CCS in Emerging Economies

Identifying the role of CCS in Mexico and Indonesia

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1 Executive Summary

Numerous reports have emphasized the importance of deploying carbon capture and storage (CCS) technologies on a large scale in developing countries. Multi-donor organizations such as the World Bank, the United Nations Industrial Development Organization, the Carbon Sequestration Leadership Forum and the Asian Development Bank continue to fund awareness raising and capacity building programmes, while commissioning specific studies in a number of developing countries. Mexico and Indonesia are two emerging economies with governments that have expressed an interest in the deployment of CCS. Using a cost-optimizing long-term energy systems analysis model, this paper examines the potential role of CCS technologies in Mexico and Indonesia up until 2050. Three scenarios have been developed and tested which assume variable degrees of climate policy stringency, a business as usual, national scenario (based on existing pledges/commitments) and a global agreement ‘2°C’ scenario (most stringent).

The model indicates a relatively early CCS deployment in Mexico from 2030 in all scenarios, whereby CCS is also deployed in the business as usual scenario in order to facilitate enhanced oil recovery. The deployment of CCS in Indonesia is delayed due to a substantial low-cost abatement potential from reducing emissions from land use management, and no CCS appears within the business as usual scenario. Under the most stringent policy targets, coal is completely removed from electricity generation in both countries by 2050, and CCS is deployed on natural gas and biomass-fired power plants. Enhanced oil recovery appears to play an important role in the deployment of CCS in both countries, and this form of storage precedes the use of depleted hydrocarbon fields and saline aquifers. This paper argues that carefully drawing on insights from long-term modelling can also support decisions on prioritizing and targeting of CCS capacity building activities, so that it is most beneficial to emerging economies. Furthermore it is recommended that the use of CCS combined with enhanced oil recovery as a serious abatement option is discussed within international climate negotiations, focusing on establishing project boundaries and monitoring procedures.

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2 Abbreviations

AOSIS	Alliance of Small Island States
BECCS	Bio-energy carbon capture and storage
CCS	Carbon capture and storage
CDM	Clean development mechanism
CO_2	Carbon dioxide
EOR	Enhanced oil recovery
EJ	Exajoule
GDP	Gross domestic product
GHG	Greenhouse gas
Gt	Gigaton
GW	Gigawatt
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KESDM	Republic of Indonesia's Ministry of Energy and Mineral Resources
LULUCF	Land-use, land-use change and forestry
MRV	Measurement, reporting and verification
Mt	Megaton
MW	Megawatt
NPV	Net present value
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational expenditure
PLN	PT Perusahaan Listrik Negara
SBMITB	The School of Business and Management at Bandung Institute of Technology
TIAM-ECN	TIMES Integrated Assessment Model of ECN
TWh	Terawatt hour
UKP4	President's Delivery Unit for Monitoring and Oversight
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar

3 Introduction

Numerous reports have emphasized the importance of deploying carbon capture and storage (CCS) technologies on a large scale in developing countries (e. g. IEA/OECD, 2009, IEA/UNIDO, 2011). Particularly the fast-industrializing and industrialized nations such as Brazil, China, India, Indonesia, Mexico, and South Africa have been highlighted as countries where CCS must be deployed in order to combat climate change. Multi-donor organizations such as the World Bank, the United Nations Industrial Development Organization, the Carbon Sequestration Leadership Forum and the Asian Development Bank continue to fund awareness raising and capacity building programmes, while commissioning specific studies in a number of developing countries. Furthermore, national governments from, e. g., the United Kingdom, Norway and Australia (primarily through the Global CCS Institute) have sponsored a range of CCS related activities and studies. However, direct support to cover investment costs in demonstration projects remains limited.

3.1 Background

In 2010 and 2011 there has been considerable encouragement by certain Parties within the UNFCCC meetings to allow CCS to become an eligible project activity under the Clean Development Mechanism (CDM). Currently the CDM is the only financial mechanism which incentivises investment in CO_2 abatement technologies from developed to developing countries under the Kyoto Protocol. At the UNFCCC Conference of Parties in Durban 2011, CCS was recognized as an official project activity, albeit with the proviso that projects involving CCS must comply with an additional set of regulatory controls[1]. However despite the quite significant lobbying efforts made by Parties including Australia, Saudi Arabia and Norway, the inclusion of CCS in the CDM and the accompanying agreement on the modalities and procedures, there have been no new CCS project proposals submitted to the CDM Executive Board. The low CO_2 price on the carbon market combined with uncertainty on the future of the Kyoto Protocol post-2012 are obvious influencing factors.

Despite the lack of promise on structural mechanisms for financing CCS projects in developing countries under the UNFCCC, certain countries have taken unilateral steps in undertaking national CCS research programs. China and South Africa have outlined concrete steps to realize CCS demonstration plants prior to 2020, and Brazil and Mexico have taken steps to identify potential capture sites, storage locations and opportunities for CO_2 enhanced oil recovery. Recently, Indonesia has also expressed interest in CCS technologies, particularly in combination with biomass use.

3.2 Objectives

The primary goal of this paper is to explore the role of CCS technologies in the fast-industrializing economies of Mexico and Indonesia up until 2050. More specifically, this report will use long-term modeling to identify, based on economic constraints and storage capacity, the following aspects:

- the extent of CCS deployment in 2050,
- the timing of CCS deployment in comparison with other mitigation activities,
- the role of CCS for power generation and in industrial sectors.

In order to make the exercise as robust as possible, three different scenarios will be modeled, based on three different climate targets. Having an insight on the role of CCS in Mexico and Indonesia from an empirical perspective can be useful for national and international decision making. For example, the modeling could provide insights into the diffusion of CCS in specific sectors of industry or types of power generation, which can help target national research and development. More fundamentally, the

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[1] Officially called ‘Modalities and Procedures’ (FCCC/KP/CMP/2011/L.4).

modeling exercise could show that a country can reduce its emissions without the use of CCS in the short to medium term, and such information could be used to support decision making on where to focus international funding for CCS.

3.3 Approach

This paper uses a combination of modeling, literature and first-hand insights to identify the role of CCS in both Mexico and Indonesia up to 2050. The model based approach allows an assessment of the implications of different energy and climate policies, both on national and global level. This quantitative assessment does not aim at forecasting CCS diffusion in Mexico and Indonesia but rather illustrates the dependency of the perspectives of CCS technologies on policy measures. By developing different scenarios, including national policies on greenhouse gas (GHG) reduction and deployment of renewable energies as well as global efforts to combat climate change, the role of CCS technologies is discussed. A detailed account of the modeling methodology can be found in Section 6.1. Literature has been used to provide a background of the current energy consumption and emissions profile of the countries in focus.

Country-specific insights have been attained through in-country interviews. The national insights from Mexico decision-makers have been gathered during ECN's involvement in a CCS workshop organised by the International Energy Agency and the Mexico Secretaria de Energia in March 2011[2]. The insights for Indonesia have been gathered during ECN's involvement in a Bioenergy-CCS (BECCS) workshop in Jakarta on September 2012 hosted by the International Energy Agency, Republic of Indonesia's Ministry of Energy and Mineral Resources (KESDM) and President's Delivery Unit for Monitoring and Oversight (UKP4), the School of Business and Management at Bandung Institute of Technology (SBMITB) and the International Institute for Applied Systems Analysis (IIASA)[3].

3.4 Paper outline

Sections 4 and 5 provide an introduction into the two countries of Mexico and Indonesia respectively. These sections cover the current emissions profile, primary energy consumption, natural reserves and extraction of resources and the structure of the energy and industrial sectors. Furthermore, these sections provide a brief overview of national climate commitments, and existing policy mechanisms for CO_2 reduction, and any ongoing activities on CO_2 capture, storage or enhanced oil recovery. Section 6 documents the modeling methodology, scenario development and a description of the main results concerning CCS deployment. Section 7 aims to highlight modeling outcomes and the recommendations for national energy and climate policies that can be derived for the two countries. Section 8 draws some broad conclusions from the exercise, and recommendations from an international policy perspective.

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[2] IEA-SENER workshop on *CCS in Mexico: Policy Strategy Options for CCS, 7-8th March 2012, Mexico City.*

[3] *Bioenergy, CCS and BECCS: Options for Indonesia, 21st-22nd September 2012, Jakarta.*

4 State of the art of energy and climate issues in Mexico

4.1 GHG emissions and related energy structure issues

Mexico is a fast-industrializing country. Although hit badly by the economic recession of 2009, it has experienced year-on-year GDP growth of approximately 5% since the early 1990's. In line with this increase of economic productivity, the country's CO_2 emissions from fuel combustion have increased by 40% between 1990 and 2009, from approximately 275 $MtCO_2$ to 400 $MtCO_2$ in 2009. Fuel combustion accounted for 85% of total CO_2 emissions in 2008, followed by land use, land use change and forestry (8%), industrial production (6%) and oil and gas production (1%).

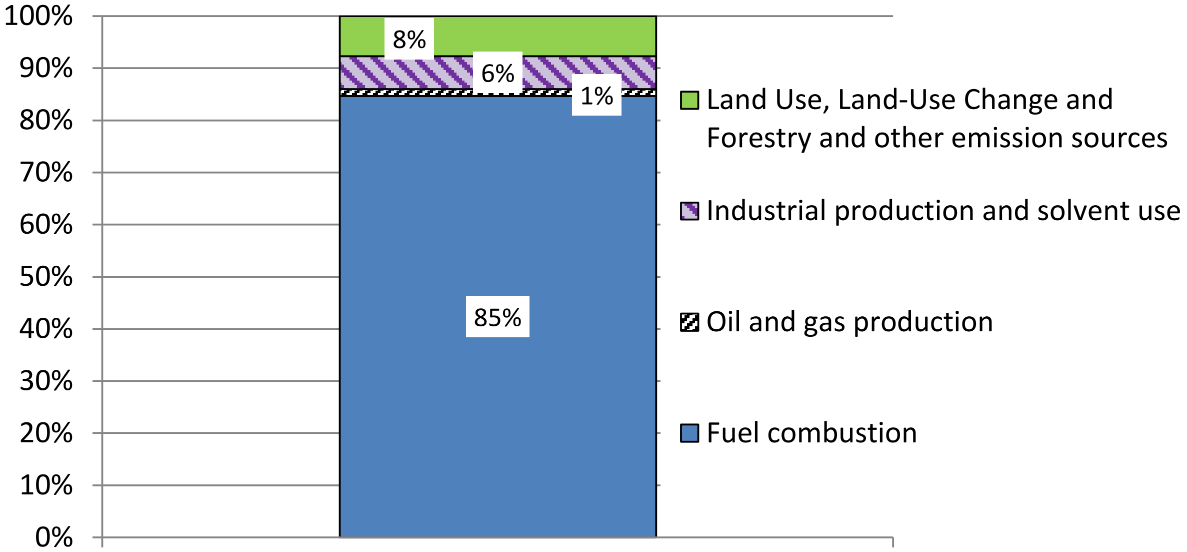

Figure 1:CO_2 emission share by activity in Mexico in 2008 (source: JRC/PBL 2011)

Mexico is the 7th largest oil producer, with oil supplying 57% of the country's primary energy supply, natural gas contributing 28%, coal and peat 4%, and the remainder provided by nuclear, hydro, biomass and renewables (IEA, 2009). Over 60% of the CO_2 emissions from fuel combustion are related to the use of oil, 30% from the combustion of gas and the remainder from coal. In 2009, the transport sector produced the largest amount of CO_2 emissions accounting for 38% (150 $MtCO_2$), with electricity production and heat generation accounting for 30 % (120 $MtCO_2$).

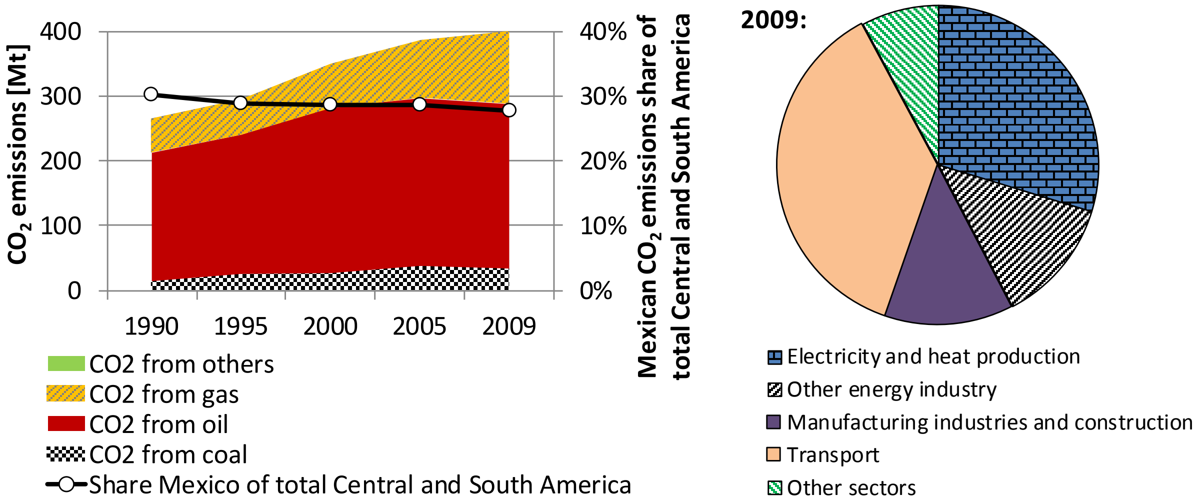

Figure 2: CO$_2$ emissions from fuel combustion in Mexico (source: IEA, 2011)

Mexico's electricity generation is largely dominated by gas-fired power plants. Figure 3 depicts the changing profiles of Mexico's electricity generation infrastructure, which until the turn of the century was primarily focused around the use of fuel oil. Since the mid 1980's, the use of fuel oil has declined and natural gas use increased. The use of coal has also seen a significant increase. The key drivers for the switch from fuel oil to natural gas is the declining national oil production, coupled with an increase of the US natural gas production, which has caused a drop in the regional gas price (IEA, 2012). The use of fuel oil in the Mexican power mix has fallen from 61% to 21% between 2000 and 2010, whereas the share of natural gas has risen from 20% to 55% (SENER, 2011). The trend in the use of natural gas is predicted to continue, with Mexican government intending to double the amount of natural gas infrastructure by 2020. Furthermore Mexico also has abundant shale gas reserves which are yet to be developed (IEA, 2012).

