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GLOBAL INDUSTRIAL CCS TECHNOLOGY ROADMAP

SECTORAL ASSESSMENT:
SOURCE-TO-SINK MATCHING
FINAL REPORT

A Report For:

UNIDO

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This report was prepared for UNIDO by Geogreen as a deliverable for the project TE/GLO/10/002.

This report was prepared by Yann Le Gallo and Anthony Lecomte.

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Geogreen is an international company dedicated to CO_2 capture and storage (CCS) development and carbon management strategy, offering consulting and engineering services for the transport and geological storage of CO_2. Geogreen's team possesses a wide range of technical, economic, and regulatory expertise and the company has tackled numerous aspects of CCS project development, including subsurface engineering, transport options/design, capture technology screening, life cycle analysis (i.e. project energy and carbon footprints), project finance and cost estimates, investment optimization via “real option” assessments, and present/future European and North American regulatory frameworks analysis. Geogreen is active in Europe, the Middle East, in North and South America and Asia.

REVISION RECORD

Revision	Date	Established	Checked	Approved	Major reasons for review and major updates
0	03/31/2011	Y. Le Gallo,	P. Le Thiez	G. Munier	Comments from UNIDO, ECN and IEA reviews: • Include cement sector regional variations and indicate and clarify hypothesis used • Detail the underlying assumption and uncertainties on the emissions (scenario, location)
1	08/08/2011	Y. Le Gallo	P. Le Thiez	G. Munier	Revised issue with inclusions that follow comments from UNIDO reviewers
2	19/08/2011	Y. Le Gallo	C. Mc Quale	P. Le Thiez	Revision for references and minor corrections

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While the authors consider that the data and opinions contained in this report are sound, they do not make any representation or warranty, expressed or implied, as to the accuracy or completeness of the report. All maps presented in this document are large scale maps built to support rationale and conclusions. They should be used for indicative purpose only and are not meant for local and/or detailed assessment of the parameters they describe. The authors stress that no detailed location-specific studies have been carried out to assess the potential projects included in this report.

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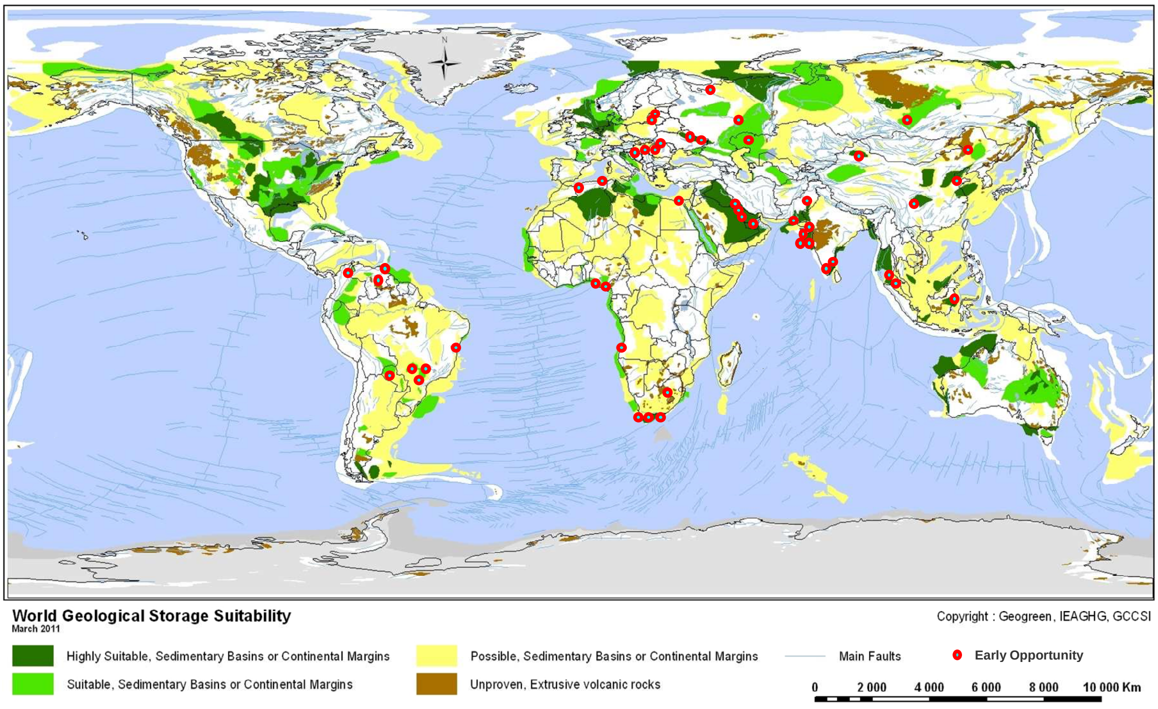
EXECUTIVE SUMMARY

The aim of this study was to perform a "source-to-sink" matching exercise on five selected industrial sectors in non-OECD countries, in order to determine the potential for industrial CCS deployment. This assessment was completed within the greater context of the UNIDO "Global Technology Roadmap for CCS in Industry" assessment. As such, this study serves as a basis for identifying some key tasks that will need to be undertaken if industrial CCS deployment is to advance to a level that is necessary for achieving global GHG emission reduction targets by 2050. The analysis performed here, which uses a qualitative source-to-sink matching approach to pair industrial CO_2 sources with geological formations seen as potentially holding sufficient CO_2 storage capacity, focuses on eleven non-OECD regions throughout the world.

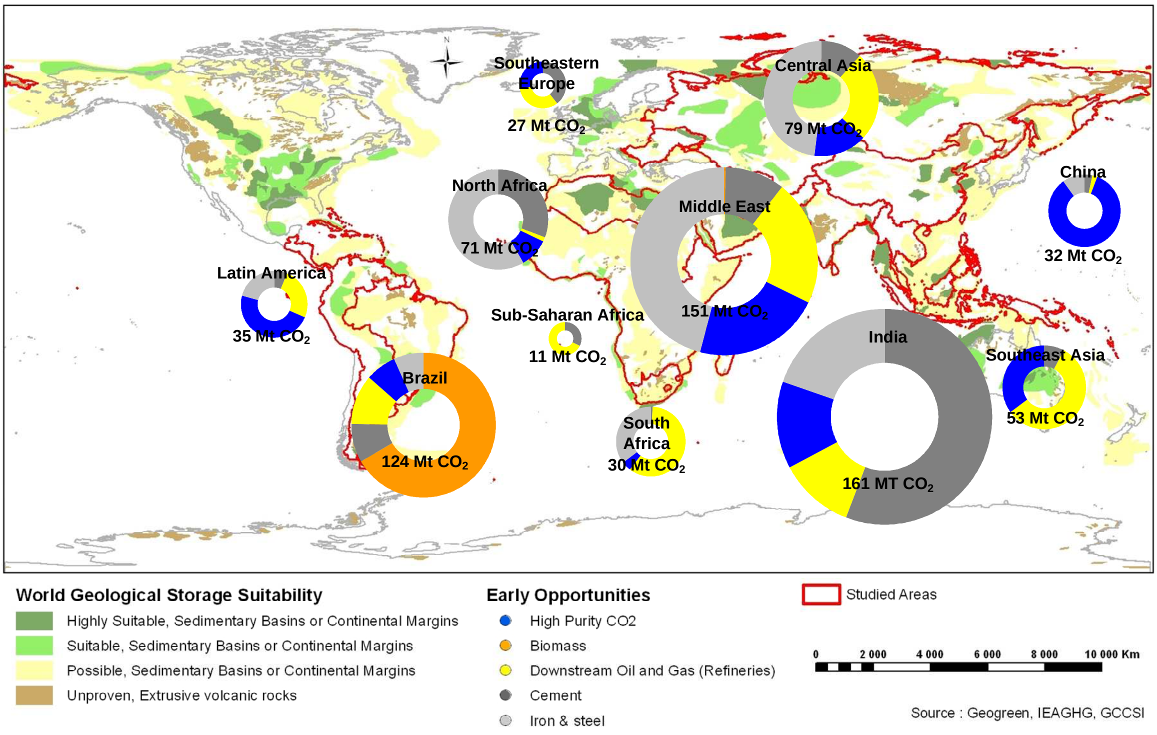
In terms of emission source inventory, this study is based on the emission source information available from the IEAGHG CO_2 database [14], which is currently the most comprehensive, publicly available database and which also provides the geographical location data needed for this study. However, due to the limited availability of public data on industrial emissions – particularly in non-OECD countries – the use of the IEAGHG database may result in a low estimate of many countries' emissions [10]. The five industrial sectors that were selected by UNIDO for consideration in this study are: iron and steel production, cement production, downstream oil and gas (refineries) biomass/bio-energy-related industries and a group of technologies considered high CO_2 purity sources (including gas processing).The CO_2 emissions from the upstream oil and gas processes, e.g. from oil sands and from the power industry are outside the scope of the study. Regional evolutions of the different sectors are in-line with the UNIDO "Global Technology Roadmap for CCS in Industry" [21] and the IEA "CCS Roadmap" [8]. Given the data limitations and the global scope of this assessment, some key assumptions that are made regarding the future locations and the evolution of the emission sources: 1) future emissions growth is viewed as due only to the expansion of the CO_2 sources documented by the IEAGHG database as existing in 2007, and 2) the carbon intensity of each sector is assumed to remain constant over the studied time period (2007-2050).

Regarding the assessment of geological CO_2 storage resources, this study employs data from a study also performed by Geogreen, the "Global Storage Resource Gap Analysis for Policymakers" which is currently under review by the IEAGHG and the Global CCS Institute (GCCSI) [15]. The IEAGHG and Global CCS Institute have granted permission for the use of the dataset developed for their study, which provides a global estimation of geological CO_2 storage suitability. The quality of the publicly available data, upon which the IEAGHG/GCCSI storage suitability database is based, varies greatly and did not indicate potential storage resources as such. Therefore, a specific methodology was developed in order to estimate regional storage resources based on available data. Nevertheless, large uncertainties are inherent to such a methodology.

As illustrated in the following figures, a limited number of potential "early opportunities" for industrial CCS deployment have been identified in this study for each of the eleven regions considered. The first figure presented below depicts the emission "hotspots" that were determined to be "early opportunities" for industrial CCS deployment within the studied regions. Only indicative locations of the early opportunities are given due to the uncertainties inherent to the methodology and goal of the global study.



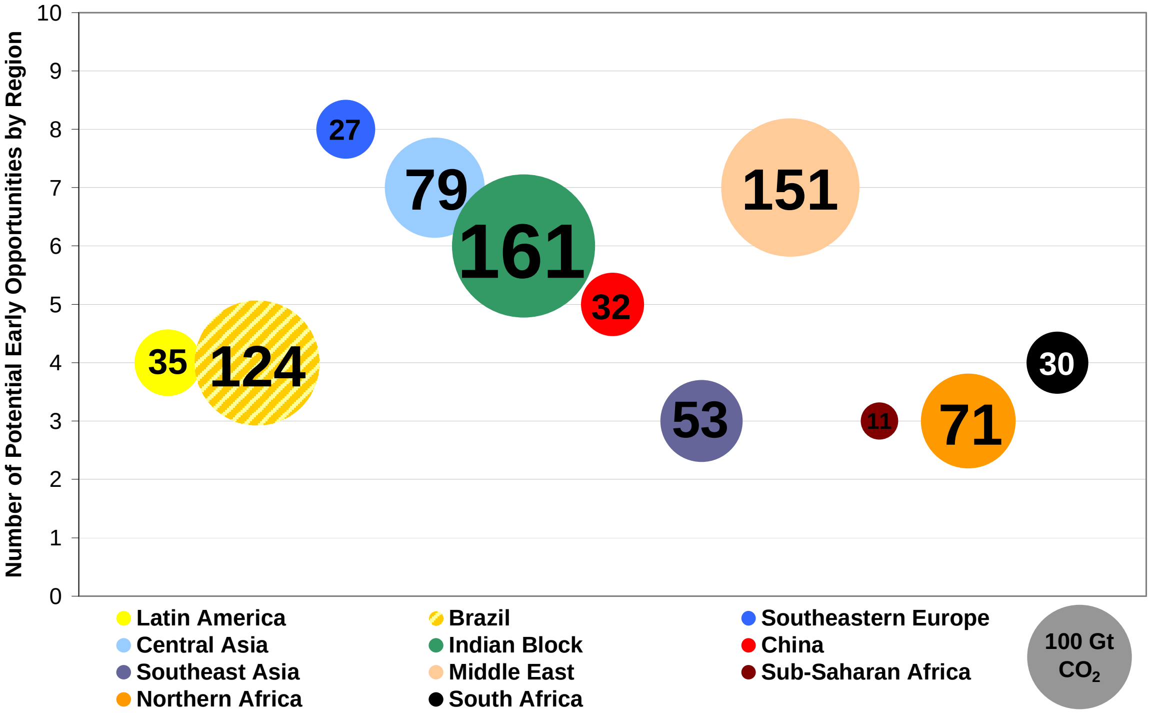
The second figure shows an overall breakdown of industrial emissions represented by the early opportunies identified within each of the studied regions.



