



CARBON CAPTURE AND STORAGE IN THE COMMUNITY OF PORTUGUESE LANGUAGE COUNTRIES

OPPORTUNITIES AND CHALLENGES

May | 2015

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TABLE OF CONTENTS

Executive Summary

The community of Portuguese Language Countries (CPLP) comprises nine member states, spread over four continents: Europe (Portugal), America (Brazil), Africa (Angola, Cape Verde, Equatorial Guinea, Guinea-Bissau and São Tomé and Príncipe) and Oceania (East Timor). The member states cover a range of Industrial, Economic and Environmental profiles, but share strong cultural and economic links.

CO_2 Capture and Storage (CCS) is not perceived as a priority for the authorities of any of the CPLP countries, although Brazil and Portugal have been involved in CCS activities for several years. All other CPLP countries, recognized as highly vulnerable to climate change impacts, have never engaged in any debate about the relevance of CCS to their environmental and climate change policies. This publication is an effort to bring CCS onto the agenda of these CPLP countries. It presents an oversight of the industrial, energy and CO_2 emissions profiles, and discusses the CO_2 storage opportunities in those countries. Brazil, which is responsible for 80% to 85% of the emissions in the CPLP, and Portugal are discussed only in terms of previous or ongoing CCS activities.

Drivers for deploying CCS activities need to be sought elsewhere other than the CO_2 emissions profile of those CPLP member states, but the drivers exist and are mostly connected to the fossil fuel production in Angola, East Timor, Equatorial Guinea and Mozambique. Use of CO_2 for EOR purposes, but also CO_2 capture connected to downstream oil (refineries) and gas processing and LNG investments planned in those countries are possibilities that should be discussed in the framework of the national climate change mitigation policies.

The rapid population and economic growth rate in the CPLP countries must be met by growing energy production and increasing manufacturing capacity. Investments are programmed in fossil fuel power plants in Angola, Equatorial Guinea and especially in Mozambique, while investments in cement factories are planned in almost every country. Aluminium smelting in Mozambique can also be an early opportunity for CCS projects, while the possibility for Bio-CCS projects should be considered given the vast bioenergy potential in almost every country, except Cape Verde, and particularly in Guinea-Bissau, Equatorial Guinea and Mozambique.

CO_2 storage opportunities linked to use of CO_2 for EOR or to depleted oil and gas fields are clear options for Angola, East Timor and Equatorial Guinea, while Mozambique and Guinea-Bissau have extensive onshore sedimentary basins, spreading to offshore, which will have good opportunities for storage in deep saline aquifers. Mozambique may also have some storage capacity in unminable coal seams, if CO_2 injection in this geologic environment proves to be a valid scenario.

In Cape Verde and São Tomé and Príncipe, two archipelago countries, the costs of insularity and population dispersion imply that CCS is unlikely to be a relevant technology. Nevertheless, the use of CO_2 in Enhanced Geothermal Systems could be of interest in Cape Verde, as well as R&D activities related to CO_2 storage in basaltic environments.

Transboundary transport and storage issues may be of interest to São Tomé and Principe, which shares an offshore basin with Nigeria; to Angola, which may need to transport CO_2 across the Democratic Republic of Congo territory to the Cabinda Enclave, and certainly to Mozambique, which could develop a business case from storage of CO_2 captured in South Africa.

The most pressing challenges for deploying CCS in any of these countries is the poor knowledge of the technology, a common feature to all CPLP countries, the lack of a clear business model applicable to developing and least developed countries and the need to assess the role that CCS can play in the economic context, energy system and emissions reductions of each country.

Cooperation within the CPLP could overcome these challenges and a set of recommendation is provided to start CCS activities in those countries identified with the highest potential.

1 The CPLP, Community of Portuguese Language Countries

The Community of Portuguese Language Countries (CPLP) is a multilateral forum aiming to foster cooperation amongst the nine sovereign states in which Portuguese is an official language. The CPLP was founded in 1996 by Angola, Brazil, Cape Verde, Guinea-Bissau, Mozambique, Portugal, São Tomé and Principe, which were joined as full members by East Timor in 2002 and Equatorial Guinea in 2014.

The Community has the following general objectives [1]:

- Political and diplomatic cooperation, especially for strengthening its presence in the international arena;
- Cooperation in all areas, including education, health, science and technology, defence, etc.;
- Implement and support projects for promotion of the Portuguese language.

The CPLP in the global context

The nine member states of the CPLP occupy a territorial area of more than 10.7 million km^2, an area larger than the United States, China or India, and almost twice the area of the European Union. Located mostly in the southern hemisphere (Fig. 1), the CPLP countries covers quite different realities such as Brazil, fifth largest country in the world, and São Tomé and Principe, the second smallest state in Africa. Brazil alone is 79.51% of the land area of the CPLP while São Tomé and Principe is only 0.01% [2].

The total population of the CPLP in 2013 exceeded 262 million people, about half of the EU population and 80% of the USA population, but with much faster demographic growth, with an annual average population growth of 1.2% per year. By 2050 the population of the current CPLP member states is expected to exceed 360 million people. Brazil has, by far, the largest population, above 200 million people (76%), but the population is growing more rapidly in Equatorial Guinea (2.8%), Mozambique (2.7%) and Angola (2.5%).

> *'Angola, East Timor, Guinea-Bissau and Mozambique are rank among the world's most vulnerable countries to climate change.'*

In 2013, the nominal Gross Domestic Product (GDP) of CPLP countries was USD 2620 billion. Average gross national product (GNP) *per capita* was USD 6821, but with a very asymmetric distribution, since Portugal, Equatorial Guinea and Brazil decisively inflate that mean. The remaining six members have an average GNP of USD 4147, with the lowest values recorded in Mozambique (USD 590) and Guinea-Bissau (USD 520). Angola, Cape

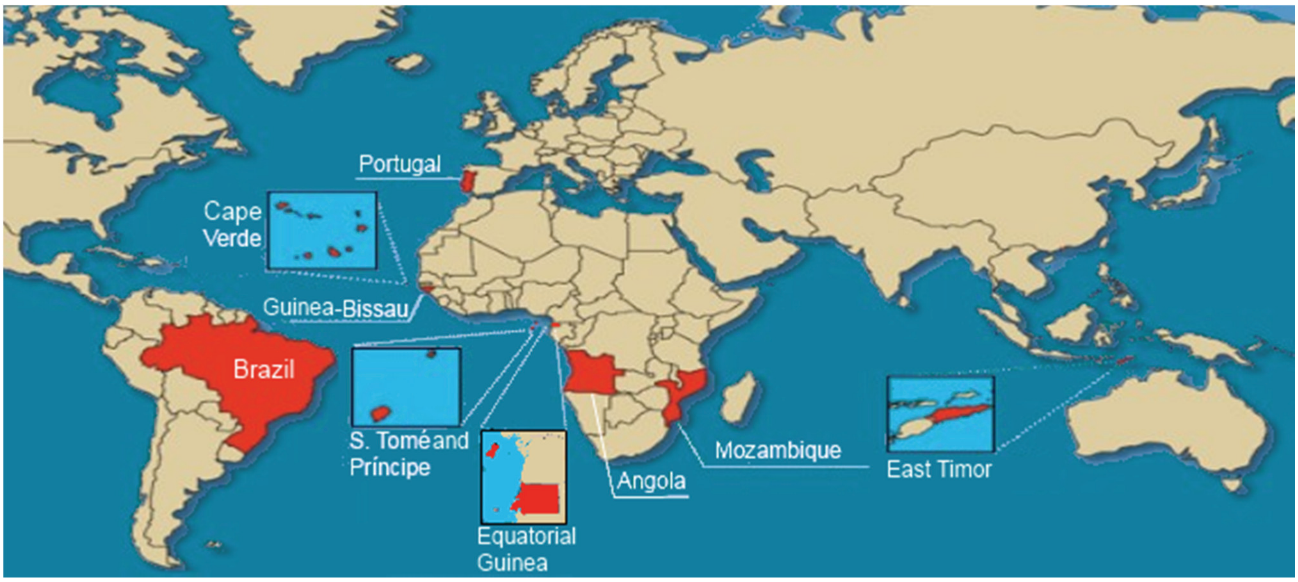

Fig. 1– CPLP member states.

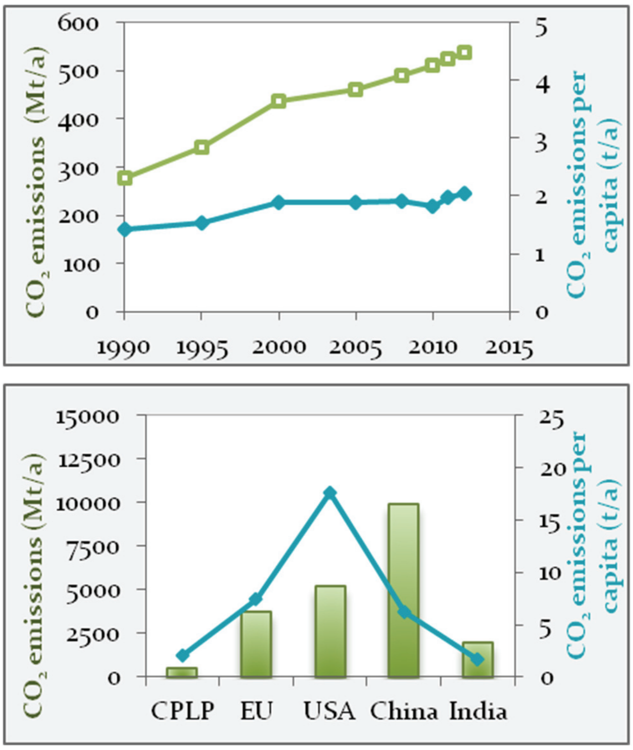

Fig. 2 – Evolution of CPLP countries CO_2 emissions and in the global context in 2012. Source: JRC [3].

Verde and Mozambique are, however, among the 10 African countries with the highest income growth between 2000 and 2012, while Guinea-Bissau is at the opposite pole, the sixth African country with the worst performance [2]. Equatorial Guinea has the highest *per capita* income in Africa, with a two-digit GDP growth rates for much of 2000 - 2010, although it has experienced modest or even negative growth in recent years. Despite the economic growth, East Timor, Equatorial Guinea, Mozambique, São Tomé and Principe and Guinea-Bissau still have high poverty rates, at or above 50% [2] and therefore are classified as *Least Developed Countries* (LDC). It is expected that by 2016 Equatorial Guinea will move into the *Developing Country* classification, a status that applies to Brazil and Cape Verde [3]. Portugal is classified as a *Developed Country*.

This socio-economic environment is reflected in low CO_2 emissions rates from the fossil fuel combustion and cement production (Fig. 2) [2]. CO_2 emissions have consistently increased from 278 Mt in 1990 to 538 Mt in 2012, an average increase of 11 Mt per year [4]. These represent a small proportion of the global emissions since the per capita value remain low, reaching 2.05 tonnes in 2012, a value comparable to that of India, but with a gradual increase from the 1.4 t/a recorded in 1990 (Fig. 2).

The distribution of emissions is very asymmetric, with Brazil consistently accounting for 80%-85% of CO_2 emissions (Fig. 3), which reflects the Brazil's dominant size in the CPLP. Guinea-Bissau, East Timor, and the archipelago countries of Cape Verde and São Tomé and Príncipe, in 2012 were together responsible for CO_2 emissions of less than 1 Mt. The distribution of per capita CO_2 emissions, differs considerably, with Equatorial Guinea (6.7 t/a) and Portugal (5 t/a) showing the highest values, with Brazil (2.2 t/a) and Angola (1.6 t/a) being the only other member states with per capita emissions above unity.

All CPLP countries, with the exception of Portugal, are located in tropical regions. According to several 'vulnerability to climate changes' indices [5-9] Angola, East Timor, Guinea Bissau and Mozambique consistently rank amongst the world's most vulnerable countries to climate change. One such index, ND-GAIN [7], assesses the vulnerability and the readiness to face climate change. It shows that Angola, Guinea-Bissau, East Timor, Mozambique and São Tome and Principe are very vulnerable to climate change and the readiness to face those changes is low. The vulnerability of Cape Verde is also high, but readiness is better. Vulnerability to climate change is lower in the Equatorial Guinea, Brazil and Portugal.

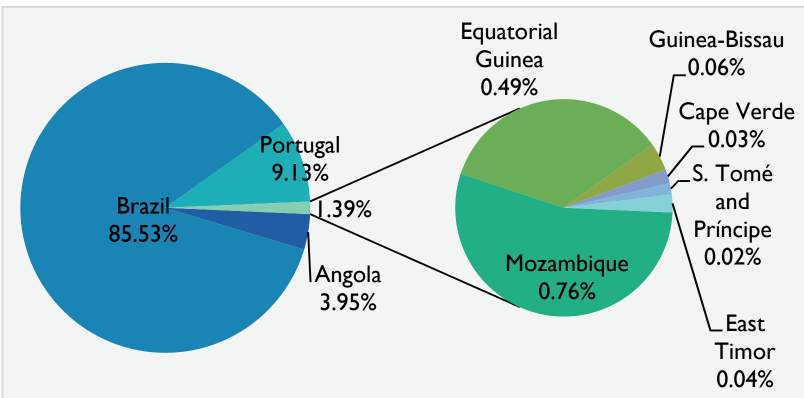

Fig. 3 – Distribution of the 538 Mt CO_2 emitted by CPLP member states in 2012. Source: JRC [3].

2 Status of CCS activities in CPLP countries

Portugal is the only CPLP member to be an Annex I Party to the United Nations Framework Convention on Climate Change (UNFCCC) and its emissions reduction targets were set within the EU-15 burden sharing agreement. All other CPLP countries are Non-Annex I parties to the UNFCCC and non-Annex B parties to the Kyoto Protocol; with no commitment to reduce CO_2 emissions. Consequently, there has been no policy or economic drivers for engaging in CO_2 reduction technologies such as CCS. Only Brazil and Portugal have consistently developed CCS activities, with the drivers being the need to assess the impact of the technology in specific sectors, namely, the power and cement sectors in Portugal and the hydrocarbon upstream sector in Brazil. Stakeholders and authorities in the other CPLP countries have been involved in workshops about the technology, but that involvement never resulted in CCS activities or projects.

This chapter addresses the past and ongoing activities in Brazil and Portugal, while the prospects for the other CPLP countries, the main focus of this report, are addressed in chapter 3.

Brazil

Brazil is, by far, the largest CO_2 emitter in the CPLP. In 2010, it was responsible for 419 Mt of CO_2 emissions from fossil fuel combustion and cement production, roughly 85% of total emissions in the CPLP [10]. Nevertheless, per capita CO_2 emissions in Brazil remain relatively low, at 2.2 t/a in 2010, partly because over 80% of Brazil's electricity is produced from hydropower (Fig. 4). On the other hand, emissions from industrial and fuel combustion sectors are high, because Brazil is one of the world's largest manufacturers of cement, aluminium, chemicals, and petrochemical feedstock, and currently ranks as the world's 12th oil producing country. Accordingly, in the near future, CCS in Brazil is more relevant for the industrial sectors than for power production.

