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Potential of Carbon Capture and Storage at Vietnamese power plants in 2040

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Abstract

Developments pathways for carbon capture and storage (CCS) in the Vietnamese power sector were simulated using a technico-economic optimal capacity expansion planning model. Our key driver is the value of avoided CO_2 emissions in 2040. On the low side, we do not find any CCS power plants used at 25 $/tCO_2$ or below. On the high side, we found 68 CCS projects installed by 2040 at 60 $/tCO_2$, for a generation capacity of 52.6 GW, about one third of the national total. This allows a 20% abatement in the total CO_2 emission of the power sector, computed over the 2010-2040 period. Between these two extremes, the implications of carbon value profiles reaching 35 and 50 $/tCO_2$ in 2040 were simulated. In the first, CCS appears used at two gas-fired and two sub-critical coal-fired power plants. In the second, CCS is used earlier, an additional two gas-fired power plants are included, and the amount of CO_2 mitigated is doubled. Additional model simulations comparing mitigation with CCS with mitigation by using renewable energy sources showed that CCS was a more expensive option.

Keywords: C*arbon capture and storage, power generation, Vietnam*

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1. Introduction

The growth CO_2 emissions from electricity generation in Asia is one of the biggest problems for climate policy. According to the Global Carbon Project (2010) "Fossil fuel CO_2 emissions to the atmosphere in 2009 were 30.8 $GtCO_2$. These emissions were second highest in human history, just below 2008 emissions, and 37% higher than in 1990 (Kyoto reference year). Coal is now the largest fossil-fuel source of CO_2 emissions. About 92% of the growth in coal emissions for the period 2007-2009 resulted from increased coal use in China and India."

In Vietnam, carbon dioxide emissions from fuel combustion increased between 1990 and 2008 from 17 to 103 $MtCO_2$ according to IEA (2010). This 496% increase is the world's largest after Benin (0.3 to 3.3 $MtCO_2$). The future looks as dramatic. According to the vision of Vietnamese agencies discussed by Nguyen (2011, p. 17), the electricity demand is expected to increase by a factor of ten between 2010 and 2040 in Vietnam in a moderate projection scenario. While emissions attributed to the Electricity and Heat sector were 30 $MtCO_2$ in 2008 (IEA, 2010), applying the ten-fold factor we would be looking at a future where the electricity sector in Vietnam emits 300 $MtCO_2$ per year. Over a population of approximately 100 million inhabitants in 2030 (United Nations 2011, medium variant), this would amount to 3 tCO_2 per year per person. This level compares with the current level in developed countries: power sector CO_2 emissions in Annex I Kyoto Parties is about 3.6 tCO_2 per year per person (IEA, 2010, p. 65/83). Such levels are not sustainable.

To mitigate the climate impacts of fossil-fuel power plants, Metz et al. (2005) and IEA (2008) consider carbon capture and storage (CCS) as a key option. This CCS technology involves capturing CO_2 at industrial facilities and burying it permanently in deep geological formations. Today there are two industrial sectors where these kind of processes are used at the Mt per year scale, the scale relevant in the electricity industry. First, CO_2 may be injected underground to Enhance Oil Recovery (EOR). This is done for example in Texas oil fields or at the Weyburn-Midale field in Canada. Second, the CO_2 produced from the purification of natural gas at the extraction site is sometimes re-injected underground to avoid emitting it in the atmosphere, for example in Sleipner under the North Sea. These two applications are relevant indeed for the oil and natural gas industry in Vietnam. But in this paper, we look at the potential of CCS for the electricity industry.

Based on a regional study including Indonesia, Philippines, Thailand and Vietnam, the Asian Development Bank (ADB, 2009, p. 195) 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."

This paper essentially elaborates on these ADB findings for the sector of power generation in Vietnam. It is organized as follows. Section 2 reviews the favorable geological conditions for carbon dioxide storage in Vietnam. Section 3 introduces our simulations based on a family of carbon prices trajectories going up to respectively 25, 35, 50 and 60 \$/tCO_2 in 2040. We refer to the Appendix for technical details on the Integrated Resource Planning (IRP) model and parameters. Section 4 presents results, providing technically detailed views about how and how much CCS could be deployed in the Vietnamese electricity sector. Section 5 discusses the policy implications and concludes.