It is important to note that the publicly available storage suitability information obtained from the IEAGHG/GCCSI report is estimated at the regional level and as such the storage capacity relative to a particular early opportunity cannot be determined. Also, since the CO_2 emissions from the power sector were beyond the scope of the study, it was found that for all regions except South Africa and the Indian Block, there is sufficient suitable storage capacity as needed by the early opportunities identified in this study. Hence, when omitting the CO_2 emissions from the power sector and other competing geological activities, there is a significant available CO_2 storage capacity to be found within the Middle East, Central Asia, and Northern and Central Africa.

When considering the limitations for storage there are certain restrictions. On one hand, in most regions access to a suitable storage location proved to be a major limiting factor, because in many cases the available storage was determined to be too far from the emissions source “hotspots” to consider them as an early opportunity, despite the capture potential. Geographical restrictions are quite significant for many industry sectors considered in the study because typically many industry locations are chosen with respect to access to raw inputs or cheap energy sources, which in many cases do not correspond to access to storage resources. On the other hand, for many major oil and gas producing regions, the limiting factor proved to be insufficient industrial CO_2 emissions compared to ample storage resources.

The storage resource assessment used here, even for oil and gas fields, is only qualitative due to the assumptions that were made to estimate the global storage resources with limited access to geological data. Furthermore, in the future, the competition for storage capacity for industries might become more acute when also considering storage capacity for CO_2 from the power sector and other geological activities. Given the uncertainties on the storage capacity estimates in most non-OECD countries at this stage, significant actions are required if the emission reduction targets as proposed in the UNIDO Global Technology Roadmap for CCS in industry are to be achieved. The next figure provided here illustrates the number of “early opportunities” found within each region and compares this to the overall amount of CO_2 emissions that these early opportunities represent. The effect of limitations in terms of available CO_2 or storage resources is quite clear given the low number of early opportunities for some of the major regional emitters.



In order to increase storage access to those regions found to have insufficient storage resources and to expand storage access to more industrial emission “hotspots”, more characterization work is needed, especially for deep saline formation-based storage resources. However, for most of the regions studied, limited information exists for non-hydrocarbon bearing deep formations. To enable the development of “first-of-a-kind” industrial CCS projects in most regions, government supported characterization programs should be initiated to confirm all potential storage resource types, i.e. the quantification of the storage capacities given in the previous figure. Ideally, both regional and site specific studies (e.g. capacity, injectivity, well integrity, and risk assessments) should be initiated for CO_2 storage in deep saline formations, depleted oil and gas fields, and storage associated with CO_2-EOR operations. In addition, site specifics studies should also be performed in order to facilitate optimal transport network configuration.

For countries already engaged in CCS development, the first phase of a CCS project development has generally been national or regional level characterization. This phase, needed to assess the possible and suitable zones, can last for one or two years prior to any site specific storage work going forward. To avoid further delay in CCS deployment in non-OECD countries, it is crucial to launch these regional scale characterization programs, which will then provide a framework for discussion and development of local CCS projects. Once geological knowledge has been acquired or updated globally, a more quantitative source-sink matching could better precise the attractive industrial CCS development opportunities.

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1. INTRODUCTION

As the global economy strives to overcome the aftershocks of the 2007 Financial Crisis and resulting economic slowdown, policy makers are faced with mounting pressure to address longer-term challenges, without stymieing a nascent worldwide recovery. Two issues of paramount importance that have been sidelined by the economic distress are climate change and resource depletion. Nevertheless, as the world economy recovers, it remains clear that new industrial developments and expansion will continue in emerging markets and while these new growth centers hold high potential as drivers of a full economic recovery, they also represent the fastest growing greenhouse gas (GHG) emission production and resource consumption hubs on the planet. If left unchecked, these emerging economic powerhouses threaten to derail any and all progress made under Kyoto and other regional climate change mitigation efforts i.e. since the global community began pursuing global emission reduction strategies under the United Nations Framework Convention on Climate Change (UNFCCC) agreement at Rio in 1992.

There are high expectations for carbon capture and storage (CCS) as an emissions mitigation solution within the power sector. However, numerous governmental and research groups also argue that there is an equally important emissions mitigation opportunity via CCS deployment within many non-power industrial sectors. Specifically, CCS describes a portfolio of emission management technologies that, when deployed and configured correctly, can offer industries a means to mitigate their global carbon impact, especially those with operations that provide vital goods and services but will remain tied to GHG emission production far into the foreseeable future.

Because a majority of new industrial development is taking place outside of largely developed Organization for Economic Co-operation and Development (OECD) countries, the concern is that the financing and/or knowledge to facilitate the level of CCS deployment on carbon-intensive industries in developing economies will be less than what is needed. There is a serious risk that these roadblocks to industrial CCS deployment within non-OECD countries could prevent the world from achieving the IPCC recommended emission reduction targets [16]. Therefore, this study has been performed as 1) an attempt to quantify the realistic potential for industrial CCS deployment within non-OECD countries with a focus on the development of feasible CO_2 storage options and 2) to provide recommendations for how policy makers can overcome potential barriers to achieving the ultimate deployment of CO_2 storage projects.

2. OBJECTIVES AND RATIONALE

Five key industrial sectors were selected for this assessment because they have been identified as high-potential industrial CCS deployment opportunities in reports by United Nations Industrial Development Organization (UNIDO) [21] and many other research institutions [5, 6]. These five sectors, as pictured in Figure 1, are defined as: 1) industries producing high purity CO_2 (i.e. coal-to-liquids, ethylene, and fertilizer/ammonia production), 2) iron and steel industries, 3) cement production facilities, 4) oil and gas refining industries, and 5) biomass industries (i.e. biomass gasification, ethanol fermentation, hydrogen production, and the use of black liquor fuels from pulp and paper production). Upstream CO_2 emissions (i.e. emissions from natural gas processing/gas sweetening), oil sands-related industries, and emissions from the power industry are not considered by this study. For natural gas processing, even if most of the storage projects (Sleipner, In-Salah, Snohvit, Gorgon) are currently developed in association with upstream gas processing, these emissions could not be included in the study. This is due to the lack of data concerning the location and the CO_2 volume and its evolution represented by the gas processing or oil/tar sands projects.

The results from this report will serve as an integral part of the Global Technology Roadmap for CCS in Industry and as such this study was carried out within a framework defined by Contract Number 2011/2 between UNIDO and GEOGREEN [22] to assess “source-sink matching” opportunities for key industrial emissions areas within non-OECD countries.

The report is structured in two major parts: 1) a presentation of the main assumptions of the study and the methodology used to conduct the qualitative source-sink matching assessment, and 2) the results of the study and a synthesis with recommendations for next steps. Details of the analysis conducted for each of the selected regions is provided in the Appendix.

The focus of this report is specifically storage-related, and as such it was not within the scope to go too deep into discussing non-storage related aspects of industrial CCS deployment. The overall drivers/issues for industrial CCS deployment outside of the OECD will be addressed by the final Technology Roadmap report. In the conclusion, several technical “bottlenecks” for storage project development are identified, which if left unaddressed could prove to be barriers for CCS deployment on industries within non-OECD countries. In addition, the report highlights several gaps relating to the accuracy and availability of both emission source data and information about the status of geological characterization efforts. Working to mitigate or at least alleviate bottlenecks as well as resolving the data availability issues are both included with the general policy recommendations provided in the final synthesis.

The study followed the work flow described in Figure 1: the CO_2 emissions sources are identified and their 2050 level estimated prior to a qualitative source-sink matching which highlight the hotspots and enable to identify the early opportunities.

All type of storage has been examined within this study: deep saline formations, depleted oil and gas fields, and to some extent CO_2-EOR potential for early opportunities. No costs evaluations have been performed within this study.

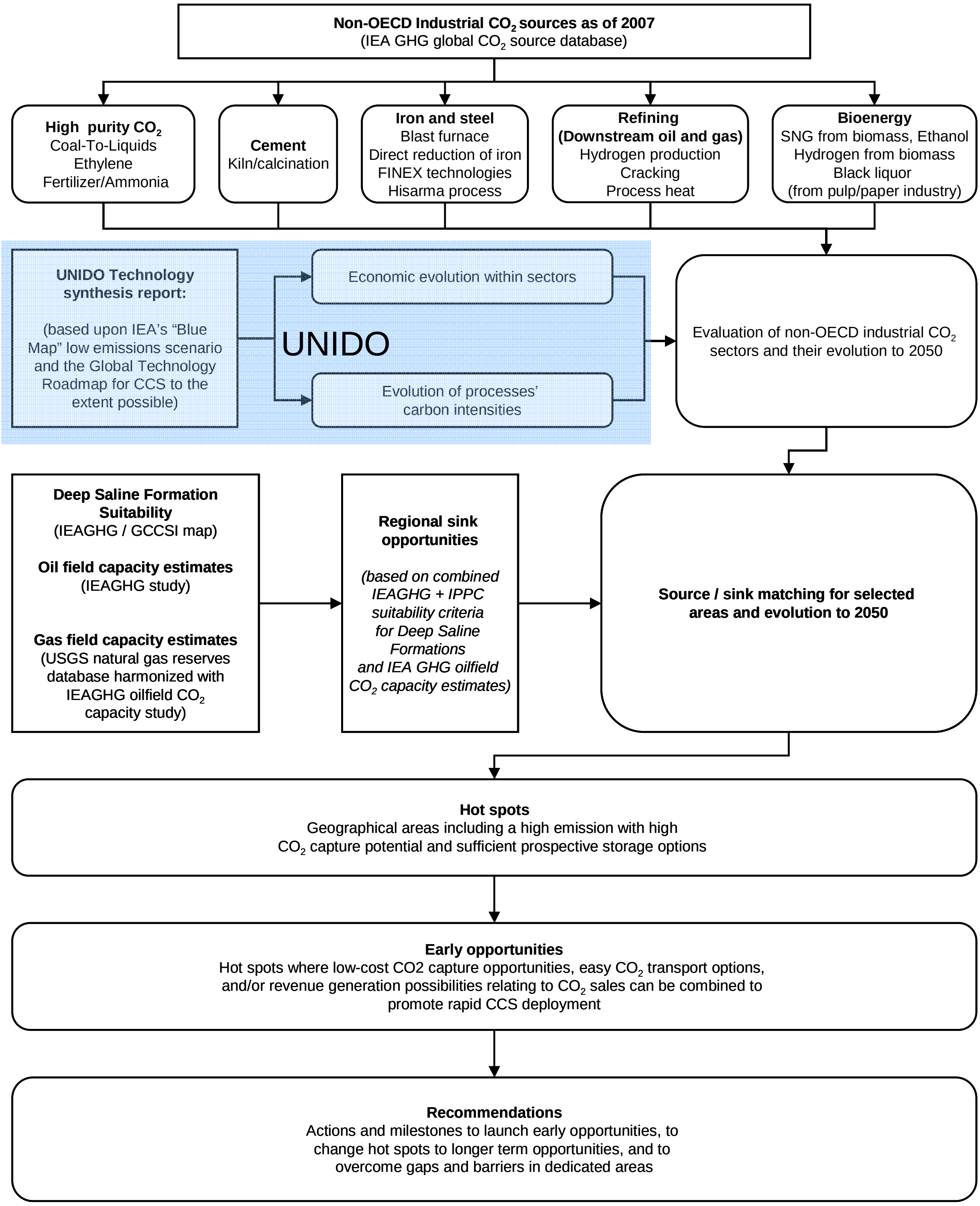


Figure 1: Work flow of the study

3. MAIN ASSUMPTIONS AND METHODOLOGY

In examining CO_2 emissions from industries in developing countries, this study covers a very broad topic. Therefore, this section will explain the methodology that has been employed to process and harmonize the wide range of data sources used in this report i.e. the basis for the ultimate synthesis and conclusion. Given that access to complete data for sources and geology for many of countries/regions considered here was not publicly available, it was necessary to make several assumptions, which will also be explained in this section. Also, as this study technical in nature, this section will provide definitions for some of the more key concepts that will be used and discussed throughout the report.