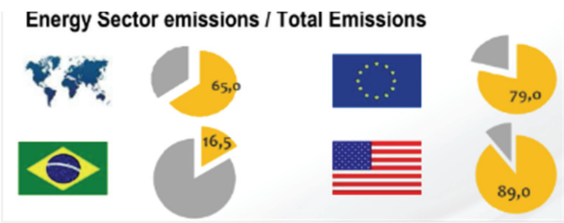

Fig. 4 –Share of CO_2 emissions from the energy sector in Brazil, EU and USA and world in 2005 [13].

Status of CCS activities

In December 2010 Brazil approved a law to reduce its emissions by 36.1% to 38.9% in 2020 compared to business-as-usual emissions, but CCS was not included in the emissions reduction portfolio. Nevertheless, state oil company PETROBRAS has been a long-term proponent of CCS and has been injecting CO_2 for Enhanced Oil Recovery (EOR) since 1987, at the Buracica oil field and at the Miranga Pilot project, where CO_2 injection began in 2009 [11].

PETROBRAS currently operates a large-scale integrated CCS project, the Lula Oil Field CCS Project, the only offshore CO_2-EOR project in the world. Since June 2013 CO_2 captured from natural gas produced from the Santos Basin, which lies between 5,000-7,000 metres below sea level, is compressed and re-injected into the producing reservoir for EOR purposes. Expectations are that 0.7 Mt/a CO_2 will be injected. By 2020, PETROBRAS expects to install 20 new floating production systems in the Pre-Salt province, many of them to include CO_2 injection for EOR purposes [12, 13].

PETROBRAS is also the leading force behind most of the R&D on CCS conducted in the country, with expected investments from 2010 to 2015 on the order of USD 150 million, mostly within the framework of two R&D Technology Programs [14]:

- EMISSÕES - Technological Program for Atmospheric Emission Reduction, comprehensive and long-term, including climate change impacts, vulnerabilities and adaptation;
- PROCO2 - Technological Program on CO_2 Management of Pre-salt, with a focus on the issues of CO_2 in the development of Santos Basin Pre-salt cluster.

In these programs together with the Federal University of Santa Catarina, PETROBRAS installed the *CO_2 MMV Field Lab*, the first of its kind in South America, designed to fill knowledge gaps in CO_2 management technologies. Another important project is the *CO_2 Capture Laboratory* in the National Institute for Space Research (INPE), with a focus on the development of new materials for hydrocarbons combustion using a chemical looping process.

PETROBRAS is also active at the international cooperation level, being a member of the IEAGHG and CSLF, and participating in several international projects. As part of the CCP initiative, PETROBRAS has invested and developed an oxy-combustion capture pilot trial on a fluid catalytic cracking unit at a research complex in Paraná, Brazil.

Many Brazilian universities and research centres are engaged in CCS R&D projects with support from PETROBRAS. In 2007, a joint venture between the company and the Pontifical Catholic University of Rio Grande do Sul (PUCRS) resulted in the establishment of a dedicated CO_2 storage research centre, the CEPAC (Centre of Excellence in Research and Innovation in Petroleum, Mineral Resources and Carbon Storage), currently one of the key R&D and capacity development stakeholders in the country. CEPAC carried out the CARBMAP project - the Brazilian Carbon Geological Sequestration Map - concluded in 2011. The project assessed storage capacity in the country and estimated an effective storage capacity of about 2000 Gt. Besides running many other R&D projects, such as the Porto Batista CBM/ECBM Pilot Site (being developed jointly with PETROBRAS and COPELMI) CEPAC has hosted several workshops to increase CCS knowledge within key stakeholders and the local community [11].

CCS in the coal industry

Although Brazil is not a major coal producer, it has mining companies active in several countries, including several CPLP members. Brazil's coal industry is investing in CCS research to develop its low-emission options and the Brazilian Mineral Coal Association (ABCM) has established the Clean Coal Technology Centre and plans to invest USD 6.5 million from 2010-16, including building a dedicated CCUS laboratory. The ABCM also collaborates with the US NETL on a CO_2 capture R&D program, and on building capacity [15].

Bio-CCS

Brazil has long been a leader in bio-fuels production. The possibility of connecting this experience with CCS is recognized in the country and bio-CCS is a focus of research. The University of São Paulo, through the Brazilian Reference Centre on Biomass and the Carbon Emission Policy and Regulation Group, is actively investigating the potential for bio-CCS in Brazil and estimate that it could contribute up to 5% of the country's emission reductions from energy production [11].

CCS in the Cement and Iron and Steel sectors

Despite the importance of the cement sector to the Brazilian economy, currently producing around 70 Mt/a of cement, and being the 5th largest producer in the world, the sector does not seem to be engaged in any major CCS R&D in the country. The Iron and Steel sector is also quite important in Brazil, but no engagement in CCS activities is known.

> *'The* carbon sequestration and climate change network *was promoted by PETROBRAS' to address challenges on CCS and climate change. USD 17 million were invested from 2006 to 2013.'*

Brazil's self-assessment on CCS

In April 2014, at a CCS roundtable in Rio de Janeiro, participants were asked to self-assess the status of CCS in the country. Participants considered that contribution of CCS to effectively address climate change was still not well understood by many officials in Brazil. Although the technology is well recognized by PETROBRAS, some business sectors and by many academics, the lack of government support was highlighted as a significant concern, with low priority given to the technology in national and sub-national climate policies in Brazil. Increasing governmental engagement in the discussion, as well as providing supportive policies and regulations that enhance the diffusion and implementation of CCS, are key issues [16].

An important step towards the development of CCS in Brazil was the recent publication by CEPAC of the Brazilian Atlas of CO_2 capture and geological storage [17]. It is expected that this publication will contribute to broaden the knowledge of CCS in Brazil, bringing more attention to stakeholders and increasing public perception.

Portugal

This publication integrates the *CCS-PT* roadmap study for Portugal, a project that clarifies the role of the technology in the Portuguese context and its potential need in the power and industrial sectors in the coming future. The *CCS-PT* project builds greatly on the data and information gathered in previous CCS activities in Portugal.

CO_2 capture activities

Several CO_2 capture studies have been conducted at academic level, but the most relevant projects were led by or involved the industry and energy sectors. The main power production company in Portugal, EDP, has been involved in several CO_2 capture projects co-funded by the EU, including [18]:

- The *NanoGLOWA* project, investigating the use of membrane technology to capture CO_2, including a pilot experiment at the Sines power plant in Portugal;
- The *DECARBIT* project, aiming to enable zero-emission pre-combustion power plants by 2020 with a capture cost of less than 15€/tCO_2, and including several pilot tests;
- The *FLEXYBURN CFB* project, aiming to develop and demonstrate a power plant concept based on the Circulating Fluidized Bed technology combined with CCS and including a 30MW pilot plant in Spain.

Another power production company, TEJO ENERGIA, under the *KTEJO* project, assessed the technical-economic viability of retrofitting its Pego coal power plant, the 2nd largest in the country.

In industrial sectors, there has been activity on CO_2 capture in the cement and oil refinery sectors. GALP ENERGIA, the main Portuguese oil company, undertook a pilot project for capture of CO_2 by algae and its reuse as biofuels. In the cement sector, the two Portuguese companies CIMPOR and SECIL have implemented pilot capture projects from clinker production through microalgae. The Portuguese cement sector companies are also involved in CCS studies carried out by the European Cement Research Academy.

CO_2 transport activities

The main research study on CO_2 transport in Portugal was the EU co-funded *COMET* project, which sought to define an integrated transport and storage infrastructure in Portugal, Spain and Morocco. The project involved most of the major CO_2 emitters in Portugal, from the energy and industry sectors, and included the definition of a pipeline network for CO_2 transport considering the cost optimization of the whole CCS chain. COMET provided the first integrated approach to the cost-effectiveness of CCS in the Portuguese context, work which was carried out and developed within the CCS roadmap. The project also included an assessment of the viability of CO_2 transport by ship.

CO_2 storage activities

Within the scope of the *KTEJO* and *COMET* projects, systematic analysis of the storage capacity in deep saline aquifers was conducted at the regional scale, resulting in effective storage capacity estimates of up to 7.6 Gt of CO_2, the vast majority (above 90%) of which in offshore environments. Storage capacity in the Douro coal basin is also being studied at University Fernando Pessoa.

> *'The CCS roadmap for Portugal clarifies the role of the technology in the Portuguese context and its potential need in the power and industrial sectors under a low carbon economy scenario.'*

Assessment of CCS status in Portugal

Portugal lacks specialized technical and scientific capacity in the various components of the CCS chain. As a first effort in building capacity, the EU *COMET* project included workshops and seminars in several Portuguese universities. The number of participants was usually above expectations, but it was recognized that the technology is still poorly known in the academic context. Knowledge about the technology among the wider public is certainly very low, as no systematic public awareness program has yet been undertaken. However, knowledge about the technology among the industry and regulators is quite high, since many of them have been, at some point, involved in CCS activities.

On the regulatory side, it is very positive that the CO_2 storage activities are now regulated by Law 60/2012, the transposition of the EU CO_2 storage Directive 2009/31/EC, and it nominated the *Direcção Geral de Energia e Geologia* as the licensing and regulating authority, with the *Agência Portuguesa do Ambiente* being engaged as the authority for Environmental and CO_2 emissions accountability.

The publication of the *CCS-PT* roadmap study, of which this report is an integral part, will contribute to a better understanding of the role that the technology can play in Portugal, enabling authorities, policy makers and stakeholders to make informed decisions regarding the deployment of the technology in the country. More information about the Portuguese *CCS-PT* project can be found at http:\\ccsroadmap.pt and at the GCCSI website.

3 Prospects for CCS activities in the CPLP

The lack of CCS activities in the CPLP countries other than Brazil and Portugal reflects the lack of drivers for deploying the technology. However, the eligibility of CCS projects within the Clean Development Mechanism (CDM) project level activities [19], the rapidly evolving CO_2 emissions profile of some of the CPLP countries and the reinforced interest in the use of CO_2 for EOR purposes, have given an incentive to assess the possibility of deploying CCS projects in CPLP countries.

3.1 Industrial and energy context and CO_2 storage opportunities

This section briefly characterizes the endogenous fossil fuel resources, the energy and industrial sectors, CO_2 emissions profile and discusses CO_2 storage possibilities for each of the CPLP countries where CCS activities have yet to be deployed. Portugal and Brazil, already engaged in several CCS projects, are not included in this analysis.

Angola

Endogenous fossil fuel resources

Angola is an OPEC member and the second-largest oil producer in Sub-Saharan Africa with almost 9.1 billion barrels of proven oil reserves. In 2013, Angola produced 94.0 Mtoe of oil (Fig. 5), amounting to almost 80% of total government revenue [20]. Natural gas production almost quadrupled over the past 20 years, from 2.5 Mtoe in 1990 to 9.5 Mtoe in 2012, but despite holding considerable reserves, Angola is still a small natural gas producer since 91% of the natural gas associated to oil production is re-injected, vented or flared. Angola only began exporting liquefied natural gas in 2013 when Angola's first LNG plant, at Soyo, started operations [20].

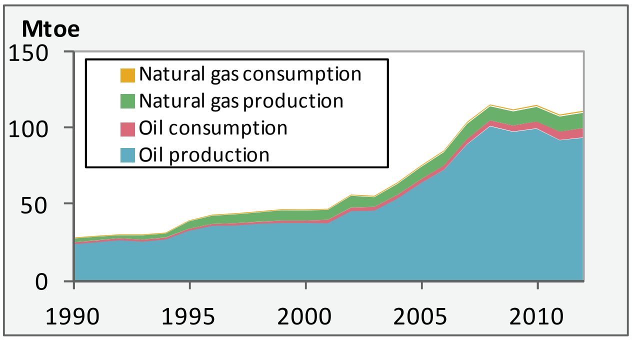

Fig. 5 – Fossil fuels production and consumption in Angola. Source: EIA [19].

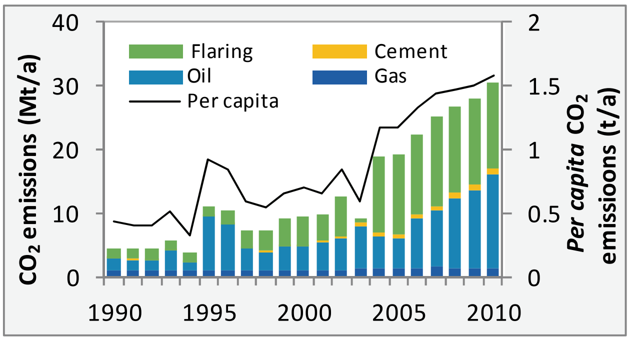

Fig. 6 – CO_2 emissions from consumption of fossil fuels, gas flaring and cement production. Source: CDIAC [9].

Table 1- Primary energy sources 2012.

	Biomass / Waste	Hydro	Oil	Gas
Energy (ktoe)	8384	343	4942	614
Share (%)	58.7	2.4	34.6	4.3

Source: IEA [20].

Primary energy consumption

Electricity supply covers only around 40% of the population [2] and in 2012, 59% of the primary energy consumption consisted of traditional solid biomass and waste [21] (Table 1). Angola consumed 4.9 Mtoe of petroleum products in 2012 (Fig. 5), almost 35% of primary energy sources, and almost twice the volume consumed a decade ago [20].

Area: 1247000 km²
Population (2013): 21.47 million
GNP (2013): USD 121 700 million

Installed electricity capacity is 1.8 GW, of which 70% is from hydroelectric plants [21]. The remainder electricity generation comes from 24 small to medium size thermal power plants [22]. Plans have been announced to increase the generation capacity to 9.0 GW by 2025 [23], mostly from dams. However, natural gas fuelled generation is likely to become increasingly important, with a 500 MW natural gas power plant in Soyo [24] scheduled to come online in 2015, and a 75 MW plant at Cabinda [24] also planned. The government aims that by 2025 electricity will be available for 60% of the population, with hydropower representing 15% of the sources, oil and gas 55%, and reducing the use of biomass to 30% [23].

Carbon intensive Industries

The cement market in Angola has enjoyed years of double-digit growth since the end of the civil war [25]. Angola has two long run cement factories [26]: the SECIL factory, located in Lobito, has a capacity of about 250 kt/a of cement; and the NOVA CIMANGOLA factory, in Luanda, with a capacity of about 1.2 Mt/a. Recent years have seen the construction of three new cement factories; CIMENFORT in Benguela province, FCKS and CIF plants in Luanda. The installed capacity is now over 6 Mt/a, but prospects for the sector are still positive and two new plants are expected to start operations by 2016.

Angola has a single small refinery, built in 1955, with a capacity of 39 000 bbl/d, but a new refinery in Lobito is scheduled to come online in 2017, with an expected processing capacity of 200 000 bbl/d [26].

High quality soil and good water supply makes farming a valuable industry for Angola and investments in fertilizers and methanol are likely to gain importance. In 2014, Angola approved a bill to promote biofuels and the Bio-Energy Company BIOCOM is developing a plantation in Malanje for the production of ethanol and 160 000 MWh of bioelectricity per year [26].

CO_2 emissions

CO_2 emissions from consumption of energy, gas flaring and cement production increased from 4.4 Mt in 1990 to 30.4 Mt in 2010 (Fig. 6), a seven fold increase following the boom in oil production and gas flaring from 2002 onwards [10]. CO_2 emissions due to venting or gas flaring account for 45% of the total emissions. Cement and gas consumption still represent a small share of the emissions, but they have been increasing in recent years due to the new plants and factories that came online. *Per capita* CO_2 emissions are low - 1.6 t/a in 2010.