2. A promising geological storage potential

BRGM (2009) and the Research Department of Geology and Mines of the Ministry of Natural Resource and Environment (TKV, 2009) examined the potential for storing CO_2 in Vietnam's underground. 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 1 000 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.

Results, presented Figure 1, show 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. The Utsira reservoir is one of the most emblematic reservoir in the world in term of reservoir properties, 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.

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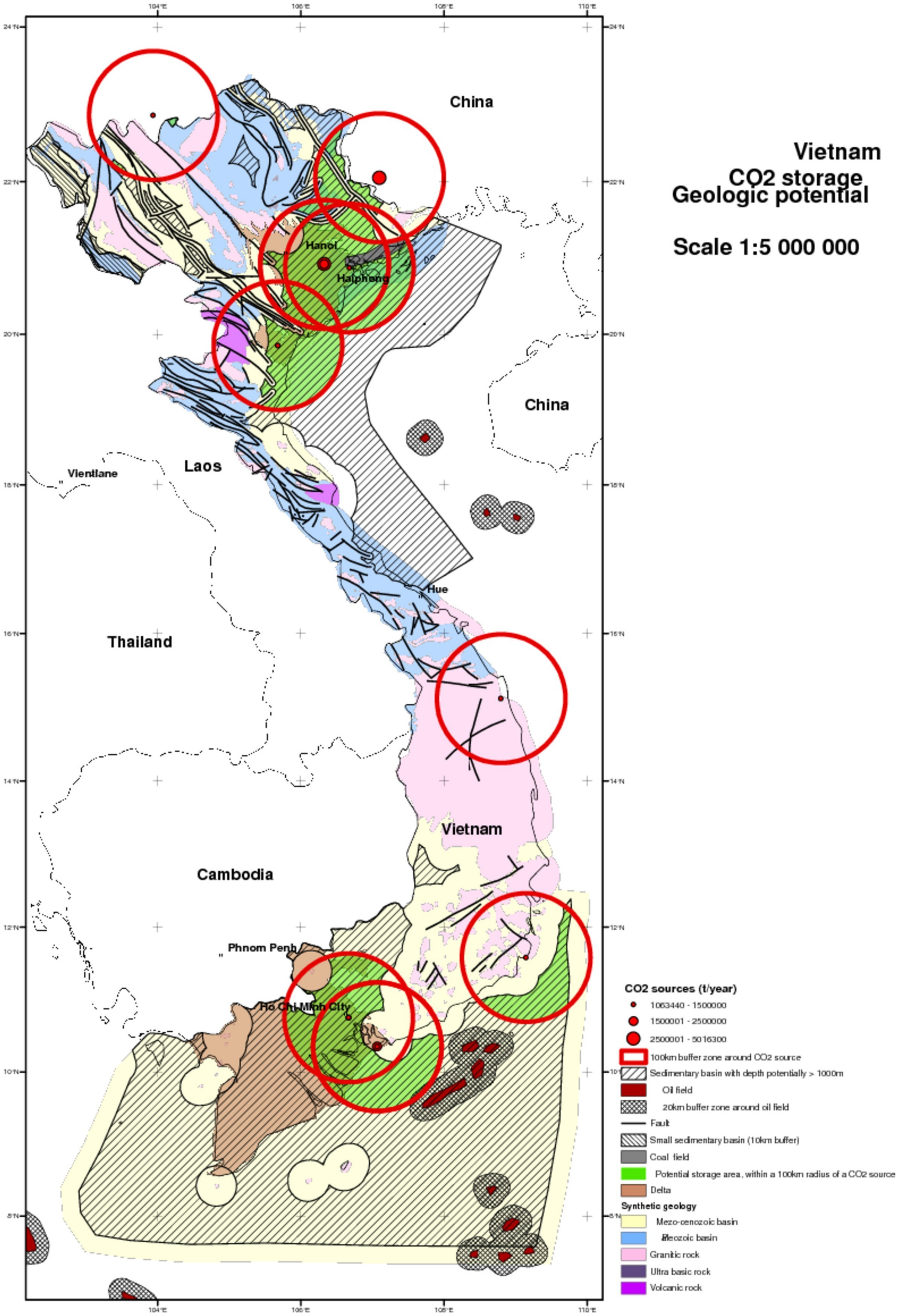

