/tonne in 2030). These actions would decrease carbon dioxide emissions respectively by 120 Mt, 160 Mt and 94 Mt in 2030. Table 6.1 describes the emission saving potential of scenarios above compared to the business-as-usual scenarios from Vietnam's nationally distributed contribution, and to the base case scenario from PLEXOS modelling. The cost of decreasing one tonne of CO2 using those three policies would be $15-25 in 2030.

Table 6.1 Emissions and emission reductions compared to BAU for the energy sector and base case, and total system cost in 2030.

	CO_2 emissions	CO_2 emission reduction		Annual cost	Abatement cost relative to base case
		Relative to BAU	Relative to Base case		
BAU	339 Mt	-		-	

0. Base case	345 Mt	2 %	-	$36bn	
1.1 Carbon tax – Low	251 Mt	-26 %	-27 %	$38bn	$20/tonne
2.1 Coal capacity cap	225 Mt	-34 %	-35 %	$38bn	$15/tonne
2.2 Coal usage cap	185 Mt	-45 %	-46 %	$40bn	$25/tonne

The third conclusion of the research is that achieving 100 Mt of yearly emission savings requires additional yearly investments of at least $2bn per year in 2030 compared to the base case (Table 6.1). Vietnam's GDP in 2030 will be over $530bn if 7 % annual growth is expected.

Different policies reduce coal generation and capacity. But to replace coal that provides stable baseload, total peak capacity grows inevitably. The current level of CO_2 emission externalities in Vietnam's energy system planning work is not supporting additions of renewables even though the country pursues to be carbon neutral by 2050. Vietnam should ways to encourage foreign investors, and for that, electricity prices must be profitable.

Policy implications

Policymakers face a challenging situation where on the other hand decreasing electricity market regulation would enable investments in the energy system, but more regulation is needed to accelerate decarbonisation and additions of renewable energy sources. The development of an energy system should be done holistically to make sure that system reliability is maintained even if the capacity of volatile renewable generation assets increases. Results of this thesis show comparison of different policy actions helping decision-makers to understand how each policy could affect the cost and emission levels of Vietnam's energy system. Furthermore, results could be used to understand the optimal energy production mix under certain circumstances and tune expectations of investment needs to the right levels.

Supported by the findings from studies by USAID (2020) and EREA & DEA (2019), this thesis highlights the need to act rapidly. First, coal generation capacity could be reduced cost-efficiently through halting permitting new coal plants and restricting coal usage in Vietnam's energy system. Secondly, regulations or policies to support renewable energy sources are needed to reduce the dependency on coal capacity. Gas power should be made more competitive against coal to help secure system reliability and balance in an energy system where renewables have a bigger share. Thirdly, the role of funding is highlighted during the energy transition. Securing funds from foreign investors and collaborating technology providers could be helpful to accelerate the penetration of renewable energy sources into the energy mix. Vietnam is also likely to need financing support to enable the transition to lower carbon intensity. This would also reduce dependency on coal generation that possess a significant environmental risk. Fourthly, achieving the intended coal phase-out by 2040 is challenging and requires strong policies not just to support renewable energy generation but also to curb coal usage.

Decarbonisation policies and their economic impact don’t occur in a vacuum. OECD (2016) highlights some positive benefits and interactions that decarbonisation can push forward. Such are e.g. levying carbon taxes and using capital to lower other taxes might lead to more positive employment and productivity effects.

One concern related to the implementation of decarbonisation policies is adverse equity impact: decarbonisation actions might increase electricity prices which hit hardest for low-income households. Overcoming this concern to offer just energy transition is important to minimise resistance and opposition to sustainable decisions.

7. Appendices

Appendix 1. Main input parameters and assumptions for energy system modelling (Vietnam Institute of Energy, 2020a)

Table 7.1 Techno-economic parameters by technology

Technology	Operation year	Construction costs ($k/MW)	Efficiency (%)
Nuclear	2030-2045	5980	33 %
Coal subcritical	2020-2029	1515	36 %
	2030-2045	1503	36 %
Coal supercritical	2020-2029	1814	38 %
	2030-2045	1776	39 %
Coal ultra-supercritical	2030-2045	1998	43 %
Coal advanced ultra-supercritical	2030-2045	2500	50 %
Coal subcritical with CCS	2030-2045	5340	36 %
CCGT	2020-2029	930	58 %
	2030-2045	870	60 %
Small hydros	2020-2045	1762	FLHs
Onshore wind (wind speed >6m/s)	2020-2024	1650	FLHs
	2025-2029	1474	FLHs
	2030-2039	1348	FLHs
Onshore wind (wind speed 5.5-6m/s)	2020-2024	1947	FLHs
	2025-2029	1738	FLHs
	2030-2039	1531	FLHs
Onshore wind (wind speed 4.5-5.5m/s)	2020-2024	2038	FLHs
	2025-2029	1820	FLHs
	2030-2039	1602	FLHs
Offshore wind (fix foundation)	2020-2024	3110	FLHs