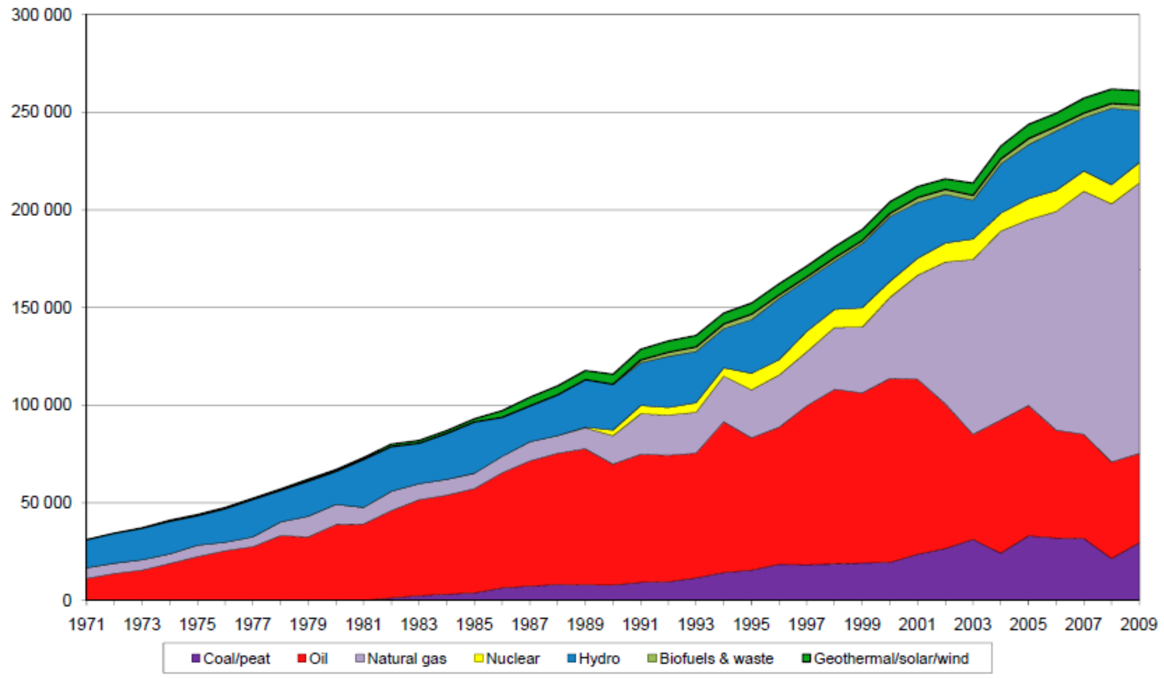

Figure 3: Electricity generation [GWh] in Mexico by fuel (source: IEA 2011b)

Between 1990 and 2006 GHG emissions from industrial processes in Mexico increased by 95% (United Nations Climate Change Secretariat, 2012). The most carbon intensive industry at present are mineral products, primarily cement and lime. Mineral production accounts for 60% of the GHG emissions from the Mexican industrial sector, followed by metal production (20%) (UNFCCC, 2011). Between 2000 and 2008, although the chemical and steel sectors have experienced reductions in energy intensity, the energy intensity of the cement industry in Mexico has actually increased by 1.8% in the same period (ABB, 2011).

4.1.1 Industrial emissions

In 2007, Mexico's cement producers had a combined output of 38.8 million tons of cement. Mexico's leading cement producer is CEMEX, which has a 48% share of Mexico's domestic cement market, operating 15 cement production plants (IBS, 2008). In 2010, cement production accounted for 31 $MtCO_2$, and this amount is expected to increase to 41 $MtCO_2$ by 2020 (CCAP, 2009). In 2008, the Mexican iron and steel industry produced 16.4 million tons of crude steel, ranking as the 15th largest produce globally (WSA, 2008). The crude steel production (conversion of iron ore to steel in a blast furnace) in Mexico accounted for 14 $MtCO_2$ in 2009, with emissions from the recycling of scrap steel (achieved in an electric arc furnace) accounting for 7 $MtCO_2$ (IEA, 2012).

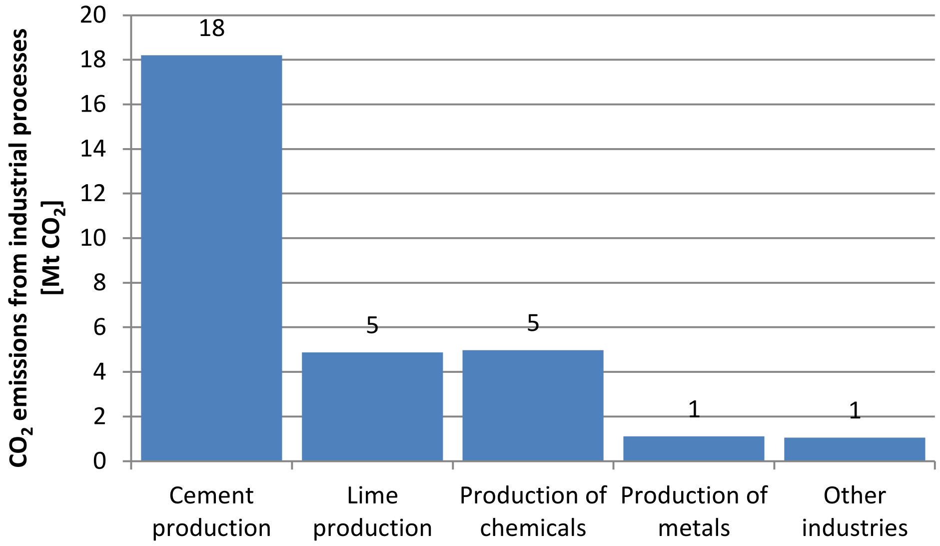

Figure 4: CO_2 emissions related to industrial processes in Mexico in 2008 (source: JRC/PBL 2011)

4.1.2 Oil production

Mexico is the world's seventh largest oil producer, with oil proceeds accounting for approximately 40% of state revenues (IEA, 2012). However Mexican oil production is in decline, with the largest oil field, the Cantarell offshore supergiant oil field, hitting peak production in 2003. According to the IEA (2012), the decline of existing oil fields has not been offset by new finds. At the end of 2010, the reserves-to-production ratio stood at 10.6 years. In order to boost production, secondary oil recovery activities, primarily the injection of nitrogen into fields has been taking place at a number of fields. PEMEX, the national oil company, has been investigating tertiary oil recovery techniques, including the use of CO_2 enhanced oil recovery (EOR). Further information on CO_2 EOR can be found in Section 4.3.

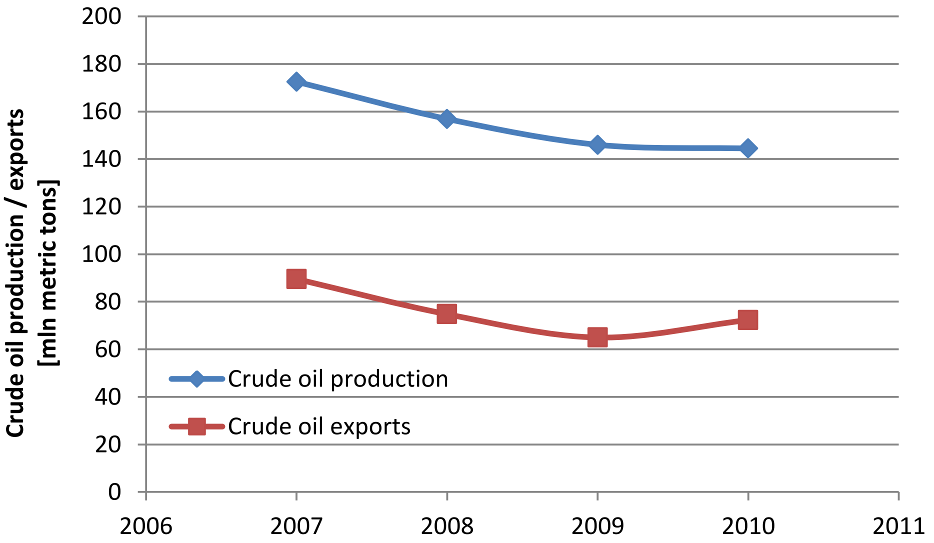

Figure 5: Crude oil production and export in Mexico (source: IEA 2011c)

4.2 Climate commitments

Mexico was the first non-Annex I country to adopt an absolute reduction target for 2050, a reduction of 50% of 2000 greenhouse gas levels. At the UNFCCC Conference of Parties 16 in Cancun in 2010, Mexico made an international pledge to reduce emissions by 30% compared to business as usual (BAU) by 2020, conditional on international financial support. This is considered a very ambitious target. According to Climateactiontracker (2012), Mexico has enacted a number of energy efficiency, renewable energy and greenhouse gas reduction policies between 2008 and 2012. However, an impact analysis of these policies estimates that the envisaged emission reductions will amount to emissions reductions of approximately 12% against BAU by 2020.

The most important action the Mexican government has taken to reduce emissions, is the General Law of Climate Change in Mexico, passed in April 2012. This law enshrines the emission reduction targets mentioned above, including another target for 35% of the electricity generated in the country to come from renewable sources. As well as setting a number of principle objectives of the Mexican climate change law, the act also established the Inter-ministerial Commission on Climate Change (CICC) to coordinate policy development in the various federal agencies, and the Council on Climate Change (CCC) which acts as the permanent consultative body of the CICC (IDLO, 2012). The law also obliges the Ministry of Finance in combination with other relevant ministries to develop systems of subsidies and incentives for non-fossil fuels, energy efficiency, sustainable public transport and renewable energy generation.

At this early stage of climate change policy, there are no concrete policies that can act to incentivise the deployment of CCS. Existing policies in electricity generation and industrial production are generally targeted to energy efficiency and co-generation technologies. There are currently no taxes on carbon or emissions trading scheme in place.

5 State of the art of energy and climate issues in Indonesia

5.1 GHG emissions and related energy structure issues

Indonesia has the fourth highest population in the world and the third fastest growing economy with a 5.2% year-on-year increase in primary energy consumption. The CO_2 emissions of Indonesia are dominated by land use change and forestry, and also by peat fires. Estimations of peat fires and land-use change in Indonesia have considerable uncertainty, but in the second National Communication to the UNFCCC the figure of 1.1 $GtCO_2$ for the year 2000 was stated. The emissions from the combustion of fossil fuels are more reliable, with annual CO_2 emissions of approximately 375 $MtCO_2$ in 2008 (EDGAR, 2008). The average growth in industrial emissions is around 7% per year, with business as usual scenarios indicating that CO_2 emissions could rise to 1.15 $GtCO_2$ per year by 2025 (Minchener, 2012). Nevertheless, Indonesia has currently one of lowest CO_2 per capita levels amongst fast-industrialising developing economies, behind Thailand, Brazil and Mexico. In 2009, only 65% of the population had access to electricity.

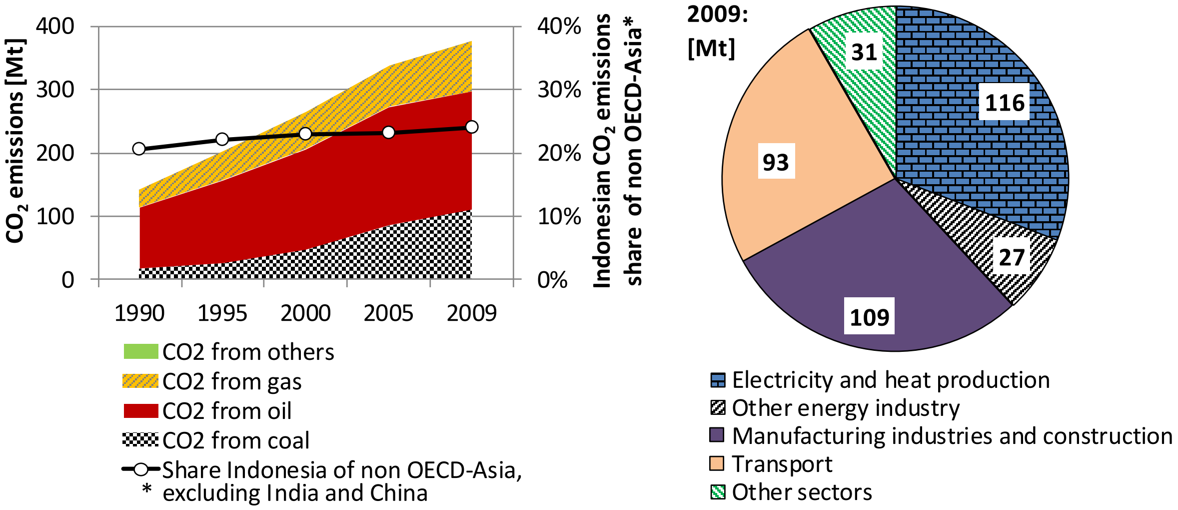

Figure 6: CO_2 emissions from fuel combustion in Indonesia (source: IEA 2011)

Indonesia has huge proven reserves of natural gas, hard coal and lignite, and significant proven reserves of oil. Based on current demand, this equates to over 80 years national supply of natural gas, and around 250 years supply of hard coal and lignite combined (BGR, 2010). One limiting factor for the development of Indonesia's resource exploration are the restrictions and regulatory burdens on foreign investments. The proven reserves of oil are 550 Mt. Annual demand outstrips supply by 62 Mt to 49 Mt (BGR, 2010).

Until the mid 1980s, electricity generation in Indonesia was dominated by oil. Since then, coal has become the primary fuel source in the power sector at 47%. Natural gas also increased to 33%. In 2009, Indonesia's installed power generation capacity was 27.8 GW_e, with fossil fuels accounting for 86%, 8% hydroelectric and 6% from geothermal and other renewables (IEA, 2009). 86% of the country's power generation capacity is owned and operated by PT Perusahaan Listrik Negara (PLN), which holds the monopoly over distribution activities (Minchener, 2012). It is understood that demand for electricity is increasing at a rate of 8% per year, and demand is outstripping supply.

PLN estimates that 2,500 MW of new power generation capacity is needed each year. In 2006 the Government of Indonesia announced a fast track programme to install an additional 10 GW of coal-fired power generation by 2010, which has subsequently been delayed to 2013 (Minchener, 2012). This additional capacity is expected to produce an additional 55 Mt CO_2.

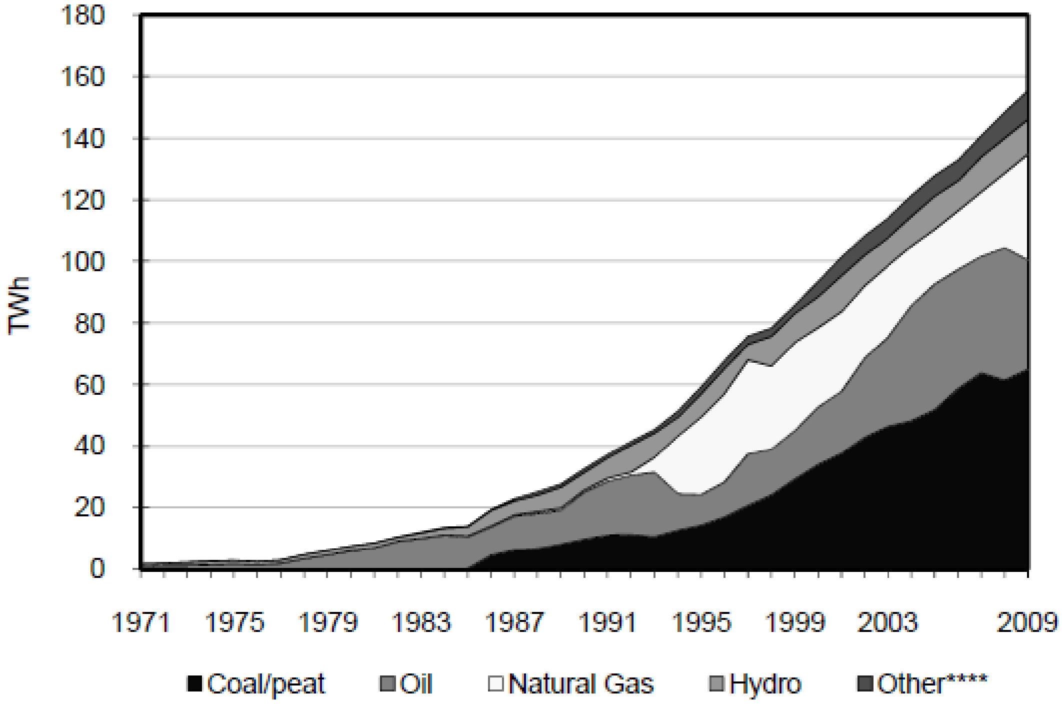

Figure 7: Electricity generation in Indonesia by fuel (IEA, 2011b)

5.1.1 Industrial emissions

Total emissions from the Indonesian industrial sector were 45 Mt CO_2, in 2005. The mineral sector, accounted for approximately 70%, followed by production of chemicals (20%) and the bulk of the remaining emissions from metal production. The emissions from the mineral sector are largely from cement production, while the chemical sector emissions are largely related to ammonia production. In 2009, the combined CO_2 emissions from oil refining and natural gas processing were estimated at 17.3 Mt CO_2 (DECC, 2009).

