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Abstract

Vietnam plans to develop dozens of new coal-fired power generation units over the next 20 years. If they are indeed build, in order to avoid a dangerous level of global warming, it may appear necessary to dispose of these plants' CO2 by burying it in deep underground geological formations instead of releasing it into the atmosphere, using Carbon Capture and Storage (CCS) technology. We show that CCS has a technical potential in Vietnam, according to the geology and the industrial geography. To discuss under which economics conditions this potential could actualize, we examine two scenarios for 2050. In the first scenario, CO2 is used in Enhanced Oil Recovery (EOR) only. EOR technology makes CCS cheaper by injecting CO2 in partially depleted oil field, aiming to recover more oil. The second scenario considers CCS deployment in coal-based power plants, on top of using it for EOR. This happens after 2035, since according to a survey of 15 national experts, CCS would not be a priority for the next 20 years in Vietnam. That scenario assumes international financial supports to initiate demonstration projects after 2025, that Vietnam develops an affluent economy, that China paves the technology way, and that capture-ready is given some attention in the near term.

Keywords: Carbon capture and storage, capture ready, power generation, Vietnam, scenario

1. Introduction

(Boden, Marland, and Andres 2013) measured that fossil fuel CO_2 emissions to the atmosphere in 2014 were 9.8 GtC, and coal burning was responsible for 42% of those. This is not sustainable, and all the more worrying that countries like China, Vietnam, Indonesia, and India are adding coal-based power generation units faster than countries like Germany or USA are retiring them. To make coal-power generation compatible with a low-carbon economy, the industry has been demonstrating the technology of CO_2 capture and storage (CCS), to dispose of the CO_2 underground instead of releasing it in the atmosphere (Metz et al. 2005).

CCS technology seems a priori relevant for Vietnam, a lower middle income country with billion tons of coal reserves, who as of 2016 officially plans to open one new 500 MW goal-fired electricity generation unit every three months in the years to come (The Government of Vietnam 2016). Yet CCS is not in the energy policy agenda in the country, according to our survey of local stakeholders (H.A. Nguyen-Trinh and Ha-Duong 2015) who furthermore anticipated that CCS would remain a low priority question in Vietnam for the next twenty years.

We argue that the prospective availability of CCS at some point in the future do raise questions about the power plants being built today, in 2016. These plants will probably still be operating in 2050, should they be build with a CCS retrofit in mind ? This is of course only interesting to do if there is a plausible perspective that the plant will have to be retrofit with CCS in the future. In order to help the reader assess the plausibility of such perspective, this manuscript exposes two long-term narrative scenarios about the prospect of CCS in Vietnam.

This manuscript is organized as follows. Section 2 describes what is CCS and what is capture-ready, focusing on the relevance of these technologies for Asian countries. Section 3 review the literature on CCS in Vietnam. We show that the industrial and geological conditions are favourable for carbon dioxide storage, even if neither capture readyness nor CCS RD&D is on the political agenda. Section 4 exposes two visions of CCS technology penetration in Vietnam up to 2050. The first scenario limits it to Enhanced Oil Recovery (EOR) – a technology which could help the country extract more oil from existing fields and defray the cost of CCS. The second scenario describes a future where, in addition to EOR, CCS comes to be used at coal-based power plants, justifying capture readyness. Section 5 discusses policy implications and concludes.

2. Literature review

2.1 Carbon capture and storage exists at the industrial scale

This section illustrates how it is technologically feasible to capture CO2 emitted from burning fossil fuels, compress it and then bury it underground in geologic formations for a very long time (Metz et al. 2005).

According to (GCCSI 2016), fifteen large scale CCS demonstrations projects were operating in 2015. The majority was deployed in the United States and Canada, with 2 in the EU and 3 in the rest of the world. None was in Asia. But when it comes to development, the focus of moves from projects in North America (three in advanced planning) towards projects in Europe and China (a combined eight in advanced planning). Here are a few examples from GCCSI (2016) database of how it operates today at the industrial-scale of $MtCO_2$ per year:

- Australia has build the largest greenhouse gas mitigation project undertaken globally to inject into a dedicated geological storage formation : the Gorgon Carbon Dioxide Injection Project. Over its life, the project will avoid the emissions of over 100 million tonnes of carbon dioxide extracted as part of a gas processing facility on Barrow Island. Australia, a major coal exporter, is taking leadership on CCS R&D and started a 10-year program “CCS Flagship” in the country with a total funding of AU$2.425 billion.
- Many CCS projects have been launched and undertaken in China. Shenhua group Ordos Carbon Capture and Storage demonstration project is China’s largest CO2 storage in deep salt/deep saline formations operation, its first entirely coal-based full chain CCS demonstration project, and one of the first CCS projects undertaken in a developing country. In the first phase, it has injected around 300,000 tonnes of CO2 into deep saline aquifers in the Ordos Basin, Inner Mongolia, captured from a coal-to-liquids (CTL) plant. In phase 2, the project intends to capture and sequester around one million tonnes of CO_2 each year from the plant.
- Boundary Dam is the largest of the coal–fired facilities operated by the SaskPower company in Canada. The coal is mined about 13 km from the plant. At the end of 2013, production Unit 3 was refurbished with carbon capture. In July 2016, the CO_2 capture unit at Boundary Dam surpassed the capture of one million tonnes of CO_2 since operations began in October 2014 and that the facility is on track to capture 800,000 tonnes of CO_2 in 2016. The CO_2 captured is used primarily for Enhanced Oil Recovery (EOR) at the Weyburn Oil Unit, transported over 66 km by the new purpose-built Rafferty CO_2 pipeline.