	2025-2029	3040	FLHs
	2030-2039	2573	FLHs
Offshore wind (float)	2020-2024	4310	FLHs
	2025-2029	4210	FLHs
	2030-2039	3614	FLHs
Large-scale solar	2020-2024	1119	FLHs
	2025-2029	1003	FLHs
	2030-2039	886	FLHs
Geothermal	2020-2029	2982	10 %
	2030-2045	2671	11 %
Biomass	2020-2029	2010	31 %
	2030-2045	1892	31 %
Waste to power	2020-2029	4986	28 %
	2030-2045	4563	29 %
Tidal	2020-2045	2961	FLHs
Rooftop solar	2020-2024	1119	FLHs
	2025-2029	1003	FLHs
	2030-2039	886	FLHs
Internal combustion engine (LNG)	2021-2029	740	47.5 %
	2030-2039	690	48 %

Table 7.2 Cost structure of some technologies

Technology	Unit capacity	Start-up cost ($/MW)	Min generation (% of MW)	Ramp-up/down speed (%/hour)	Min start-up time (h)	Min stopping time (h)
Nuclear	1000	260	50 %	1.2	6	6
Coal subcritical	600	180	60 %-30 %	0.6-2.4	4	2
Coal supercritical	600	180	60 %-30 %	0.6-2.4	4	2

Coal ultra-supercritical	600	180	40 %-30 %	3.0	4	2
CCGT	250	131	45 %-20 %	4.2-12	4	2
Biomass	25	180	40 %-30 %	6.0	4	2

Table 7.3 Land use fees per region

Region	Range of land-use fee ($/m^2)	Average land-use fee ($/m^2
North	1.65-4.78	2.75
Central North	1.52-4.35	2.88
Middle Central	1.3-4.35	2.57
Highland	3.26-5.87	4.57
Central South	3.35-18.5	6-8.5
South	3.13-19.57	6-10.3

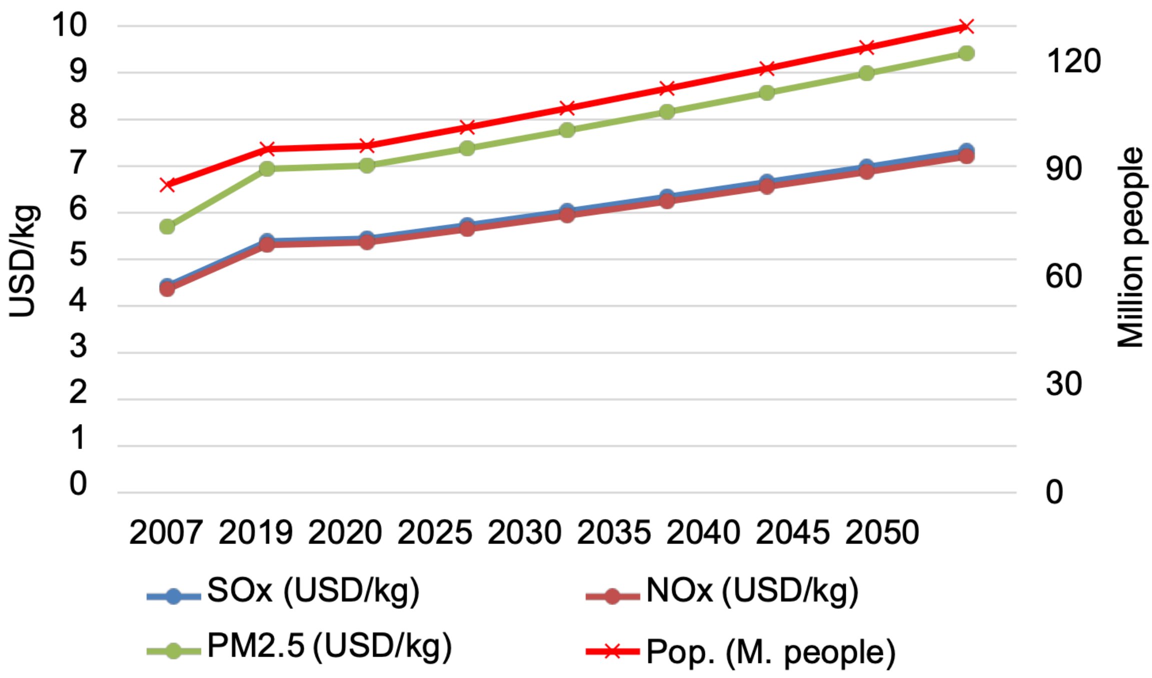

Figure 7.1 Development of emissions' external costs 2007-2050

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