Opportunities for CO_2 storage

CO_2 storage opportunities in Angola must be sought in the sedimentary basins, namely in deep saline aquifers, depleted oil and gas fields and use of CO_2 in EOR. Other potential scenarios, such as storage in coal seams and in ultramafic and basaltic rocks, are not feasible due to the lack of extensive coal and volcanic provinces in Angola.

Seven sedimentary basins are known in Angola [27], grouped into **Atlantic basins** and **Interior basins** (Fig. 7. The Atlantic basins, composed by the Cenozoic-Cretaceous coastal basins (Lower Congo basin, Kwanza basin, Benguela basin and Namibe basin) are those currently being explored and developed for hydrocarbon resources. Currently, oil production comes entirely from the Lower Congo basin, in the Cabinda and Soyo areas, almost exclusively from offshore fields. In the Soyo area there is small-scale onshore production (Fig. 7).

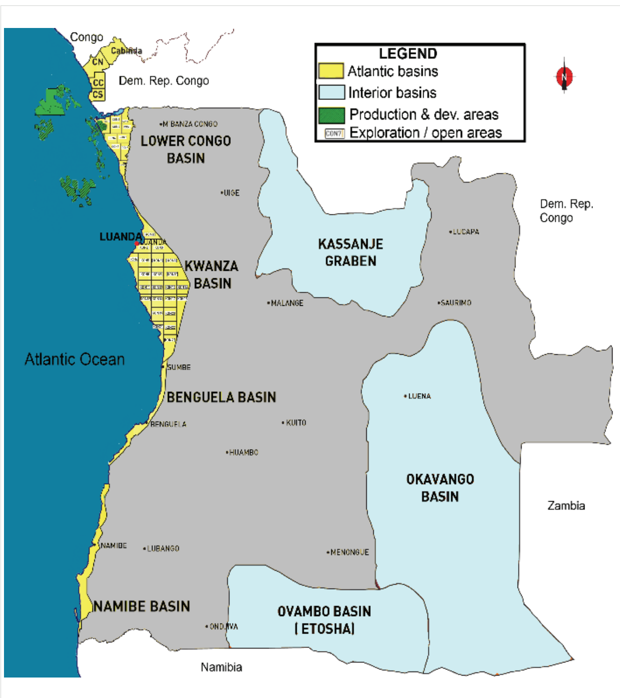

Fig. 7 – Sedimentary basins in Angola. Adapted from SONANGOL [26].

The obvious targets for CO_2 storage are the exploited oil fields in the Lower Congo basin, particularly in the Soyo area since it is favourably located with respect to the main industrial sources. The Cabinda area may be less attractive given the longer transport distances. Transboundary storage and transport issues may be important for the Soyo and Cabinda areas, due to the proximity with Democratic Republic of Congo territory, and specifically to address issues of onshore transport to the Cabinda region.

'Depleted oil fields and use of CO_2 in EOR in mature oil fields are promising options for CO_2 storage in Angola.'

The oil field sector that are becoming depleted present ideal opportunities since the cap-rocks have proved their adequacy and the fields are well characterized. The possibility of utilizing CO_2 in EOR in the depleted sectors is of obvious interest and should be addressed from an economic perspective.

The Kwanza basin, particularly in its onshore sector, seems very promising and worth screening for CO_2 storage in deep saline aquifers, given the existence of salt formations that could both provide good cap-rocks and be the source of high salinity groundwater due to salt leaching. This basin has an extensive onshore sector (the largest from the Atlantic basins) and is very well located with respect to the sources in and around the country capital, Luanda.

On the other hand, the onshore sectors of the Benguela and Namibe basins are very narrow and are likely to be unsuitable for storage of large volumes of CO_2, due to geological structure constraints. Thus, in these basins, and particularly in the Benguela basin where stationary sources (cement factories) exist, efforts to assess CO_2 storage capacity should probably focus on the offshore sectors, with the obvious penalty of higher storage costs compared to onshore storage scenarios.

The Interior basins, composed by the Kassanje graben, the Okavango basin and the Ovambo (Etosha) basin are virtually unknown since field work in those areas could only start following the end of the civil war. They are now being the subject of interest by the national oil company, SONANGOL. They are also very distant from the main industrial development centres and CO_2 sources, and appear to have less interest for CO_2 storage.

Cape Verde

Primary energy consumption

Cape Verde comprises an archipelago of 10 islands, located around 570 km from the west coast of Africa. Despite its scarce natural resources, Cape Verde has seen fast economic growth over recent decades [20] and since 2007 has been classified as a Developing Nation [3], being together with Brazil and Portugal, the only CPLP member states that are not classified as a Least Developed Country. This economic growth was reflected in an increase in primary energy consumption.

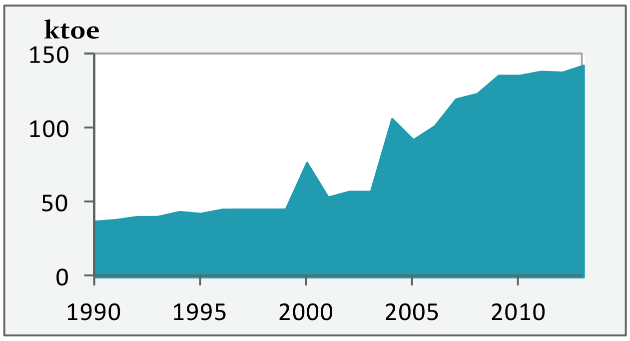

Fig. 8 – Oil consumption in Cape Verde. Source: EIA [19].

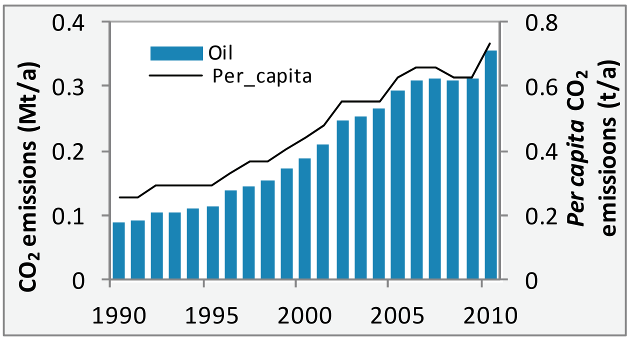

Fig. 9 – CO_2 emissions from consumption of fossil fuels. Source: CDIAC [9].

Table 2 - Primary energy sources 2008.

	Biomass	Wind	Oil
Energy (ktoe)	2.8	0.5	118
Share (%)	2.3	0.4	97.3

Source: IEA [20].

From 1990 to 2012, petroleum products consumption has increased by almost a factor of 4, with the bulk of that increase occurring since 2003, from 37.6 ktoe to 138.0 ktoe [20] (Fig. 8). Since Cape Verde does not have any endogenous fossil fuel resources, it needs to import all the petroleum products it consumes. Indigenous energy resources consist essentially of biomass, wind and solar. Although potential is very high, wind energy production is still limited (Table 2).

Area: 4033 km²
Population (2013): 499 000
GNP (2013): USD 1888 million

As of 2013, the electricity grid covered around 87% of the population [2] (100% coverage in the main islands), water desalination consuming up to 10% of the electricity production. Installed capacity in 2012 was 156.5 MW, with 78% of the capacity being provided by diesel thermal power plants, and the remainder being covered by wind (17%) and solar sources (5%) [28].

The fast economic growth needs to be met with a growing energy capacity, and the government plans to have an installed capacity of 300 MW by 2020 [29]. This energy need is likely to be met by renewable sources, since the country has excellent wind and solar capacities. Cape Verde is one of the 15 countries with the best wind resource in Africa and the potential for solar energy of Cape Verde is very high: 6 kWh/m² per day. A recent study has also indicated that there is 3 MW of geothermal capacity on Fogo island [30]. In total renewable capacity is estimated at about 2600 MW. The Cape Verde government commitment is that, by 2020, renewable sources will provide 50% of the power mix, with at least one island fully supplied by renewable energies [29].

CO_2 emissions

The economy of Cape Verde is service-oriented, with commerce, transport and public services being responsible for 70% of the country's GDP. Given the archipelago nature of the country, with power production facilities specific to each island, the diesel power plants are not large single sources. Furthermore, there are no major industry CO_2 sources, such as cement factories or refineries. CO_2 emissions are mainly connected to oil products as the primary energy source. The trend of CO_2 emissions has followed economic growth, increasing by a factor of 4 from 1990 to 2010, but emissions are still low, staying at just 0.35 Mt in 2010, with the *per capita* values around 0.73 t/a (Fig. 9).

Prospects for CCS activities

Given the low level of CO_2 emissions and the near absence of large point sources, which is likely to continue, given the renewable energy potential and the archipelago nature of the country, CCS is probably not a relevant climate change mitigation technology for Cape Verde.

There are, however, CCS related activities that could be relevant for Cape Verde. The Cape Verde islands are of volcanic origin, although only the Fogo Island remains active. On this island there are several natural emissions at fumaroles, mostly hot sulphur steam, but possibly also linked to natural CO_2 [30]. It is suggested that research activities be carried out into these natural emission sources to test leakage detection methodologies, especially airborne geophysics, and the effects of natural CO_2 emissions to the surrounding environments.

Furthermore, basalts outcrop extensively in several islands of the archipelago, and can provide suitable conditions for research projects focused on CO_2 storage through *in situ* mineral carbonation in those rock types, complementary to the field tests being conducted in Iceland and in the Columbia River basalts in the USA.

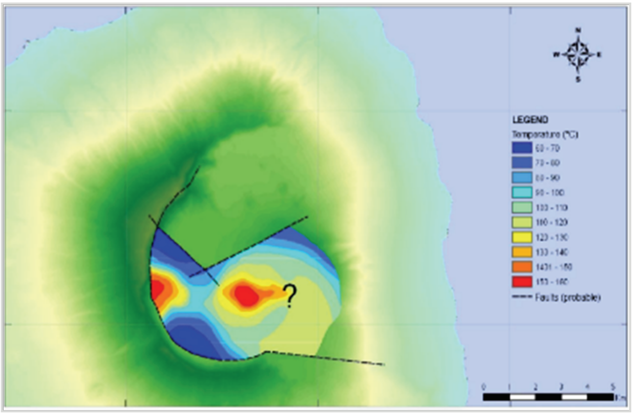

Fig. 10– Geothermal potential in the Fogo island, Cape Verde. Adapted from Gesto Energy [29].

A further relevant CCS activity for Cape Verde is envisaged in connection to the geothermal potential identified by GESTO ENERGY on Fogo Island [30]. A total geothermal capacity of around 3 MW was estimated for a reservoir inferred from geophysical data to be at least 100 m deep (Fig. 10). There are, however, doubts about the existence of a proper geothermal reservoir, since water samples were not conclusive. The use of CO_2 as a fluid to Enhance Geothermal Systems (EGS) is being studied actively at the R&D level (e.g. [31]). In this process CO_2 is injected to recover heat from dry or saturated rock, since CO_2 is more efficient than water, with a fraction of the injected CO_2 being sequestered in the rock by mineral carbonation or simply by migrating away from the injection and recovery wells. If the use of CO_2 in EGS is proved technical and economically valid, it

may be an option for production of geothermal energy from dry rocks in the Fogo Island. The lack of major CO_2 sources in the archipelago will be an obstacle for economic viability, but both geothermal projects and CCS projects are admissible activities in the CDM and issues about economic viability may be overcome if the value of CDM credits improves.

'The use of CO_2 as the circulating fluid in EGS seems to be the most interesting option for Cape Verde, especially in the framework of CDM projects.'

Therefore, although CCS is probably not a climate change mitigation technology required for Cape Verde, there are activities that can be relevant for the national and international R&D community and could motivate the involvement of the relevant authorities in CCS awareness events. The Cape Verde volcanic islands can be a natural laboratory for international cooperation on R&D related to natural CO_2 emissions effects and monitoring, CO_2 storage in basalts and eventually for use of CO_2 as the working fluid in EGS projects, since these may allow for exploitation of the existing geothermal resources under the scope of CDM projects.

East Timor

Endogenous fossil fuel resources

East Timor became a sovereign state in 2002 and joined the CPLP that year. Despite a 2002 ranking of being amongst the poorest countries in the world, East Timor has seen since then an average economic growth of nearly 9% per year [2]. This rapid growth cannot be dissociated from offshore oil production at the Timor Gap. East Timor proven oil reserves are estimated at 554 million barrels. In 2012, Timor-Leste produced 4.1 Mtoe of oil (Fig. 11). Natural gas exploration is yet to begin, but the reserves are vast, estimated at 201 Gm^3, with ongoing negotiations to define the location of processing facilities [20].

East Timor's economy is one of world's most natural resource-dependent, with around 90% of the government budget being derived directly from petroleum revenues.

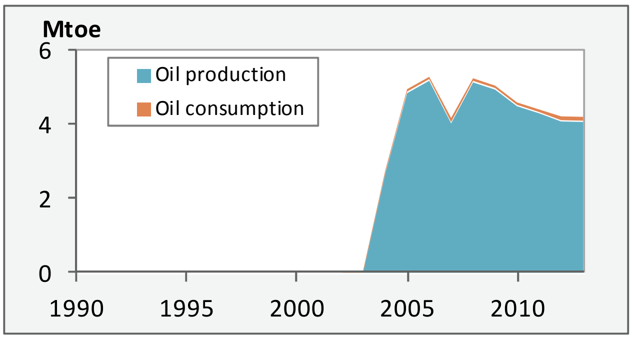

Fig. 11 – Oil production and consumption in East Timor. Source: EIA [19].

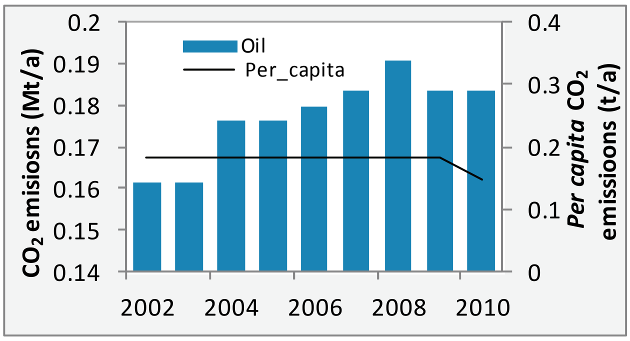

Fig. 12 – CO_2 emissions from consumption of fossil fuels. Source: CDIAC [9].

Primary energy consumption

East Timor is heavily dependent on imports for power generation, with more than 75% of oil imports being used for electricity production through diesel-generator sets [32]. Nevertheless, traditional use of biomass and waste are a significant proportion of the primary energy sources in the country, perhaps responsible for around 90% of the energy requirements for cooking and heating applications [20].

Area: 14954 km²
Population (2013):1.178 million
GNP (2013): USD 311 million

The electricity generation system is small and fragmented, and is mainly based on small and medium size diesel power plants. The installed capacity in Dili, the capital, is 19 MW, while, in the rest of the country, capacity is roughly 16 MW. Another 10 MW are installed by large consumers as their sole power supply or as backup. The electrification is overwhelmingly concentrated in urban areas, with an electrification rate of only around 37% [32]. Plans are underway for the expansion of the power generation infrastructure, with the proposed installation of an additional 210 MW. The country has significant renewable energy potential, with hydropower able to supply 75 MW to 95 MW and with good prospects for wind and solar energy. By 2020, the government plans that 50% of the power is generated from renewable sources [33].