Figure 1: *Geological formations potentially favorable for CO_2 storage in Vietnam. Source: BRGM/TKV (2009, p. 34).*

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These opportunities are not being exploited presently. DNV (2005) submitted a CCS project at the White Tiger (Bach Ho) Field in the Cuu Long basin for funding under the Clean Development Mechanism (CDM). It would have involved CO_2 capture from a coastal Natural Gas Combined Cycle plant, pipeline transport for 144km, and EOR with storage in offshore oil fields. As the first commercial CCS project in Asia, it would have had a high demonstration value, with emission reductions of approximately 7.7 $MtCO_2$ per year, facilitating the recovery of an average of 50 thousand barrels of crude oil per day. However, the Executive Board of the CDM has not approved any CCS project to date.

3. Method, model and scenarios

We used the bottom-up mixed-integer linear programming Integrated Resource Planning (IRP) model (Shrestha and Nguyen, 2003) to compute lowest-cost expansion plans for electricity generation capacity in Vietnam. In the model, integer decision variables represent the number of generation units to be installed in each year of the planning horizon. The total system cost is minimized subject to constraints on energy demand, plant availability, resources availability, as well as many other technical and economic constraints. The model is based on a database of 29 electricity generation technologies. Ten of these involve CCS. Further details of the IRP model and its parameters are presented in the electronic appendix.

The baseline scenario was defined by assuming that today's national development plan is enacted. This provides an estimate of the expected total cumulative CO_2 emissions in Vietnam's electricity sector between 2010 and 2040. Under this scenario, coal, natural gas and electricity will have to be imported in 2040. The baseline's optimal plan uses few renewable energy sources, and no CCS.

To assess the potential for CCS deployment in Vietnam's electricity generation sector between 2010 and 2040, we assumed an hypothetical and unspecified climate policy in which planners include various schemes of positive carbon price. Our key driver is the carbon value trajectory. Four cases were considered (all prices are based on 2008 $US), with carbon value gradually increasing from 5 US$/$tCO_2$ in 2010 to various levels in 2040. The four cases are respectively denoted LCV, MCV, HCV, and VHCV for the low, middle, high and very high carbon value, see Table 1.

Scenario	**LCV**	**MCV**	**HCV**	**VHCV**
CO_2 value in 2040 (\$/tCO_2)	**\$20**	**\$35**	**\$50**	**\$60**
Sub-critical Coal with CCS	0	2	0	0
Supercritical Coal with CCS	0	0	2	36
IGCC Coal with CCS	0	0	0	28
NGCC Gas with CCS	0	2	4	4
Total number of power plants with CCS	**0**	**4**	**6**	**68**

Table 1*: Number of power plants with CCS in Vietnam in 2040, by technology and mitigation scenario. Each scenario is defined by a carbon value trajectory increasing to a different 2040 target. Summary results of the IRP model simulations by the authors.*

Besides the CO_2 value trajectory, the scenarios were otherwise identical in all parameters. The same average load demand forecast, transmission and distribution loss, and electricity use were applied (see the Appendix). We allowed fuel switching, but in these scenarios the use of renewable energy sources was constrained to be no greater than in the baseline.

4. Results

For each carbon value trajectory, the IRP model computed the optimal capacity expansion plan and CO_2 emissions in the sector over the outlook period. We defined CO_2 emissions abatement as the difference from the baseline value. Each simulation describes an extend to which carbon dioxide storage opportunities could be developed to achieve CO_2 emissions cuts in the power sector. The presence of CCS into the generation portfolio depends on the total lowest system cost, not only on comparative individual cost of a plant. Constraints on the building rate of new units, the unit size of a plant, as well as the interplay between generation unit size, available energy generation sources corresponding to the demand of electricity at certain time are all influent factors. Results for 2040 are presented Table 1 by power plant type and Figure 2 as total installed capacities.

The low carbon price case (LCV column in Table 1) shows that at or below 25 \$/tCO_2 , CCS does not enter into the Vietnamese electricity generation portfolio.