3.1. DEFINITIONS

In this study, the following definitions are used:

- **Deep saline formation:** any water bearing formation whose salinity is exceeding sea water salinity
- **High emission zone:** a geographical area with a significant number of industrial CO_2 emissions/sources.
- **Hotspot:** a geographical area that includes both 1) a high emission zone with a large potential for CO_2 capture and 2) sufficient prospective storage options (e.g. deep saline formations and/or oil and gas fields) as needed to accommodate the storage of these emissions over the lifetime of the identified capture opportunities.
- **Early opportunity:** a hotspot where low-cost CO_2 capture opportunities, easy CO_2 transport options, and/or revenue generation possibilities relating to CO_2 sales can be combined to promote rapid CCS deployment, e.g. a high emission zone with economically feasible CO_2 capture and transport opportunities, which is also conveniently located near a region with extensive oil and gas activities or located directly above a highly suitable deep saline formation. Due to the low costs, early opportunities should be pursued as strategic targets for early industrial CCS project development.
- **Suitability:** a qualitative geological formation ranking system (i.e. as highly suitable, suitable, possible, unproven, or unsuitable) for CO_2 storage potential defined by the IEAGHG/GCCSI study [15]. It is based upon current CO_2 characterization activities as well as both historical oil and gas prospectivity as defined by the IPCC [16] and/or other geological exploration activities.
- **Storage resource:** the concept of a “storage resource” is similar to the concept of theoretical “oil in place” used by the oil industry. As such this so-called “resource” must be classified prior to having any precise meaning. A storage resource classification, as defined by the IEAGHG [13], is presented in a chart in Figure 4.
- **Storage capacity:** this refers to the portion of the overall storage resource determined to represent the “practical storage capacity” as defined in Figure 4 from the IEAGHG [13]. This

practical storage capacity, as opposed to the formation's "suitability", can be further divided into proved, probable, and possible storage capacity, which is based on the determined (i.e. quantifiable) ability of that formation to receive injected CO_2. Typically, the practical storage capacity ranges between 1 and 6% of the storage resource [13].

In this study, the future emissions (2050) are assumed to be located at the current (2007) locations (see section 3.8). Therefore, early opportunities will be analyzed considering their expected growth between 2007 and 2050 based upon the specific evolutions of the industrial sector in the region.

Emissions and storage resource are expressed in Million tonnes (1 Mt = 10^6 tonnes) or Giga tonnes (1 Gt = 10^9 tonnes)

3.2. AREAS OF FOCUS

Developing regions in the world, i.e. non-OECD member countries, are the focus of this study and to simplify this assessment, the non-OECD countries were divided up between eleven "areas of focus" as are illustrated in Figure 2. These areas were determined based on economic trends, their emission profiles, and the area's storage resources and are not necessarily defined according to any political or cultural groupings. Most areas consist of multiple countries, except in the cases of some major developing economies, i.e. China, Brazil, South Africa and India.

The eleven regions are thus defined as follows:

1. Latin America: Argentina, Bolivia, Colombia, Ecuador, Paraguay, Peru, Suriname, Uruguay, Venezuela, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Trinidad and Tobago
2. Brazil
3. South-Eastern Europe: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, Montenegro, Romania, Serbia, Ukraine, Moldova
4. Central Asia: Kazakhstan, Mongolia, Uzbekistan, Georgia, Kyrgyzstan, Turkmenistan, Azerbaijan, Armenia, Tajikistan, Afghanistan, Russia
5. Indian Block (South Asia): India, Bangladesh, and Nepal
6. China (Including Taiwan)
7. Southeast Asia: Brunei, Cambodia, Indonesia, Laos, Malaysia Myanmar (Burma), Papua New Guinea, Philippines, Singapore, Thailand, Vietnam
8. Middle East: Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen, Pakistan
9. Central Africa: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique,

Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, Somalia, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe

10. Northern Africa: Algeria, Egypt, Libya, Morocco, Sudan, Tunisia, Western Sahara
11. South Africa

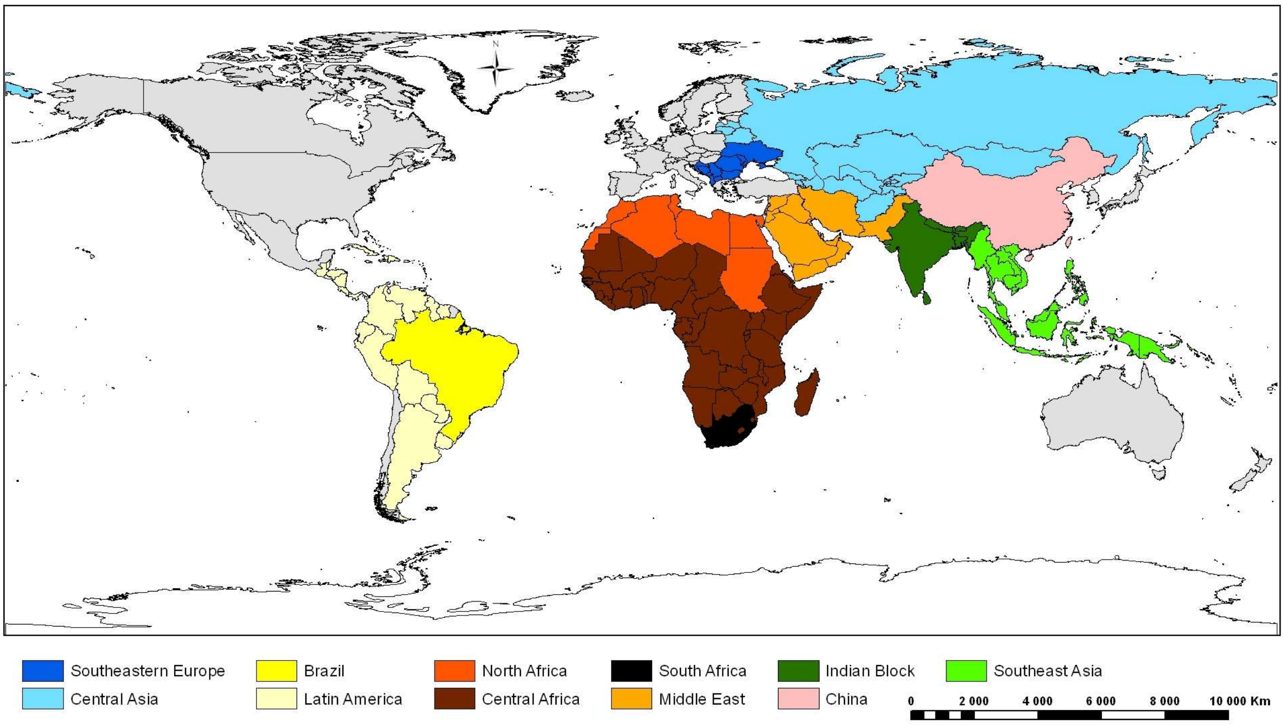
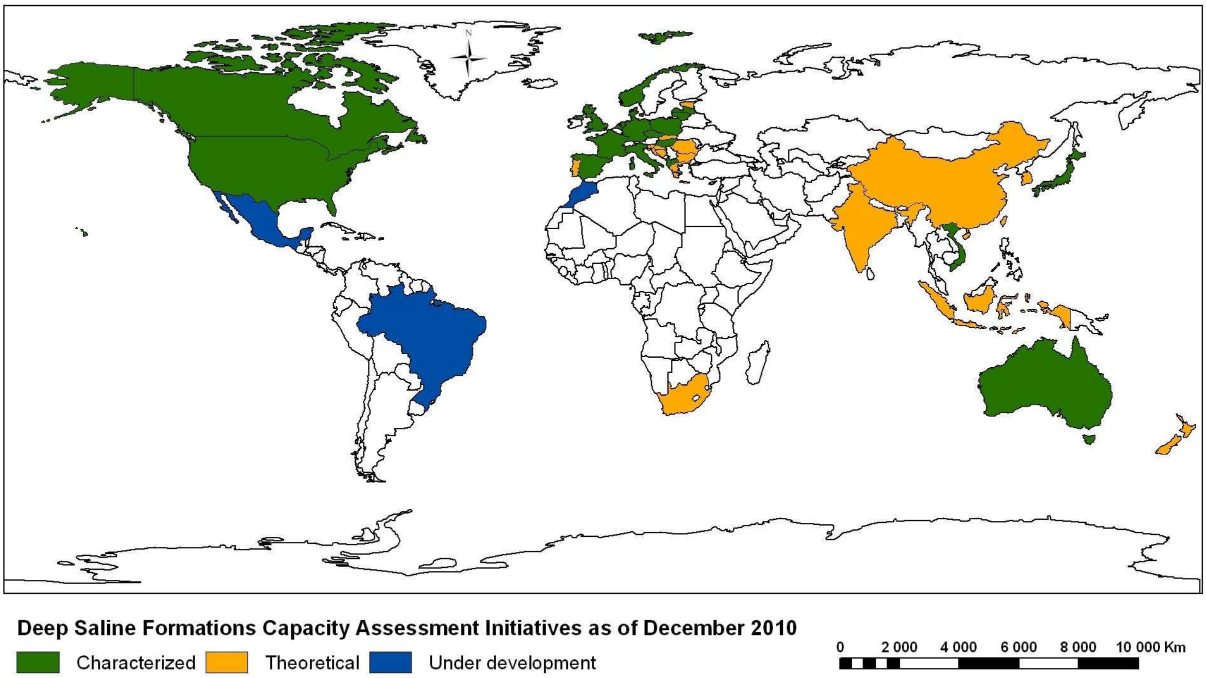


Figure 2: “Regions of interest” for this study

3.3. STORAGE INFORMATION

One issue that could limit the uptake of CCS throughout the developing world is that the potential CO_2 “sinks”, i.e. practical storage capacity, have not been quantified for most of these regions (or at least this data has not been made public). In fact, no “carbon atlas” exists at the global scale because the coverage of any CO_2 storage capacity assessments completed to date has been limited to states or regions and mostly to the OECD.

It is nevertheless important to recognize that several countries have made significant strides towards characterizing and quantifying their storage resources. In the United States, the Department of Energy (DOE) and its associated National Energy Technology Lab (NETL) are leading a nationwide “NatCarb” project, which has systematically gathered existing data and then conducted a variety of CO_2 injection tests to validate regional storage possibilities. Currently, the NatCarb project is expanding so as to incorporate Canada and Mexico into a North American Carbon Atlas [7]. Beyond North America, Australia and Western Europe have also made extensive progress in characterizing and classifying their potential CO_2 storage resources [2, 24].