Carbon intensive Industries

Other than the diesel power plants, there are, currently, no major stationary sources in the country, such as refineries, cement or steel factories. However, the government has been promoting internal and foreign investments in key industrial areas. TIMOR GAP, the national oil company, has announced plans to build the first refinery and petrochemical plant at Nova Betano to provide diesel, gasoline, jet-fuel, and LPG.

The East Timor government is committed to natural gas from the *Great Sunrise* gas field being processed in a LNG plant to be built onshore, in Beaço, on the south coast of the country [33]. However, no agreement has been reached yet with the joint venture owning the concession rights for the gas field.

Australian based companies BGC and SWAN ENERGY have announced the construction of a cement factory in Baucau, the 2nd largest city in the country, with a processing capacity of 1.5 Mt of cement per year. Construction is scheduled to start in 2015 [34].

CO_2 emissions

CO_2 emissions are mainly related to the consumption of petroleum products, namely for power production, given the absence of other large point sources. As such, CO_2

emissions are very low, reaching only 183 kt in 2010 [10]. Emissions have increased since 2002, when the country become a sovereign state, but *per capita* CO_2 emissions are still very small, just around 0.15 t (Fig. 12). Nevertheless, the planned industrial investments (refinery, petrochemical plant, cement factory and LNG plant) will increase significantly the emissions of the country in the coming years.

Opportunities for CO_2 storage

According to the East Timor Strategic Development Plan [33], the increase in electricity production capacity will be achieved primarily through renewable sources, so it is not likely that the power sector emissions will increase significantly. Thus, the motivation for CCS activities in East Timor is likely to be connected with the oil and gas production and processing, and associated industrial investments (refinery, petrochemicals, LNG).

East Timor sits in an extremely complex tectonic setting, at the eastern end of and just south of the Banda Volcanic Arc, the surface expression of subduction as the Australian crustal plate moves underneath the Eurasian plate. For the last 5 million years that subduction has become 'locked' in the Timor region, causing the island of Timor to be thrust upwards [35].

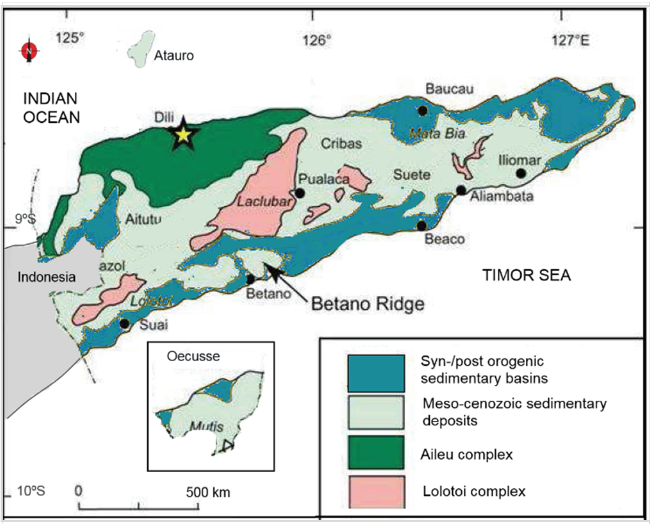

Fig. 13– Simplified geology of East Timor. Adapted from Thomson et al. [34].

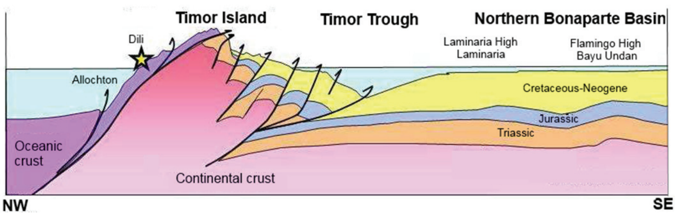

Fig. 14– Schematic of East Timor tectonic framework. Adapted from Thomson et al. [34].

The complex tectonic setting is reflected in the chaotic geology, with the island broken into many structural units. Basement (Lolotoi Complex) and metamorphic rocks (Aileu Complex), resulting from the continental collision (Fig. 13) are unsuitable for CO_2 storage. Mesozoic sediments lie in basins on top of these basement lithologies and Cenozoic and recent reefal limestones continue to be laid down (Fig. 14). The geology in the southern coast of the East Timor is dominated by these Meso-Cenozoic sedimentary basins. However, the fragmented and chaotic nature of rocks leaves little prospects to consider CO_2 storage, as is proved by the many oil and gas seeps along the southern coast of the island [36]. The same tectonic constraints apply offshore.

CO_2 storage is being considered in countries in complex tectonic conditions (e.g. Japan, Indonesia), and the Nagaoka pilot injection site, in Japan, proved that CO_2 storage sites can remain unaffected even if subjected to magnitude M=6 earthquakes in close vicinity to the injection site. Nevertheless, a precautionary approach should consider CO_2 storage in East Timor only in connection to the oil and natural gas fields, not only because containment conditions are guaranteed, but also because pressure increases would be smaller than considering storage in deep saline aquifers.

The possibility of utilizing CO_2 for EOR in the exploited sectors is of obvious interest and should be addressed from an economic perspective in the future, since production is still recent and fields may yet be far from maturity and depletion.

Although it is likely that in the near future large scale CO_2 sources will be built in East Timor, the sensible approach is probably to consider that CCS activities in East Timor would most likely be connected to the oil and gas exploration industry, either through the use of CO_2 in EOR activities, or by injection of CO_2 in depleted oil and gas reservoirs in the offshore sectors currently being exploited. In that respect, it is relevant that Australian companies are involved in the production of hydrocarbons in the Timor Gap, given the Australian experience in CO_2 storage.

'The tectonic setting of East Timor advises for considering storage of CO_2 only in depleted oil and gas fields or for EOR.'

Equatorial Guinea

Endogenous fossil fuel resources

Equatorial Guinea is the most recent member of the CPLP, having joined the community in July 2014. It is the third-largest oil producer in sub-Saharan Africa, after Nigeria and Angola, with proved reserves of 1.1 billion barrels, and with a production of 14.9 Mtoe in 2012, entirely from offshore fields (Fig. 15). Natural gas reserves are also significant, amounting to 36.8 Gm^3, and the country is a net exporter of natural gas, with dry natural gas production increasing from 1.2 Mtoe in 2001 to 7.3 Mtoe in 2012. Most of the natural gas is processed and exported from a local LNG plant which produced 4.9 Gm^3 of LNG in 2012 [20]. The LNG plant runs a single train, and a second train is to start operations 2016 [37].

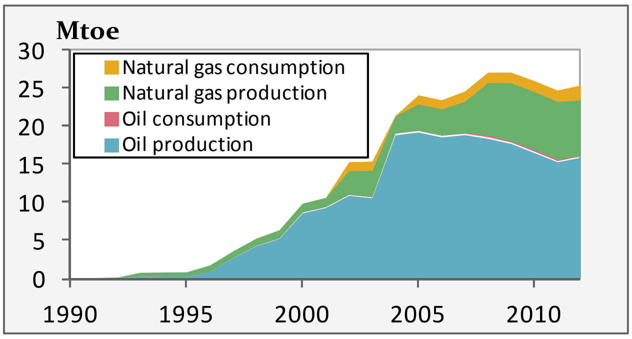

Fig. 15– Fossil fuels production and consumption in Equatorial Guinea. Source: EIA [19].

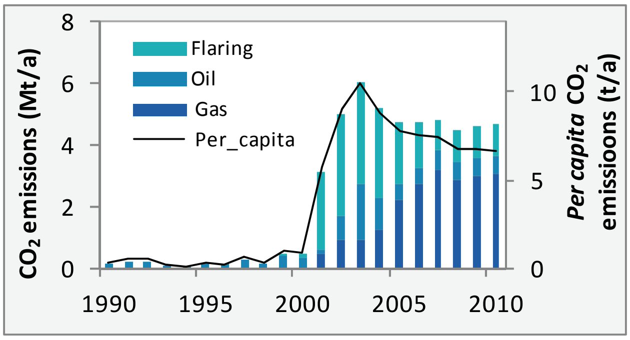

Fig. 16 – CO_2 emissions from consumption of fossil fuels. Source: CDIAC [9].

Equatorial Guinea's economy is heavily dependent on the oil and gas industry, which accounted for almost 95 percent of its GDP and 99 percent of its export earnings in 2011 [2].

Primary energy consumption

Natural gas became the primary energy source after 2000, following the start of hydrocarbons production, and in 2008 was responsible for 77% of the primary energy supply. Oil products and traditional use of biomass, which dominated the energy sources in the 1990's, are now responsible for minor shares, respectively 20% and 3%. Renewable sources were poorly exploited [38]. However, this scenario changed in 2013, when the Djibloho dam, on the Wele River, went online with an installed electricity production capacity of 120 MW, about three times the previous existing capacity in the country [20].

Area: 28051 km^2
Population (2013): 757 thousand
GNP (2013): USD 15570 million

The electrification rate is now one of the highest in Central Africa, covering 66% of the population [39]. There are still about 40 MW of electricity capacity provided by gas-fired power plants (the Punta Europa plant and the AMPCO plant having a joint capacity of 34 MW) and by oil-fired power plants. Hydropower potential is very high, estimated at some 2600 MW, and further investments are planned, including the Sendje river hydro scheme which is due for completion in 2015, with a capacity of 200 MW.

Carbon Intensive Industries

Apart from the oil industry, Equatorial Guinea's economy is based on agriculture, forestry and fishing, so that no major industrial CO_2 sources exist, other than the LNG plant and gas flaring. Equatorial Guinea does not have an oil refinery, but the Government has announced plans to open a 20 Mbbl/d refinery in Mbini [20]. OPHIR ENERGY also announced the construction of a Floating LNG plant[40].

There are no cement factories in the country, but a factory with a production capacity of 3000 t/d has been commissioned and operations should start in 2016 [41].

With an estimated biomass potential of 400 tonnes/ha or more, Equatorial Guinea has extensive biomass coverage [42]. Potential for bioenergy production is high [43], but no investment plans have been announced yet.

CO_2 emissions

CO_2 emissions in Equatorial Guinea experienced a remarkable increase with the onset of hydrocarbon production in 2000. In 1999 CO_2 emissions were at 0.36 Mt, but in 2000 those emissions increased almost 10 fold, to 3.1 Mt, with the vast majority coming from the flaring of gas at oilfields. CO_2 emissions peaked in 2004 at

5.2 Mt, and since then stabilized at around 4.6-4.7 Mt/a (Fig. 16). Although flaring still remains an important share of the emissions (about 20%), the consumption of natural gas in power plants and in LNG plants make for around 65% of the total CO_2 emissions [10].

Per capita emissions show a similar trend, having stabilized at around 6.7 t/a, the largest per capita emissions among the CPLP countries and the second largest in the African continent, behind South Africa.

Opportunities for CO_2 storage

The geology of the onshore sector of Equatorial Guinea is almost entirely composed by Precambrian crystalline basement [44], comprising igneous and metamorphic rocks that underlie most of the central and eastern mainland of Equatorial Guinea and unsuitable for CO_2 storage. Prospects for onshore CO_2 storage are very scarce and restricted to a very narrow band of sedimentary rocks that are exposed only along its coastal region (Fig. 17).

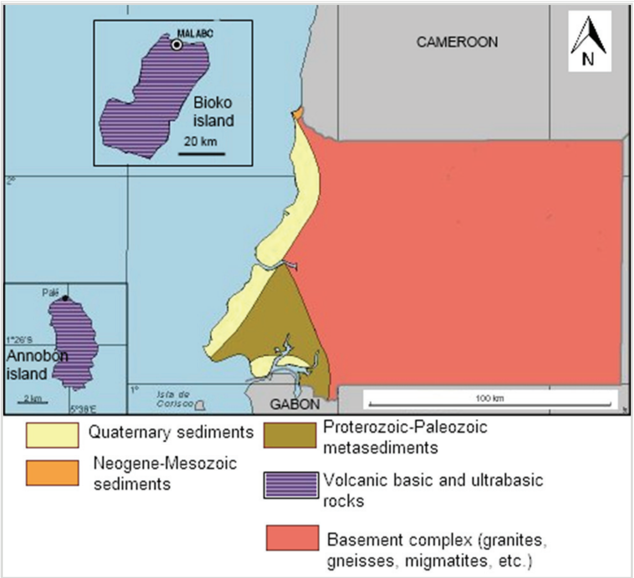

Fig. 17 – Simplified geology of Equatorial Guinea.

The Atlantic volcanic islands of Pagalu and Bioko are part of the Cameroon Volcanic Line and are composed by basic and ultrabasic rocks. Academic R&D and two ongoing pilot tests in Iceland and the Columbia River basalts (USA) indicate that these geologic environments may be favourable for CO_2 storage, since they seem to promote fast mineral carbonation of the CO_2. The Bioko island, where the capital city Malabo is located, is also the location of the largest CO_2 stationary sources in the country, the LNG plant and the gas-fired power plant.

CO_2 storage opportunities in Equatorial Guinea should probably focus primarily in the offshore area, both immediately offshore from the mainland territory, in the Rio Muni basin, in the Okume and Ceiba oil fields, and offshore from the Bioko island, in the Zafiro and Alba oil and gas fields [45]. Those sectors are very well known and, as they become oil depleted, can provide good opportunities for CO_2 storage.

The possibility of using CO_2 for EOR purposes is also an opportunity. Given the importance of oil production the national hydrocarbon companies, GEPETROL and SONAGAS, are surely fully aware of the advances in the use of CO_2 for EOR purposes. Furthermore, several of the oil companies acting as concessionaires (e.g. PETROBRAS and CHEVRON) in the Equatorial Guinea are experienced in CO_2 injection projects, not only connected to EOR, but also as part of the CCS chain.

Moreover, the oil exploration studies may have led to identification of saline aquifers. Bioko Island is the centre of many of the industrial investments expected for the country, and the shallow continental shelf just north from the island is well known from oil exploration efforts and can provide adequate conditions for CCS projects. In the mainland territory, one should consider possible CO_2 storage connected to the refinery at Mbini, if the project moves ahead. The shallow continental shelf between the Ceiba oil fields and the mainland territory may provide opportunities for CO_2 storage connected to that refinery.

Bio-CCS projects are particularly suitable in Equatorial Guinea, given the large biomass potential, potentially significant storage capacity and a mature hydrocarbon industry able to provide the technical and regulatory background for implementing CO_2 storage. Bio-CCS may also be particularly appropriate to consider under the CDM. Although no plans have been put forward for industrial scale utilization of biomass or biofuels production in Equatorial Guinea, the potential for coupling it with CCS is high.

‘Ongoing industrial investments, mature oil industry, high biomass potential and likely good offshore storage conditions are favorable factors for CCS in Equatorial Guinea’

Guinea-Bissau

Primary energy consumption

Guinea-Bissau is one of the CPLP founding member states, but political instability since 1998 has caused the country to be among the poorest countries in the world and led to difficulties in cooperation activities in the CPLP. Democratic elections held in May 2014 were praised by the CPLP and expectations are that cooperation activities with the community will increase with political stability.