In the medium carbon price case, the value of avoided CO_2 emissions in the model goes up to 35 \$/tCO_2 in 2040 (MCV columns). The optimal generation plan selects four CCS power plants. They enter towards the end of the planning horizon. Two gas-fired electricity generation plants (2x750 MW) start being used in 2030. Operating up to 2040, they produce 119 TWh to the grid and save about 39 MtCO_2 .

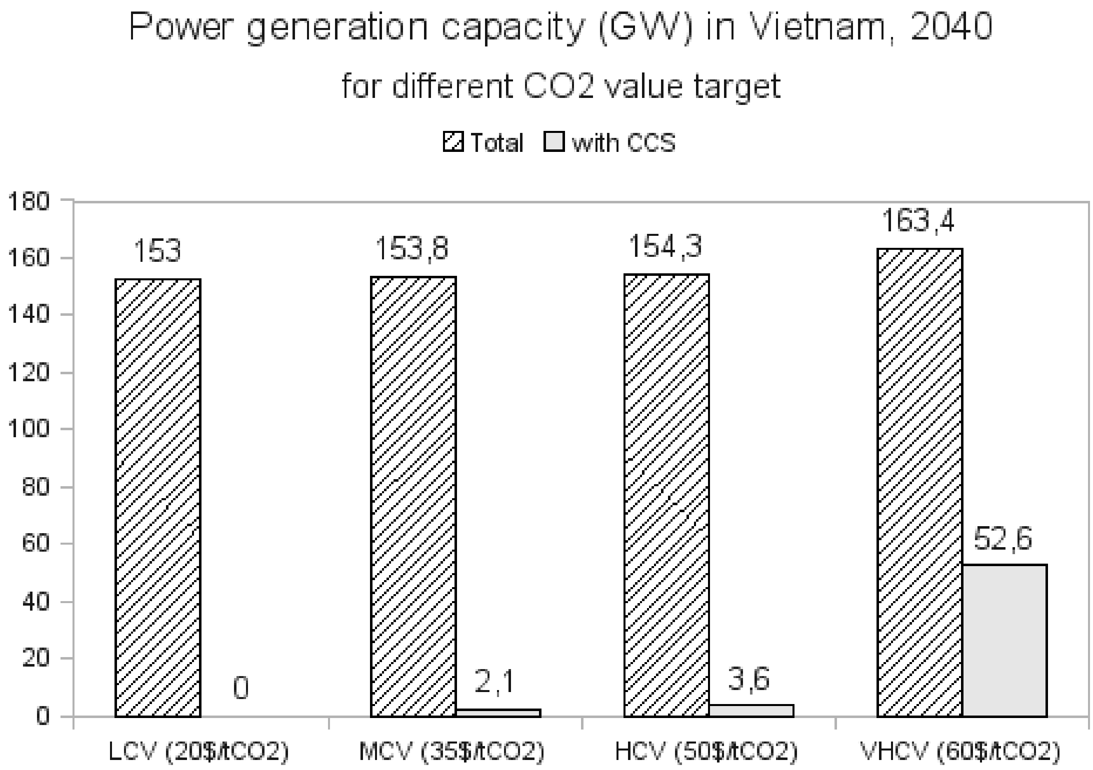

Figure 2: *Summary results of the IRP model simulations. Installed power generation capacity in Vietnam for various level of carbon value, in 2040, total and with CCS.*

In addition, one sub-critical coal-fired generation plant (300 MW) is retrofitted with CCS in 2038 when the price of carbon rises to 33 $/tCO2 and another one (300 MW) enters the system by 2040. As they are called only for three and one year, they provide 1.6 TWh to the grid and save only 1.35 MtCO_2 of emissions.

Between these four plants, the 2.1 GW of generation capacity with CCS is relatively small compared to the 154 GW total energy capacity within the system by 2040 (see Figure 2).

Carbon value in the 'high' case increases gradually from 5 $/t$CO_2$ in 2010 to 50 $/t$CO_2$ in 2040 (HCV). The IRP model computes that four gas-fired generation units with CCS (4x750 MW) would be used, each producing 11.5 TWh per year. The first two units would be dispatched by 2030, the others two one year later. In addition, two supercritical coal-fired generation plants (2x300 MW) with CCS start operating in 2030.