These examples show that CCS can be used to reduce emissions from fossil fuel burning installations and from fuel processing facilities. They substantiate the claim that CCS has the potential to allow deep cuts in greenhouse gases emissions. Although CCS is expensive compared to the value of avoided CO_2 in most carbon finance markets today, some affluent countries like Norway have at times imposed CO_2 taxes higher than the cost of CCS. There are not many alternatives to control emissions for large industrial installations, besides shutting them down.

The BLUE Map scenario described in (IEA 2008) quantified the role that CCS could have in a portfolio of actions to mitigate CO_2 emissions, particularly those coming from coal power plants. In that scenario, CO_2 storage in year r 2050 reaches over 10 $GtCO_2$, and cumulative storage of CO_2 worldwide over the period 2010-2050 is around 145 $GtCO_2$. The BLUE road-map proposed an ambitious CCS growth path with 100 projects globally by 2020 and over 3400 projects by 2050. In Asia, China and India are together were to implement 21 CCS projects by 2020 and 1260 CCS projects by 2050, and to account for 37% of total global CCS projects by the same year. This ambitious roadmap will not come to pass in reality. Brad Page, CEO of Global CCS Institute (2015) summarizes that "*It is very clear that we now need to shift into a higher gear if CCS is to play its full part in addressing climate change*"

2.2 CCS in Southeast Asia and China

CO2 emission of the East Asia Pacific region have increased more than threefold over the past twenty years. In a report by the Asian Development Bank, (Tharakan 2011) estimated that the primary energy demand in the Southeast Asian countries (ASEAN) will increase by about 76% during the period 2007-2030. Of all energy sources used in the region, coal would increase the most. As a consequence, energy-related emissions are set to double by 2030 compared to 2007. (World Bank 2010) warned in another study that under the continuation of current policy, emissions of CO2 would double from about 7.2 Gt in 2009 to 14.3 Gt by 2030 in China and EAP5 countries.

Based on a regional study of climate change economics including Indonesia, Philippines, Thailand and Vietnam, (Asian Development Bank (ADB) 2009) argued that in Southeast Asia, "*mitigation through CCS could become feasible as the carbon price rises toward 2050, with reduction potential of up to 22% of emissions under the BAU scenario*" in addition to consumption changes and fuel switching. The study found that under an S550 global climate strategy, "*when the carbon price rises to around 25.5 \$/tCO_2 , injection of CO_2 into deep saline aquifers is projected to become economically feasible by 2050 and would help capture as much as 133 MtCO_2 per year, 6% of the BAU emission in that year.*"

In spite of these perspectives, CCS is not a technology priority for South East Asian countries. Energy policies are understandably more focused on contributing to sustained economic growth, addressing poverty and security. Even in climate change policies, CCS takes a backseat at best. In Vietnam for example, the overall climate policy strategy is to orient the domestic ressources towards adaptation, and leave mitigation leadership to international ressources.

The regional interest is mostly oriented towards Enhanced Oil Recovery (EOR). For example, Indonesia began examining the EOR potential since 2003 (Indonesia CCS Study Working Group 2009). Overall, the existing CCS action in South East Asia are one-off and project oriented, it has not progressed towards locationally appropriate CCS regulatory frameworks.

China is the major emitter of greenhouse gases in the region, and about 90% of its emissions come from burning of fossil fuels. (H. Liu 2010) argues that the deployment of the full range of low-carbon technologies, including CCS, is essential for the PRC to decarbonize its power sector and achieve long-term climate change mitigation goals. For many years, approximately 1 GW of new coal-fired power plants began construction in China every week. Even with very strong incentives for energy efficiency, renewable and other low-carbon technologies, including nuclear power, coal is likely to remain a dominant part of PRC s energy mix until at least up to 2035. Using CCS could reduce of CO_2 emissions from the Chinese energy sector by 100 and 380 million tons in 2030 and 2050 respectively (CCICED 2009).

The pace and scale of demonstration and deployment of CCS in China will have a significant impact on the overall global potential of CCS to play its role in decarbonizing economic growth. The government promotes CCS research, development and demonstration since 2005 and continuously increases the program's funding (ADB 2012, 20012). (Zhu and Fan 2013) focused on the investment decision to retrofit an existing supercritical pulverized coal (SCPC) unit with CCS technology and four uncertainty factors: electricity price, carbon price, CCS investment cost and CO_2 additional O&M cost. The study found that the CCS retrofit investment decision is most sensitive to additional O&M costs for CO_2 capture, and the existing level of CCS technology, but the existing policy framework do support the plant owner to retrofit the existing SCPC unit with CCS.

2.3 Capture ready concept in plant design and regional planning

In 2010, the three main organisations working on CCS proposed the following definition:

"*a CCS Ready facility is a large-scale industrial or power source of CO_2 which could and is intended to be retrofitted with CCS technology when the necessary regulatory and economic drivers are in place. The aim of building new facilities or modifying existing facilities to be CCS Ready is to reduce the risk of carbon emission lock-in or of being unable to fully utilize the facilities in the future without CCS (stranded assets). CCS Ready is not a CO_2 mitigation option, but a way to facilitate CO_2 mitigation in the future*" (Christopher Short 2010).