Guinea-Bissau does not have any proved indigenous fossil fuels resources and all petroleum products are imported. Energy statistics for Guinea-Bissau are outdated, but according to the 2007 energy balance, the consumption of oil (Fig. 18) was dominated by the transport sector (40.6 ktoe), followed by electricity production (0.946 ktoe) and the residential sector (0.240 ktoe) [46].

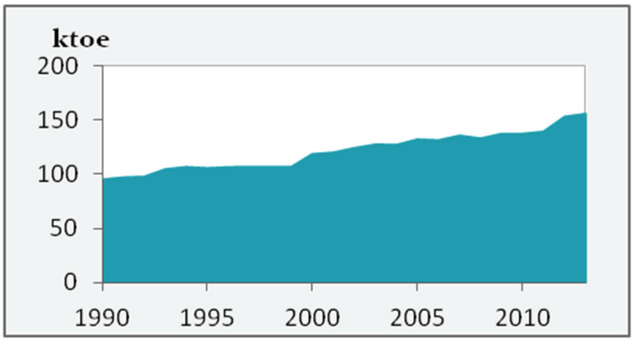

Fig. 18 – Oil consumption in Guinea- Bissau. Source: EIA [19].

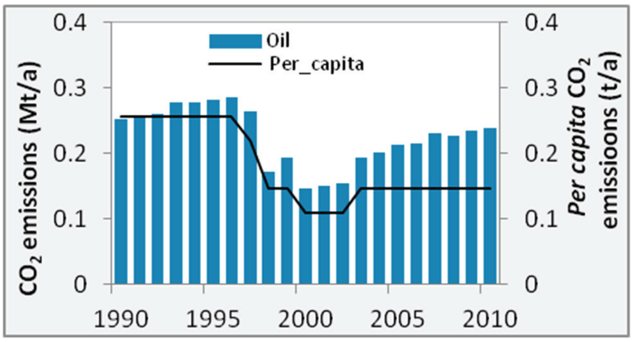

Fig. 19 – CO_2 emissions from consumption of fossil fuels. Source: CDIAC [9].

Table 3 - Primary energy sources 2008.

	Biomass	Oil
Energy (ktoe)	107.3	111.7
Share (%)	49.0	51.0

Source: IEA [20].

Area: 36125 km²
Population (2013):1.704 million
GNP (2013): USD 858 million

In 2008 the total primary energy consumption of 219 ktoe was almost evenly split by oil products (51% of the share) and by traditional use of biomass (49%) (Table 3). In fact, biomass represented over 95% of the total energy consumed by households in Guinea-Bissau [47].

The installed electricity capacity in 2008 was 21 MW, but electricity production and distribution has almost collapsed since 2000 and only 20% of the population has access to public electricity, mainly in the capital city, Bissau, and in seven other urban centres [48]. The country's entire public power system is operating on 5.5 MW of generation capacity, 25% of what it had been before the 1998 internal conflict. Power production is completely dependent on petroleum products through several small size diesel power plants, despite the high potential for renewable energies [46].

Indeed, the country has extensive renewable energy resources, especially for hydropower, estimated at about 184 MW from the rivers Corubal and Geba, solar energy, with average solar radiation of 4.5 to 5.5 kWh/m^2 per day, and biomass. Despite this large potential, few plans are known for investments in this area, although the government has announced plans to increase solar PV to cover up to 2 % of overall energy consumption by 2015 [46, 47].

Guinea-Bissau has also very good conditions for biofuel projects, and a project funded by the FACT Foundation and World Bank began in 2010. Both institutions have since then pulled out from the project. Hopefully, political stability will allow the country to engage in strategic development plans for this and energy sources.

CO_2 emissions

The economy of Guinea Bissau is based on agriculture and fishing. Other than diesel power plants, there are currently no major point source emitters in the country, such as refineries, cement or steel factories [48]. A private company has announced the intention of building a cement factory with 500 kt/a capacity, with construction scheduled to begin in 2015 [49]. Because of high costs, the development of petroleum, phosphate, and other mineral resources is not a near-term prospect.

Currently, CO_2 emissions are mainly related to the consumption of petroleum products, and emissions are very small, with a maximum of only 0.238 Mt in 2010, but with a marked decrease since the onset of political turmoil in 1998. The *per capita* emissions, amounting to 0.26 t/a in 1990, had in 2004 decreased to 0.15 t/a (Fig. 19) [10].

Opportunities for CO_2 storage

It is likely that the Guinea-Bissau has very favourable conditions for geological storage of CO_2. Although the eastern half of the country is composed by Palaeozoic-Precambrian basement rocks covered by sediments up to ± 30 m, unsuitable for CO_2 storage, the western half corresponds to the Guinea-Bissau sub-basin, a part of the Meso-Cenozoic Senegal basin (Fig. 20). Onshore the sub-basin presents very thick sedimentary sequences, dating from the Oligocene to Present, generally with sandstone to clayish lithologies [50].

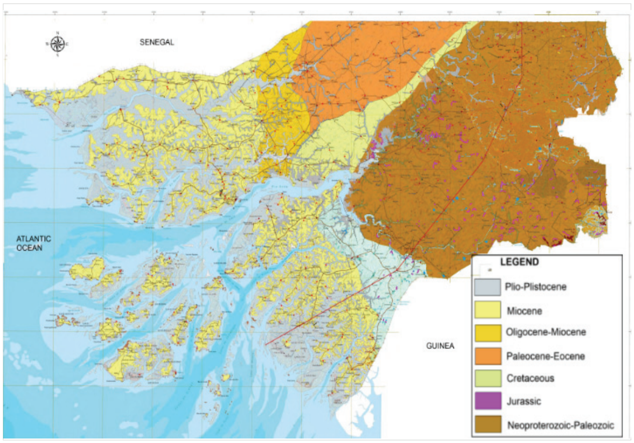

Fig. 20– Simplified geology of Guinea-Bissau. Adapted from Alves et al. [50].

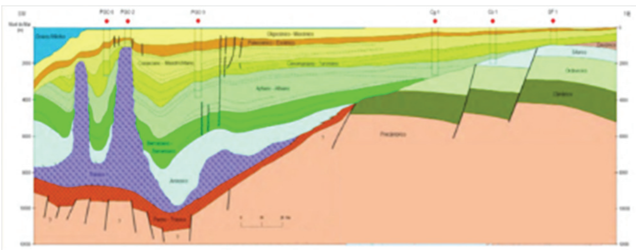

Fig. 21– Schematic geological cross-section of Guinea-Bissau. Adapted from Alves et al. [50].

The sedimentary sequence thickens westward, i.e. to the offshore territory (Fig. 21). The offshore sequence includes sediments from the Jurassic to the Quaternary, but the Cretaceous sedimentation dominates the sequence. Overall, the basin is characterized by a depocenter with sedimentary sequence up to 2.5 to 3 km thick onshore, and about 12 km thick, with many salt domes in the offshore sector [51].

The general sequence in the Jurassic is composed predominantly by limestones with intercalated layers of shales and evaporites, while the Early Cretaceous is abundant on thick limestones and sandstones deposits, with the upper Cretaceous bearing extensive shale layers [51]. It is likely that suitable reservoirs and cap-rocks complexes can be identified both in the Jurassic and Cretaceous and in the deeper layers of the Oligocene. The general structure of the basin with a smooth dip from east to west, apparently without major structural complexities, is favourable for the occurrence of high salinity groundwater in depth, due to prolonged contact with the potential reservoirs, and to hydrodynamic trapping of CO_2 due to regional-scale flow.

'Bio-CCS is probably the sector with the highest potential for CCS projects in Guinea-Bissau.'

Given this geologic framework, it is likely that Guinea-Bissau has very good conditions for CO_2 storage potential in deep saline aquifers, both onshore and offshore, and despite the poor prospects to implement CCS projects in Guinea-Bissau, it is certainly worth to conduct a storage capacity assessment in the country.

Guinea-Bissau authorities and institutions have never been involved in any CCS related activities and the level of knowledge about the technology is likely to be very low. Political stability seems to have returned to the country, with internationally monitored elections successfully conducted in 2014, and thus with increased participation of the country in CPLP activities. Nevertheless, the disruption of local economic conditions, security, higher education and public administration during the past decade, will require years to turn round. It is not likely that CCS activities can be deployed in the country in the short term. Activities to raise the knowledge about CCS in Guinea-Bissau should focus on inviting representatives of public authorities (from the Ministry of Environment, Ministry of Economy, Designated National Authority to the CDM) to participate in raising awareness, workshops or short courses conducted in other CPLP member countries. In particular, raising awareness about Bio-CCS should be a priority, since this is probably the sector with the highest potential for CCS projects in Guinea-Bissau.

Mozambique

Endogenous fossil fuel resources

Mozambique is one of the most promising countries in Africa in terms of natural gas and coal resources. In 2012 Mozambique produced only 3.5 Mtoe of natural gas from two onshore gas fields (Fig. 22), but recent years have seen massive offshore natural gas discoveries, with proved reserves estimated at 2800 Gm^3, placing Mozambique behind only Nigeria and Algeria in Africa. Production is to begin in 2018 and a LNG facility is under construction in the Cabo Delgado Province [20].

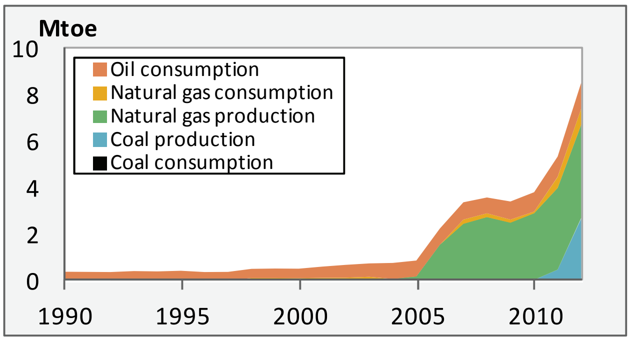

Fig. 22 – Fossil fuels production and consumption in Mozambique. Source: EIA [19].

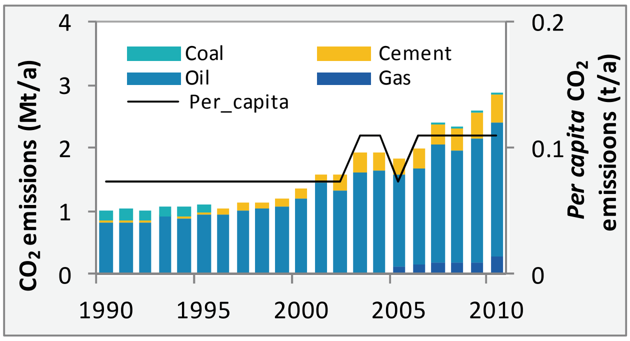

Fig. 23 – CO_2 emissions from consumption of fossil fuels and cement production. Source: CDIAC [9].

Table 4 - Primary energy sources 2012.

	Biomass / Waste	Hydro	Oil	Gas	Coal
Energy (ktoe)	8288	1284	783	73	10
Share (%)	79.4	12.3	7.5	0.7	0.1

Source: IEA [20].

Mozambique is the 2nd largest coal producer in Africa, with 4.9 Mt in 2012, and it is estimated that the Tete Province still holds large untapped reserves. Coal-to-liquids (CTL) is also being considered in the country, with a USD 9.5bn plant to transform the waste coal in the Tete basin into liquid fuels [52].

Area: 799380 km^2
Population (2014): 23.97 million
GNP (2013): USD 15563 million
(INE,2014)

According to the IMF [53], fossil fuel production can increase Mozambique's economic growth by 2% annually in the period 2013-23.

Primary energy consumption

As of 2012 only 20% of the Mozambique population had access to electricity [2] and about 79% of the primary energy consumption consisted of traditional biomass and waste [21]. In 2012 Mozambique consumed 783 ktoe of petroleum products, composing 7.5% of primary energy sources. Natural gas and coal are residual (less than 1%) primary energy sources (Table 4).

Electricity generation in Mozambique was 16.7 TWh in 2011, almost 100% from hydropower and just a minute proportion from natural gas. Plans have been announced to bring online Mozambique's first coal-fired power station next to the coal mines in the Tete Province in 2015, and two large scale coal power plants are to be built also connected to the NCONDEZI ENERGY and VALE coal mines, bringing the total generation capacity to 9 GW. Given the extent of natural gas discoveries, it is likely that its contribution to electricity production will increase. The Ressano Garcia 175 MW gas power plant started operations in 2014 and several others gas power plants are scheduled to start operations in the coming years, namely the 100 MW Maputo plant, the 40 MW Kuvaninga plant and the Temane 400 MW power plant. [20].

Forecasts for electricity consumption from domestic sources (excluding large industrial consumers), in a 6% per year economic growth scenario, indicates that by 2030 the power demand will be at least 1350 MW and electricity consumption at least 83 TWh.

Carbon intensive Industries

Mozambique’s construction sector has one of the strongest growth outlooks in Sub-Saharan Africa. Annual cement production capacity reached 2 Mt in 2011, but the government planned to double it by 2013. CIMENTOS DE MOÇAMBIQUE is the main producer in its Matola factory and grinding units at Dondo and Nacala. The government has publicized plans to build three new factories with a total capacity of 750 kt/a in the Maputo Province [25].

Mozambique's first oil refinery is being built in Nacala with a capacity of 300 000 bbl/d, and will be operational in 2018 [20]. In the mining sector, aluminium mining is one of the most important revenue generators, with MOZAL aluminium smelter (a significant CO_2 source, with direct emissions of 15 t CO_2 per ton of processed aluminium and requiring vast amounts of energy), is among the largest in Africa, with a production capacity of 250 kt/a.

The Government has approved 14 projects for biofuel production, but the majority have yet to be deployed. Still, PETROBRAS expects to begin ethanol production in a 20 Ml/a distillery [54] and GALP has announced plans to build a biofuels refinery in Sofala [55].

CO_2 emissions

CO_2 emissions from fossil fuels and cement production are small, having increased from 1.0 Mt in 1990 to 2.9 Mt in 2010, due to a steady rise in oil consumption, but also connected to the increase in cement production (Fig. 23). Since 2005, CO_2 emissions connected to natural gas use have also steadily increased. *Per capita* emissions are the lowest among CPLP countries, only 0.11 t/a in 2010 [10], but with the onset of natural gas and LNG production, continuing coal mining, and the investments announced in the energy and industrial sectors, the *per capita* emissions should see a rapid rise in the next decade.

Opportunities for CO_2 storage

The Mozambique National Strategy for Adapting and Mitigating Climate Change 2013-2025 [56] acknowledges the need to consider clean coal technologies for CO_2 emissions reduction in coal power plants and the possibility of deploying CCS projects in the country.

Since large scale natural gas production is only scheduled to begin in 2018, the use of depleted gas fields is unlikely to be feasible in the coming decade, except in the onshore Pande and Temane fields, operating since 2004, but relatively small in size. Interest in CO_2 storage in unminable coal seams has been declining worldwide, but the Tete province has some of the largest coal reserves in the world and two coal power plants are planned for the region. Thus, the possibility of CO_2 storage in unminable coal seams should not be discarded entirely, since the source-sink match would be perfect.

'Mozambique is the African CPLP country with the most drivers to engage in CCS projects.'