Thus, compared to the previous case, this scenario uses twice the number of CCS gas-fired generation units, it uses higher efficiency CCS coal technology, and uses it sooner. For the period 2030-2040 generation units with CCS would produce 240.6 TWh to the electricity network and reduce emissions by 78 MtCO_2 , nearly twice as much as in the previous case.

We now turn to the very high carbon value case, to explore an upper bound of the abatement potential that CCS has to offer in Vietnam's power sector. The climate policy signal reaches \$60 in 2040. In this case, the simulation's result is a 20% emissions reduction for the power sector compared to the baseline in 2040. CCS in the Vietnamese electricity sector appears a possible key climate policy option. Over 2030-2040, 68 electricity generation plants with CCS would be built. The generation capacity with CCS would start at 5.9 GW by 2030, accounting for 5.4% of the system energy capacity, then increase to 52.6 GW, or 32.2% capacity, by 2040. In terms of energy production, plants with CCS would provide 7.3% of total electricity production (588.4 TWh) by 2030 and 24.6% (1212 TWh) by 2040. The kind of CCS power plants selected by the IRP model were: supercritical coal, IGCC, and NGCC. In terms of cumulative climate policy results, this case suggests that using CCS could save about 1300 $MtCO_2$ during 2030-2040.

5. Discussion and concluding remarks

In 2011, there is still no operational large power plant integrating carbon capture and storage anywhere in the world. In our simulations, it is only by 2030 that the first units come on line in Vietnam. Yet there are a few policy implications relevant in the near-term, if only to keep options open in case the country develops a strong domestic CO_2 emissions mitigation policy in the future.

First, as demonstrated by the White Tiger project proposal, opportunities for EOR by CO_2 injection in Vietnamese oil fields are there now. These could reduce storage costs or even produce a storage co-benefit, enhancing the cost-competitiveness of CCS-based power generation plants in Vietnam. Metz et al. (2005) provided that enhanced oil production onshore with CCS could generate 10-16 \$/tCO_2 of net benefits. This was with oil prices before 2003. Benefits of deploying CCS with EOR in Vietnam could be higher with higher oil prices.

Second, a rational climate policy balances the marginal costs of all mitigation options. Developing coal and gas with CCS in the Vietnamese power sector should be compared to developing renewable energy sources. To this end, we computed another scenario accounting for the reserves of national renewable resources available for electricity production (Nguyen et al., 2009). We found that many GW of power generation capacity using renewable sources like biomass or wind were cost-effective at carbon prices varying from 6 to 10 \$. At these levels, CCS without EOR is not competitive.

Three, there are strong international cooperation efforts pushing towards the development of

CCS in the name of "flexibility mechanisms". Bakker et al. (2011) constructed marginal abatement cost curves for CCS in developing countries in 2020. According to them, there is a 70–100 $MtCO_2$/yr mitigation potential below 30 $/$tCO_{2eq}$, mostly in the natural gas processing sector. To realize this mitigation potential, international agencies are seeking ways to finance CCS projects in developing countries. The United Nations decided at the Cancun conference that CCS could be eligible under the Clean Development Mechanism (CDM) in principle (COP-16, 2010). But this is only if a number of issues are resolved, and the future of the whole Kyoto Protocol system post 2012 is unclear.

Thus financing CCS projects in coal-intensive Asia-Pacific developing countries is still an open climate policy question. When it is resolved, Vietnam may be a natural candidate to benefit from the financial mechanism. Networking and capacity building, for example by joining global CCS institutes and research forums, could help to be ready by then.

Four, there is currently very few, if any, national or regional research center with necessary basic research facilities and infrastructures to study the conditions of CCS development in Vietnam. Other Asian countries are more advanced on this front (GCCSI, 2009). In Indonesia, the national R&S center for oil and gas technology has been designated as the focal point in performing specific research and development of CCS. China has publicly available incentives and policies regarding CCS demonstration and early deployment. In Vietnam some 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.

Five, 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.