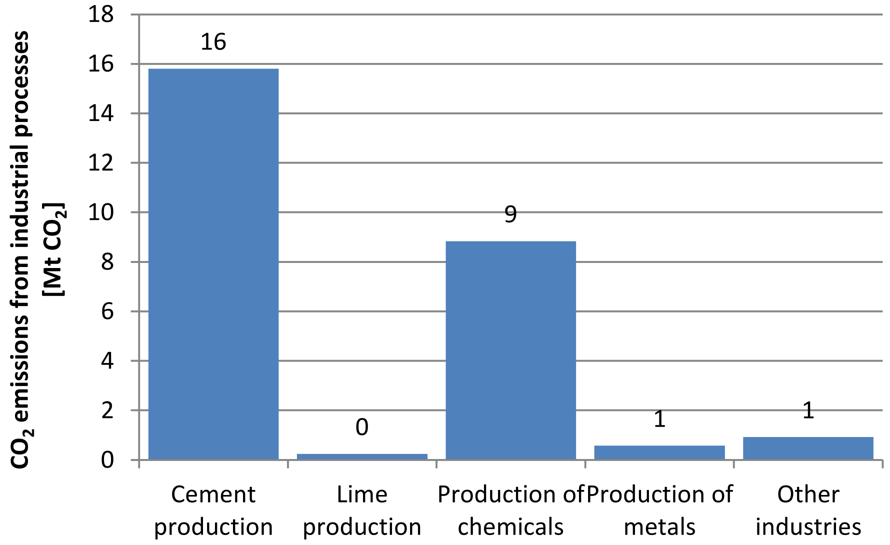

Figure 8: CO_2 emissions related to industrial processes in Indonesia in 2008 (source: JRC/PBL 2011)

5.1.2 Oil production

Indonesia's oil production peaked in 1977, producing 1,65 million barrels per day without any enhanced oil recovery techniques used. Oil production peaked again in the early nineties, when Chevron Pacific Indonesia implemented enhanced oil recovery techniques using a combination of steam and water injection into aging fields in Sumatra. Since 1995, oil production has been declining quite rapidly, with production capacity mainly dominated by mature fields. Indonesia's oil and gas regulator BPMigas, announced in 2012 that the oil companies Chevron, Pertamina and Medco were proposing further use of enhanced oil recovery techniques, and urged other oil producers operating in the country to do the same (AsiaOne, 2012).

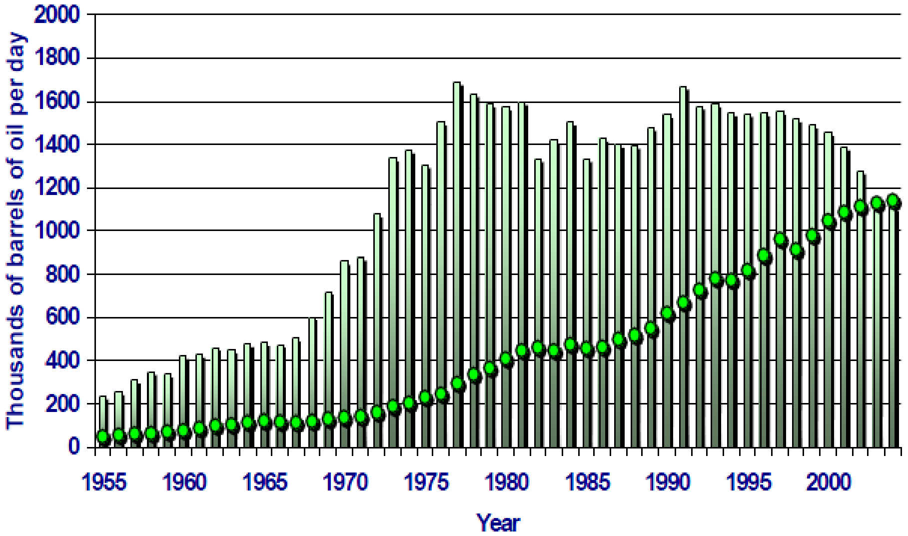

Figure 9: Oil production (bars) and consumption (dots) in Indonesia (1955-2005) (Kadir et al. 2010)

5.2 Climate commitments

At the G20 meeting in Pittsburgh in 2009, the Government of Indonesia committed to voluntarily reduce GHG emissions by between 26% and 41% compared to a ‘business as usual’ scenario. The lower value relates to a reduction that can be reached through unilateral actions, with higher emission reductions based on international support. The business as usual scenario has yet to be developed, but will need to be based on detailed sectoral data and in line with national development priorities. In 2011 presidential decree 61 was signed into force, creating a National Action Plan to Reduce GHG Emissions, known as RAN-GRK, for implementing activities that directly or indirectly reduce GHG emissions according to the national target. Activities for achieving the unilateral targets include:

- sustainable peal land management,
- reduction of the rate of deforestation,
- energy efficiency,
- carbon sequestration though forestry,
- reduction of solid and liquid waste,
- low emission transportation.

Currently, each of the 33 Indonesian provinces are developing provincial level action plans, identifying suitable mitigation actions and developing the multi-sectoral BAU baselines which allow to determine emissions reductions. As of September 2012, roughly one-third of the provinces have developed an action plan (Sekretariat-rangrk, 2012).

In total, the national 26% reduction proposed is translated into an abatement of 767 $MtCO_2e$ per year by 2020. The greatest emphasis on emission reductions is placed on forestry and peat land management, expected to achieve a saving of 672 $MtCO_2e$. The contributions of industry, energy and transportation are relatively small, at 1 MtCO2e and 38 $MtCO_2e$ respectively, although these figures could increase to 5 MtCO2e and 56 $MtCO_2e$ with international support (the 41% target) (Brulez, 2012).

In terms of general energy policy in Indonesia, in 2006 the Presidential Decree No.5/2006 was passed, which sets an energy supply mix target for 2025. This target includes reducing the share of oil to less than 20% (cf. the share of 55% in 2005), increasing the share of natural gas to 30% (22% in 2005), increase the share of coal to more than 33% (17% in 2005), and with 5% targets for renewables, geothermal and the use of biofuels. There is also a minimum 2% target for the production of liquefied coal (MOE Republic of Indonesia, 2010).

There are currently no specific policies or instruments for the reduction of CO_2 in Indonesia which could potentially provide an incentive for CCS. However, Indonesia has welcomed awareness raising and capacity building actions that have been offered by multinational organizations. In 2009, the UK Department for Energy and Climate Change commissioned a significant study to assess the potential for CCS in Indonesia, including source-sink matching and transportation possibilities (DECC, 2009).

The Asian Development Bank recently announced the possibility of co-financing a CCS pilot project in Indonesia, with between 10-12 million USD provided to the ADB by the UK government (Thakaran, 2012). A pilot project could be co-financed by the Government of Japan, with Japanese entities already involved in two CCS studies, one commercial (no public information available), and one by the Japanese Petroleum Exploration Company and the Institute Teknologi Bandung which is investigating technologies for access deep strata at sites of CO_2 injection (SATREPS, 2011).

6 Perspectives of CCS Technologies

6.1 Methodology

The deployment of CCS technologies depends on the energy and climate policy framework set on national and global level. In order to assess the impact of different policy measures on the perspectives of CCS technologies in the two emerging countries Mexico and Indonesia, a model based approach is applied. By the use of a scenario analysis the role of CCS technologies to meet the set policy targets is quantified. Thereby the model-based analysis focuses rather on the long-term perspectives than on the near-term development.

TIAM-ECN is the TIMES Integrated Assessment Model of ECN used for long-term energy system analysis. TIAM-ECN has a global scope, represented by 15 world regions of which Mexico is a single region and Indonesia is part of the region “Central and Southeast Asia”. TIAM-ECN is a linear optimization model simulating the development of the global energy economy from resource extraction to final energy use for the time horizon until 2100. The objective function of TIAM-ECN is the minimization of the total discounted aggregated energy system’s costs calculated over the full time horizon and summed across all regions. The main cost components included in the objective function are the investment costs and fixed plus variable operation and maintenance costs for the energy conversion technologies. TIAM-ECN is characterized by a comprehensive technology database, representing various fuel transformation and energy supply pathways. With respect to CCS technologies, the TIAM-ECN model consists of different types of CCS power plant technologies (pre-, post- and oxyfuel-combustion for coal, natural gas and biomass) as well as CCS for industrial applications and for the production of alternative fuels like hydrogen. CCS-related research work based on TIAM-ECN can be found in Rösler et al. (2011), Keppo and van der Zwaan (2012) and van der Zwaan et al. (2012). Since TIAM-ECN is based on a partial equilibrium approach with demands for energy services responding to changes in their respective prices through end-use price elasticities, savings of energy demand and corresponding cost variations are accounted for in the objective function as well.

Apart from EOR, the deployment of CCS is heavily dependent on commitments to reduce greenhouse gas reductions, either through national or worldwide agreements and subsequent measures. Three scenarios are introduced representing three different developments concerning GHG reduction commitments and policy measures on efficient energy use and renewable energies (Table 1).

Table 1: Scenario definition

Scenario	Description
BAU	Business as usual, No climate policy measures
NAT	National climate policies according to Copenhagen pledges and assumed continuation
GLO	Global coordinated action to reach global 2˚C climate target, including strong national climate policy measures for the transition phase to the coordinated action

The business as usual scenario (BAU) includes no direct measures to reduce GHG emissions through an emissions cap or carbon tax. Moreover, in the BAU scenario a strengthening of the today’s efforts to support the deployment of renewable energies and other low carbon technologies is not assumed. Consequently the energy supply and the resulting emissions reflect a least-cost supply trajectory without climate policies.

Although there exists no global coordinated scheme for the long-term reduction of GHG emissions, unilateral GHG emission reduction commitments have been pledged during the UNFCCC climate conferences in Copenhagen and Cancun (UNFCCC 2011). Several countries revised their targets and raised adopted mitigation targets later on (Climateactiontracker 2012). Due to the fact that for some countries more than one emission reduction target has been stated or climate targets might be ambiguous or related to the general development of the climate policy negotiations, significant uncertainties concerning the national mid-term targets exist. With respect to the ambition of the GHG mitigation targets a set of less ambitious climate policy targets and a stringent one can be identified.

In the scenario NAT the existence of less ambitious national climate policy measures is assumed for 2020 as well as additional measures to support low carbon technologies (renewable energies and nuclear). These targets have been implemented for each model region. For the EU-27 a GHG reduction by 2020 of 15% compared to 2005 statistical data is implemented. For Mexico and Indonesia GHG reduction targets for 2020 are related to the BAU-emission[4] level and are assumed to reduce in the NAT scenario by 12% for Mexico and by 11% for Indonesia. Past 2020 the continuation of national efforts to reduce GHG emissions is implemented in the NAT scenario. With respect to the contribution of renewable energies to total electricity generation in 2020 a share of 17% has been targeted for Mexico and 8% for Indonesia.

The scenario GLO represents a climate policy framework with ambitious GHG reduction targets not only on national level but also on global level. For the near term the existence of stringent national climate policies is assumed, leading to a global coordinated action by at least mid of the century in order to reach the global long term climate target of the limitation of global mean temperature increase by the end of the century to 2 °C compared to pre-industrial level. Consequently, the national GHG reduction targets set for the year 2020 are below those of the NAT scenario, which means for the EU-27 a reduction compared to 2005 by 25% by 2020 and for Mexico a reduction by 22% by 2020 compared to the BAU scenario and for Indonesia by 20% respectively. In addition to the ambitious GHG reduction targets, scenario GLO also includes strong policies on low carbon technologies. The scenario assumes a share of renewable energies of total electricity generation of 35 % in 2020 for Mexico and 15% in 2025 for Indonesia.

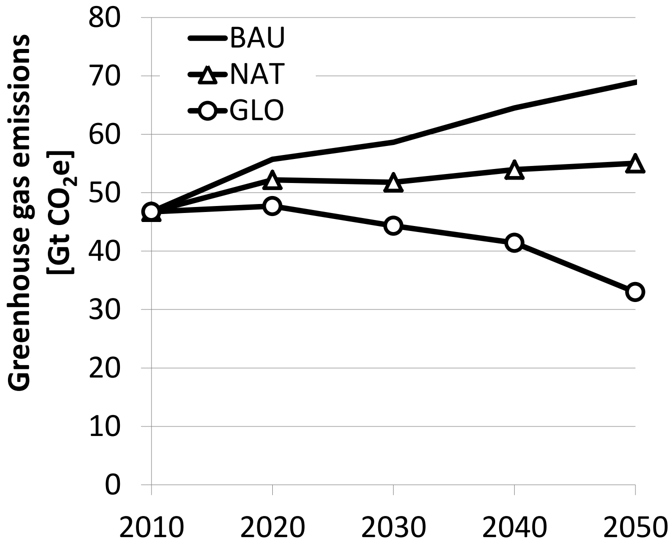

Figure 10: Global greenhouse gas emissions in the three policy scenarios

Driven by the increasing population (worldwide 9.2 billion in 2050) and the economic growth (on average 2.9% p.a. between 2010 and 2050) the global GHG emissions increase in the BAU scenario to about 60 $GtCO_2e$ in 2030 and almost 70 $GtCO_2e$ in 2050 (Figure 10). Under the absence of climate policies the growing energy demand is mainly satisfied by the use of fossil fuels. Between 2010 and 2050, the primary energy consumption increases by 70% to 730 EJ worldwide, whereas coal consumption more than doubles. Less ambitious national climate policy targets (NAT) would lead to a reduction of global GHG emissions compared to the BAU scenario by 4 $GtCO_2e$ in 2020 and 14 $GtCO_2e$ in 2050. Compared to 2010 this is equivalent to an increase of global GHG emissions by 8 $GtCO_2e$ until mid of the century. Under stringent climate policy targets (GLO) GHG emissions in 2020 are about 8 $GtCO_2e$ below the baseline, meaning a stabilisation of GHG emissions on the level of 2010. In the long-run GHG emission decline to 44 $GtCO_2e$ in 2030 and 34 $GtCO_2e$ in 2050, which is in 2050 half of the baseline emissions.