Source: IEAGHG – GCCSI [15]

Figure 3: Initiatives for capacity assessment for deep saline formations by country

In addition to the large coordinated characterization projects and some other more nascent efforts within the OECD as seen in Japan, South Korea, and New Zealand; some initial mapping and characterization projects are nevertheless moving forward outside of the OECD, notably in China, South Africa, and in Brazil. Furthermore, most countries with significant oil and gas production activities have indirectly characterized their storage resources with their exploration activities. Even though much of this data is not public, the general information that is available is useful as a means for extending the regional characterization results into uncharacterized regions with some public oil and gas related data. Moreover, many oil and gas exporting countries have begun to screen their oilfields internally to know what potential exists for CO_2 storage/oil production increases using CO_2-EOR. Nevertheless, the practical storage capacity as defined by IEA remains largely undetermined for a majority of the regions in this study.

Therefore, a primary task of this study was to quantify, to the extent possible, feasible storage options for the industrial emission hubs to be identified within eleven areas of focus. In addition to data taken from several IEAGHG oil and gas field studies [11, 12], the storage information used within this study is underpinned by a study regarding worldwide storage suitability by the IEAGHG, the Global CCS Institute (GCCSI), and Geogreen[1]. The following subsections will explain the treatment of this data.

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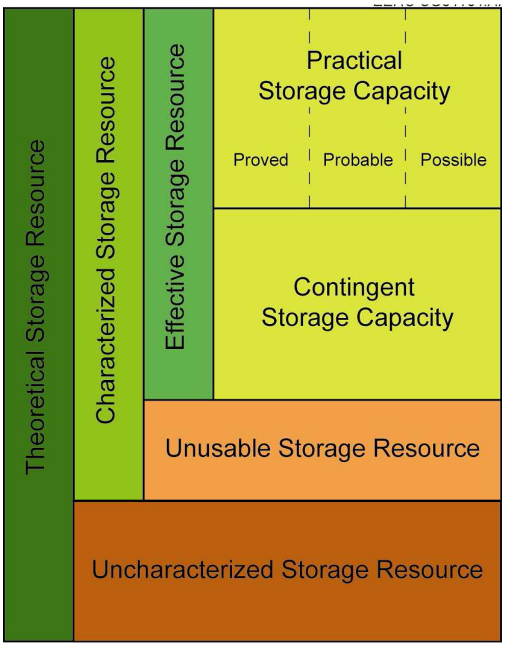
[1] The Gap Analysis study [15] was written in tandem to this study and is currently in the process of being reviewed.

3.4. DEEP SALINE FORMATION

It is difficult to estimate the effective storage resource of a single sink when considering deep saline formations without carrying out a detailed geological characterization and CO_2 injection tests. However, most of the storage resource assessment work to date has been carried out or at least compiled by national geological surveys, which often release reports at regional or national levels.

Given the wide range of data and knowledge that exists for deep saline formations, it was imperative to employ a system for classifying available and unavailable information. Therefore, this study has used a storage resource ranking system as defined by the IEAGHG in Figure 4 [13]. In this report, a "theoretical storage resource" is defined as the absolute pore volume within a geological storage target, i.e. after the target's fundamental geological characteristics can be used to classify it as exhibiting potential CO_2 storage properties. When quantified, the theoretical storage resource simply represents the maximum value from a range of storage capacity possibilities. As no restrictions or constraints are applied to the theoretical storage resource calculation that would take into account the wide range of limitations, the resulting value for capacity is unrealistically high.



Source: IEAGHG [13]

Figure 4: Static capacity assessments

As such the theoretical storage resource needs to be classified and in this case it is simply divided between characterized and uncharacterized storage. Conversely, suitability is a more detailed means for classifying the theoretical storage resource. Suitability is a qualitative ranking of geological formations (i.e. highly suitable, suitable, possible, unproven, unsuitable) and these classifications are assigned to formations based upon both their exploration history (e.g. from mining or oil and gas activities) and their prospectivity for CO_2 sequestration as defined by the IPCC [16].

Returning to the IEAGHG classification system, a storage resource can be considered as characterized when it is comprised of known reservoirs and formations, which allow for its pore volume to be estimated more precisely [13]. An effective storage resource can be identified by taking into account the characterized pore volume estimations, meaning that once calculated, the formations' pore volumes allow for the overall "characterized storage resource" to be divided between effective (i.e. useable storage) and unusable storage. However, once a storage resource has been characterized as "effective", there are limits as to what extent the capacity can be validated. Formations with CO_2 storage potential can be validated and characterized to some extent, using core samples and injection tests, as being "proved", "probable", and "possible" on a site by site basis. However, only when a CO_2 injection project has been in operation for some time can the so-called "contingent" storage capacity be assessed, which would include pore space within the target storage complex that was unaccounted for by initial tests or pore space beyond the storage complex that is later determined to hold storage potential.

The IEAGHG recently completed a study[1] in cooperation with the GCCSI and GEOGREEN to review and harmonize and assemble together all global storage capacity assessment efforts that have been published so as to create the CO_2 storage suitability map illustrated in Figure 5 [15]. However, because the available data was not homogeneous in terms of both its quality and availability it was difficult to achieve a useful assessment by employing the IEAGHG system alone. Specifically, the information used to produce the map in Figure 5 includes CO_2 characterization, and oil and gas field information that has not necessarily been screened for effective CO_2 storage potential.

Various suitability criteria used by published characterization efforts were harmonized and divided into four simplified categories: highly suitable, suitable, possible, and unproven. These hybridized categories can be understood as follows. Highly suitable areas are those which are highly characterized and a majority of the target formations represent effective and practical storage resources. However, even in highly suitable areas, some of the formations remain uncharacterized. Suitable areas are similar to highly suitable areas in their overall geological properties but less data is available so fewer formations have been validated as "practical storage" and they contain a larger percentage of uncharacterized formations. Possible areas contain few characterized formations but are estimated to hold the rock types that are needed for storage. Lastly, there are several ongoing research projects to validate the potential for storing CO_2 in volcanic/basaltic formations but as these studies have not yet advanced to the demonstration scale they have been classified here as "unproven". The remaining areas shown in white and grey represent formations for which no data exits or that have been deemed unusable respectively and the blue represents offshore zones beyond the continental shelves. Indeed, we do not expect many CCS projects to inject in geological formation located in deep waters (apart from pre-salt plays in Brazil).

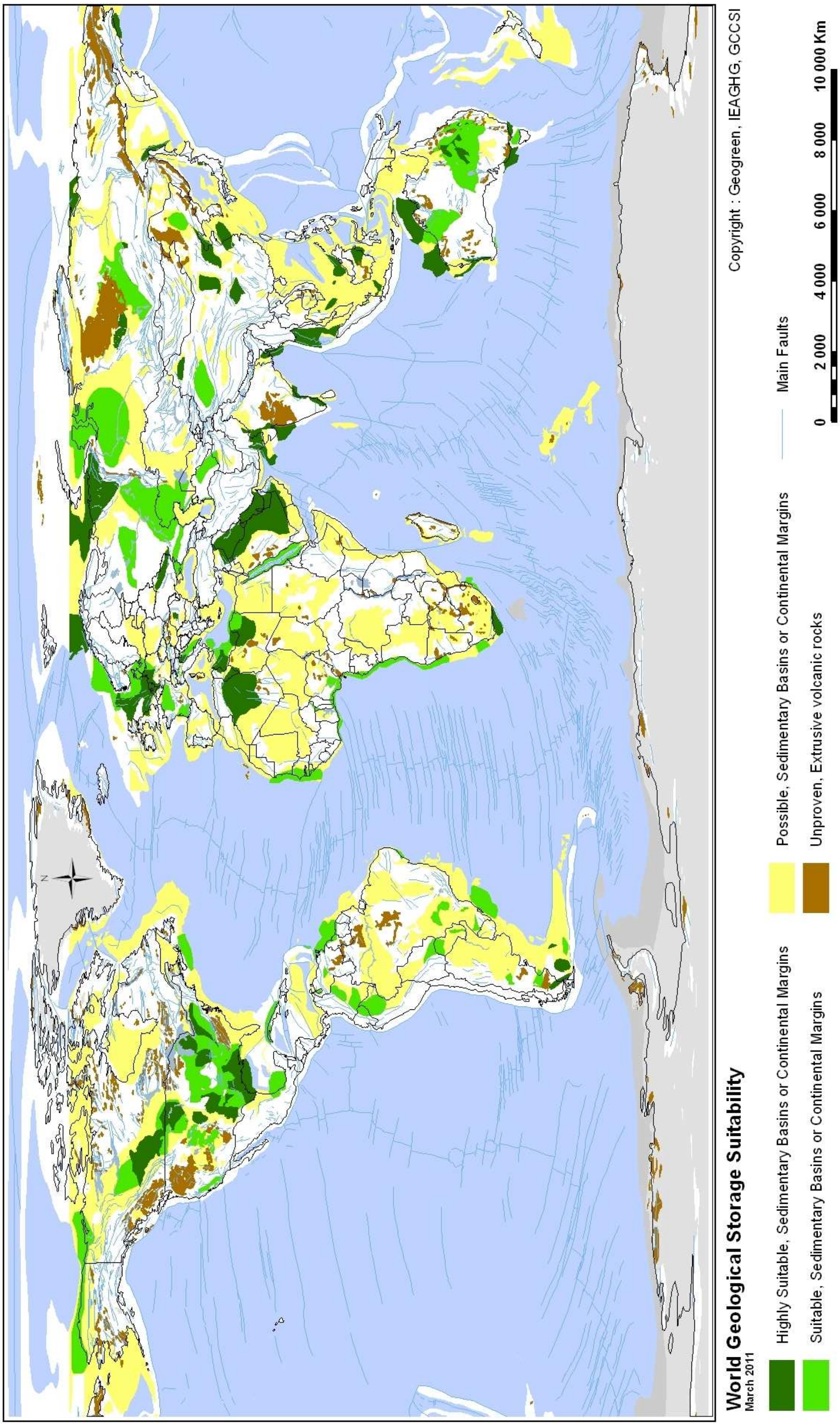


Figure 5: CO_2 storage suitability accounting for geological and petroleum knowledge