However, the most interesting options for storing CO_2 in Mozambique are deep saline aquifers in the extensive sedimentary basins that cover 38% of the onshore territory and most of the offshore Mozambique Channel.

Six sedimentary basins are known in Mozambique (Fig. 24). The interior basins (Lake Niassa Basin, Maniamba Basin, Middle Zambezi Graben and Lower Zambezi Graben) are relatively small and are part of Karoo Supergroup [57]. Their remote location probably disqualifies the Niassa and Maniamba basins for CO_2 storage.

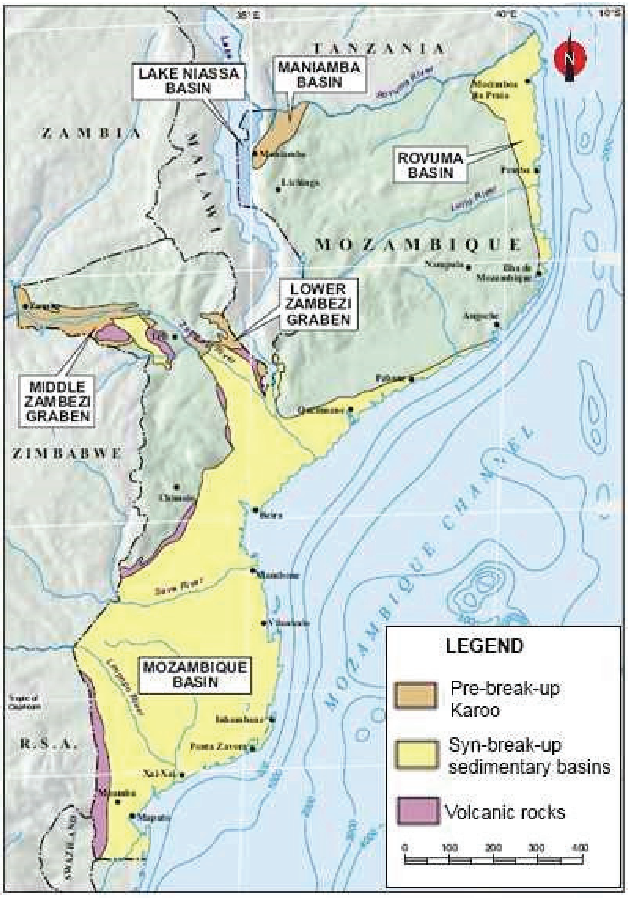

Fig. 24– Sedimentary basins in Mozambique. Adapted from ENH [56].

The Middle and Lower Zambezi grabens are structurally linked to the occurrence of the Tete coal province. The geological structure is quite complex [58], but the proximity to major CO_2 sources that are under construction or planned, make it relevant to screen these basins for CO_2 storage potential.

The coastal basins (Mozambique basin and Rovuma basin) are much larger, and where knowledge of deep geological conditions is higher, since it is there that hydrocarbon exploration has been active, with massive gas discoveries in the offshore part of the Rovuma basin. A report by DNV estimated the storage capacity of the Mozambique basin at a minimum value of 2400 Mt CO_2. M. Alberto in a undergraduate project [59] estimated the storage capacity in the Rovuma basin from 235 Mt to 470 Mt, with a particularly good source and sink match since the storage capacity was identified in the same areas where natural gas processing and LNG plants are planned to be built in the Rovuma basin, namely in the Palma and Pemba municipalities. Although these are preliminary estimates, they indicate that Mozambique may have extensive onshore CO_2 storage capacity, more than enough for its own needs.

Given the investments announced in the energy and industrial sectors, the importance of the coal and natural gas resources to the national economy, Mozambique probably has good incentive to engage in CCS activities. A further driver is the business opportunity resulting from storing CO_2 from neighbouring countries, such as South Africa (the largest CO_2 emitter in Africa), if such activities become admissible under international regulations.

São Tomé and Príncipe

Endogenous fossil fuel resources

São Tomé and Príncipe (STP) consists of two archipelagos around the two main islands: the island of São Tomé and the island of Principe, about 140 kilometres apart, located in the Gulf of Guinea, west Africa. It is the smallest Portuguese-speaking country and the 2nd smallest state in Africa, after the Seychelles.

Currently STP does not have any endogenous fossil fuels production, but according to the African Development Bank (AfdB), STP it is on the verge of becoming an oil producing country, with expectations for production to start in 2016, in a Joint Development Zone (JDZ) with Nigeria, in the gulf of Guinea. The baseline estimates are on the order of 500 million barrels of oil, resulting in a STP share production of 28 000 barrels per day for twenty years [60].

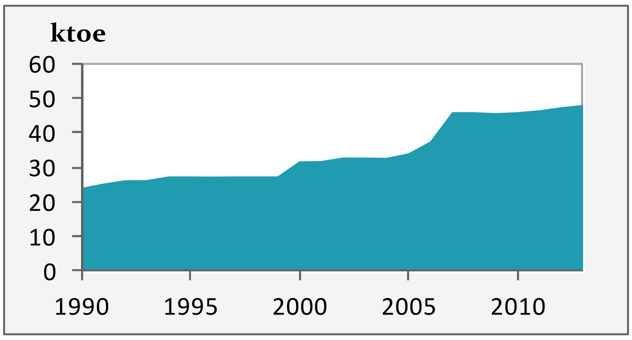

Fig. 25– Oil consumption in São Tomé and Príncipe. Source: EIA [19].

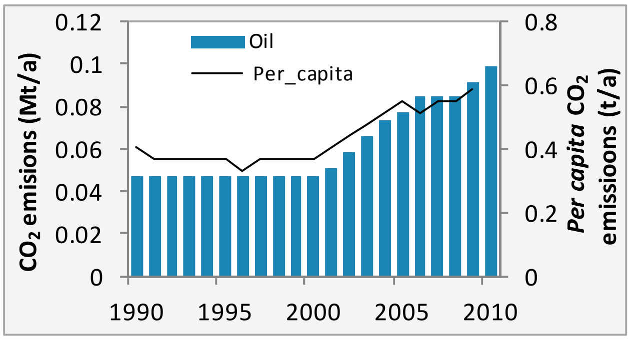

Fig. 26– CO_2 emissions from consumption of fossil fuels. Source: CDIAC [9].

If oil exploration becomes a reality in the coming years, it is expected that by 2020 growth in STP will be largely driven by the oil sector.

Primary energy consumption

The population of STP is only 193 thousand and primary energy consumption is small, with traditional biomass (such as firewood and charcoal) being heavily used for cooking and heating purposes [2]. The other main source of primary energy is oil, the imports of which in 2013 were 47 ktoe [20] (Fig. 25).

Area: 1001 km²
Population (2013):193 thousand
GNP (2013): USD 311 million

Installed grid-connected power production capacity in STP is around 28.5 MW, with diesel power plants providing 26 MW and the remaining 2.5 MW from hydroelectric power. An additional 10 MW of diesel power is generated in isolated grids and auto-production. Grid coverage does not extend to the entire population, but about 60% has access to grid electricity.

There is considerable potential for development of hydropower resources in São Tomé and Principe. In addition to the currently installed 2.5 MW hydro capacity, 31.4 MW of potential has been identified in 14 sites. The rising demand for electricity is expected to require up to 40 MW of additional generation capacity by 2019, potentially calling for exploitation of the full hydroelectric potential [61]. Solar energy also has good opportunities, since the average daily insolation in São Tomé and Principe is 5.2 kWh/m^2, without significant seasonality.

The economy of STP is based essentially on agriculture, with tourism gaining some relevance lately. There are no locally based large CO_2 emissions industrial sectors, such as refineries, cement or steel factories.

CO_2 emissions

CO_2 emissions are mainly related to the consumption of petroleum products, given the absence of other large stationary sources aside from diesel power plants. Total CO_2 emissions are very small, with a maximum of only 90 kt in 2012 (Fig. 26). Emissions have been increasing steadily since 2000, but *per capita* emission are still very small, less than 0.6 t/a [10]. Expectations are for an increase with continued economic growth, but given the population size and insularity costs for developing industrial activities, *per capita* CO_2 emissions are likely to remain low. If oil production becomes a reality in the coming years, flaring could increase significantly the CO_2 emissions.

Prospects for CCS activities

The STP islands are composed by massive shield volcanoes which rise from the floor of the Atlantic Ocean, over 3000 m below sea level. The volcanoes formed along the Cameroon line, a line of volcanoes extending from Cameroon southwest into the Atlantic Ocean. Most of the rocks composing the São Tomé Island are basalts. The island of Príncipe is also of volcanic origin, with basaltic, phonolitic and tephritic compositions. According to academic R&D these lithologies may be suitable for storing CO_2, since their mineralogy is particularly favourable for mineral carbonation, in which the dissolved CO_2 reacts with the rock and precipitates as carbonate minerals, providing CO_2 sequestration in the solid phase. This concept is being tested in pilot projects such as CARBFIX, in the Iceland, and the Columbia River Basalt, in the USA.

Offshore from the volcanic centres, the Exclusive Economic Zone of STP is mostly composed by sediments, including in JDZ, where oil production may develop [62].

Currently, the economy and CO_2 emissions of STP do not justify investments in CCS projects. Given the low level of CO_2 emissions and the near absence of large point sources, which is likely to continue due to the population size and insularity costs, motivation for CCS activities in

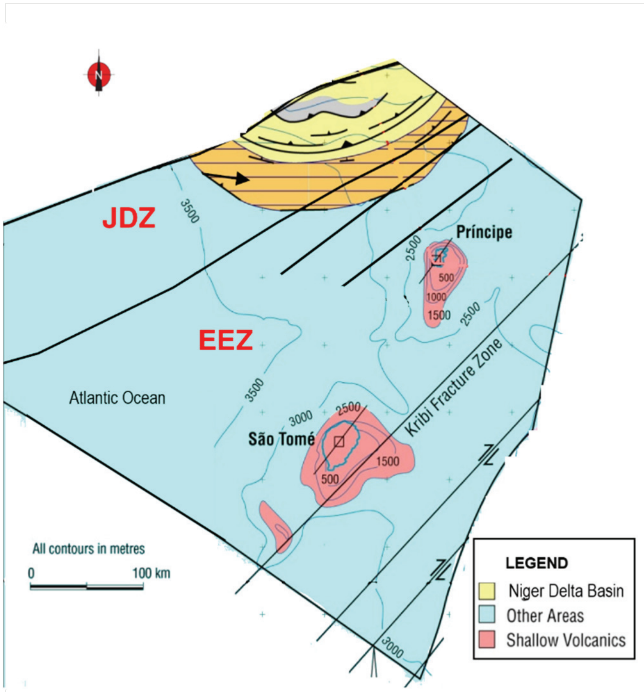

Fig. 27– Simplified geology of São Tomé and Príncipe, including Exclusive Economic Zone (EEZ) and Joint Development Zone (JDZ) with Nigeria. Adapted from ANP [61].

'Relevance of CO_2 storage in São Tomé and Príncipe can come from development of the oil industry or from transboundary storage issues with Nigeria.'

STP can only come in connection to deployment of oil production in the Gulf of Guinea, specifically with respect to use of CO_2 in EOR. Still, the lack of CO_2 sources in STP implies that CO_2 would have to be acquired in other countries.

STP shares a maritime border with Nigeria, one of the largest CO_2 emitters in Africa, and it is conceivable that transboundary CO_2 storage could become of relevance for STP, if Nigeria eventually chooses to store CO_2 in the Niger Delta Basin, which spreads across the maritime border between the two countries in the JDZ (Fig. 27), a possibility being studied by the Nigerian Petroleum Technology Development Fund.

The national oil authority (*Agência Nacional do Petróleo*, ANP-STP) and the CDM Designated National Authority should be involved in any knowledge sharing activities related to CCS in order to build the capacity to discuss the use of CO_2 of EOR and possible transboundary storage issues with Nigeria.

3.2 Sectors with potential for CCS activities

This section seeks to identify the prospects for the main sectors where CCS projects can be considered. Along with the power production sector and CO_2 use in EOR, five industrial sectors, regarded as early opportunities in the IEAGHG/UNIDO 'Technology Roadmap' [63], are considered: cement; iron and steel; downstream oil; Bio-CCS; high CO_2 purity sources (e.g. LNG, gas processing, CTL). Less common prospects are grouped under 'other prospects'. Table 5 summarizes the prospects for CCS activities per sector in the CPLP member states characterised in the previous section.

Mozambique), in general plans are not focusing on new fossil fuel power plants, including Portugal and Brazil, due to the availability of renewable energy resources.

The exception seems to be Mozambique, with several planned new natural gas and coal power plants that will use endogenous coal resources. The coal power plants are being promoted by the mining companies, including the Brazilian VALE, and synergies can be found to implement CCS projects in those power plants. CCS projects in connection to the new natural gas power plants in Angola and Equatorial Guinea should also be considered.

Table 5 – Prospects for CCS activities per sector in the CPLP countries under consideration

	Angola	Cape Verde	East Timor	Equatorial Guinea	Guinea-Bissau	Mozambique	São Tomé and Príncipe
Power production	Main investments in hydro. Two new gas plants.	No major sources. Archipelago country.	No major sources. Large renewable potential.	Main investments in hydro. One gas plant.	No major sources. Large hydro potential.	Two new coal power plants. Several new Gas plants.	No major sources. Archipelago country.
Cement	Several cement factories active or planned.	None	Planned cement plant.	Investments announced in cement factory.	At the moment, no existing sources.	Several cement factories active or planned.	None
Downstream oil	One active refinery and 2nd planned.	None	Planned refinery and petroch .facility	Investments in a refinery uncertain.	None	First refinery to come online in 2018.	None
Bio-CCS	Good biomass potential. One biofuel project	No potential. Sub-sahelian climate.	High biomass potential. No projects known.	High biomass potential. No projects known.	High biomass potential. No projects known.	High biomass potential. Several biofuel projects approv.	High biomass potential. No projects known.
EOR	Oil producer. Mature fields.	-	Recent oil Producer.	Oil producer. Mature fields.	-	-	May become an oil producer.
High purity sources	Gas producer. One LNG plant.	None	LNG plant planned.	Gas producer. One LNG plant, 2nd planned.	None	LNG plant in construction. A CTL project.	None
Other prospects	-	EGS with CO_2	-	-	-	One aluminium smelter.	-

No prospects. No existing or planned sources	Marginal prospects, source may be planned,	Fair prospects, but no sources or not more than one source.	Good prospects, several existing or planned source.

Power production sector

A common feature of most of the CPLP countries is the high population growth rate, with an average of 2.1% per year for the countries characterized in the previous section. Given this demographic growth, the economic development rates and low electricity penetration, there is the expectation that the next decades will see a boom in the power production capacity. This is reflected in national energy strategies, with all countries planning to considerably increase the capacity and expand national grids. However, because of the vast renewable energy resources available in most of those countries, namely hydro and solar (also wind, for Cape Verde and

Carbon intensive industries

Industrialization is still reduced in the countries being considered, and the cement, downstream oil and iron and steel sectors are under development. Nevertheless, several CPLP countries have ongoing or planned investment in some of those sectors.