The plant is designed to be technically capable of retrofit and built in an appropriate location where it deal with potential roadblocks such as conflicting land use, environmental and other permits, public awareness, and identification of service providers, see (Bohm, M.C. 2007; IEA 2007) for more details on the engineering requirements.

Building a capture ready plant costs more, because additional constraints bear on the project. For example, it may lead to choose a more sophisticated combustion technology than classical boilers. To examine the political feasibility and techno-economic aspects of capture readyness, (Sekar, R.C. 2007) calculated net present values of plants NPVs under different CO_2 tax levels and growth rates. The results shows that an Integrated Gasification Combined Cycle (IGCC) plant is more expensive to build and operate than a Pulverize Coal (PC) plant, but less expensive to retrofit for CO_2 capture. (Bohm, M.C. 2007) expanded upon this analysis to include the option of building a capture-ready IGCC plant in addition to a baseline plant, pointing out the lower carbon tax level at which a retrofit is economically justified.

Building capture ready is crucial to prevent a 'carbon emission lock in' in countries building up a coal-based power generation capacity. (Li, Liang, and Cockerill 2011) examined 74 coal-fired power plant sites in China found that only 19% of sites appear to have a high retrofitting potential. Paying for the capture-ready real option cost as an insurance does not make business sense. The bottom line would only be impacted if there were under credible treats of CO_2 emissions mitigation measures.

(Liang et al. 2010) proposed that fossil fuel plants issue tradable capture options to finance capture readyness. By introducing the capture option concept, China or other developing countries could speed up CCS technology development and make capture ready investors diversify risk, and offer global warming investors an alternative investment opportunity. The authors assessed the value of a capture option and capture ready plant for a 600 MW supercritical pulverized coal power plant in China. The study found that the gross value of capture ready, at an 8% discount rate, varies from \$0.4m to \$84.4m and the capture option is valued at \$15.1m to \$167.3m for two of the four scenarios developed.

Regional planification can facilitate the adoption of capture ready in new coal plants. (Zhou et al. 2013) investigated CCS options for Guangdong, the most economically developed province in China. The project "Guangdong, China's First CCS Ready Province" (GDCCSR) provides a comprehensive review to decision makers on the necessity, feasibility, and roadmap for the CCS development in the province. (Li et al. 2011) evaluated the benefits of a 'CCS Ready Hub' approach and a regional 'CCS Ready' strategy, in the case study of Shenzhen city in southern China. It found that financing 'CCS Ready' at regional planning level can reduce the overall cost of building integrated CCS systems. It recommended that the location of existing large emissions sources should be taken into account when planning new CCS ready plants or a CCS ready hub.

3. The conditions for CCS in Vietnam

This section reviews the drivers influencing CCS in Vietnam at the 2050 time horizon. We look first at the fundamentals of the economy/energy system, then examine the geologic conditions, and finally review other studies on CCS and on the energy system scenarios.

3.1 Demography, economy, fossil fuel reserves and coal plants under construction

Vietnam is a densely populated country. During the period 2000-2010, annual growth rate of population density in Vietnam was 1.7%, reaching 264 persons per km2 by the end of 2010. The population is concentrated in the Mekong and Red river deltas. It population will reach 101.6 million by 2025, with population growth slowing somewhat over time. In 2012, about 70 percent of the population living in rural areas, however growth in urban population greatly has been outstripping rural population growth, as the rapid urbanization and industrialization processes in Vietnam.

Vietnam's economic growth rates have been at high for the last 25 years, around seven percent annually. In next decades, Vietnam expects to keep relatively high economic growth rate as it catches up with the more affluent countries and has a dynamic demography. The energy demand is increasing faster than the economy by a factor 1.7.

	Total proved reserve at end of 2015	**Reserve/Production ratio**
Oil	600 million ton	33.3 years
Natural gas	600 billion cubic meter	57.9 years
Coal	150 million tonnes	4 years

Table 1: Vietnam fossil fuel reserves. Source: (British Petroleum 2016)

Table 1 displays Vietnam's fossil fuel reserves. At the current production rate Vietnam would exhaust its proved reserves of oil before 2050, and natural gas by 2075. These numbers evolve over time, as exploration finds additional reserves, and the production levels change over time. This is particularly true for Coal, where the numbers from BP are very far from those in the master plan on the development of the coal industry (Nguyen Tan Dung 2016). The latter states that "*As of December 31, 2015, total coal reserves and resources were estimated at about 48.88 billion tons, including around 2.26 billion tons in reserves and 46.62 billion tons in resources, of which 0.34 billion tons are peat."* Coal production of Vietnam increased from 34 million tons in 2005 to 44 million tons in 2009, and seems to have reached a peak since (GSO 2015). The country is expected to become a net importer in 2017(Viet Nam News 2015).