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[4] The GHG emissions of the BAU-scenario used in this analysis deviate from those stated by the countries within their national communication to UNFCCC. Thus, the national emission reduction targets referring to the Copenhagen pledges and the Cancun pledges have been amended for the climate policy scenarios used in this analysis.

6.2 The role of CCS under different energy policy regimes in Mexico

6.2.1 Greenhouse gas emissions and primary energy consumption

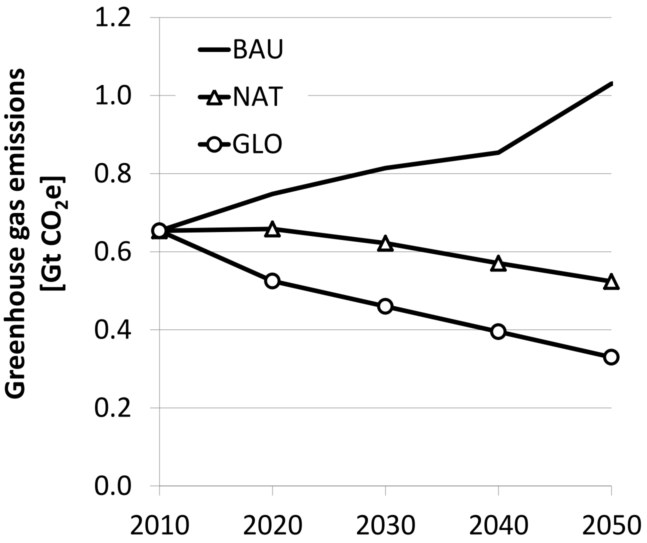

Figure 11: GHG emissions in Mexico in the three policy scenarios

The GHG emissions in Mexico increase in the BAU scenario from 0.65 Gt in 2010 to about 0.8 Gt in 2030 and 1 Gt in 2050 (Figure 11). Although no explicit GHG reduction targets are included, the BAU scenario is characterised by a strong diffusion of modern energy conversion technologies and efficiency improvements. Thus the GHG emission development of the BAU scenario is below the baseline of the 4th national communication to the UNFCCC and corresponds for the near-term closely to the development of the emission at current policies (Climateactiontracker 2012). In the scenario with a less stringent national GHG mitigation target (NAT) the GHG emissions remain at the current level until 2020 and decrease further with an annual reduction of about 1% until 2050. The reduction in 2020 corresponds to a reduction target of 20% compared to the baseline without current policy measures and a reduction target of 12% compared to the baseline with policy targets (Climateactiontracker 2012). The scenario GLO shows a GHG emission pathway with very stringent near- and long-term climate policy targets (30% compared to the baseline without climate policy measures in 2020 and 50% reduction by 2050 compared 2002 level). In scenario GLO the Mexican GHG emissions until 2050 are rather determined by the strong national climate policies than by the mitigation obligations arising from a global coordinated action in order to achieving the 2˚C climate target.

The GHG emissions trajectories as well as the achievement of the GHG mitigation targets are strongly related to the development of the CO_2 emissions. Near-term policies affect especially the CO_2 emission in the electricity sector in which the least-cost GHG mitigation options can be found. In the long run, the electricity sector offers the opportunity to realise negative emissions by applying biomass-based CCS technologies. For deep emission reductions this flexibility of the electricity sector allows the sectors with more costly GHG mitigation options, like the transport sector or certain industry branches, to reduce less or to shift their emission reductions to later periods. Consequently, the electricity sector reduces its CO_2 emissions disproportionally compared to the other sectors.

In 2030, the CO_2 emissions in the electricity sector reduce compared to baseline by 40% in the NAT scenario and under strong national climate policies and global coordinated action (GLO) by more than 90%.

Additional to the emission reductions in the power sector, CO_2 mitigations in the industry and transport sectors is necessary. However, GHG mitigation measures in these sectors are more costly compared to those in the power sector and thus realised later.

The primary total energy consumption doubles from the 2010 level of 7.4 EJ until 2050, independent of the climate policy. However, the climate policies have a significant impact on the fuel mix and choice of technologies (Figure 13). Fossil fuels remain dominant, while renewable energies grow substantially under climate policies.

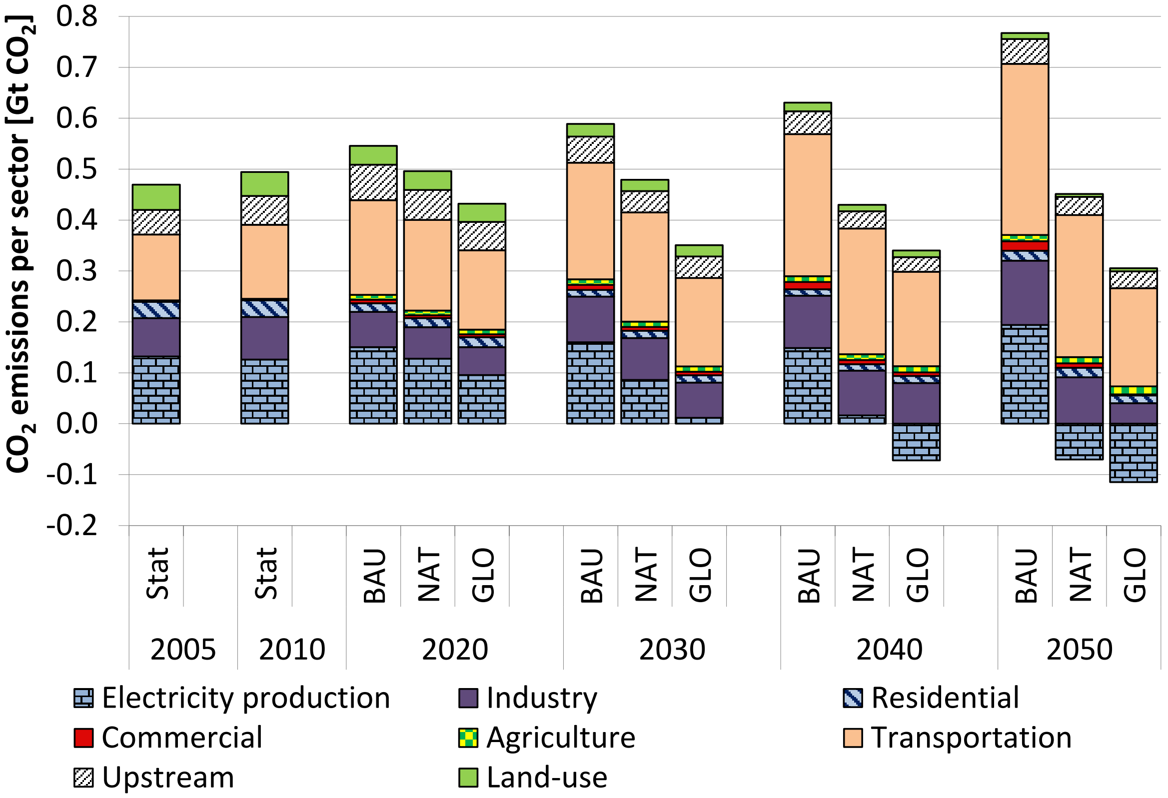

Figure 12: Development of CO_2 emissions in Mexico in the three scenarios

For future use of fossil energy under a carbon constrained energy policy, CCS technologies play an important role (scenarios NAT and GLO). But there are also opportunities for CCS independent of climate policy issues but related to enhanced oil recovery (scenario BAU).

Mexico's near-term targets to reduce GHG emission and the opportunities to increase oil production are drivers for starting the deployment of CCS technologies in 2020 in all three scenarios. At capture quantities between 2.3 and 3.5 $MtCO_2$ in 2020, CCS technologies are initially applied in the electricity sector. Depending on the GHG mitigation obligation coal (BAU) or natural gas technologies (NAT and GLO) are applied. With respect to the total primary energy consumption fuel consumption in CCS technologies represents less than 1% in 2020. The share of CCS technologies of primary energy consumption grows to 2 – 4% in 2030 and to 7 – 29% in 2050. When climate policies are in place (NAT and GLO), coal is hardly used without CCS past 2040. In the BAU scenario coal consumption grows by a factor of seven between 2010 and 2050 to 2.5 EJ in 2050 with a CCS share of 38%. This increase of coal is not reached in the climate policy scenarios, in which coal consumption increases compared to 2010 by a factor of two to three. Depending on the stringency of the climate target, CCS technologies using coal are applied for different energy supply purposes. Under the less stringent climate policy targets (NAT), coal based CCS technologies are preferably applied for the generation of electricity, whereas under very strong climate targets alternative fuels (esp. hydrogen) are produced from coal with CCS technologies. Hydrogen transport systems with fuel cells allow deep GHG emission reduction in the transport sector by both high combustion efficiencies compared to internal combustion engines, resulting in a lower energy consumption and a carbon-free combustion process. Thus CCS technologies contribute indirectly to the decarbonisation of the transport sector.

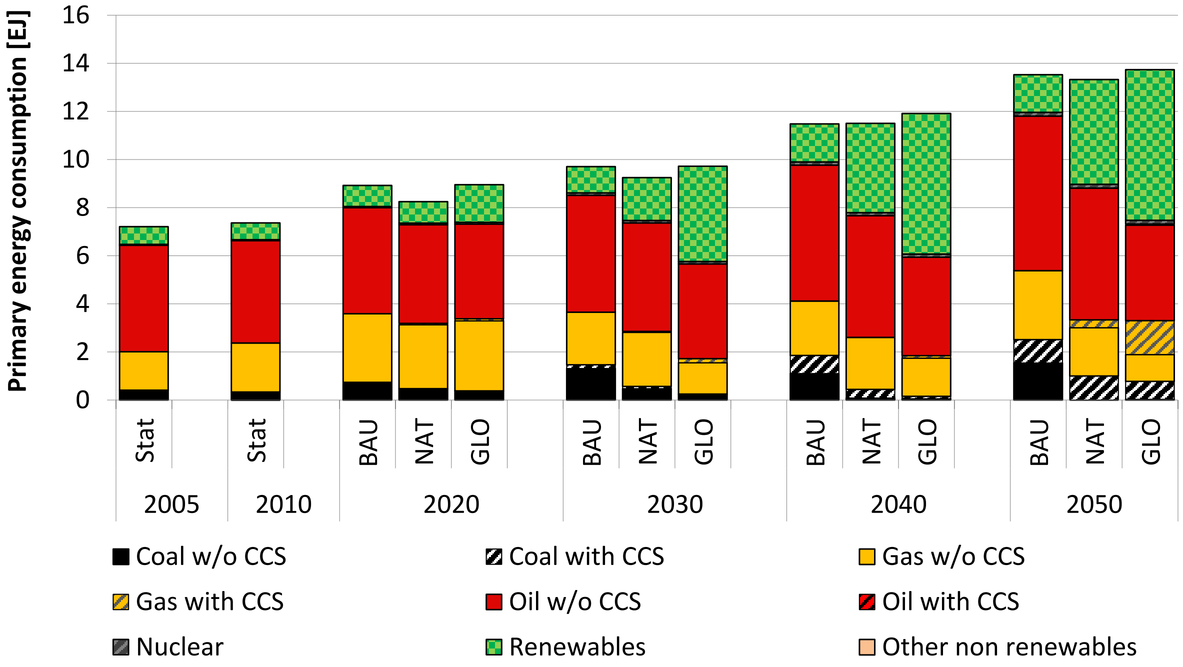

Figure 13: Primary consumption in Mexico in the three scenarios

Apart from fossil fuels, which retain their dominant share of the primary energy consumption until 2020, renewable energy consumption increases significantly. From a share of about 10% in 2010 they grow by 2050 to about 12% in the BAU scenario, 33% in the NAT scenario and 46% in the GLO scenario.

6.2.2 CCS in the electricity sector

Major deployment of renewable energy can be observed for the electricity sector (Figure 14). Depending on the policy scenario renewable energies gain a share of total electricity generation in 2050 between 20% (BAU) and 75% (GLO).

Assuming CCS technologies are commercially available by end of this decade, CCS deployment in Mexico starts in 2020 with about half a GW based on coal in BAU and with 1 to 1.5 GW natural gas CCS (Figure 15). Natural gas CCS represents the option with the lowest specific CO_2 emissions among fossil-fuelled technologies and would be a preferred option to meet the near-term climate targets at a strong growing electricity demand.

Post 2020 a further 14 GW of coal CCS capacity are commissioned in the BAU scenario until 2050, generating up to 110 TWh (2050) and delivering up to 75 $MtCO_2$ p.a. for enhanced oil recovery. No other CCS technologies are applied in the BAU scenario. According to the cost assumption for carbon capture technologies as well as for CO_2 transport and storage the supply of CO_2 for EOR could be realised at 40 USD/tCO_2.

The comparison of the scenarios shows, that with increasing stringency of the climate targets coal based CCS technologies are substituted by natural gas based ones. In order to gain net negative emissions biomass CCS technologies become competitive. Under less stringent climate policies (NAT), CCS capacity additions between 2030 and 2050 amount to 14 GW for coal and 16 GW for biomass and 2 GW for natural gas. Under more ambitious climate targets (GLO) coal based CCS power plants are less advantageous compared to natural gas and biomass. Consequently 11 GW of natural gas CCS and 17 GW of biomass CCS power plants capacity is added between 2030 and 2050 in scenario GLO.