Cement sector

The construction sector is developing fast in many of these countries, and cement production is following, with new factories to be built in almost every country, except for Cape Verde and S. Tomé and Principe, due to the costs of insularity. The cement industry seems to grow particularly fast in Mozambique and Angola. INTERCEMENT, a Brazilian based cement company, but with facilities in Portugal, has investments planned in some CPLP countries, as does SECIL, a Portuguese based cement company. Assembling a cluster of the cement companies investing in the CPLP countries to discuss CO_2 capture could prove a valuable activity.

Downstream Oil

Although several CPLP countries are producing oil and have oil as one of its primary energy sources, only Angola has a small refinery. However, Angola, Equatorial Guinea, Mozambique and East Timor, have refineries being built, commissioned or planned, and East Timor is also planning to build a petrochemical facility. However, uncertainty is perceived in some of those plans, for instance in Equatorial Guinea and East Timor, and due to the size of the economy of these countries, these refineries will probably remain one of a kind for each of those countries for the coming years. Nevertheless, at least in Angola and Mozambique it could be interesting to discuss the potential for implementing CCS in those refineries.

Iron and steel

The Iron and Steel sector is irrelevant in any of the countries being assessed, and investments have not been announced. It is unlikely that CCS will be relevant for that sector in these CPLP countries.

Bio-CCS

With the exception of Portugal, all CPLP countries are within the tropical or equatorial region. Biomass potential is very high, except for Cape Verde, marked by a sub-sahelian climate. Several of the countries have identified biofuels as an area for investments (namely Angola, Mozambique and Equatorial Guinea) and ongoing projects are frequently led by consortia involving local/governmental companies and Portuguese (e.g. GALP) and Brazilian (e.g. PETROBRAS) companies. Relevant synergies within the CPLP may exist in this area and efforts should be made to identify potential bio-CCS projects.

CO_2 use in EOR

Angola and Equatorial Guinea have consolidated oil production industries which have been producing for several years, and some fields are now mature or reaching depletion. Oil production in East Timor is more recent. In general, production is undertaken by international oil companies with supervision and/or consortia with national oil companies. Use CO_2 for EOR is a possibility, especially for Angola and Equatorial Guinea, which also have high CO_2 concentration sources (LNG plants) near the production fields. Synergies can exist in the CPLP since PETROBRAS has much experience in EOR, as does the Portuguese oil company PARTEX. These companies, as well as the other Portuguese oil company, GALP, are involved in oil exploration and production in Angola, and some in Equatorial Guinea.

High CO_2 purity sources

Gas Processing / LNG

Natural gas production and processing are ongoing activities in Angola and Equatorial Guinea, each country having one operational LNG plant. Gas processing and LNG plants are also planned in East Timor and Mozambique, when these countries initiate natural gas production. Natural gas processing and LNG are early opportunities for CCS projects and interaction with the planned investments should be sought in order to find synergies from CO_2 capture at those sources. In particular the vast natural gas reserves in Mozambique and its location, near sites with storage capacity could be adequate for deployment of CCS projects in this sector. The existing LNG plants in Angola and Equatorial Guinea are well located with respect to exploited oil and gas fields and, particularly the new Floating LNG plant in Equatorial Guinea may present interest for integration with CO_2 storage.

Coal to Liquids (CTL)

Coal mining in Tete province in Mozambique has produced a vast quantity of waste. The South African company CLEAN CARBON INDUSTRIES announced a prefeasibility study and an agreement with Mozambique's Ministry of Energy for a 9.5 billion USD CTL plant that will transform the waste coal in the Tete basin into liquid fuels. The prefeasibility study already includes CO_2 capture at the CTL plant and transport by pipeline to the coast, for storage in geological formations. Although the implementation of the CTL project does not seem to be dependent on the CCS component, the fact that it has been discussed with the local authorities may have raised the profile of CCS in the country.

Other Prospects

Aluminium smelting

A large scale CO_2 source in Mozambique is aluminium smelting. Aluminium smelting produces directly around 15 tonnes of CO_2 per tonne of aluminium processed, and indirect emissions from the impressive amount of electricity required in the process (15 MWh per tonne of aluminium). Studies should consider the possibility of implementing CCS projects in Mozambique in connection to aluminium smelting. The MOZAL plant in Mozambique, with a production capacity of 250 000 tons of aluminium per year, is likely to have a reasonable source-sink match since it is located in Maputo, on the Mozambique sedimentary basin.

CO_2 utilization for Enhanced Geothermal Systems

The utilization of CO_2 as a working fluid in Enhanced Geothermal Systems (EGS) is still mostly at R&D stage, but if proved viable, it could be considered for Cape Verde. The process aims to use CO_2 to recover heat from the reservoir, but a fraction of the injected CO_2 will remain sequestered in the rock. Volcanic rocks, namely basalts, are the dominant geology in Cape Verde and storage of CO_2 by *in situ* mineral carbonation could be an indirect benefit from the use of CO_2 in EGS.

Taking into consideration all the opportunities identified, the most interesting cases for implementing CCS projects in the CPLP countries are in the oil and gas industry, either using CO_2 in EOR processes, which could be particularly relevant for Angola, Equatorial Guinea and East Timor, or in natural gas processing and LNG plants, in the same countries, but also and particularly in Mozambique. CCS projects in these sectors would benefit from the connection with mature oil industries, from the existing regulatory framework in the oil and gas sector, and from the economic value of CO_2 when used for EOR.

In the manufacturing industries, CCS projects are more likely to be interesting in connection to cement plants, since economic growth is leading to increased demand for cement. Given the size of the countries, Angola and Mozambique seem to present the most interesting cases for implementing CCS in connection to cement production.

The potential for bio-CCS projects is also huge, although the bioenergy industry is still to be developed and to mature in any of the CPLP countries. Nevertheless, given the potential for bio-CCS to give negative emissions opportunities may exist, especially for Equatorial Guinea, Guinea-Bissau and Mozambique, if this comes to be allowed in official greenhouse gas inventories.

Mozambique seems to present other interesting cases for developing CCS projects in connection to the coal mining industry and in connection to the aluminium smelting industry.

On the opposite side are the archipelago countries, Cape Verde and S. Tomé and Principe, which do not seem to have potential to engage in CCS projects, due to their small size and dispersion of the economy. Exceptions may be the use of CO_2 in EGS projects in Cape Verde or if oil production finally kicks-off in St. Tomé and Príncipe, in which case use of CO_2 for EOR could be an option.

Table 6 – Prospects for CO_2 storage opportunities in CPLP countries under consideration

	Angola	Cape Verde	East Timor	Equatorial Guinea	Guinea-Bissau	Mozambique	São Tomé and Príncipe
Depleted oil and gas fields	Mature oil production.	None	Recent oil production.	Mature oil and gas production.	None	Gas findings. Industry still to develop.	Offshore oil industry may be developed
Sedimentary basins - onshore	Good prospects in Kwanza basin.	None	Basins in unfavourable tectonic setting.	Small onshore basin. Poorly studied.	Large sedimentary basin. Poorly studied.	Excellent prospects in Rovuma and Mozambique basins.	None
Sedimentary basins - offshore	Several sedimentary basins, well known.	Unknown	Basins in unfavourable tectonic setting.	Large sedimentary basin. Well studied	Large sedimentary basin. Poorly studied.	Excellent prospects in Rovuma and Mozambique basins.	Sedimentary basins, being explored for oil.
Coal seams	Not significant	Not significant	Not significant	Not significant	Not significant	Large coal basins.	Not significant
Mafic and ultramafic rocks	No major mafic rock provinces	Islands mainly composed of volcanic rocks.	Not significant	No major mafic rock provinces	No major mafic rock provinces	Ultramafic rocks in areas close to coal power plants.	Islands mainly composed of volcanic rocks.

No prospects.	Marginal interest or immature oil and gas production	Good or very good prospects but high costs	Very good prospects.

3.3 Summary of CO_2 storage opportunities

Section 3.1 addressed the CO_2 storage possibilities in each CPLP country under consideration. This section expands CCS storage prospects as summarized in Table 6. Storage as part of the EOR process is not included since it was addressed in the previous section.

The oil and mature gas fields that already exist in Angola and Equatorial Guinea and that may develop in East Timor, obviously present the best CO_2 storage options. However, the existence of offshore oil and gas fields are also good indications that deep saline aquifers may exist in those same countries, as well as in Mozambique and São Tomé and Príncipe where hydrocarbon reserves have been proved.

The best storage prospects for deep saline aquifers are in Mozambique and Guinea-Bissau. In Mozambique, the large Rovuma and Mozambique sedimentary basins are expected to have an effective storage capacity above 2 Gt CO_2 in the onshore, with fairly acceptable source-sink match. The basins are fairly well known from oil exploration activities. On the contrary, the deep geology of Guinea-Bissau is poorly known, but the extensive and thick sedimentary basin covering most of the onshore territory and extending offshore provides good prospects to find deep saline aquifers. In Angola, the Kwanza basin in Angola is also very interesting, particularly because it is not very distant from the main development centres and knowledge is being gathered through the ongoing oil exploration activities. This basin has a wide onshore sector and extends offshore, with both sectors probably providing suitable conditions for CO_2 storage.

Equatorial Guinea has poor prospects for onshore storage because the existing basins are very narrow. East Timor has sedimentary basins onshore and offshore, but the tectonic setting is very complex and unfavourable and a precautionary approach should favour the depleted oil and gas fields.

Cape Verde and São Tomé and Principe are volcanic archipelagos, where the onshore storage prospects can only be found in the basalts that compose much of the territory of those islands.

Mozambique is the only country that presents large coal basins and where it is possible to envisage deep unminable coal seams for CO_2 storage.

Overall, Angola and Equatorial Guinea present the best prospects for CO_2 storage capacity in depleted oil and gas fields, while the prospects for storage in deep saline aquifers in Mozambique, Angola and Guinea-Bissau are also very promising.

3.4 Drivers for deployment of CCS activities

The CPLP countries considered in this chapter are all non-Annex I countries within the Kyoto Protocol and, so far, have no binding targets for CO_2 emissions reduction. Furthermore, they are not industrialized countries with many large scale CO_2 sources and *per capita* emissions are far below the world average with the exception of Equatorial Guinea. In these circumstance, the drivers for deploying an expensive technology such as CCS must be sought somewhere else than a technical or internationally binding need to reduce CO_2 emissions.

Table 7 lists possible drivers for these CPLP countries to engage in CCS activities.

An obvious driver could be to contribute to the global effort on climate change mitigation. It should be noted that Angola, East Timor, Guinea-Bissau, Mozambique, and São Tomé and Príncipe, are all classified as having High Vulnerability to climate change impacts. In particular, Equatorial Guinea has considerable *per capita* CO_2 emissions, the second largest in Africa, behind South Africa, and thus CCS could be envisaged as an opportunity to decrease its emissions.

Perhaps a more significant driver is that the economies of Angola, East Timor, Equatorial Guinea and Mozambique are, or soon will become, highly dependent on the production of fossil fuel resources. Adoption of CCS will ensure a safer economic context in the event of internationally adopted strict and binding goals for reduction of emissions associated with fossil fuels. Furthermore, CCS can permit those countries, which also have a rapid economic growth, to decouple CO_2 emissions and economic growth.

For those countries with a mature oil industry, important commercial gains can result from the use of CO_2 for EOR, increasing the volume of oil recovered and giving an economic value to CO_2. Mature oil industries in Angola, East Timor and Equatorial Guinea can also realise business opportunities in the transport and storage components of the CCS chain, and can provide the basic regulatory framework.

Table 7 – Drivers for deploying CCS activities in the CPLP countries under consideration

	Drivers
Angola	○ Economy highly dependent on oil production. CCS enables to decouple economic growth and CO_2 emissions. ○ EOR can provide economic incentive. ○ CDM credits as a Party to the Kyoto Protocol. ○ Well-developed hydrocarbon industry provides a basis for regulatory framework; ○ High vulnerability to climate change.
Cape Verde	○ Geothermal potential could be developed in connection to use of CO_2 as the circulating fluid.
East Timor	○ Economy highly dependent on oil production. CCS enables to decouple economic growth and CO_2 emissions. ○ EOR may provide economic incentive. ○ CDM credits as a Party to the Kyoto Protocol. ○ Regulatory framework of hydrocarbon industry provides a good basis. ○ High vulnerability to climate change.
Equatorial Guinea	○ High *per capita* CO_2 emissions. ○ Economy highly dependent on oil and gas production. CCS enables to decouple economic growth and CO_2 emissions. ○ CDM credits as a Party to the Kyoto Protocol ○ EOR may provide economic incentive. ○ Well-developed hydrocarbon industry provides a basis for regulatory framework.
Guinea-Bissau	○ CDM credits as a Party to the Kyoto Protocol ○ High vulnerability to climate change.
Mozambique	○ The gas industry will become a major source of income to the country in the next decade. Coal mining is also an important source of income, as is aluminium smelting. CCS enables to decouple economic growth and CO_2 emissions. ○ CDM credits as a Party to the Kyoto Protocol ○ Existing oil and gas exploration regulatory framework and natural gas development plant provide the basic regulatory framework. ○ Economic benefit from storage of CO_2 from South Africa, if transboundary transport and storage is internationally admissible and regulated. ○ High vulnerability to climate change.
São Tomé and Príncipe	○ CDM credits as a Party to the Kyoto Protocol ○ Transboundary storage issues with Nigeria. ○ High vulnerability to climate change.

The inclusion of CCS projects within the portfolio of admissible CDM projects could be a driver, since benefits would come from Certified Emissions Reduction (CER) credits resulting from implementation of CCS projects in their territories. Currently, the value of CERs is too low and the pipeline of CDM projects (CER supply) is full.

For the specific case of Mozambique, an economic driver could exist around the storage of CO_2 from neighbouring countries, namely South Africa, the main CO_2 emitter in Africa, more than 500 Mt in 2010. Mozambique is likely to have a storage potential much above its needs and could benefit from using its pore space to store CO_2 from South Africa. The current CDM rules do not allow for CCS projects that rely on transboundary storage (i.e. CO_2 captured in one country and transported and stored in another), but if that is revised in the future – and it is expected to be revisited in the 45th Session of the UNFCCC's Subsidiary Body for Scientific and Technological Advice (SBSTA) in 2016 - an economic opportunity may exist for Mozambique.

Transboundary storage issues might also be relevant for São Tomé and Príncipe and Angola. São Tomé and Príncipe shares an offshore sedimentary basin with Nigeria, the Niger Delta Basin, and transboundary issues may arise if Nigeria decides to use this basin to store its CO_2. Also, if Angola chooses to store CO_2 in the mature oil fields in Cabinda enclave may need to transport CO_2 across territory of the Democratic Republic of Congo.

3.5 Challenges for deployment of CCS activities

The challenges to deploy CCS in the CPLP countries, or to move forward with large scale activities in those countries already engaged in CCS, are considerable and reflect many of the challenges faced by CCS globally and specifically by CCS in developing countries. Table 8 lists common challenges to the CPLP countries.