The capacity of coal-fired power plants in Vietnam has increased from 0.5 GW in 1995 to 3.3 GW by 2010 (National Load Dispatch Center 2012), and the future looks as dramatic. The capacity of all the coal-fired plant in Vietnam, operating or at various stages of construction, permitting, planning or announcement adds up to 57 GW. The Power Development Plan VII Adjusted (T. D. Nguyen 2016) targets 55 GW of coal generation capacity in 2030. In other words, Vietnam plans to open build about one 500 MW of new coal-fired power installed capacity unit every three months annually during the period 2010-2030. Coal would provide 56% of the total power generated in the country by 2030.

The closest item in the coal master plan related to CCS is that it requires"*10. The Vietnam National Coal-Mineral Industries Holding Corporation Limited shall: […] e/ Annually draw up plans on* *response to climate change for submission to the Ministry of Industry and Trade for approval;*" The general objective of the Power Development Plan VII Adjusted (T. D. Nguyen 2016) is to drive the electricity sector of Vietnam towards to a more sustainable future in which low carbon technologies are encouraged and supported for both electricity supply and demand sides. According to this Plan, the investors of power plants have to applied advanced technologies to increase efficiency of the generation process and to reduce CO_2 emissions from burning fossil fuels. Although carbon capture and storage technologies are not specifically mentioned in the Plan, with they are still considered as promising solutions for cutting CO_2 emissions from coal-fired power plants. Given that coal-related CO_2 emissions would account for more than 85% of the total CO_2 emissions from the electricity sector by 2030, applying CCS technologies in the power sector could help Vietnam achieving its emission reduction targets (8-23% as compared with the baseline by 2030) committed in the COP21 in 2015.

3.2 A promising geological storage potential

The French Bureau des Recherches Géologiques et Minières BRGN, in collaboration with its Vietnamese counterpart KVN, examined the potential for storing CO_2 in Vietnam's underground (BRGM 2009; KVN 2009). The study screened the location and capacity of depleted oil/gas reservoirs; deep saline aquifers; and coal formations which satisfied the constraints: (i) The sediment formations should be deeper than 1000 meters; (ii) they should be 20 kilometers away from major faults or known oil fields; (iii) no more than 100 kilometers away from a CO_2 source emitting more than 2.5 $MtCO_2$ /yr.

Figure 2 shows that there are promising offshore storage opportunities near most Vietnamese coal power plants. Regarding capacity, the BRGM/TKV study examined the quality of reservoirs identified in the Vietnamese offshore basins and the size of these basins. Results allows to forecast more important storage capacities than in the case of the Utsira reservoir in the North Sea, which is one of the most emblematic reservoir in the world and could enable the storage of CO_2 for a great share of the European needs (20 000 to 60 000 $MtCO_2$).

As first steps in Vietnam, there appear to be specific opportunities to:

- Enhance oil recovery while storing CO_2 in the river basin area of Cuu Long.
- Enhance coal bed methane recovery while storing CO_2 in Quang Ninh coal basin.
- Store CO_2 into depleted oil fields in Cuu Long, Song Hong, and North end.

These opportunities are not being exploited presently.

CO_2 can be transported from the emitted sources to storage sites by onshore pipeline, by offshore pipeline or by ship. CCS project developers, depending on distance between CO_2 capture and storage sites, will select one or a combination of several methods for CO_2 transport. For example, pipelines and ships are likely to be used for long distances. If the transport distances are shorter, pipelines have more advantages. Regional planning for transport infrastructures may create CO_2 logistic hubs in ports and around heavy industry.

3.3 Studies on CCS in Vietnam

Several studies on CCS in Vietnam have been conducted, all sponsored internationally. They demonstrate that there is an international interest within the South East Asia region about the role of CCS as a mitigation option against climate change in Vietnam.

The Agence Francaise de Development (AFD) supported a preliminary assessment of storage sites, emissions sources, transport links and regulatory environment. The study revealed promising opportunities for storing carbon emissions geologically and for commercial use in EOR and ECBM projects (KVN 2009). IEA and the Global CCS Institute carried out a series of workshops to introduce CCS to national ministries in Vietnam and Malaysia during early 2010. The Asia-Pacific Economic Cooperation completed an initial evaluation of geological storage potential for countries in S.E. Asia and a study of CCS-ready power plants in the region (APEC 2005), which did not include Vietnam.

The subsequent (ADB 2012) study is perhaps the most complete document available on CCS in Vietnam. The study found that the top 14 oil and gas fields offshor Vietnam offer 900 megatons of CO2 storage capacity. And that CCS increases the levelized cost of electricity from supercritical coal plants by 78% and from natural gas combined-cycle plants by 55%. The study proposes a roadmap to reach the first commercial-scale CCS operation in Vietnam in twenty years.

Petro Vietnam (PV) in collaboration with Mitsubishi Heavy Industries conducted two feasibility studies for CO2-EOR in the Rang Dong (Aurora) and Bach Ho (White Tiger) oil field. Applying the CCS technology of Enhanced Oil Recovery, the White Tiger CCS project is the first commercial CCS project in Asia (Zero Emission Resource Organisation 2010). In the project, CO2 would be captured from a coastal combined cycle natural gas power plant. It would be transported via a 144 km undersea pipeline, and then injected at 4 000 m depth to enhance the oil recovery in the White Tiger offshore oil fields, in the Cuu Long basin. The initial annual CO_2 capture of the project was estimated of 4.6 million tons. It proposed further expansion to 7.4 million tons per year, resulting in the recovery of an average of 50 thousand barrels of crude oil per day (DNV 2005; Nubuo Imai and Scott Reeves 2004).