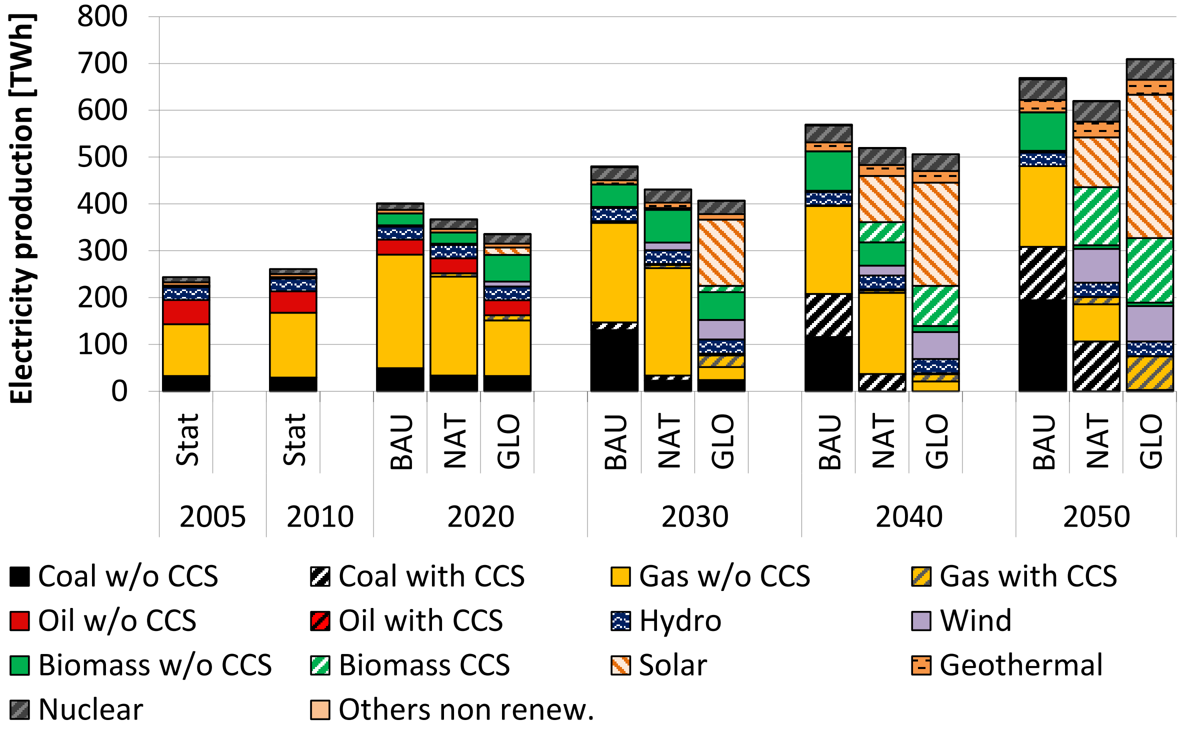

Figure 14: Electricity generation in Mexico in the three scenarios

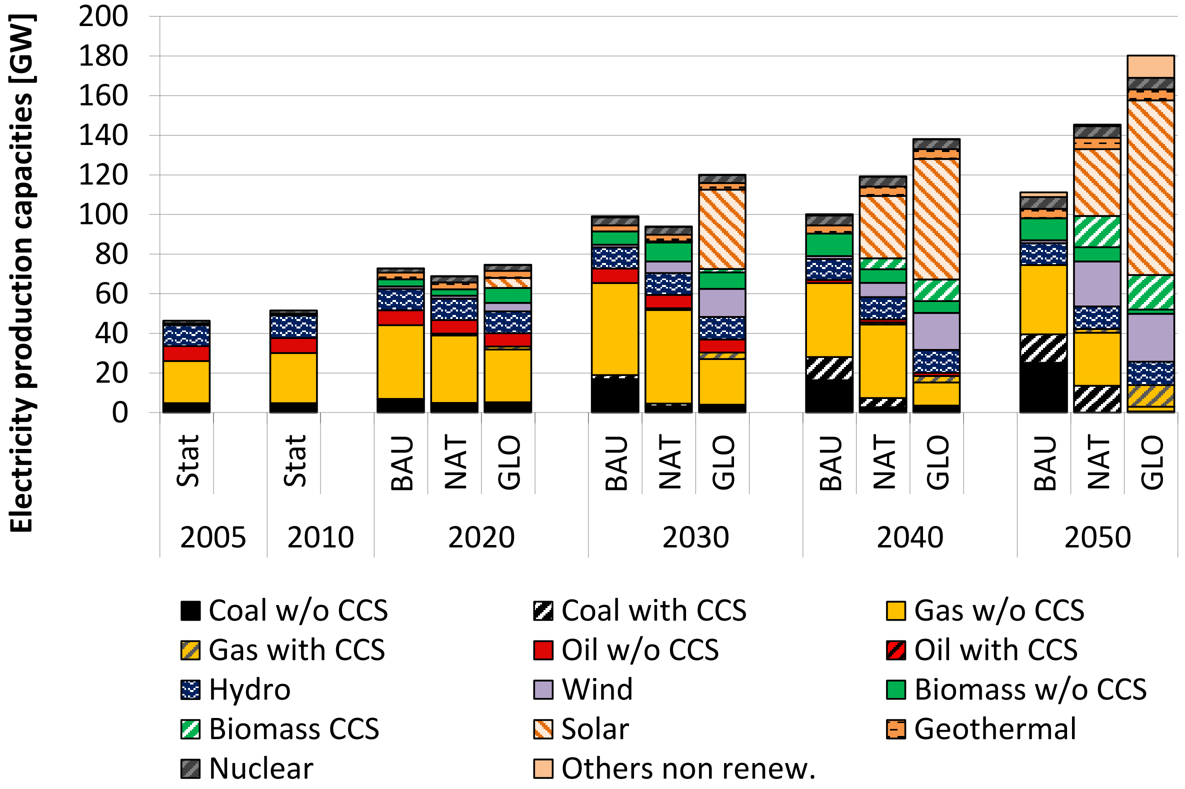

Figure 15: Electricity generation capacity in Mexico in the three scenarios

6.2.3 Carbon captured and stored

Over the time horizon until 2050 the total capture quantity accumulates to 1.8 $GtCO_2$ in the BAU scenario, 2.9 $GtCO_2$ in the NAT scenario and 3.7 $GtCO_2$ in the GLO scenario (Figure 16). An uptake of carbon capture and storage can be observed in 2040 with annual capture quantities larger than 50 $MtCO_2$. In the GLO scenario the highest annual quantity of carbon captured is reached with 260 $MtCO_2$ in 2050.

CCS from electricity generation represents the main carbon capture source among all three scenarios. With respect to the cumulative CO_2 quantities, the share of CO_2 being captured in the electricity sector varies from 92% (BAU) to 63% (GLO). This shows that CCS represents an important GHG mitigation technology for the industry sector and for the upstream fuel production and transformation. In scenario GLO about 0.8 $GtCO_2$ are captured in the upstream sector until 2050, mainly from hydrogen production (0.6 $GtCO_2$) and from natural gas production (0.2 $GtCO_2$). In the industry sector about 0.6 Gt CO_2 is captured until 2050, primary from natural gas based processes (80%) and coal using processes (20%).

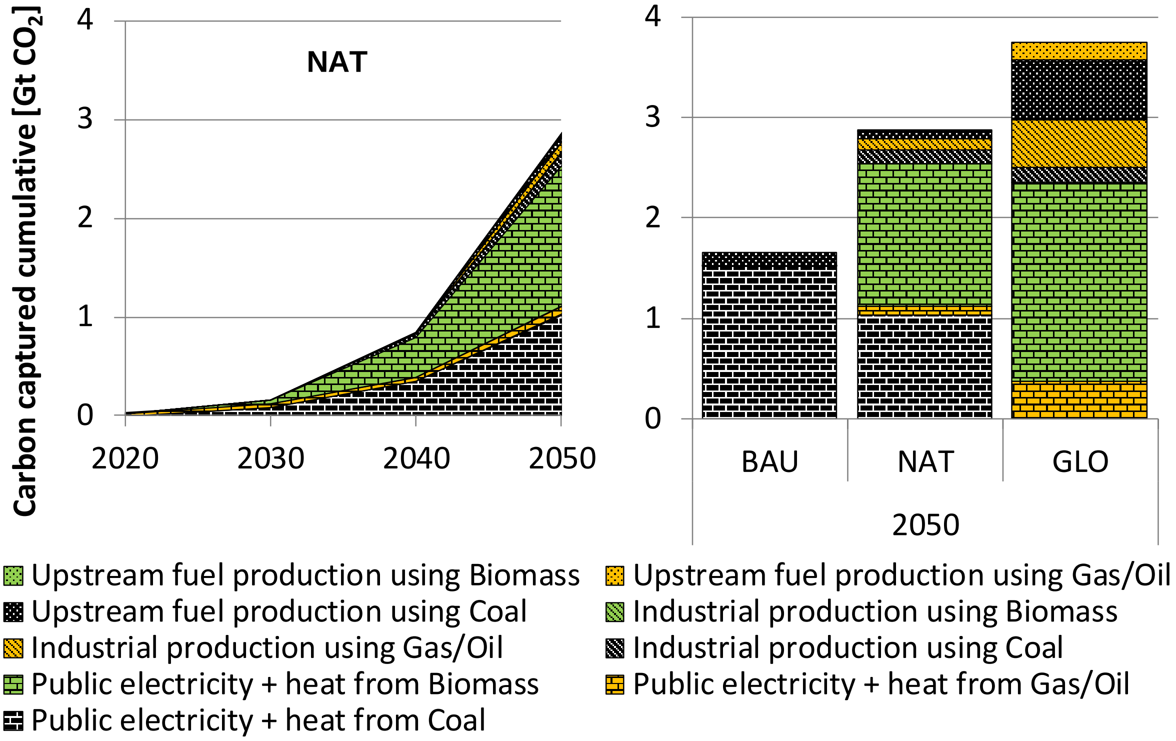

Figure 16: Cumulative CO_2 captured and stored in Mexico

CO_2 used for enhanced oil recovery and stored underground is the dominant storage option in all three scenarios until 2040 (Figure 17). The annual injection of CO_2 to increase oil production grows from 2-3 $MtCO_2$ p.a. in 2020 to 80-94 $MtCO_2$ p.a. in 2050. Under the assumed cost parameters for CO_2 transport and storage with EOR (12 USD(2005)/tCO_2 stored), CCS contributes in all scenarios to compensate decreasing crude oil production by injecting 1.8 $GtCO_2$ until 2050 (Figure 18). This quantity corresponds to the assumed total EOR storage capacity for Mexico and implies entire usage of the available EOR capacities by mid of the century. At recovery rates of 0.35-0.45 t CO_2/bbl (GCCSI, 2012) EOR can increase the total crude oil production by 26 EJ until 2050, corresponding to 8% of the total conventional crude oil resources (proved reserves and new discoveries) or 30% of the proved reserves of about 14 billion barrels (Talwani, 2011).

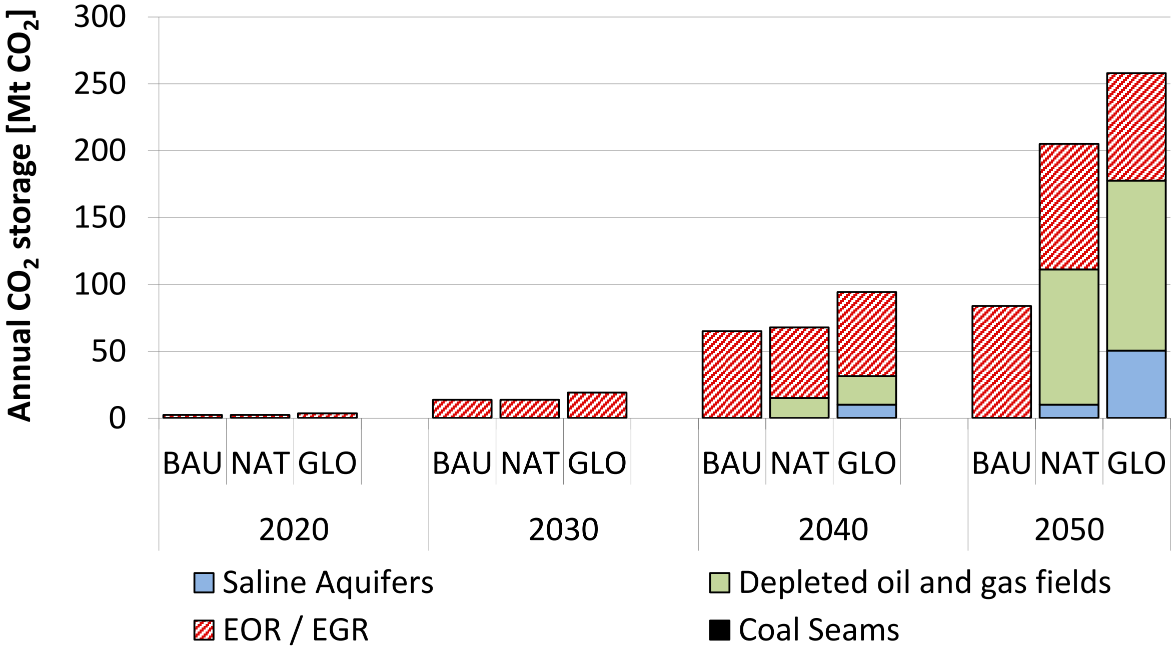

Figure 17: Annual CO_2 storage in Mexico

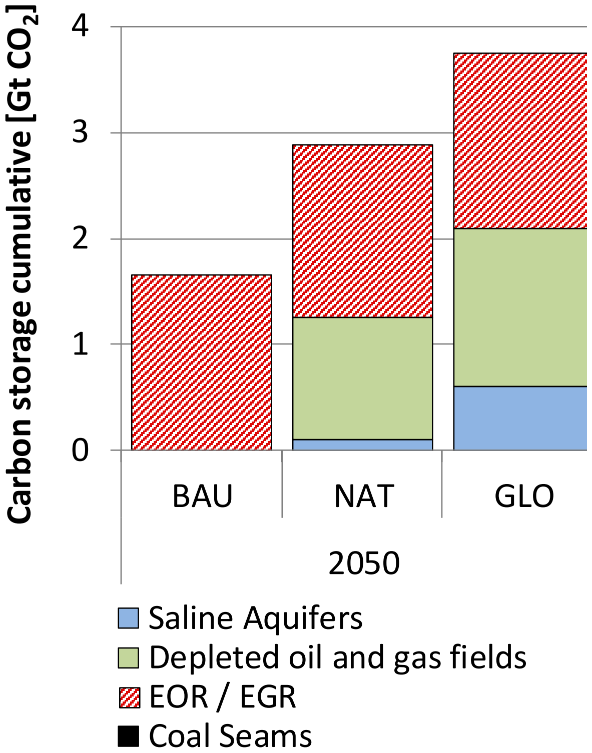

Figure 18: Cumulative CO_2 stored in Mexico

Although the domestic oil consumption decreases under the existence of climate policy measures, mainly due to substitution effects in the demand sectors, EOR remains an important CO_2 storage option in the scenarios NAT and GLO. Besides EOR, CO_2 is also stored in depleted oil and gas fields beginning in 2040. Since the assumed EOR storage capacity is almost reached in 2050 deployment of saline aquifers and depleted oil and gas fields is required to store the captured CO_2. Annual storage quantities in 2050 amount to 100 $MtCO_2$ (NAT) to 130 $MtCO_2$ (GLO) for depleted hydrocarbon fields and to 10 Mt CO_2 (NAT) to 50 Mt CO_2 (GLO) in saline aquifers. Cumulatively until 2050, 1.5 Gt are stored in depleted oil and gas fields and 0.6 $GtCO_2$ in saline aquifers. It has to be pointed out that these results presume the existence of the appropriate legal and regulatory framework as well as public acceptance for the construction of the corresponding CO_2 transport infrastructure.

The importance of EOR for the Mexican energy production is supported by on-going research in this field. As part of the PEMEX enhanced oil recovery strategy on the 19 largest oil fields in Mexico, CO_2 EOR pilot project are taking place at the Ku-Maloob-Zaap, ATG North and South fields. EOR (currently with nitrogen) is already applied for Cantarell offshore oil field from which about one third of Mexico's crude oil production comes from. Another proposed CCS project aims at transporting the CO_2 over a 150 km pipeline to Pemex's offshore oil fields (Lacy, 2011).

6.2.4 Summary Mexico

Through the modelling exercise conducted, to achieve the emissions reductions aimed for in both the NAT and GLO scenarios, CCS is deployed in Mexico from 2020. Under both of the carbon restrained scenarios, natural gas becomes the most important fossil fuel used for electricity generation, with gas-fired electricity generation combined with CCS appearing as a mitigation option in both the NAT and GLO scenarios from 2020. By 2050, under the GLO scenario, natural gas electricity production combined with CCS appears as the only form of electricity generation utilizing fossil fuels. The combination of biomass with CCS is introduced into the energy mix in the NAT and GLO scenarios by 2030, and becomes a significant form of negative-emission electricity generation by 2050. The combination of natural-gas and biomass electricity generation with CCS, and a large proportion of electricity generation from solar and wind power, means that in both the NAT and GLO scenarios the Mexican energy sector actually achieves negative emissions by 2050.