To sum up, Vietnam has promising geological formations less than 100km away from fossil-fuel power plants. We found a 20% abatement potential with CCS in the power sector in the case where the CO_2 value go up to 60 $/$tCO_2$ in 2040. With lower carbon values, there is only a handful of generation units with CCS in 2040. Mitigation by using renewable energy sources appears cheaper. EOR with CCS has been already proposed. But the question of how to internalize the value of reducing CO_2 emissions remains open.

6. Acknowledgements

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7. References

Asian Development Bank (ADB), 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review*, Available at: http://www.adb.org/Documents/Books/Economics-Climate-Change-SEA/default.asp.

Bakker, S., Mikunda, T. & Tinoco, R.R., 2011. *Potential impacts of CCS on the CDM*, Available at: http://www.co2-cato.nl/cato-2/publications/publications/potential-impacts-of-ccs-on-the-cdm.

Bureau des Recherches Géologiques et Minières (BRGM), 2009. Où sont les capacités de stockage du CO2 au Viet Nam ? In Forum Économique et Financier, 8th Session. Ha Long, Vietnam. http://www.adetef.org.vn/website/index.php?option=com_content&task=blogcategory&id=30&Itemid=58. Vietnamese version KVN (2009) KHA NĂNG THU GIU KHÍ CO2 TAI VIET NAM ĐÉN ĐÂU ?

Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (COP-16), 2011. Decision 7/CMP.6. Carbon dioxide capture and storage in geological formations as clean development mechanism project activities. Available at: http://cdm.unfccc.int/Reference/COPMOP/index.html.

DNV, 2005. *The White Tiger Oil Field Carbon Capture and Storage (CCS) project in Vietnam*, Executive Board of the Clean Development Mechanism. Available at: http://cdm.unfccc.int/methodologies/PAmethodologies/pnm/byref/NM0167.

Global Carbon Project (GCP), 2010. Carbon Budget and trends 2009. Available at: http://www.globalcarbonproject.org/carbonbudget/ [Accessed July 7, 2011].

Global CCS Institute (GCCSI), 2009. *Strategic Analysis of the Global Status of Carbon Capture & Storage. Report 5: Synthesis report*, Available at: http://www.globalccsinstitute.com/resources/publications/strategic-analysis-global-status-carbon-capture-storage.

IEA Greenhouse Gas R&D Programme (IEA GHG), 2008. *CO2 capture and storage. A key carbon abatement option*, International Energy Agency - Energy Publications. Available at: http://www.iea.org/textbase/nppdf/free/2008/CCS_2008.pdf.

International Energy Agency (IEA), 2010. *CO2 Emissions from Fuel Combustion 2010 - Highlights-*, Available at: http://www.iea.org/publications/free_new_desc.asp?pubs_ID=2143.

Metz, Berg, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.), 2005. *IPCC special report on carbon dioxide capture and storage*, New York, United States: Cambridge University Press. Available at: http://www.ipcc.ch/publications_and_data/_reports_carbon_dioxide.htm

Nguyen, Nhan Thanh & Ha-Duong, Minh, 2009. Economic potential of renewable energy in Vietnam's power sector. *Energy Policy*, 37(5), pp.1601-1613. doi:10.1016/j.enpol.2008.12.026

Nguyen, Nhan Thanh, 2011. *Programmer le développement soutenable dans un pays en voie de développement: Une optimisation sociale du secteur électrique au Vietnam*. Paris, France: Ecole des hautes études en sciences sociales - EHESS. Available at: http://tel.archives-ouvertes.fr/index.php?halsid=59pr23ra5if6eh6ia4755g2o46&view_this_doc=tel-00593573&version=1 [Accessed July 7, 2011].

United Nations, Department of Economic and Social Affairs, Population Division, 2011. World Population Prospects: The 2010 Revision. Available at: http://esa.un.org/unpd/wpp/index.htm [Accessed June 28, 2011].

Shrestha, R.M., and Nguyen, Nhan Thanh 2003. The Integrated Resource Planning (IRP) Model, An User's Guide. *Working Paper*, Energy Program, AIT, Bangkok, Thailand.. http://thanhnhan.nguyen.free.fr/The%20manual%20of%20IRP%20Model%20-%20Version%204.1.pdf [Accessed July 28, 2011]