Vietnam submitted the White Tiger CCS project to the UNFCCC for funding under the Clean Development Mechanism (CDM). This was the first CCS-based CDM proposal, registered in 2005. It would have had a high demonstration value. The Executive Board of the CDM has not approved any CCS project to date. Doing so would probably have flooded the market and driven down the price of Certified Emission Certificates (CER). It is only at the Cancun conference (COP-16, 2010) that the United Nations decided that CCS could be eligible under Clean Development Mechanism (CDM) in principle. But this is a posthumous victory: the CER price is too low to interest investors, the principle decision leaves a number of practical issues to be resolved, and the whole Kyoto Protocol system has been quietly left to die at the COP 21 in 2015.

3.4 CCS in scenarios of the Vietnam energy system

Figure 1 compares the result of four different studies about scenarios planning for electricity generation capacities of Vietnam up to 2030. In the figure, the S1 scenario corresponds to the official PDP7 plan published in 2011, before the 2016 adjustment.

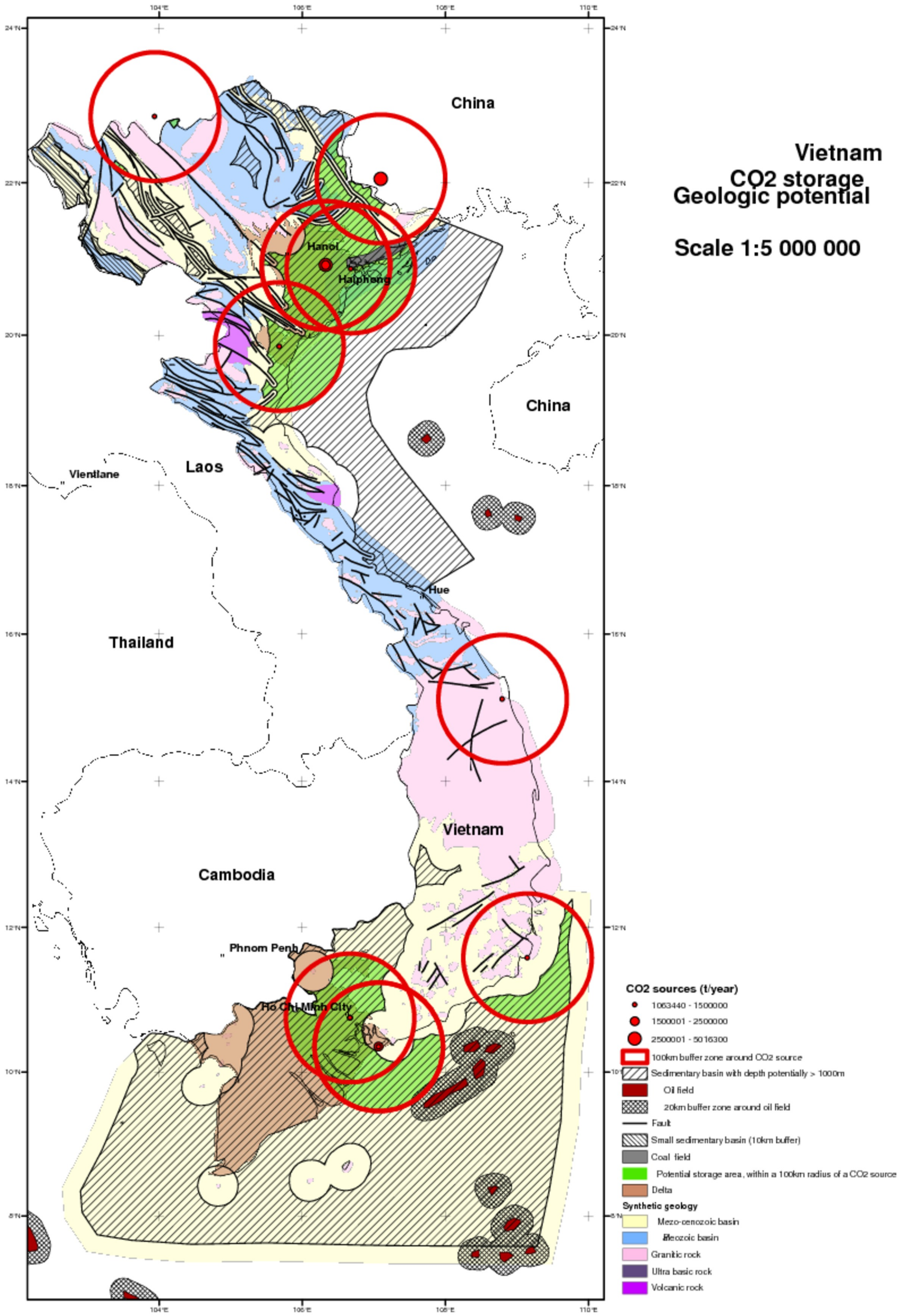

Figure 2: Geological formations potentially favorable for CO_2 storage in Vietnam (BRGM/TKV 2009, 34)

S2 scenario is from (N. T. Nguyen 2011). These energy system simulations show that the total electricity generation capacities of Vietnam would be 100GW by 2030, about 20% lower than reference scenario of the 7th national power development plan. To the best of our knowledge, this is the only study to also examine the role CCS could play as climate policy instrument in the Vietnamese power sector. It found that with the carbon price increasing gradually from 5 US$/t CO_2 in 2010 to 60 US$/t CO2 by 2040, Vietnam would have a generation capacity of 52.6 GW by 2040 using CCS, accounting for 24.4% of the total capacity in 2040. These result in 1.3 Gt of CO_2 abated in the power sector of Vietnam during the period from 2030 to 2040.