Interestingly, CCS also appears as a mitigation option in the BAU scenario by 2030. According to the exercise, from 2030 coal becomes a more significant energy carrier in Mexico in the BAU scenario. The combination of coal and CCS accounts for approximately 3% of electricity production in 2030, increasing to 16% in 2040. The reason for the deployment of CCS on coal-fired power plants is the use of CO_2 for enhanced oil and gas recovery. In the BAU, all of the cumulative total of CO_2 stored by 2050 is for the purpose of enhanced oil recovery. In fact, in all three scenarios, the cumulative amount of CO_2 injected for EOR until 2050 remains constant at approximately 1.8 $GtCO_2$. EOR is required to increase and sustain the level of hydrocarbon recovery in order to meet the demand for oil and gas in the transportation and electricity generation sectors, respectively. The primary energy consumption supplied by oil and gas is rather inelastic between the three scenarios between 2020 and 2050.

The following bullet points highlight the most important developments in terms of the role of CCS in Mexico towards 2050, according to the TIAM-ECN model:

- BAU:
    - Electricity generation – In the BAU we see CCS deployment from 2030 onwards related to coal-fired power generation. Coal-fired power generation capacity equipped with CCS equals 2 GW in 2030, and increases to 14 GW in 2050. No other CCS deployment appears in the BAU.

    - Industrial sectors – In 2050, approximately 130 Mt of the cumulative CO_2 stored originates from CO_2 capture from upstream fuel production using coal. This upstream fuel production is understood to be the production of alternative fuels for use in the transport sector.

- NAT:
    - Electricity generation – In the NAT scenario we see a much larger reliance on gas-fired power than coal. CCS is deployed from 2030 onwards on a proportion of Mexico’s coal-fired power stations, equalling a capacity of 1 GW. By 2050, all coal-fired power stations in Mexico are equipped with CCS, equalling a capacity of 14 GW. 2040 sees the introduction of biomass combined with CCS in the power sector, which reaches 7 GW installed capacity by 2050. In 2050, natural gas with CCS contributes to emissions reductions from the power sector, with an installed capacity of 2 GW.

    - Industrial sectors – In 2050, approximately 90 Mt of the cumulative CO_2 stored originates from upstream fuel production mainly using coal, and 240 Mt from industrial production using coal and natural gas.

- GLO:
    - Electricity generation: In the GLO scenario, coal is removed from power generation by 2040, and gas is the predominant fossil fuel. CCS is first deployed in 2020 on natural

gas-fired power plants to an installed capacity of 1 GW, and increases to 11 GW in 2050. Biomass combined with CCS is introduced in 2040 similar to the NAT scenario, however with a slightly larger capacity, reaching 17 GW by 2050.

Industrial sectors – Data for 2050 outlines a significant role for CCS in industrial sectors. A total of 1,390 Mt of the cumulative CO_2 stored (3,750 Mt) is assumed to be captured from industrial sectors, particularly upstream fuel production using coal and industrial production using natural gas or oil.

6.3 The role of CCS under different energy policy regimes in Indonesia

6.3.1 Greenhouse gas emissions and primary energy consumption

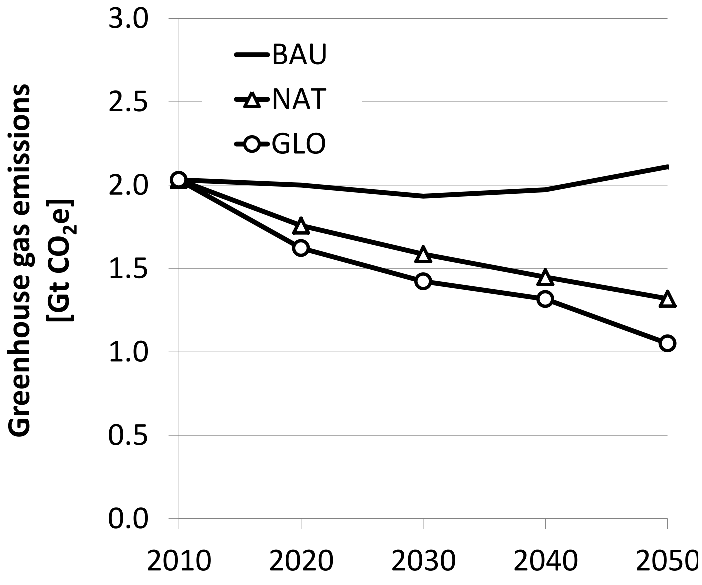

Figure 19: GHG emissions in Indonesia in the three policy scenarios

Under absence of GHG mitigation policies (BAU scenario), the total GHG emissions decrease slightly until 2030 and increase afterwards to 2.1 Gt in 2050 (Figure 19). This development is characterised by decreasing emissions from Land-use, Land-use change and forestry (LULUCF) and increasing GHG emissions from fuel combustions and industrial processes (Figure 20). This development of emissions from LULUCF assumes the effectiveness of non-energy policy related measures on broader environmental issues related to agriculture and forestry, like conservation of biodiversity and water management, which are assumed to take place in all three scenarios. This approach follows the projection of emissions from LULUCF[5] of the IEA (2012) who state an average decrease of the global GHG emissions. It is also assumed, that emissions from peat lands and peat fires do not increase significantly compared to today's level, which requires fire prevention measures for both large plantations as well as for small scale agricultural areas. Due to these assumptions, the baseline used in this analysis deviates from those of Indonesia's second communication to the MoE (2010). Since CO_2 emissions from LULUCF represent currently about one third of Indonesia's total GHG emissions, the measures taken on the management of agricultural area and forests have a high impact on the achievement of the climate targets. Concerning the associated costs of GHG mitigation in the forestry sector and for land-use changes high uncertainties exist ranging from about 10 USD/tCO_2 to 90 USD/tCO_2 (MoE, 2010). The marginal abatement cost curve on the technical potential for GHG mitigation of Indonesia's LULUCF and peat-related emissions shows comparable low cost at significant abatement quantities for fire prevention measures and sustainable forest management and reforestation as well as peat rehabilitation (Figure 21).

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[5] excluding emissions from peat land

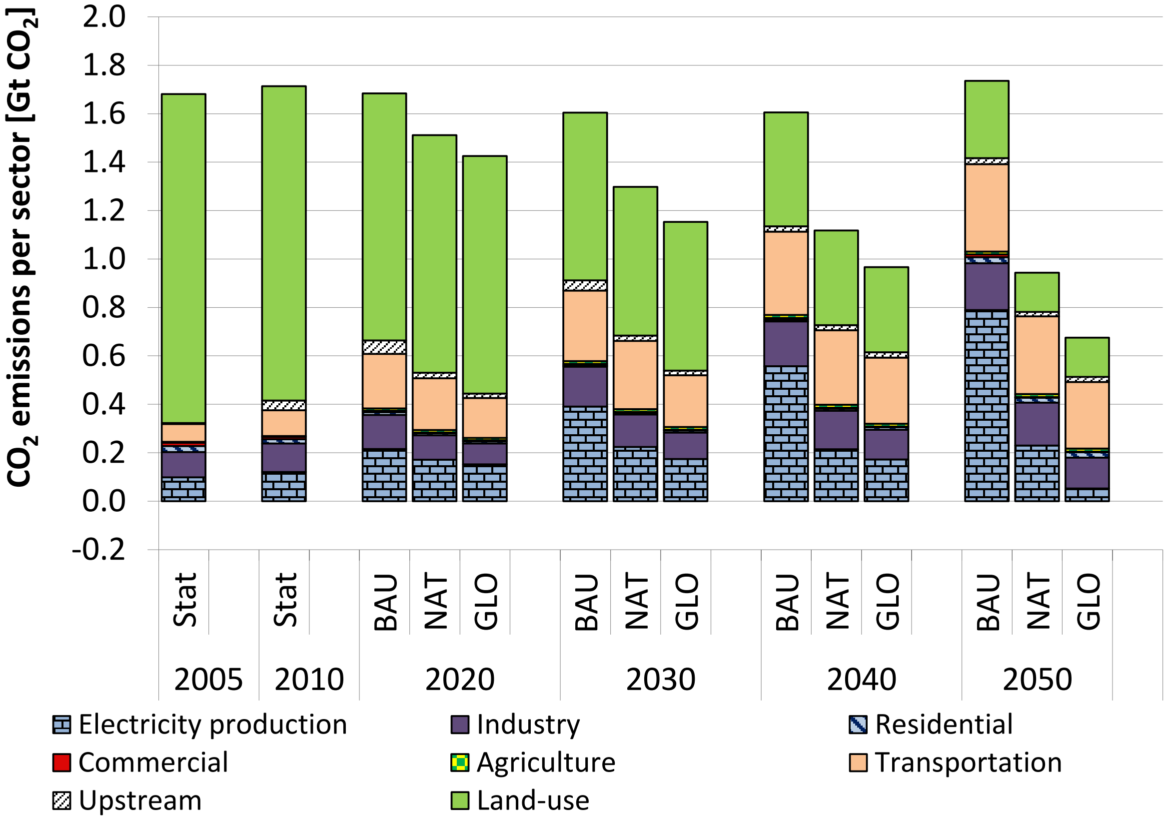

Figure 20: CO_2 emission in Indonesia in the three scenarios

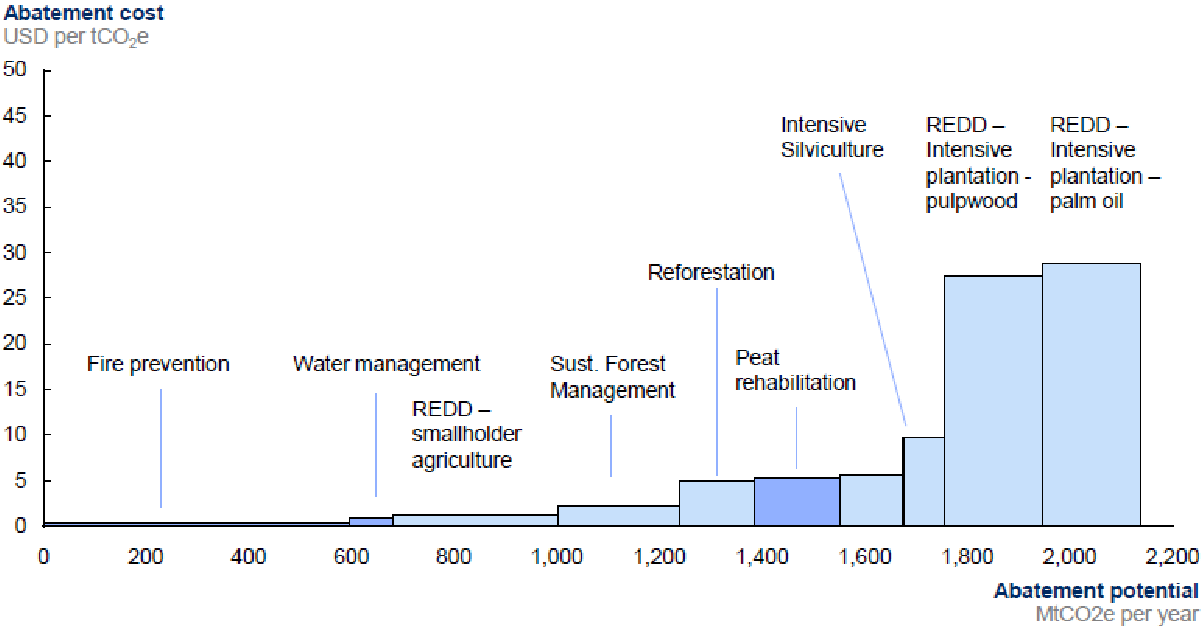

Figure 21: Marginal abatement cost curve for LULUCF and peat related GHG emissions in Indonesia (DNPI, 2010)

The CO_2 emissions from combustible fuels and industrial processes[6] increase until 2050 compared to the 2010 emission level in all scenarios. This development is driven by strong economic growth, which is assumed at annual average growth rates of 4% until 2050 and an increase of the population of 40% until 2050 compared to 2010.

Under the absence of climate policy measures (BAU scenario) the CO_2 emissions increase until mid of the century to 1.4 $GtCO_2$, which represents an increase compared to 2010 by factor of 3.5. Main source of the CO_2 emissions is the electricity sector, in which the strong increase is mainly driven by coal-based electricity generation. CO_2 emissions from electricity generation grow by 80% between 2010 to 2020 to 0.22 $GtCO_2$ in the BAU scenario. Past 2020 represents the electricity sector with 0.4 $GtCO_2$ in 2030 and 0.8Gt CO_2 in 2050 about half of the overall CO_2 emissions in the BAU scenario.

The existence of climate policy measures has significant impact on the CO_2 emissions in the electricity sector. The CO_2 emission from electricity generation remain until 2050 under both climate policy scenarios (NAT and GLO) under the 2020 emission level of the BAU scenario. The lowest emissions are reached under strong climate policy measures and global coordinated action (GLO) with 0.06 $GtCO_2$ in 2050. Compared to Mexico, for which the total CO_2 emissions of the electricity sector turned to net negative emissions in 2040/2050, Indonesia's achievement of the climate targets is rather determined by the development of LULUCF emissions. This allows lower CO_2 emissions reductions in the energy sectors, especially the electricity sector. Under the existence of binding GHG reduction commitments, mitigation potential for LULUCF and the related policies will have an impact on the deployment of CCS technologies in Indonesia. This can represent an uncertainty factor for the perspectives of CCS in Indonesia and an effective policy on land management could contribute to reduce these uncertainties in the future. In the case, that uncertainties about the development of CO_2 emissions from LULUCF cannot be reduced, a separate emission reduction target for the energy sector could decrease the risk of investments in low-carbon technologies.