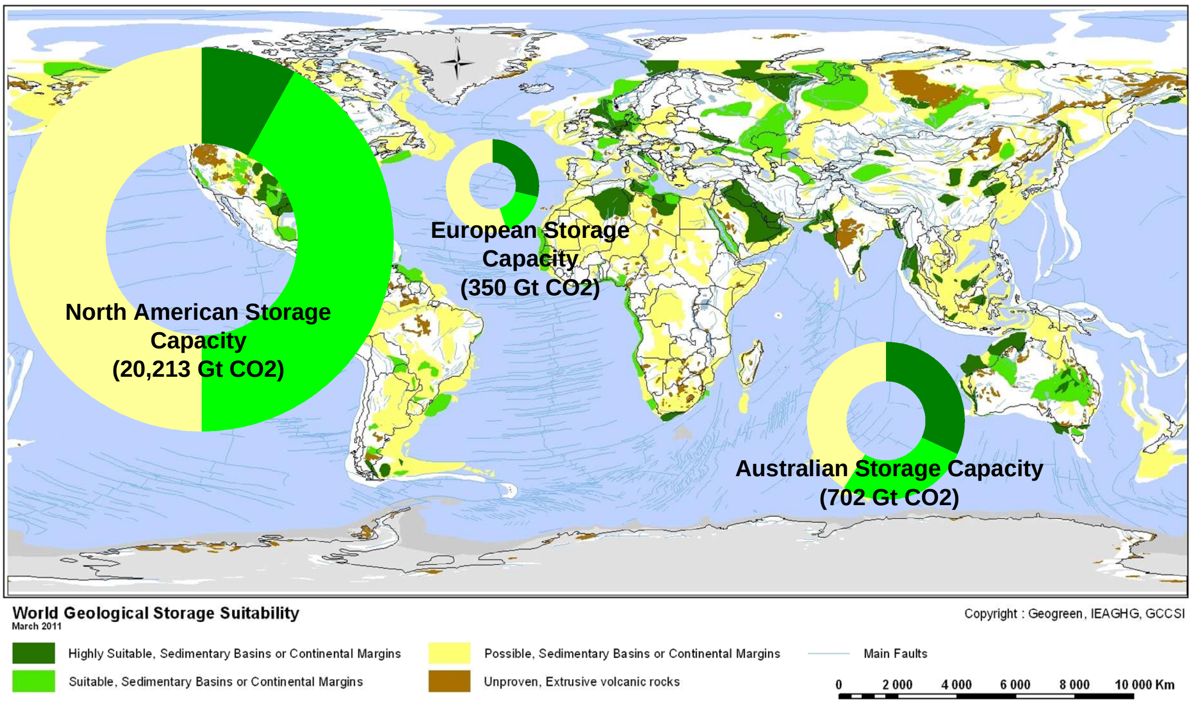


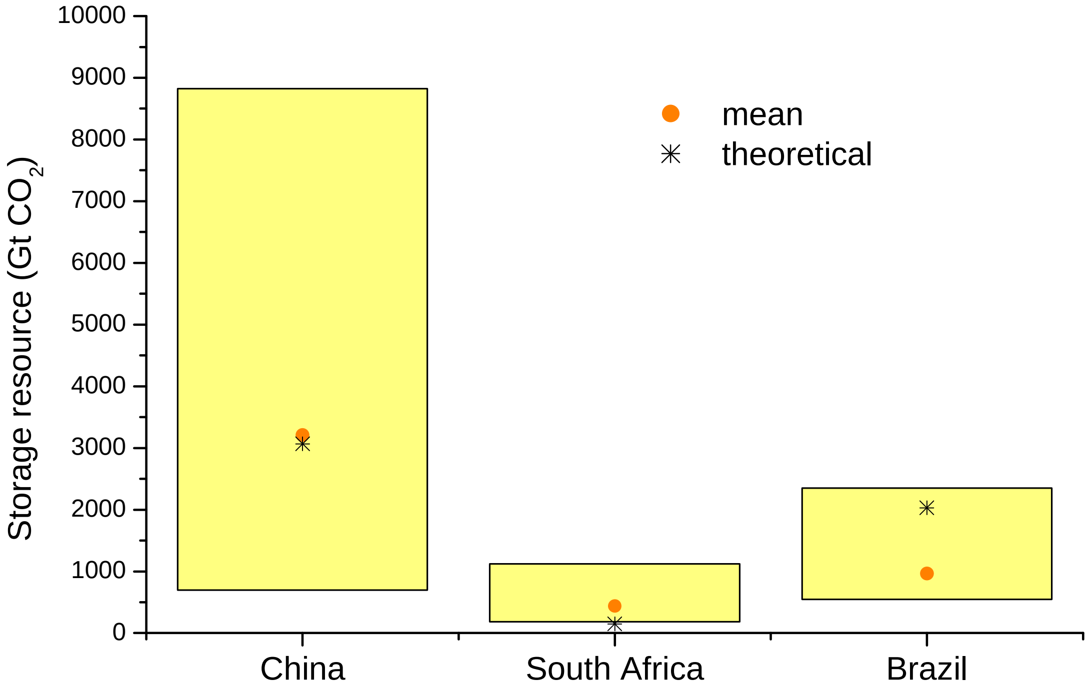
Figure 6: Deep saline CO_2 storage resources for regions with capacity assessment initiatives

Using the detailed information on storage resources from North American NatCarb project [7], the Australian assessment [2], and the areas analyzed by the EU-GeoCapacity project [24], along with some additional data taken from these recent national/regional assessments (Figure 6), it was possible to benchmark the new suitability ranking using data with a wide quality range.

Once the various regional suitability/characterization studies were incorporated and calibrated with the new system, it was possible to extend the new classification into many of the selected areas of focus where no capacity assessments have been published where oil and gas exploration data were available from industry experience and ongoing CO_2-EOR operations. Due to concerns about seismicity, the major fault lines were also included in the assessment as seen in the final map in Figure 5 and should be taken into account when considering storage options. Nevertheless, there remain significant gaps across the map, especially where neither characterization nor oil and gas data were available. More information about how the map was constructed is available in the IEAGHG study [15].

It was necessary to use existing characterization maps as a means to produce a capacity assessment in the eleven areas of focus, where few in-depth characterization activities have gone forward to date. Thus, using the surface density of CO_2 storage (Mt CO_2/km^2) obtained from storage capacity for Europe, North America and Australia enumerated in Figure 6, it was possible to extrapolate the storage resource wherever no assessment took place. However, when considering the resulting estimates for China, South Africa and Brazil in Figure 7, estimates are quite uncertain when compared to the published theoretical resource [3, 4, 20]. In addition, one shall note the published data on storage resources also imply large uncertainties and should be considered with cautions [16]. Although some formations have no doubt been included with no geological information or that are likely unusable, the areas to be considered for geological storage (i.e. the highly suitable, suitable and possible areas) provide an estimate of theoretical storage resource based upon an average of the general characteristics for the area (Figure 5).

The mean may be considered as an (imperfect) estimator of the storage resource in deep saline formations when such assessment does not exist.



Note: Yellow bar represents the uncertainties on the computed storage resource

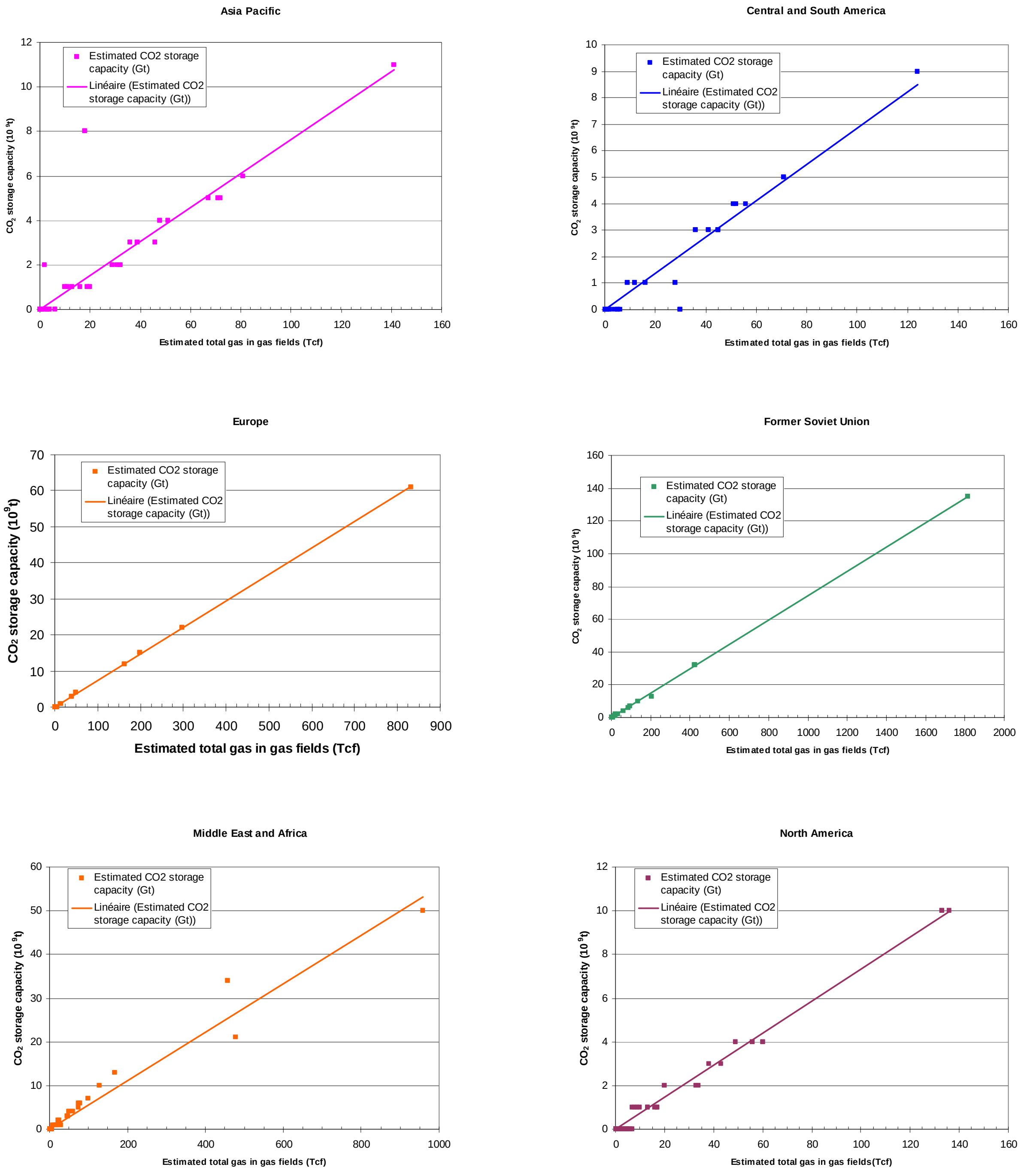
Figure 7: Comparison of existing storage resource estimates for China, Brazil and South Africa

There is obviously a large uncertainty associated with the methodology as illustrated by the yellow bars in Figure 7, which can only be reduced through regional or local studies. This is especially important for non-OECD country where such initiative as the “Atlas on Geological Storage of Carbon Dioxide” in South Africa or Carbmap in Brazil should be promoted [3, 20]. To estimate deep saline formation effective storage resources and practical storage capacities would require detailed geological and fluid flow studies.

3.5. DEPLETED OIL AND GAS FIELDS

When considering storage in oil and gas fields, either depleted or considering Enhanced Oil Recovery (EOR), storage capacity will be directly related to detailed knowledge of the oil and gas production and composition which is not publicly available. In the study, the IEAGHG assessments of CO_2 storage in depleted oil and gas fields are used to estimate the storage potential of the different regions [11, 12].

From the IEAGHG study on major depleted gas fields, it is possible to correlate the CO_2 characterized storage resource with the volume of gas originally in place for different fields leading to linear best fit curves (lines in Figure 8) [11]. The different correlations derived from Figure 8 have been used at regional level.



Source: IEAGHG [11]

Figure 8: Gas field estimated storage capacity for different regions

From the IEAGHG study on depleted oilfields [12] and UNIDO study [16] reported in Table 1, it is also possible to correlate the CO_2 characterized storage resource with the original volume of oil in place (OOIP).

Table 1: Estimated CO_2 Storage Potential from the Application of CO_2-EOR in World Oil Basins

Region Name	CO_2 EOR Oil Recovery (MMBO)	Miscible Basin Count	CO_2 Oil Ratio (tonnes/Bbl)	CO_2 Stored (Gt)
Asia Pacific	18,376	6	0.27	5.0
Central and South America	31,697	6	0.32	10.1
Europe	16,312	2	0.29	4.7
Former Soviet Union	78,715	6	0.27	21.6
Middle East and North Africa	230,640	11	0.30	70.1
North America/Non-U.S.	18,080	3	0.33	5.9
United States	60,204	14	0.29	17.2
South Asia	-	0	N/A	-
Sub-Saharan Africa and Antarctica	14,505	2	0.30	4.4
Total	**468,530**	**50**	**0.30**	**139.0**

Source: UNIDO [23]

These methods enable estimates of the CO_2 storage potential either in depleted oil and gas fields or through CO_2-EOR. The uncertainties associated with the methods used in this high level analysis may be quite important: for example, estimating the performance of CO_2-EOR usually requires several months of study and details data acquisition program for a single field [16].