S3 refers to (Hoang Anh Nguyen-Trinh and Ha-Duong 2016). We computed power sector development plans based on a higher energy efficiency of the economy. By comparing the energy intensity of economic growth in Vietnam with other countries in South and South East Asia, we argued the official PDP-7 plan overestimated the power intensity of Vietnam. There is room to catch up the energy efficiency levels of other countries, which suggest that Vietnam could purse energy conservation and carbon emission reductions without impeding economic growth. In addition, we modelled external costs of the electricity generation technologies in the power sector in Vietnam. Internalizing these costs bring more incentives to develop cleaner power technologies in the country. Again, these factors lead to less coal use than the S1 scenario.

S4 by (K. Q. Nguyen 2008) also introduced external costs in the power sector. It examined the impacts of environmental and health damages from electricity generation on power development plans in Vietnam from 2005 to 2025. In the baseline of the study, generation capacity grows from 11 GW in 2005 to 74 GW in 2025. Including external costs in the total production cost of electricity changes the generation mix. There is 11 GW less of coal power plants, but 3 GW more of gas turbine and 15 GW of geothermal, wind, and biomass by 2025.

These three examples show that a majority of studies focus on renewable energies and energy efficiency and give little specific attention to CCS in Vietnam. This is still true in the most recent reports. (Kimura and Phoumin 2016) recognizes the importance of low carbon coal, but offers no

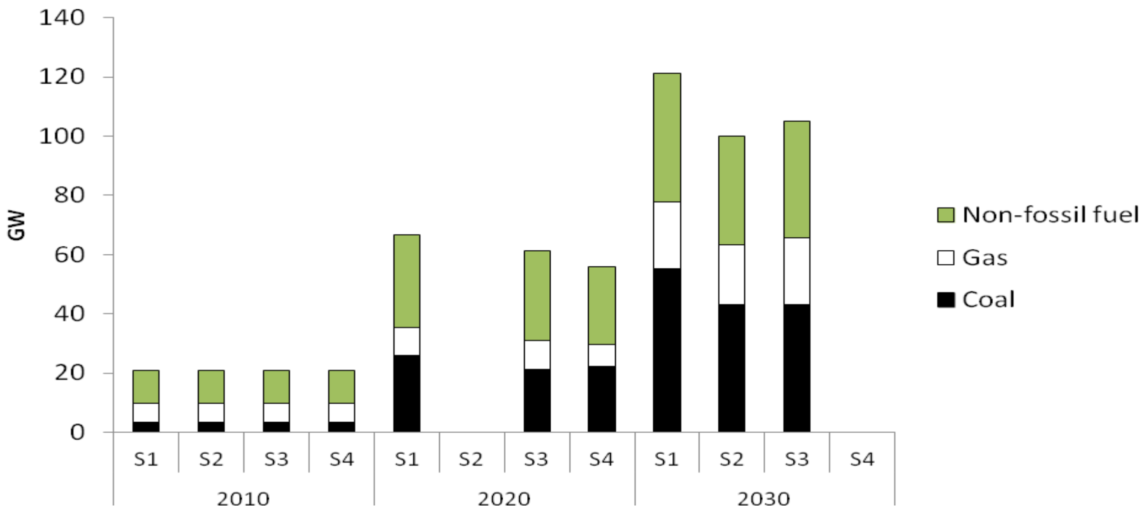

Figure 1. Future Vietnam power generation mix capacity in different studies (Unit: GW). S1: the 7th Power Development Plan, S2: N.T. Nguyen (2011), S3: H.A. Nguyen et al. (2016), S4: Khanh Q.Nguyen (2008)

specific vision for deployment. The Vietnam energy sector assessment and roadmap by (Aruna K. Wanniachchi et al. 2016) from ADB does not mention CCS at all. The World Bank report on Vietnam low-carbon development path by (Audinet et al. 2016) mentions once CCS in the list of acronyms and once in the bibliography, but it is not mentioned in the text or used in the scenarios.

Overall, our analysis of the literature shows that there is no specific CCS in Vietnam scenario, the closest available exercise are the simulations in (N. T. Nguyen 2011) PhD. thesis and the roadmap by (ADB 2012).

4. Two scenarios for CCS in Vietnam

4.1 The social conditions

Figure 3 presents influences and interests of different stakeholder groups in CCS deployment in Vietnam. Most groups have a low interest in the technology, since there is no actual project on the ground in Vietnam. Domestic Environmental NGO lobby for the nation to stop building new coal power plants as soon as possible, we have not heard them take a position on CCS. Neither did we hear about CCS from the national power generation company Electricité du Vietnam or the national coal mining company.