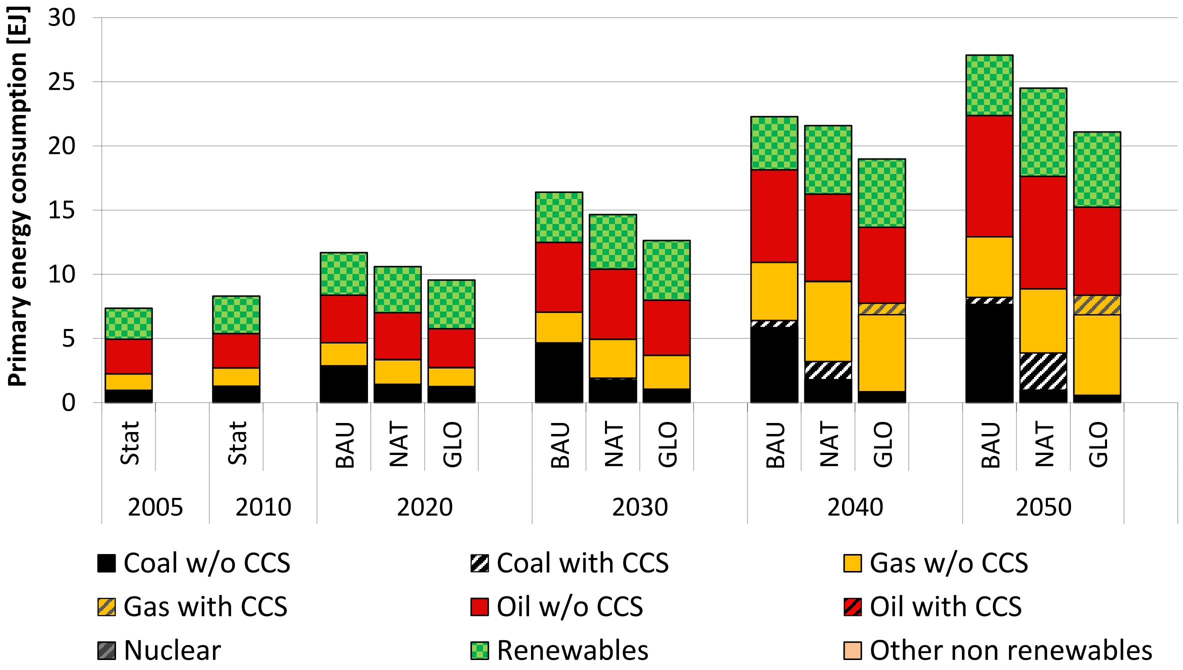

Figure 22: Primary energy consumption in Indonesia in the three scenarios

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[6] In the following the description of CO_2 emissions is referred to CO_2 emissions from combustible fuels and industrial processes only and does not include LULUCF emissions if not stated otherwise.

The primary energy consumption increases by 2020 to a level of about 10 EJ and afterwards until 2050 to 28 EJ in the BAU scenario and 21 EJ in the GLO scenario. Thereby, the share of fossil fuels increases by 2050 compared to 2010 to about 80% in the BAU scenario and about 70% in the scenarios NAT and GLO. The largest growth can be observed for coal, which increases by factor of eight in the period 2010 to 2050 to 10 EJ in 2050. The coal demand can be almost entirely covered by domestic resources. Compared to the BAU scenario, in which 240 EJ of coal are consumed between 2010 and 2050. The coal consumption declines by 50% under less stringent climate policies (NAT) and to less than 20% under stringent climate policies (GLO). The trend of a decreasing coal consumption in favour of an increasing consumption of natural gas, hydro, wind, solar and geothermal energy at tightening the GHG reduction target, that was already observed for Mexico, is valid for Indonesia as well. For biomass, the consumption pattern differs in the two climate scenarios in the long-run (2050). Under stringent national climate policies and a global GHG reduction regime to achieve the 2˚C target (GLO), less biomass is consumed domestically compared to less stringent national climate policies and the absence of a global scheme to meet the 2˚C target at equal biomass production level. The reason for this shift is driven by increased net exports of biomass to regions, which have less favourable biomass potentials, like India.

Similarly to Mexico, in Indonesia the use of CCS technologies starts in 2020 in all three scenarios, driven by the increase of the crude oil production through EOR. However, CCS in Indonesia deploys with respect to the total primary energy consumption less strongly than in Mexico. In 2030 less than 1% of the primary energy is used in CCS technologies and in 2050 between 2% (BAU) and 11% (NAT and GLO).

6.3.2 CCS in the electricity sector

CCS technologies are primarily deployed in the electricity sector with a major uptake of the technology development in 2040. Before 2040 total installed CCS capacity is less than 1 GW independent of the climate policy regime. The resulting CCS electricity generation does not exceed 2% of the total production. Past 2030, CCS electricity generation increases rapidly to 150 TWh in 2040 (19 GW) and 360 TWh (45 GW) in 2050 in the NAT scenario. In the NAT scenario coal-based CCS power plants represent the generation option with competitive generation costs at a CO_2 price level of about 70 USD(2005)/t CO_2 (2040/2050), whereas under more stringent climate targets and consequently higher CO_2 prices (180-200 USD(2005)/t CO_2 in 2040 and 2050) natural gas CCS technologies are more advantageous. Under stringent climate policies (GLO) electricity generation from natural gas contributes with 140 TWh to 21% of the total electricity generation in 2040. This share increases to 24% (225 TWh) in 2050. The corresponding generation capacities amount to 18 GW in 2040 and 29 GW in 2050. Additional to natural gas CCS technologies, biomass CCS power plants produce 17 TWh in 2040 and 96 TWh in 2050 with an installed capacity of 2 GW and 12 GW respectively. Under stringent climate policies in total 320 TWh are generated with CCS in 2050 and represent one third of the total generation in Indonesia. Thus the total cumulative electricity generated with CCS are under both climate policy regimes at the level of 5,000 TWh until 2050.

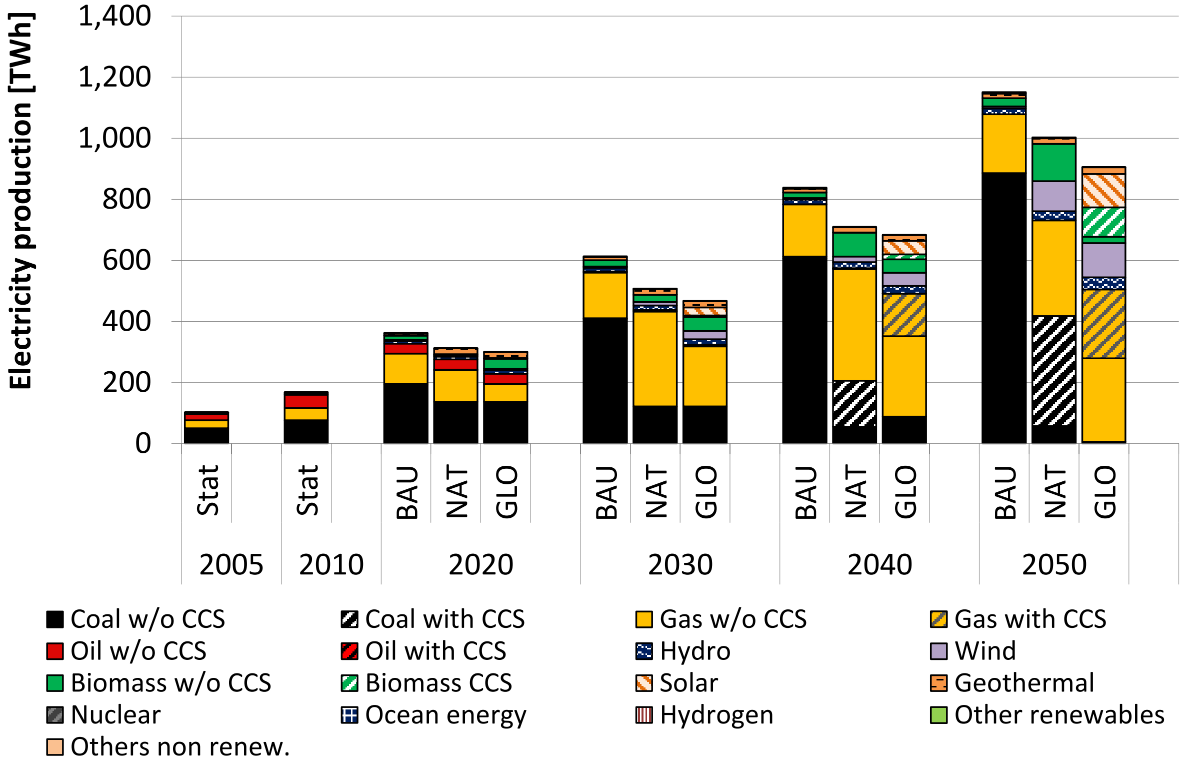

Figure 23: Electricity production in Indonesia in the three scenarios

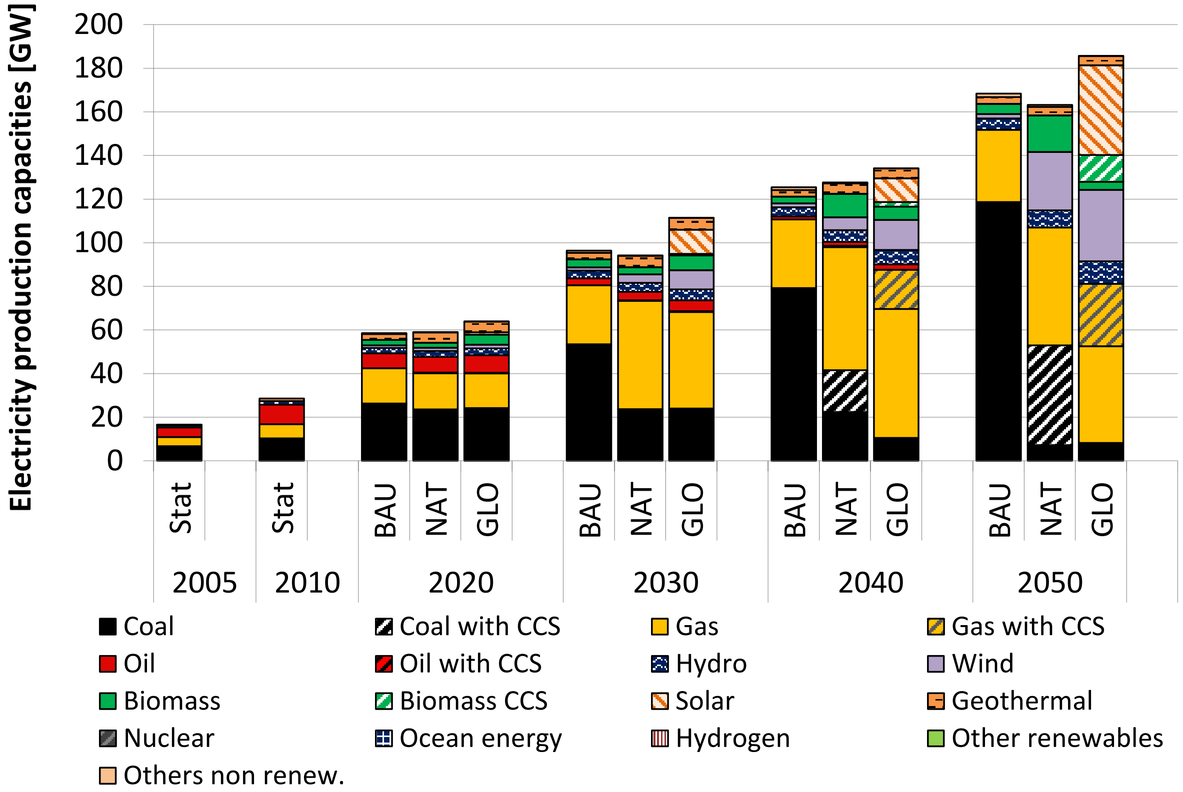

Figure 24: Figure 15: Electricity generation capacity in Indonesia in the three scenarios

6.3.3 Carbon captured and stored

The total CO_2 capture quantities differ significantly among the scenarios. By mid of the century 0.6 $GtCO_2$ are captured in the BAU scenario, 3.6 $GtCO_2$ under less stringent national climate policies (NAT) and 2 $GtCO_2$ under stringent climate policies (GLO) (Figure 25). In both climate scenarios almost all CO_2 is captured in the electricity sector. This shows, that for equal cumulative electricity generation in the scenarios with climate policy, the double amount of CO_2 has to be captured and stored under less stringent climate policy (NAT) compared to scenario GLO. The negative CO_2 emissions from biomass CCS accumulate to almost 1 $GtCO_2$ until 2050

In the BAU scenario half of the CO_2 is captured in the upstream sector from coal. The production of alternative fuels with CCS in combination with EOR allows to increase the oil extraction in Indonesia by 4 EJ until 2050 and to produce about 2 EJ of synthetic fuel.

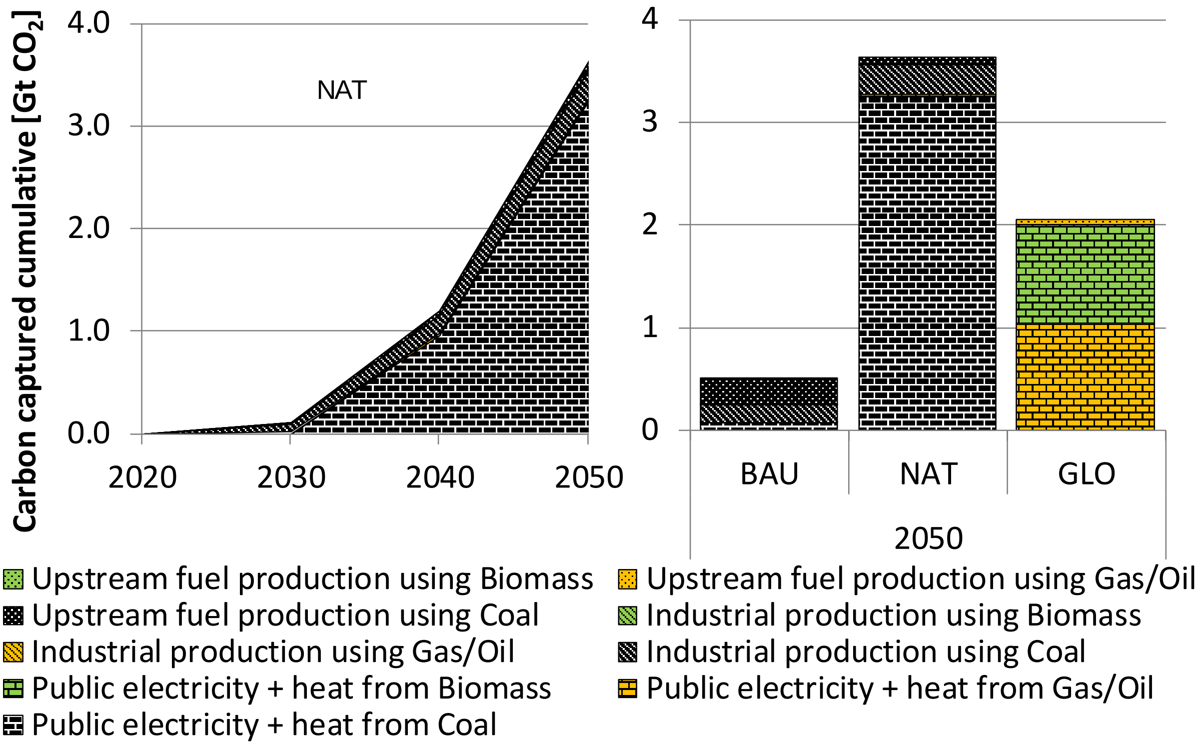

Figure 25: Cumulative CO_2 captured in Indonesia in the three scenarios

In the BAU scenario all CO_2 is stored by using EOR. The annual CO_2 storage quantity in combination with EOR increases to a level of 20 $MtCO_2$ in 2040 and 2050. By mid of the century 0.6 $GtCO_2$ are used for EOR and stored underground (Figure 26). Besides EOR additional CO_2 storage capacity is needed to store the CO_2 in the scenarios with climate policies (NAT and GLO). In both scenarios 0.3 $GtCO_2$ are stored in saline aquifers until 2050. In the NAT scenario, additional 1.7 $GtCO_2$ are injected in depleted oil and gas fields and 1.1 $GtCO_2$ in coal seams. Coal seams represent compared to aquifers and hydrocarbon fields a costly storage option with more than 15 USD(2005)/tCO_2.