Table 8 – Challenges for deploying CCS activities in the CPLP countries under consideration

Awareness and technical challenges	Poor knowledge about the details of the technology among the high level decision makers in companies and academics, even for those countries where CCS activities are ongoing. The existence of a Centre of Excellence on CCS (CEPAC) has help to surmount that challenge among academics in Brazil.
	Uncertainty about the storage capacity in each country and in many cases (for those countries without large scale oil and gas exploration) scarcity of information about deep geology.
	Lack of technical capacity for the CCS value chain, probably a common feature to all CPLP countries, but easier to surmount in those countries with a mature oil industry (Angola, Brazil, Equatorial Guinea, East Timor) for the storage and transport components of the CCS chain.
	No program for knowledge transfer from experience in developed countries to least developed countries.
	Need to engage in pilot scale projects in those countries (Brazil, Portugal) that have assessed its storage capacity but need to clarify issues such as injectivity, induced seismicity, etc.
Economic challenges	Business case for CCS in low income countries is not clear and companies have yet to realize the potential for business opportunities.
	Lack of studies addressing the potential economic value of CCS in EOR in the oil producing CPLP countries.
	Wait and see approach; with CPLP countries waiting for the deployment of CCS at the international scale, despite the local specificity of transport and storage options.
	Unclear path for the CDM and low CER price (due to a lack of demand) and CO_2 price.
	Lack of information on the funding opportunities for CCS activities, especially for projects in Africa.
Policy and regulation challenges	Inexistence of studies on the role that CCS could play in the national environmental plans, since in most cases there is no binding CO_2 emissions reduction target. Almost every CPLP country has put forward or is developing its climate change action strategy, but CCS is mentioned only in the Portuguese Roadmap and Mozambique strategic plan.
	Poor knowledge about the details of the technology among policy makers and regulators.
	Lack of an assessment about how national laws could adopt specific regulation on CCS, a matter solved only in Portugal with the translation of the EU CCS directive.
	Undefined internationally policy for climate change mitigation.
	Regulation for transboundary transport and storage, which could be impairment to a CCS business case for countries such as Mozambique, São Tomé and Príncipe and Angola.

Low level of knowledge about the technology in every CPLP country is a critical factor. This is particularly the case for awareness and technical challenges, with poor knowledge about the details of the technology preventing decisions makers from understanding how the technology could be relevant for each country and for the research community to engage in R&D projects (such as assessing storage capacity or deploying capacity building courses). This latter issue was partly solved in Brazil through the leading role of PETROBRAS and CEPAC.

Knowledge transfer programs from the large-scale CCS projects to developing economies are focused almost entirely on China, India or South Africa, and no perspectives exist for engaging least developed countries in these knowledge transfer efforts.

The business case for CCS is not clear and even less so in countries with the environmental and economic profile of most of the CPLP countries, except perhaps in what concerns the use CO_2 for EOR. The obvious business model for CCS in LDC countries, selling CER credits from the CDM mechanism, is at a stall and will remain so until the CO_2 value becomes attractive. Sources of funding for CCS projects, even the lowest cost R&D projects, need to be clarified, especially for the African countries.

As for the policy and regulatory challenges, the most pressing issue is the lack of detailed studies that clarify the role that CCS could play in each country in the medium term (2030 and beyond), an issue that was addressed in Portugal by the CCS roadmap, but that is lacking in all other CPLP countries.

Transboundary transport and storage is an opportunity for CPLP countries with common borders with large scale CO_2 emitters, such as Mozambique, but it may be a challenge for Angola, if CO_2 has to be transported to Cabinda across territory of Democratic Republic of Congo in order to reduce transport costs.

4 The way forward – realizing the potential for cooperation

Cooperation between the CPLP member states occurs in multiple areas of economy, technology, health, science, and at multiple levels, from bilateral agreements to the broader scope provided by the CPLP secretariat. The cooperation is rooted on the long lasting cultural links between the member states and the unifying bond of a common language.

4.1 Recommended actions

CCS is not perceived as priority for governments of CPLP countries. Nevertheless, the drivers and challenges faced by the CPLP countries have many common features, pointing to the need for systematic cooperation on CCS related activities, for which a set of recommendations is provided in this chapter.

Raising awareness and knowledge sharing

Knowledge and information about CCS as a climate change mitigation technology is weak in all CPLP countries, and the profile of the technology needs to be raised amongst those authorities and institutions where CCS is likely to be more interesting. Raising awareness should be primarily directed towards high level authorities, potential regulators, environmental NGOs, managers of industrial sectors and academics, to foster discussion on the role that the technology could play in each country. Raising awareness activities should engage all CPLP countries, but focusing initially in those countries already engaged in CCS activities, Brazil and Portugal, and those with the highest potential for engagement in CCS activities: Mozambique, Angola, and Equatorial Guinea.

The organization of an annual workshop directed at high level authorities and managers would be an appropriate way to promote awareness raising and knowledge sharing between CPLP countries. Organization of the workshop and short-course could rotate between the different CPLP countries, and the technical content should be increasing between workshops, culminating in capacity building events and short technical courses, where the main focus would be on providing skills in the technical areas required in the CCS chain.

Other valuable knowledge sharing activities could be:

- Expansion of the content about the CCS opportunities to each of the CPLP countries as presented in section 3.1 of this publication, and production of leaflets in Portuguese with that content;
- Translation into Portuguese of the some of the many technical brochures and leaflets about CCS that have been produced by several institutions (e.g. GCCSI, CO2GEONET, CSLF, IEAGHG, etc...);
- Promotion of MSc and PhD thesis on CCS chain topics for students of the main universities in the CPLP countries.

Storage capacity assessment

Storage capacity assessment is an essential preliminary step for considering CCS projects. Portugal and Brazil have already engaged in capacity assessment and ranking qualification of basins, and that work should be developed into more detailed studies.

A storage capacity assessment project should be launched to quantify how much CO_2 can be stored in geological formations and the suitable locations with respect to the mains sources or development centres in each country. The study should target primarily deep saline aquifers and depleted oil and gas fields in Angola, Guinea-Bissau, Equatorial Guinea, East Timor and Mozambique, with this country also assessing the storage capacity in unminable coal seams. Storage in mafic volcanic rocks should be considered in Cape Verde and São Tomé and Príncipe.

The assessment should engage the Geological Surveys and/or oil Regulators in each country, as well as geologists from the main universities to ensure capacity building. Brazil and Portugal would ensure knowledge transfer from similar projects conducted in those countries. Implementation of this activity could start at the first raising awareness workshop, by creating a task force to conduct a scanning study to identify existing geological information, technical resources existing in each country, sources of funding and prepare a proposal for storage capacity assessment at the regional scale.

Clarifying the role for CCS

Work similar to that developed within the CCS Roadmap for Portugal provides insights about the impact of CCS in the economic context, energy system and emissions reduction of each country. Similar studies based on energy system models can clarify the role of CCS and its interplay with other climate mitigation options for each CPLP country. Brazil has enough information to engage immediately in such a study, but the other CPLP countries would have to initially identify their storage capacities and sources. This should culminate in the identification of early opportunities for CCS projects in the CPLP countries. Priority for these studies would follow the potential for CCS activities, for instance, Brazil, Mozambique, Angola and Equatorial Guinea.

CO_2 use in EOR

Use of CO_2 for EOR is well known among the oil industry and regulators of those oil producing countries in the CPLP, notably Angola, Brazil, Equatorial Guinea and East Timor. A specific workshop should be put together to discuss the use of CO_2 in EOR, bringing oil and gas producing companies and regulators together. One of the aims of the workshop should be to define an industry led team to assess the possibility of EOR with CO_2 in CPLP countries.

Brazil's PETROBRAS and Portugal's PARTEX have extensive experience on EOR, as do several of the companies operating in the oil and gas producing countries, and the technical resources and capacities would be guaranteed from the very beginning. Since EOR is a process with economic value, this would be an industry funded activity.

CDM and transboundary transport and storage

Two policy and regulating issues should be discussed, and eventually co-ordinated, between the authorities and potential regulators of CCS in CPLP countries: i) the evolution of CCS in the CDM, since carbon credits from CCS projects in the scope of the CDM represent possible business cases for most of the CPLP countries; and ii) the CDM rules about transboundary CCS projects, namely the possibility of one country using its pore space to store CO_2 emissions captured from a neighbouring country, a business case for Mozambique, and a possible relevant issue for São Tomé and Príncipe, while transboundary transport maybe relevant for Angola.

4.2 Funding opportunities

None of the CPLP countries has a specific program to fund CCS related activities, although some CPLP cooperation mechanisms and bilateral funding agreements include climate change mitigation among the possible sponsored activities. Funding opportunities can also be sought from international funding programs and institutions that have specifically devoted resources to CCS projects and activities.

CPLP Special Fund

The CPLP Special Fund is the primary source for funding cooperation activities within the CPLP. Funding can be requested for Projects or for Specific Actions, such as workshops and conferences. Cooperation has concentrated mainly in priority areas such as education, health, citizenship, and human resources training, but environment and climate change mitigation has also been considered. Funding from the Special Fund requires the support from focal points all CPLP member states and activities most engage at least three member states. Currently the CPLP Secretariat can participate as a partner in international projects, allowing a more robust institutional framework.

Portuguese Carbon Fund and the Fast Start programme

The Portuguese Carbon Fund (FPC) was created to contribute to the fulfilment of the national CO_2 emissions target set under the Kyoto Protocol. The mechanism remains active after 2012 and focuses mainly on funding Portuguese based projects and activities. However, the FPC also committed some 36 M€ from 2010 to 2012 for emission reduction projects in the Portuguese speaking developing countries, through the FAST START programme. It is not clear the continuity of the FAST START for the next years, but the FPC has still among its aims the cooperation with the CPLP countries. In fact, the Portuguese budget for 2015 allocates 500 000€ from the FPC to the CPLP secretariat activities within the climate change scope.

World Bank CCS Capacity Building Trust Fund

Since December 2009, the World Bank has managed a CCS Capacity Building Trust Fund (WB CCS TF) supported by the government of Norway, UK and the Global CCS Institute. The trust fund aims to share knowledge and build capacity on CCS in World Bank partner countries. Programs have been launched in Botswana, South Africa, China, Kosovo, Indonesia, Egypt, Jordan, Maghreb, and Mexico, including building capacity workshops and storage capacity assessments. The fund received contributions of some USD 57 million and among the planned activities is support to pilot CCS projects in South Africa and Mexico.

Global CCS Institute Development Program

The Global CCS Institute has among its CCS advocating tasks the funding of capacity building and projects in developing countries. Most of those resources have been devoted to cooperation with large CO_2 emitters, such as China, India and South Africa, but Brazil has also benefitted from those resources to develop its CO_2 Storage Atlas and building capacity activities. The Global CCS institute was also the main funding source for the workshop on cooperation on CCS between CPLP countries, which took place in September 2013 in Lisbon, and is sponsoring the CCS roadmap project in Portugal.

African Development Bank

The AfDB does not have any specific funding program for CCS projects or activities, or any official policy towards CCS. However, in its *Climate Change action Plan 2011-2015*, it includes support to investments in 'Low Carbon Development'. Although CCS is not mentioned in the plan, the possibility of support for CCS activities should not be discarded, in particular if associated to bio-energy, a technology in which AfDB sees a lot of potential for Africa. From the nine CPLP member states, six are African countries, and if these countries envisage CCS as a technology of interest, dialogue with the AfDB should be initiated.

Asian Development Bank CCS fund

East Timor is the only CPLP country with access to the Asian Development Bank (ADB) and specifically to the CCS fund managed by this institution. Funding comes mostly from the UK and Australian governments and amounts to around USD 74 million which have been primarily directed to projects in India, China, Indonesia and Vietnam. It is not to be discarded that CCS activities between CPLP member states including East Timor could be eligible to ADB funding.

Carbon Sequestration Leadership Forum

The Carbon Sequestration Leadership Forum (CSLF) maintains a Capacity Building Fund available to developing countries that are members CSLF members, which is the case of Brazil. Capacity building activities between CPLP countries including Brazil could be eligible for funding from the CSLF. That was the case, for instance, of the workshop on cooperation on CCS between CPLP countries, which took place in September 2013 in Lisbon, and the series of short courses on CCS organized by CEPAC from 2012 to 2014 in Porto Alegre (Brazil).

Green Climate Fund

The Green Climate Fund (GCF), established in 2010 by the United Nations Framework Convention on Climate Change (UNFCCC), could be an important source of funding, and it has explicitly included CCS as an eligible funding activity. The activities that can be deployed by CPLP countries is still at an initial stage, but if preliminary studies (storage capacity, role of CCS in each country) allow identifying early opportunities for pilot or commercial scale projects, the GCF may be a relevant source of funding.

5 Conclusions

The environmental and climate change mitigation policies in any of the nine CPLP member states have, so far, not considered CCS as a priority. Brazil is responsible for around 85% of the CO_2 emission in the CPLP and, together with Portugal, are the only countries in the community engaged in CCS activities.

An analysis of the present-day CO_2 emissions in the other CPLP countries cannot find many drivers for deploying a costly technology as CCS. Moreover, the archipelago nature of some CPLP countries, such as Cape Verde and São Tomé and Príncipe, with dispersed population and insularity costs, discards CCS as a relevant climate change mitigation technology in these countries.

Nevertheless, fossil fuel production plays a central role for the economies of Angola, Brazil, East Timor, Equatorial Guinea and Mozambique. Furthermore, almost every CPLP country has ongoing or planned investments for industrial development. This is the case especially for the cement production sector, for the downstream oil and gas sectors, with investment in refineries, gas processing and LNG facilities, and for the power producing sector, particularly in Mozambique with several planned coal and natural gas power plants.

CCS can ensure a safer context for those economies in the event of internationally adopted strict and binding goals for reduction of emissions associated with fossil fuels. Furthermore, CCS can allow those CPLP countries to decouple CO_2 emissions and economic growth. Business opportunities may also exist from the use of CO_2 for EOR or from transboundary transport of CO_2 from South Africa for storage in Mozambique extensive sedimentary basins. Bioenergy potential is also very high in several CPLP countries and bio-CCS projects should be considered.

The challenges to bring CCS to the national agendas have been identified and are considerable. The most significant are the lack of knowledge about the technology among stakeholders and the lack of a business model for CCS in developing and least-developing countries, except for the use of CO_2 for EOR, since the inclusion of CCS in the CDM has not provided the driver anticipated.

Brazil and Portugal have already a significant activity on CCS and efforts to bring CCS into the agenda of other CPLP countries should focus Mozambique, Angola, Equatorial Guinea and East Timor. Recommended actions include:

- Raise awareness between policy makers, regulators and stakeholders, by engaging them in workshops and seminars about the technology;
- Conduct an assessment of the CO_2 storage capacity in the CPLP countries, ensuring knowledge transfer from similar works carried out in Brazil and Portugal;
- Clarify the role that CCS may play on the economic context, energy system and emissions reduction of each country, ensuring knowledge transfer from the CCS roadmap in Portugal. Such a study could be particularly useful for Brazil, but also for Mozambique and Angola, where it could indicate early opportunities for CCS projects
- Discuss the opportunities resulting from the use of CO_2 in EOR, in those countries with mature oil fields, such as Angola and Equatorial Guinea, and ensuring knowledge transfer from Brazilian and Portuguese companies;
- Develop common approaches to regulatory issues such as role of CCS in the CDM and transboundary transport and storage, an important issue for Mozambique, and possibly for Angola and São Tomé and Príncipe.

The sooner the CPLP countries include CCS into the range of cooperation activities, the higher the chances to identify the opportunities resulting from deploying CCS as a climate change mitigation technology.

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CARBON CAPTURE AND STORAGE IN THE COMMUNITY OF PORTUGUESE LANGUAGE COUNTRIES

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