From their perspectives, stakeholders have different interests and influences on the CCS activities, either at local level or global level. The concerns of local level is associated with delivery of local benefits, socio-environmental aspects and heath/safety impacts. Local communities/governments, industries and investors often deal with issues in this level. At the global level, policy makers or research institutes give discussions on climate change and development of the economy as a whole.

Table 2 presents the SWOT analysis for policy makers. We assess they are the most influential stakeholders on CCS in Vietnam process. They have the opportunity to set the regulatory framework and to communicate to other stakeholders the importance of the CCS options. The State directly owns the main companies in the energy sector, and also has effective ties with the media and the education and training institutes.

Existing policies of Vietnam are not strong enough and lack of regulations to support the promote CCS application. Many environmental laws and regulations were enacted before CO2 became a concern. There are no regulations for land-use and monitoring a long time projects as CCS. The absence of regulation to classify CO2 emissions as a waste in Vietnam could inhibit CCS deployment.

CCS projects are only feasible with financial assistance, because they require substantial capital, and other low-carbon energy options are more competitive. At the moment, the Vietnam Environment Protection Fund is too weak to provide incentives to CCS projects. Most commercial banks in Vietnam are not strong enough to finance a CCS project, and lending would be severely limited by the risk due to uncertain policy framework.

	Low stakeholder interest	High stakeholder interest
High stakeholder influence	Policy makers Local community/government Electricité du Vietnam VinaCoMin Local and international media Investors	CCS industry and researchers International carbon finance Fossil-fuel power industries PetroVina
Low stakeholder influence	Renewable energy industries Domestic environmental NGOs Education and training institutes	

Figure 3: Influences / interest matrix of different stakeholder groups in Vietnam

Strengths	Weaknesses
-The ability to issue policies regarding CCS industry	-Lack of technical knowledge -Lobbied by other industries
Opportunities	**Threats**
-Giving subsidies, framework for co-operations -Lobbied by CCS industry	-Do not pay attention to CCS deployment

Table 2: SWOT analysis of the stakeholders: Policy makers/Regulators

In this context, the two scenarios are first differentiated by the government policy with respect to CCS. In one scenario, CCS is used only for EOR because the State keeps its hands off. In the other scenario, CCS is used at most gas and coal-fired power plants in Vietnam following a planned state intervention. Table 1 lists the assumptions setting the two scenarios apart with respect to the main drivers of the technology adoption.

Driving forces	Low scenario: CCS only EOR	High scenario: CCS in power
Government stance on CCS	Laisser faire. Climate policy instruments are generic	Intervention to promote it with specific incentives.
Economic growth until 2050	Trapped at middle-income level	Catches up with South Corea and Japan
CCS technology costs	A global ban on coal hurts CCS scale up.	General adoption of CCS in China and elsewhere push costs down
Carbon price trajectory	Implicitly weak, below 30USD/tCO_2 in 2050	Most nations adopt a notional price of carbon reaching 50 USD/tCO_2 in 2050

Social acceptance	No, an international convention against onshore CCS is discussed.	Yes, most storage in Vietnam is offshore
Alternative technologies	Solar and wind win the cost race	Coal with CCS remain more expensive for new capacities, but capture-ready plants are retrofit rather than closed.

Table 3: CCS scenarios: Driving forces

4.2 Low Scenario: EOR CCS only

The context of the low scenario is that the growth of Vietnam's economy in next decades would not be as strong as expected, it remains in the middle-income class. Vietnam does not set quantitative targets to control its CO_2 emission level in absolute terms before 2030.

Technical and societal constraints hinder the deployment of large-scale CCS in the world. Thus the effects of scale and technology learning progress are limited. The costs of technology does not fall rapidly, and CCS remains by 2050 a relatively expensive option for reducing GHG emissions, compared to solar and wind energy with battery storage. There are environmental and social issues with a few early carbon storage projects, which lead to a global movement against onshore geological storage. While these incidents do not happen in Vietnam, they bear in the country which is densely populated and well connected.

In addition to cost issues, investments are discouraged by risks created by international disputes about the control some of the best storage fields off shore between Vietnam, Philippines, China and other countries. There are no attractive international carbon trading schemes where Vietnam can take advantages of reducing its CO_2 emissions.

With factors presented above, CCS incentives and regulatory measures remain inexistent. The country never issues policies to encourage the deployment of CCS. The main players to develop CCS projects are from the private sector. A joint management of storage projects is implemented at the local and industrial level. There are training programs for engineers and technicians who can work for CCS projects, but they are pushed by a few industrial sectors and located in other Asian countries.

In this future, Vietnam develops CCS projects exclusively in oil industry where the recovery of CO_2 can contribute to lower costs because oil recovery allows a return on investment. In this scenario, CCS occurs only at EOR projects like the one in the White Tiger field. The main CO_2 transport method used is shipping by boat, internationally within the Asia region. There is an international ban on producing CO_2 from pure natural CO_2 fields, but natural gas processing facilities can still sell their CO_2 for EOR as a by product. Another part of the CO_2 used for EOR comes power plants and industries located in a few port cities in affluent Asian countries who have a significant carbon price.

4.3 High Scenario: CCS in power

This scenario describes a future where CCS is used at most gas and coal-fired power plants in Vietnam.