Under stringent climate policies (GLO) less storage capacity is required until 2050 compared to scenario NAT. Consequently CO_2 storage in coal seams is not deployed and injection into hydrocarbon fields reduces by 0.4 $GtCO_2$ to a total storage amount of 1.4 $GtCO_2$ until 2050 compared to NAT.

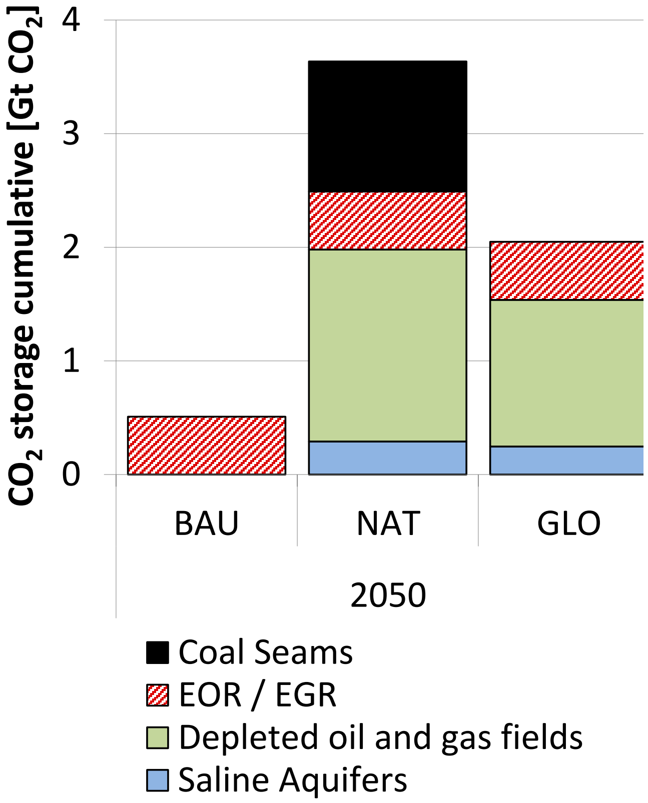

Figure 26: Cumulative CO_2 stored in Indonesia

6.3.4 Summary Indonesia

The TIAM-ECN model indicates that the deployment of CCS in Indonesia occurs later or at a lower level compared to Mexico, caused by the availability of low-cost mitigation options within the agricultural and forestry sector related to emissions from LULUCF in Indonesia. Similar to Mexico, introduction of CCS is seen in the electricity generation sector. Depending on the climate targets, CCS technologies face good opportunities for the application in coal, gas and biomass power plants. Under absence of climate targets (BAU scenario) CCS technologies (mainly in industrial sectors) could contribute to the supply of CO_2 for EOR. The total quantity of CO_2 stored in relation to EOR cumulates until 2050 to about 500 $MtCO_2$, independent from climate policy measures. Climate policies drive the deployment of CCS apart from EOR

Under the NAT scenario, CCS appears to play an important role in capturing CO_2 from coal-fired power plants from 2040. Unlike the BAU, whereby electricity generation is dominated by coal-fired power plants without CCS by 2050, electricity generation under the NAT is achieved with an almost equal combination of coal with CCS, natural gas and renewable sources.

The following bullet points highlight the most important developments in terms of the role of CCS in Indonesia towards 2050, according to the TIAM-ECN model:

- BAU:
    - Electricity generation – In the BAU we see limited CCS deployment in electricity generation, just 1 GW of installed capacity of CCS in coal-fired power generation by 2050.

    - Industrial sectors – In 2050, approximately 0.4 Gt (80%) of the cumulative CO_2 stored originates from CO_2 capture from industrial sources, primarily upstream fuel production using coal and industrial production using coal.

- NAT:
    - Electricity generation – CCS is deployed from 2040 onwards on approximately half of Indonesia's coal-fired power stations, equalling a capacity of 19 GW in 2040. By 2050, 85% of coal-fired power stations in Indonesia are equipped with CCS, equalling a capacity of 46 GW.

    - Industrial sectors – In 2050, approximately 0.4 $GtCO_2$ of the cumulative CO_2 stored (4 $GtCO_2$) originates from industrial production using coal.

- GLO:
    - Electricity generation: In the GLO scenario, CCS is first deployed in 2040 on natural gas-fired power plants to an installed capacity of 18 GW, and increases to 29 GW in 2050. Biomass combined with CCS is introduced in 2040 with 2 GW installed capacity, increasing to a more substantial capacity of 12 GW by 2050.

    - Industrial sectors – There is only few CO_2 captured from industrial sources in the GLO scenario since fossil fuels are substituted by electricity and renewable energy (mainly biomass).

7 Discussion

The TIAM-ECN model identifies the lowest cost energy system structure given the carbon constraints of each scenario. A number of insights can be drawn from the results of the model, which could help to support decision making while developing energy and climate policy in Mexico and Indonesia. This section aims to highlight a number of findings regarding the developments in energy use, energy mix and the role of CCS in the two countries.

7.1 Implications energy and climate policy

7.1.1 Mexico

In terms of energy developments in Mexico, to meet Mexico's national climate commitments, gas and oil emerge as the key energy carriers, while coal has a relatively minor role to play. The continued importance of oil in the future primary energy consumption of Mexico shown by the TIAM-ECN model indicates that important political decisions have to be made in order to meet demand. With regards to Chapter 4 of this report, national oil production is in decline. Demand can either be met by increased imports and/or boosting national output. The TIAM-ECN model suggests that by 2020, Mexico will become a net importer of oil, a conclusion which is shared with the International Energy Agency. This places emphasis on the availability of enhanced oil recovery techniques, including CO_2 injection, to reduce Mexico's reliance on foreign oil imports through to 2050. In terms of storage of CO_2, EOR is the only form of storage under the carbon constrained scenarios until 2040, where storage in depleted oil and gas fields occurs. Storage in saline aquifers takes place in 2050.

In the NAT scenario in the modelling exercise, CCS equipped power production assumes a relatively small role in the electricity production during 2020 (1 GW) and 2030 (3 GW). However, with 3 GW of installed generation capacity (1 GW coal, 1 GW gas, 1GW biomass) incorporating CCS by 2030, these developments are certainly significant compared to the demonstration phase of the technology today. Under the GLO scenario in 2030, the CCS deployment is more substantial with 3 GW natural gas and 2 GW biomass. Given that lead times from planning to realisation of large power plants alone can reach multiple years, combined with the additional pipeline route and storage site characterisation, the building of national technical capacity for the technology should find place in Mexico's energy and climate policies.

Although this report focuses on the role of CCS, the significant position of renewable energy sources in the future energy system of Mexico must be highlighted. The co-existence of several low-carbon technologies, like renewable energy technologies and CCS might lead to an effective and cost-efficient climate mitigation strategy for the first half of this decade. In 2040, the NAT scenario indicates 32 GW of installed capacity of solar power, and 7 GW of installed capacity of wind power. Such a deployment rate is realistic, but will require an aggressive policy approach. To put this into perspective, Germany, one of the leading countries in photovoltaic technology deployment, announced in October 2012 that it had reached 32 GW of photovoltaics connected to the national electrical grid. This expansion in capacity has been achieved through a feed-in tariff which costs €14 billion euros per year for wind and solar combined, funded through surcharges of electricity prices (equating to an approximate 15% rise on prices). The feed-in tariff has led to a massive ramp up of installed solar capacity, which stood at just 1 GW installed in 2004 (BMU, 2012).

7.1.2 Indonesia

In the absence of climate policy measures, coal will dominate electricity production in Indonesia, accounting for $0.8GtCO_2$ per year by 2050, approximately half of the national CO_2 emissions. Under the NAT and GLO scenarios, the model indicates that the use of coal without CCS in electricity generation must peak in 2020 at 24 GW installed (10 GW installed in 2010). From 2030, under carbon constrained scenarios, natural gas outstrips coal use in power generation, with 50 GW of installed capacity (7 GW installed in 2010). In terms of natural reserves, Indonesia has abundant natural gas reserves and currently exports half of its 3,000 billion cubic feet of annual gas production. However, increased demand for natural gas may require exports to be reduced, and/or domestic production to be increased.

Unlike Mexico, the significant deployment of CCS occurs much later in Indonesia, in 2040. Prior to 2040, the installed capacity of CCS is less than 1 GW independent of the scenarios. The delayed introduction of CCS and renewable energy sources in the NAT and GLO scenarios is due to the large abatement potential from LULUCF, of approximately 2 $GtCO_2$ for marginal costs below 30 USD/tCO_2. The LULUCF abatement potential is included in the TIAM-ECN model, coming to the result, that about 90 % of the national emission reduction in the near-term can be realised through forestry and peat land management, which is in line with the Indonesian National Action Plan RAN-GRK (Brulez, 2012). However such abatement measures are particular difficult to measure, and therefore create particular uncertainty regarding the necessary deployment of technologies in the power and industrial sectors. There is a potential risk of relying on such emissions reduction measures unless agreed and transparent monitoring methodologies can be established. For the next two to three decades climate mitigation measures based on LULUCF emission reductions are expected to be dominant but later on GHG emission reductions in the energy sector gain importance.

From 2040 in the NAT scenario, with competitive GHG avoidance costs of 70 USD/tCO_2, we see significant deployment of CCS on coal-fired power plants. In the GLO scenario, with competitive avoidance costs of 180-200 USD/tCO_2, we see deployment of CCS on natural-gas fired power plants by 2040, and on biomass plants by 2050. What we do see however is approximately 1$GtCO_2$ captured from industrial production using coal and upstream sectors from 2030, which facilitates EOR in Indonesia. Analogous to Mexico, EOR is the only form of CO_2 storage prior to 2040.

7.2 The role of enhanced oil recovery

Based on the exercise conducted and current activities taking place in Mexico and Indonesia, the activity of EOR utilizing CO_2 appears to be both of national importance, and very important for the future development of CCS. Independent of the scenarios modelled, EOR precedes storage in depleted oil and gas reservoirs and in saline aquifers. CCS combined with EOR also occurs in the BAU scenarios in both countries, meaning that the activity may be financially viable in these countries now or in the future without climate policy measures (see Figure 17).

Placing CCS and EOR in a climate perspective is a politically sensitive issue, as the primary goal of CCS is usually understood to one of reducing CO_2 emissions permanently. However, according to Jaramillo et al., (2009), a life cycle inventory of CO_2 use in enhanced oil recovery, including the refining of the oil into petroleum and combustion, actually leads to a positive carbon balance. Assuming that similar analyses provide the same insight, the argument for CCS combined with EOR is a particularly awkward concept to place in a UNFCCC mechanism as the CDM. Certain parties such as the Alliance of Small Island States (AOSIS), have expressed the view that downstream emissions from the recovered hydrocarbons would have to be accounted for in any CDM methodology (UNFCCC, 2012). A consensus must be reached, as this issue is effectively a ‘go no-go’ decision for the CCS/EOR combination as a GHG abatement activity rather than a pure industrial activity.

In addition to the political issue of combining anthropogenic CO_2 for use with EOR, there are also a number of technical and practical issues to mention. During CO_2 flooding of oil fields, approximately half of the CO_2 injected returns to the surface with the extracted oil, and is subsequently separated and re-injected. Current EOR reservoir management strategies are designed to achieve maximum additional oil production using as little CO_2 as possible,[7] rather than to ensure the safe storage of large amounts of CO_2 for geological timeframes. Technically speaking, injecting CO_2 into active oil reservoirs can lead to issues with raised reservoir pressures which could lead to fracturing of the caprock and displacement of in-situ reservoir fluids. The presence of multiple legacy wells (previously

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[7] For the purposes of EOR, CO_2 can have values of up to $40 USD/t (Heidug, 2012).

drilled wells not longer used) which have not been plugged with CO_2 resistant cements may also pose problems to storage integrity (Heidug, 2012).

If anthropogenic CO_2 is to be used for EOR, and the CO_2 stored is to be treated as not-emitted under UNFCCC national inventories and qualify for carbon crediting through regulations such as the Clean Development Mechanism or the European Union's Emissions Trading System, the CO_2 injected will have to be subjected to measurement, verification and reporting (MRV) procedures. There are no transparent examples of MRV procedures for CCS-EOR which are in accordance with the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006). Indeed, of the 12 $MtCO_2$ captured from anthropogenic sources and used for EOR in the United States, all the CO_2 is reported as emitted because MRV data is unavailable (Zakkour, 2012). If CO_2-EOR is to be considered as an effective GHG mitigation option, the development of MRV procedures that can demonstrate what is happening to the injected $CO_{2,}$ is vital to its success (Heidug, 2012).

8 Recommendations for international policy

The primary objective of this report has been to identify the role CCS in the future energy systems of Mexico and Indonesia, based on long-term energy systems analysis using the TIAM-ECN model. Understanding primary energy consumption trends, current power generation and industrial infrastructure in developing countries is essential for targeting the deployment of CCS capacity building programmes. Carefully drawing on insights from long-term modelling can also support decisions on the type of capture technologies which are most relevant for a particular country, such as capture from coal or gas fired power plants, or whether capturing CO_2 from industrial sectors or biomass processes is important. For example, this modelling exercise suggests that in terms of cost optimization, CCS has a roll to play in Mexico’s energy system from 2020/2030, whereas the technology emerges at a later stage in Indonesia in 2040. Naturally, indications from long-term modelling represent just one factor to be used in targeting capacity building, and other factors such as political willingness and commercial interests may play a more prominent role. Nevertheless, a suitable recommendation for multi-lateral donor organisations such as the World Bank and the Asian Development Bank, would be to consult country specific long-term energy systems analysis when designing a CCS capacity building programme.

From the modelling conducted, one of the key findings is a very strong link between the deployment of CCS and EOR in the near to mid-term. There is an opportunity to combine long-term CO_2 storage with EOR, however the benefits from a climate perspective may not be initially clear. Removing EOR from the equation makes CCS less cost competitive towards other GHG reduction options and could delay the use of CCS as a technology for long periods. CCS for EOR could help to build capacity, expertise, infrastructure, and legal and regulatory provisions to support the transition to conventional CO_2 storage. However there are a number of policy and regulatory barriers which prevent CO_2-EOR from becoming established as ‘true’ mitigation option. In order to move forward on this issue, a number of key policy recommendations are given:

- The role of CCS/EOR as an appropriate GHG mitigation option under the auspices of the UNFCCC must be clarified, particularly on the issues of downstream emissions from additional oil produced.

- If CCS/EOR is considered as a potentially important abatement option, in line with the results of this report, standard practices and regulatory guidelines must be developed to ensure effective measurement, reporting and verification procedures.

- Assuming that CCS/EOR is recognised by the UNFCCC as an important abatement option, from a developing country perspective, possible Annex 1 to non-Annex 1 funding mechanisms could be discussed, as existing mechanisms such as the CDM are unlikely to be suitable. Given that CO_2/EOR may potentially happen in certain countries independent of whether ‘climate financing’ is available or not, financing could focus on offsetting the costs of MRV and/or maximising the amount of CO_2 safely stored.

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