However several points concerning conversion of oil and gas fields into CO_2 storage or EOR must be taken into account:

- There is a specific “window of opportunity” during which EOR can be implemented on a hydrocarbon field. The field’s depletion date depends on the price of oil or gas, the cost of production for a given field, and the dismantling obligation after field closure. When a field has been declared “depleted” that does not mean there are no more hydrocarbons to produce. Rather; this simply it means that production is no longer economically attractive given the current hydrocarbon price and production costs.

- Not all fields are eligible to CO_2 storage. Candidate fields must possess a certain number of physical characteristics in order to be converted. The necessary characteristics involve factors such as caprock integrity, injectivity issues, the number and type of wells used for the production, etc. Moreover, some fields are not sufficiently large to receive CO_2 from an emissions source over the CCS' projects lifetime (assumed for this study to be 30 years) and thus the project would need to be shifted over to a new source once the first field is full. CO_2-EOR operations should also possess some key properties in terms of structure and oil composition in order to be convertible (e.g. a field oil gravity superior to 17.5°API, an adapted minimum miscibility pressure, proper mechanical and geochemical integrity, etc.).

- The common practice of CO_2 recycling limits the potential to treat most CO_2-EOR projects as storage operations [5]. The CO_2 used for EOR in most cases acts as a valuable commodity and therefore oilfield operators will work to minimize the amount of this commodity that they need to purchase. Part of the CO_2 injected for EOR purposes will ultimately flow to the producing well (i.e. CO_2 breakthrough) and can then be recycled or vented if CO_2 costs is not an issue. Thus, the volume of the CO_2 produced (and recycled) tends to increase over time and as such, new CO_2 volumes (purchases) as needed to sustain the EOR process (e.g. from the capture plant) will decrease over time. For smaller fields; most of the CO_2 can eventually be recycled and it can even be produced and sent to an adjacent field once the old EOR operation has ceased to be profitable, which means very little CO_2 will be left stored in the field. This is less of an issue with larger oilfields because they can store a great deal more of CO_2 and as a result, much more CO_2 becomes permanently trapped throughout the field and cannot be reproduced. In order for CO_2-EOR to become a confirmed CO_2 storage technique; strict rules about CO_2 storage accounting and recycling need to be put into place.

- A high CO_2 procurement cost can limit CO_2-EOR potential: As mentioned by the NRC, *"the single largest deterrent to expanding production from CO_2-EOR today is the lack of large volumes of reliable and affordable CO_2. Most of the CO_2 used for EOR today comes from natural CO_2 reservoirs, which are limited in capacity"* [19].

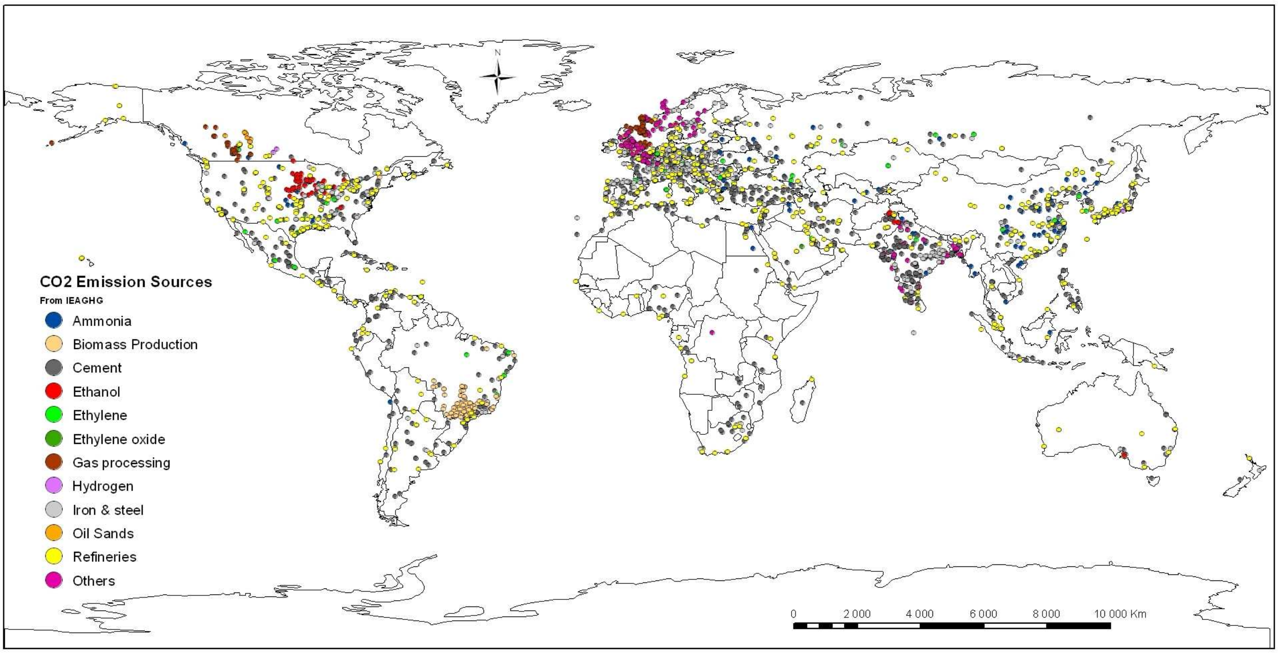
Furthermore, storage options may be considered in depleted oil and gas fields, i.e. beyond the commercial life of such fields. Depending upon the maturity of the different world oil provinces, significant storage opportunities may arise as the global hydrocarbon production is expected to decrease. For example, most of the North Sea oil and gas fields should be reaching the end of their commercial life and may therefore be available for new storage opportunities. On the other hand, EOR or EGR opportunities may develop in the Middle East which might trigger development of CO_2 transportation infrastructures and deep saline aquifers storage opportunities. The economic drivers for CO_2-EOR and storage are quite different [5]. Hence, EOR projects may not drive storage projects deployment.

To conclude, CO_2-EOR has the potential to offset some of a CCS project's costs via CO_2 sales/oil production. This could prove to be a significant advantage in the current context of weak incentives to address industrial emissions. It could drive an increase in demand for industrial CO_2 in some specific regions if capture costs are acceptable and oil prices are high enough. However, CO_2-EOR alone will be incapable of driving large-scale CCS deployment.

3.6. CO_2 EMISSION SOURCES

As laid out by the workflow in Figure 1, the selection of GHG emissions data shall be performed. After some research and careful consideration on the part of the authors, and discussions with this study's advisory group, the IEAGHG global emissions database was selected as the most complete source of emissions data for the areas of interest [14].

This publicly available database, illustrated in Figure 9 is based upon 2007 emissions data and is the result of a collaborative data collection effort organized by the IEAGHG to provide detailed global GHG source information.



Source: IEAGHG [14]

Figure 9: CO_2 emissions sources

3.7. EMISSION SOURCE DATABASE

One of the issues with examining emissions at the global scale is that public/collaborative database maintenance efforts will be hard-pressed to remain consistent, up-to-date, and accurate. Even though the IEAGHG database was by and large the best publicly available source for global emissions data, there were nevertheless some uncertainties on many of the locations and emissions levels for numerous GHG sources, in particular in the non OECD countries [14]. As a result, the source-level emission reported in this database may diverge from other country-level emission databases maintained by the UNFCCC and the IEA. The accuracy issue is particularly acute when attempting to account for economies such as China or India, which are experiencing significant growth and shifts in regional emissions trends and source locations.

Once the IEAGHG dataset was selected as the core data source, it became apparent that these inconsistencies and gaps would need to be addressed to the extent possible. As such, the results of this study are based upon a cleaned and updated version of the 2007 IEAGHG database, reflecting some basic improvements. However, a complete overhaul/update was not possible given the constraints of this particular study and therefore one the recommendations given at the end of this report is a concerted effort to build an updated and streamlined publicly available emissions database.

For the purposes of the UNIDO study, it was necessary to group industrial emissions types so as to remain consistent with the previous UNIDO studies [21]. Taking the IEAGHG defined emission sectors shown in Figure 9, the point-sources were divided into the five UNIDO defined industrial emissions categories that follow:

Table 2: Industry sectors considered in the UNIDO Global Technology Roadmap for CCS

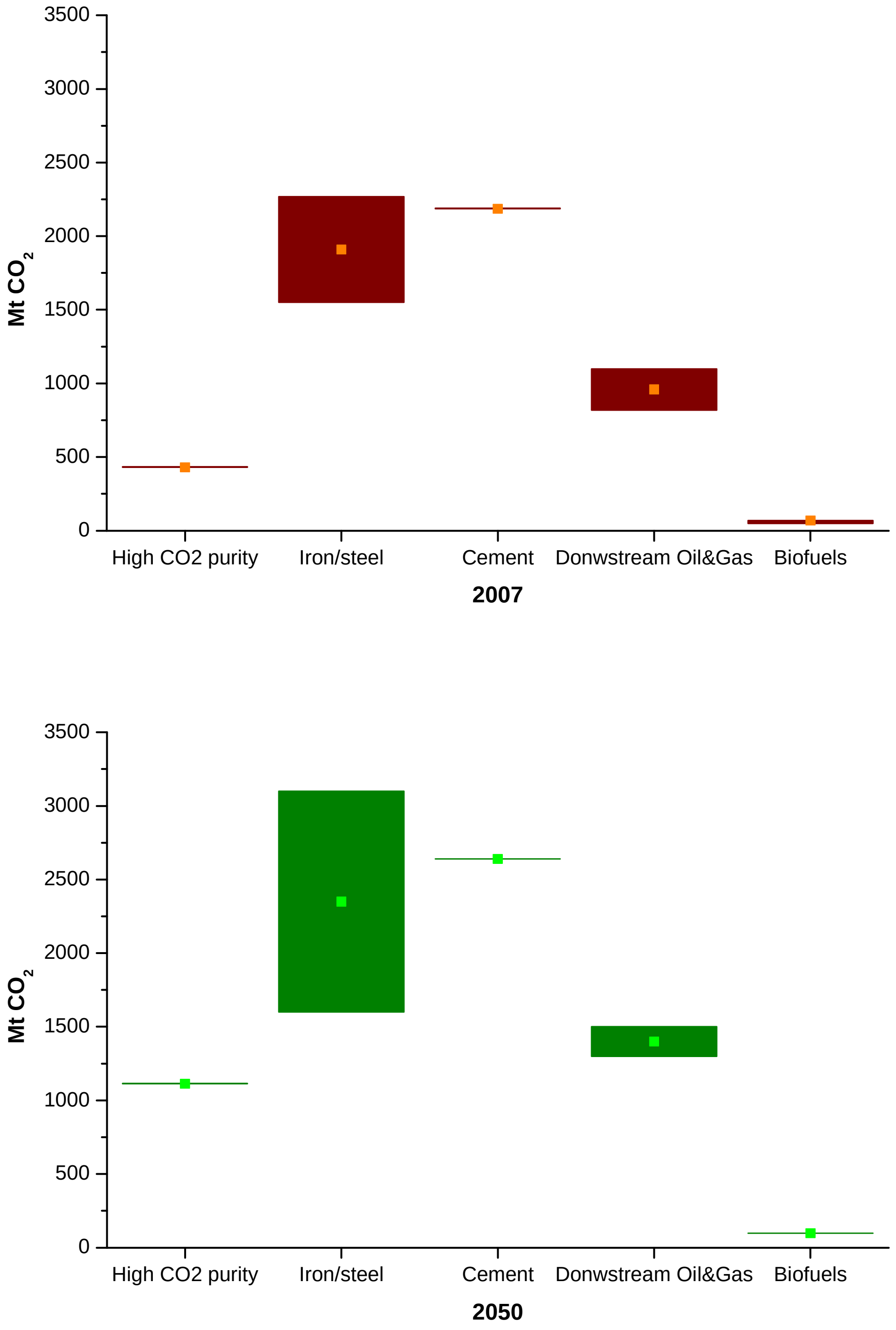
High purity CO_2	Natural Gas Processing Coal-To-Liquid Ethylene Fertilizer/Ammonia production Ethylene Oxide production
Iron and steel	Blast Furnace Direct Reduction of Iron FINEX technologies Hisarma process
Cement	Kiln Calcination
Downstream Oil and Gas (refineries)	Hydrogen production Cracking Process heat
Biomass	Synthetic natural gas Ethanol production Hydrogen from biomass Black liquor (Pulp & Paper)

The harmonization criteria given in Table 2 were applied to the IEAGHG database includes CTL emissions such as in South Africa and aggregates them in the Downstream Oil & Gas (Refineries). Consequently for this study CTL is considered with the Downstream Oil & Gas. The oil sands CO_2 emissions will not be considered in the current study as they are only significant in Canada. The upstream oil and gas sector, i.e. gas processing for sale gas, and the power sector are beyond the scope of the study.