In this scenario, the economy of Vietnam keeps growing fast. By 2050 it is above the middle-income status. Transformation into a high-density urban society lead to a greater demand for environmental quality by citizens. The knowledge-based economy allows for rapid progress in energy efficiency, which match the increase the demand for energy. Considering that there are enough announced coal power plants to realize the Power Developpement Plan VII adjusted, the government suspends indefinitely the authorization of new coal power plants. Coal-fired power plants do dominate the generation sector of Vietnam from 2020 onward. The total capacity of coal-fired power plants would increase to 55 GW by 2030.

CCS finally takes off in the international context, as China, Australia, South Africa and a few other countries consider it a Nationally Appropriate Mitigation Action. This reduces the technical barriers, and drives down the costs of CCS technology to a point where an affluent Vietnam can afford it by 2040. Vietnam and other countries in the region benefits CCS capacity building programs from IEA, ASEAN, APEC and industry associations.

In this scenario, storage activities are still initially driven by the oil industry, who seeks to extend the end life of offshore oilfield by CO_2 flooding. But the government plays a central role early on. Incentive systems (e.g. taxes, subsidy ...) are implemented, as soon as 2020 for R&D, to setup a pilot project, with the goal to have a commercial scale demonstrator by 2035. In parallel, the government announces that coal fired power plants build after 2020 will have to be capture-ready.

The electricity generation sector is an active player for CO_2 transport activities. In collaboration with provincial authorities, two CO_2 hubs are setup in the country: one in Hai Phong, the other in the south. The CO_2 collected exits the hubs both by a combination of ship and by pipelines, depending on market conditions.

5. Policy discussion and concluding remarks

Vietnam has promising geological formations for CO_2 storage less than 100km away from present and future fossil-fuel power plants. It could technically play a significant role in the deployment of CSS among the ASEAN countries, however there is no commitment to the technology in Vietnam, not even much interests in CCS research and development.

In developing countries, the energy policy goals are to provide affordable energy to the whole population, and enhance and sustain energy security. For this, the immediate priorities are to increase the energy efficiency and add generation capacity. The Government of Vietnam has concerns about climate change and its negative impacts. But as of late 2016 it is still forming action plans to reduce carbon emissions in next few decades. It remains to be seen if CCS is part of these plans.

If Vietnam was asked to take a national position towards CCS, it would logically be that CCS is expensive and should be developed by rich countries who have an historical responsibility in climate change. Without international financial supports and necessary technology transfers, Vietnam could only be interested in CCS as far as it contributes to the energy security of the country. EOR does. But CCS in power plants increases the consumption of fuel. As coal is more and more imported, CCS would actually affect negatively the energy security. Whether international cooperation or carbon finance can support CCS in Vietnam also remains to be seen.

For these reasons, the scenario “CCS EOR only” appears to us closer to business as usual than the scenario “CCS in power”. However, the future is open, and the “CCS in power” scenario is much more compatible with a world avoiding a dangerous level of global warming. International and national climate policies are progressing fast, so both scenarios remain plausible. In our opinion, energy policy in Vietnam should not indefinitely defer thinking hard about CCS for the following reasons:

- Given Vietnam's plans to expand the use of coal to produce electricity, questions on CCS will inevitably have to receive answers someday. These answers will depend a lot on the decisions taken about building capture ready today or not.
- As demonstrated by the White Tiger project, there are opportunities for EOR by CO_2 injection in Vietnamese oil fields. These could reduce storage costs or even produce a storage co-benefit, enhancing the cost-competitiveness of CCS. (Metz et al. 2005) provided that enhanced oil production onshore with CCS could generate 10-16 $/t$CO_2$ of net benefits. This was with oil prices before 2003. Benefits of deploying CCS with EOR will rise proportionally to oil prices in the long run.
- There are international cooperation efforts pushing towards the development of CCS in third countries under flexibility mechanisms. International or bilateral agreements may offer ways to finance CCS projects in developing countries. For example, there are low-hanging fruits in the natural gas processing sector. Vietnam might benefit from such financial mechanisms. Networking and capacity building, for example by joining global CCS institutes and research forums, could help to be ready by then.

China has world-leading research at universities, with policies and industry incentives for CCS demonstration and early deployment. Indonesia designated the national R&D center for oil and gas technology as the focal point in performing specific research and development of CCS. In contrast, in Vietnam there is currently very few, if any, research centre with the necessary facilities and infrastructures to study the conditions of CCS development. Research centers currently performing R&D activities related to energy and climate change could be involved in CCS research, at least to clarify the strategic position in the wider reflexion on the climate change, energy sources and development policy.

Many countries are in the process of building the legal frameworks for CCS. International cooperation/collaboration could provide Vietnamese lawmakers with examples. An early integration of CCS ready regulations into the current approval processes for thermal power projects could help to facilitate the adoption of CCS later, and assist project developers in assessing the feasibility of their plant being storage ready.

The two scenarios we presented are original –as in previously unpublished– but also not original –as in generic, not surprising to any expert in the field. In the low scenario CCS develops for EOR, in the high scenario it is in addition used in many coal and gas power plants. This is because they are unsurprising that these scenarios are plausible. Both should be considered for long-range business and policy planning. A scenario in which CCS is used in fossil-fuel power plants in Vietnam cannot be excluded. There is an real option value to building capture-ready power plants today.

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