3.8. EMISSION EVOLUTION

Using the emissions evolution calculations taken, UNIDO was able to estimate the evolution path for the five sectors between 2007 and 2050 based on the 2008 IEA “business as usual” (BAU) emissions scenario, as illustrated in Figure 10 [21]. However, it should be noted that large uncertainties exist for the IEA BAU scenario, which could have significant impacts on how these sectors/emissions would evolve in actuality. The UNIDO Roadmap scenario was designed to correspond with the overall IEA 2008 CCS Roadmap and is therefore based upon the IEA Blue Map [10]. This means that roughly 20 percent of the 10 Gt of CO_2 emissions expected from non-OECD countries in 2050 will need to be captured and stored (i.e. about 2 Gt of CO_2/year).

The current study thus focuses on the evolution of non-OECD industrial CO_2 emissions between the two time horizons: 2007 to 2050 (i.e. a reference year reflecting the IEA emissions data and the end year from the UNIDO Roadmap) and a UNIDO-defined industrial sector evolution hypothesis [21]. Local CO_2 emissions from a given source are assumed to follow the regional trends for the overall sector to which it has been assigned as illustrated in Table 3, based on the IEA BAU projections for those sectors. Beyond this, in some cases it was possible to apply a different growth rate for some geographical regions sectors based on localized projections, e.g. for the iron and steel and cement sectors [10, 21].



Source: UNIDO [21]

Figure 10: Evolution of the CO_2 emissions for the industrial sectors between 2007 and 2050

3.9. QUALITATIVE SOURCE-SINK MATCHING APPROACH

When compared, the emissions source and CO_2 storage suitability data allowed for the identification of industrial CCS deployment opportunity “hotspots”, which were then evaluated based on their overall emission footprint. A 100 km clustering range was used to establish what could represent the likely extent of a typical CO_2 collection network from emission sources within an industrial area.

This 100 km range means that no one source in the cluster is located more than 100 km away from any other and was assumed based on several factors. First, CO_2 pipeline transport costs directly correlate to both the volume of gas being piped and the distance it is transported. As industrial CO_2 sources are generally smaller than power sector sources, this diminishes their potential to achieve economies of scale i.e. leads to an increase in the transport cost (per tonne CO_2 stored). Second, because few CCS projects currently exist, early opportunities will rarely benefit by gaining third-party access to existing CO_2 transport networks. Given these issues, it is typically uneconomical to extend CO_2 collection networks beyond 100 km. Ideally, the ultimate CO_2 sink should allow lie within 100 km. Nevertheless, the economically acceptable distance between the source and the sink could prove to be superior to 100 km in some cases depending on local parameters, e.g. low capture/storage costs, high storage suitability, local topography conditions for transport, and/or large volumes of CO_2.

Thus hotspots were established applying the 100 km range to concentrated emission areas. By applying a moving average (based on the five industrial source categories) to the industrial emission sources contained within the “hotspot”, it was possible to identify the most significant industrial emission hubs within the study regions.

Once the hotspots and their contained sources were established, the distance of the hotspot to the closest sink was calculated according to a ranking of sink locations based on suitability. The geographical information system (GIS)-based storage suitability map shown in Figure 5, which Geogreen developed for an IEAGHG and GCCSI study, was used as a basis for this qualitative source / sink matching analysis [15]. Based on the map, if a given emission hotspot is close to a highly suitable area, then the distance reflects such proximity. If the emission hot spot is not close to a highly suitable area, then the closest suitable area is accounted for. If neither a highly suitable, nor a suitable area is close to the hot spot, then the distance to the possible area is taken.

One key assumption of this study was that future emissions growth will continue to take place within the primary industrial areas, observable using 2007 IEAGHG emissions database [14]. As such, the “early opportunity” areas that are ultimately selected in this study are based upon 2050 emissions projections applied to that data. This means that as time approaches 2050, current hot spots are expected to grow rather than move. Consequently, the calculations performed within this study would need to be adjusted if these current activity centers shift over the next 40 years.

Another assumption used throughout this study is that the carbon intensity for the selected industrial sectors will remain constant from 2007 to 2050. However, oil production, for example, will likely need to rely on increasingly unconventional feedstock, which tends to be more carbon intensive. This would ultimately lead to an increase in the downstream oil and gas sector's overall carbon intensity. As a counter example, new projects deployed within the iron and steel industry sector tend to exhibit an overall decrease in carbon intensity. Given the difficulties entailed in estimating carbon intensity changes at the global scale and because no reliable published information could be found for all five sectors, these evolutions have not been taken into account.

Finally, one limitation of this study is that, because emissions from power industry are not considered (i.e. an estimated 55 percent of global CO_2 emission in 2050), strong competition may arise between industrial and power emission sources for locally available transport infrastructure and/or storage resources [17]. Conversely, it is also possible that transport and CO_2 storage synergies could arise in certain areas, e.g. hubs that co-treat industrial and power-sector CO_2 and this would have an impact on how CCS deployment evolves. Ultimately, if local economic and regulatory conditions become suitable more quickly than expected, the CCS projects that are ultimately recommended in this report ideally should be initiated much earlier.

4. KEY RESULTS

4.1. DATA CONSISTENCY AND METHODOLOGY

It is important to recognize that the analyses performed during this study were carried out using publicly available data or reports. The storage options considered are the deep saline formations and oil and gas fields. Moreover, the storage resource estimates that have been conducted for the target storage formations imply large uncertainties and as such, significant additional studies are required in order to confirm the storage potential for all considered formation types/suitability rankings. Thus, storage resources are only qualitative and should be used cautiously.

This study was performed as a qualitative technical assessment and as such economic policies, CO_2 valorization options, existing regulatory frameworks, and policy evolution have not been considered at this stage. Specifically, the economic impacts of CO_2-based enhanced oil recovery (CO_2-EOR) are not applied to the results. Also, while many of these factors have significant effects on the overall timing of a CCS project, it is important to mention that these elements are critical for storage development strategy planning. For instance, development planners should anticipate storage characterization studies, which are necessary prior to constructing a validated storage facility, as typically requiring between four and twelve years to complete (depending on financing and regulatory requirements) [15].

While performing the source-to-sink matching for the five industrial sectors at the global scale, several key challenges were identified as factors affecting the results:

- Data consistency: the data available was often inconsistent both in terms of CO_2 emissions but also in terms of CO_2 storage resources and much work is needed to improve CO_2 source reporting from the non-OECD countries. Furthermore, significant characterization efforts need to be performed across the areas of interest in this study if CCS is considered.
- Accuracy of geographical location of sources and sinks: many of the data points had no/partial/inaccurate geographic coordinates. It would be very helpful for the IEAGHG emissions database to be completely renovated, especially given that the emission sources in fast developing economies such as India or China are evolving rapidly.
- Future evolution of the industrial sectors considered in terms of both carbon intensity and regional trends: it is very difficult to model regional carbon intensity changes, especially in light of the data limitations given above. For example, it was necessary in the context of this study that concentrated industrial areas would be the sites of future growth but this will not always be the case.

This report builds upon the results from a study for the IEAGHG and the Global CCS Institute regarding worldwide storage suitability [15], and on several IEAGHG studies treating major oil and gas field data [11, 12]. The CO_2 emission database that was used here was elaborated using the open source 2007 IEAGHG emissions database [14]. However, as was stated earlier, several difficulties were encountered during the study, with numerous CO_2 emission sources either wrongly located or with missing geographical coordinates. Information relating to geological CO_2 storage resource characterization is seldom available to the public. For oil and gas fields, the assessment was carried out at the regional level using extrapolated data based on IEAGHG studies. However, the geographical extensions of the hydrocarbon fields are not publicly available. A geological database from the USGS was used to estimate the volumes of hydrocarbons “in place” [1]. Here as well the USGS database was limited in that it only provided the center point for most of the identified hydrocarbon fields. Nevertheless, using oil/gas in place estimates it was possible to calculate some rough CO_2 capacity estimations for the identified fields.

The characterization of deep saline formations as geologic CO_2 storage resources is even less certain. Extensive capacity/suitability work for deep saline formations has only been performed by state-led studies in parts of Western Europe, North America, Australia, and a few other regions in the OECD. For the areas of interest in this study, much less work has been done to date, with only a few preliminary characterization studies having been performed in some of the more major non-OECD economies like China, India, Brazil, and South Africa. Given the lack of data, a theoretical CO_2 storage resource estimation model has been computed and calibrated based on public characterization studies carried out in Europe, North America, and Australia. The resulting estimator gives only an approximate evaluation of the storage resources, but this estimation was necessary given the aforementioned limitations.

Finally, a key assumption for this study concerned the future evolution of the different industrial sectors from 2007 (the reference year of the emissions database) to 2050 (the target horizon for CCS deployment). In addition, it was important to account for the regional disparities for industrial evolution thought the areas of interest. Thus, the evolution scenario used in this study and applied to the selected industrial sectors, is based upon the IEA CCS Roadmap and their 2008 ETP Blue Map scenario. The average regional changes in industrial activity are provided in Table 3 and reflect the mean evolution of the industry sectors in the “low” baseline scenario in 2050 [8].

Table 3: Average evolution for UNIDO CCS roadmap industrial sectors (2007-2050)

	World	Latin America	Brazil	South-eastern Europe	Former Soviet Union	India	China	Southeast Asia	Middle East	Central Africa	North Africa	South Africa
High CO_2 purity	159 percent											
Iron/steel	23 percent	50 percent	50 percent	18 percent	18 percent	367 percent	9 percent	126 percent	641 percent	641 percent	641 percent	23 percent
Cement	32 percent	127 percent	127 percent	12 percent	12 percent	222 percent	-34 percent	137 percent	111 percent	111 percent	111 percent	32 percent
Downstream Oil and Gas	46 percent											
Biomass	67 percent											

Source: IEA [10] and UNIDO [21]

4.2. GLOBAL RESULTS

This section will provide an overview of the results of this study, with the regional breakdown of these global results to be covered in the following sections. The results presented here are valid given the assumptions of the study.

- Ultimately, about 50 hotspots were identified as potentially providing early opportunities for industrial CCS development with feasible CO_2 storage options worldwide (as is illustrated in Figure 14) and these locations could be developed into the primary CO_2 hubs for their regions.

- For most regions studied, the storage location proved to be the limiting factor because in many cases, potential storage formations were determined to be too far away from the emissions sources, i.e. beyond the 100 km range assumed in this study.

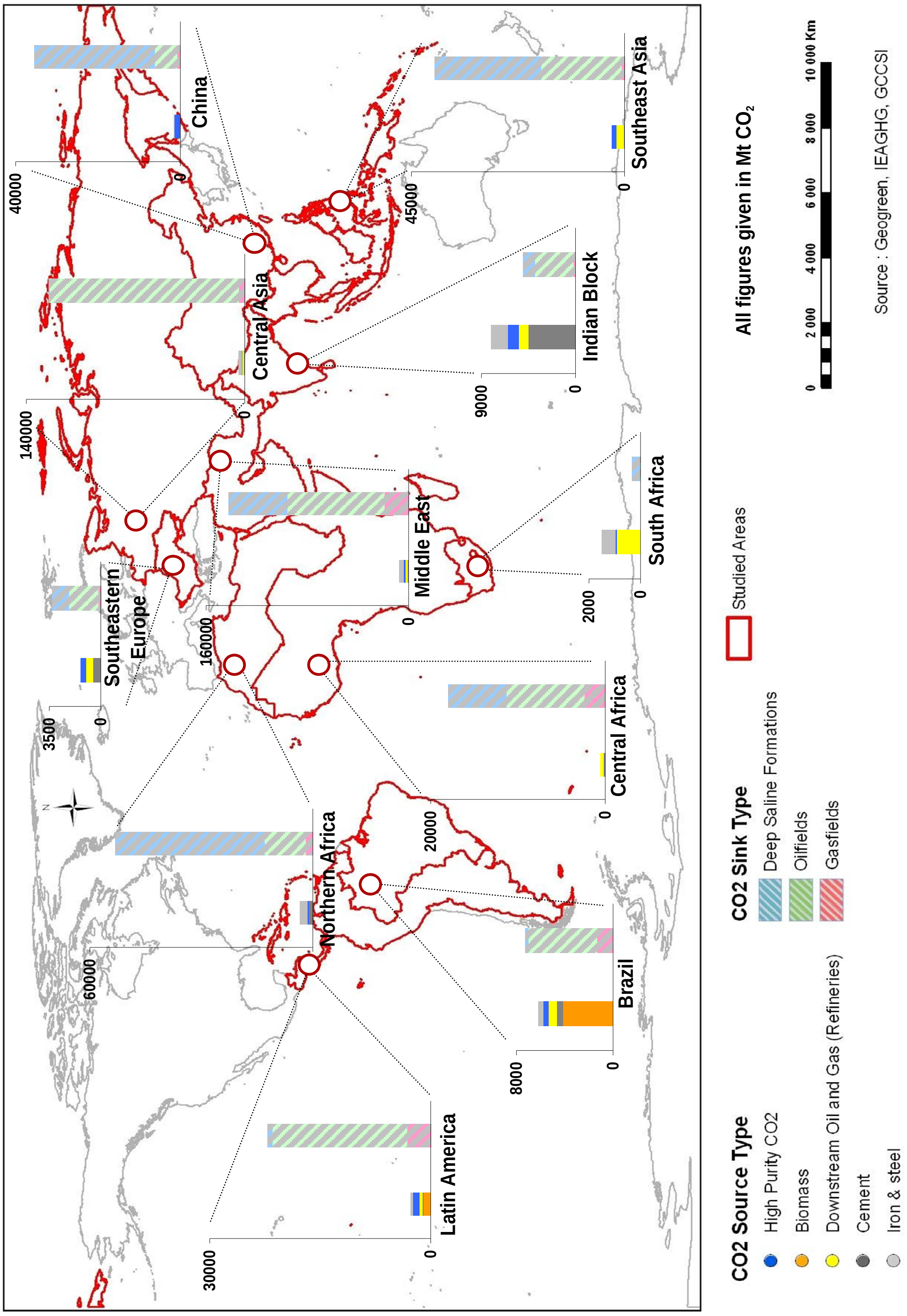
- For some of the major oil and gas producing regions, where significant storage potential exists within depleted oil and gas formations, not enough CO_2 is available as would be needed to develop a significant number of projects. For example, this lack of CO_2 proved to be a limiting factor for much of the Middle East and Russia.

- Given the significant uncertainties linked to oil and gas field storage opportunities (as discussed in section 3.5), non-hydrocarbon bearing “deep saline formations” will undoubtedly play a significant role in these early industrial opportunities because these formations offer a huge potential in many regions. Moreover, deep saline formations are more widespread than oil and gas fields.

- It is important to bear in mind that the source to sink matching performed in this study was done qualitatively; meaning that the sources contained within early opportunities are within proximity to suitable storage but the capacity of that suitable storage cannot be quantified at the local scale due to limited data availability. Nevertheless; it is worth noting that 50 years worth of emissions from the sources identified as early opportunities in the Indian Block and in South Africa represent more CO_2 emissions than could be contained by the entire regions estimated suitable storage capacity. The early opportunity sources in Brazil are very close to filling the entire region’s storage capacity as well.

- Biomass is expected to play a significant role as a feed stock for CCS in Brazil, which is a major producer of sugarcane-based ethanol. Given the present stage of the biofuel industry’s development outside Brazil, biomass potential appears more limited elsewhere.

The illustration in Figure 11 provides an overview of the global-scale source-to-sink matching performed for industrial emission sources in the areas of interest and gives the potential volumes of CO_2 emissions that could be captured from the early opportunities by region in comparison with the entire region’s storage capacity. The emissions are computed with a 50 year plant lifetime and constant annual emissions (2050 emissions) over the entire period. The storage capacity is compute assuming a volumetric efficiency of 1% [13].



Source : Geogreen, IEAGHG, GCCSI

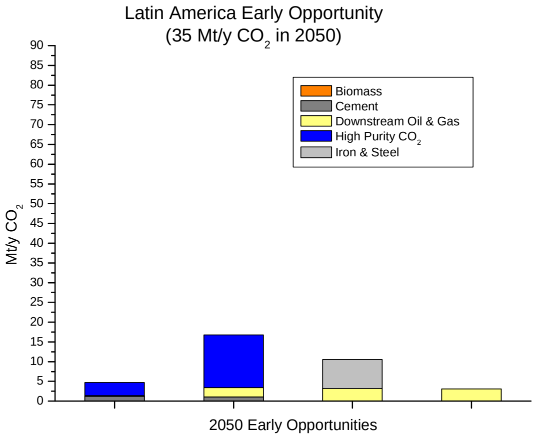
Figure 11: Qualitative source to sink matching based on identified early opportunity emissions up to 2050 by region compared to that region's overall suitable storage capacity

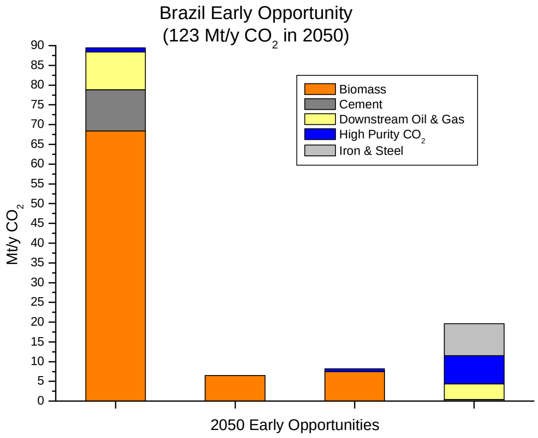
4.3. REGIONAL ASSESSMENT

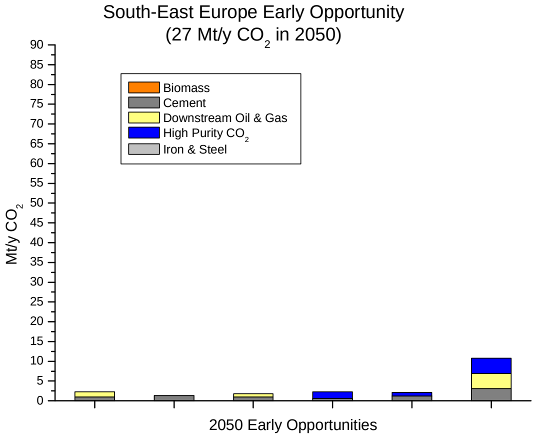
The current study should be considered as a qualitative source-to-sink matching for the industrial emissions within non-OECD countries (see section 3.2). This section gives a regional breakdown of the results and presents the approximate geographical locations and number of early opportunities for industrial CCS project development within the study's timeline up to 2050. A summarized description of the analysis and results are provided here, both in terms of hotspots and early opportunities. Even though the evolution of emissions is estimated up to 2050, early opportunities should nevertheless be developed as early as possible.

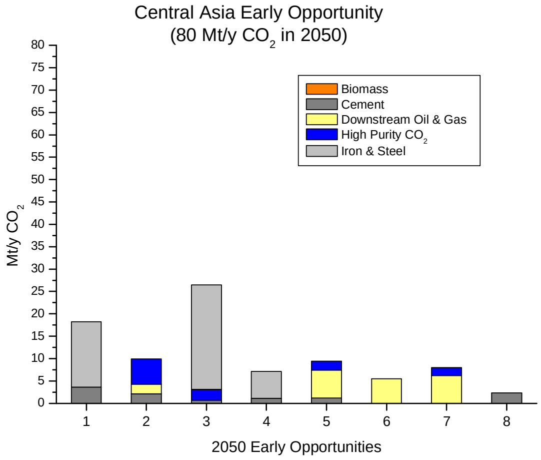
The geographic locations for individual hotspots are given for indicative purposes only. In practice, a variety of local constraints could lead to alternative deployment configurations at the local scale. Furthermore, it could prove interesting to pursue additional industrial development opportunities away from the main hotspots identified here, but these special situations would need to be reviewed on a case-by-case basis and thus these opportunities are not included in the study.

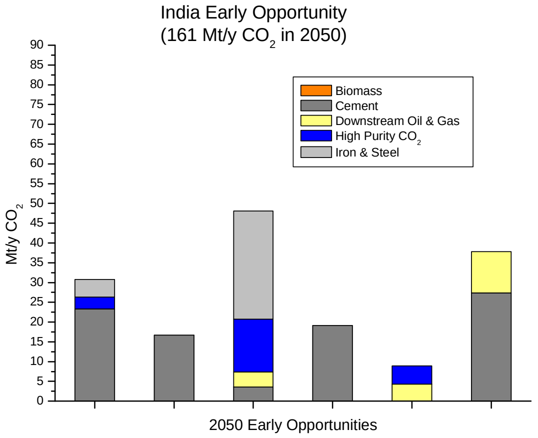
The regional results for source breakdown by hotspot are provided in Figure 12. The horizontal axis represents the number of early opportunities in a given region. However, given the qualitative assessment carried out in the current study, only indicative locations may be given for each early opportunity as detailed in previous sections. Then Figure 13 aggregates the early opportunities identified in each region. These results are strongly dependent on the emission source database which may be weaker in the non-OECD countries and may underestimate the opportunities. Lastly, Figure 14 summarizes the early opportunities identified for all regions. Nevertheless, in order to develop any of the identified early opportunities, detail engineering studies need to be carried out both in terms of the design of the CO_2 emission collecting networks and for the local storage opportunities, with practical capacity assessments being performed for both for oil and gas fields and the deep saline formations. The details of the assessments for the different regions are provided in Appendix A.

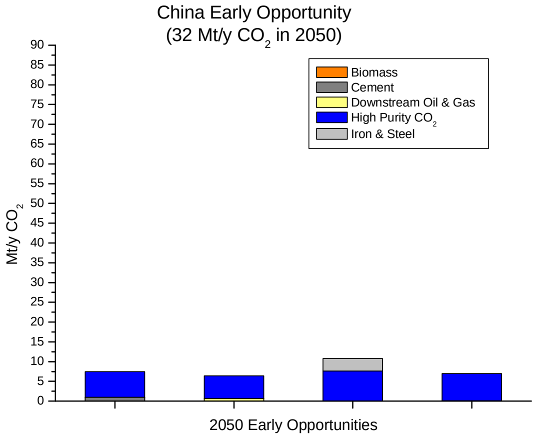

Latin America Early Opportunity
(35 Mt/y CO_2 in 2050)


Brazil Early Opportunity
(123 Mt/y CO_2 in 2050)


South-East Europe Early Opportunity
(27 Mt/y CO_2 in 2050)


Central Asia Early Opportunity
(80 Mt/y CO_2 in 2050)


India Early Opportunity
(161 Mt/y CO_2 in 2050)


China Early Opportunity
(32 Mt/y CO_2 in 2050)

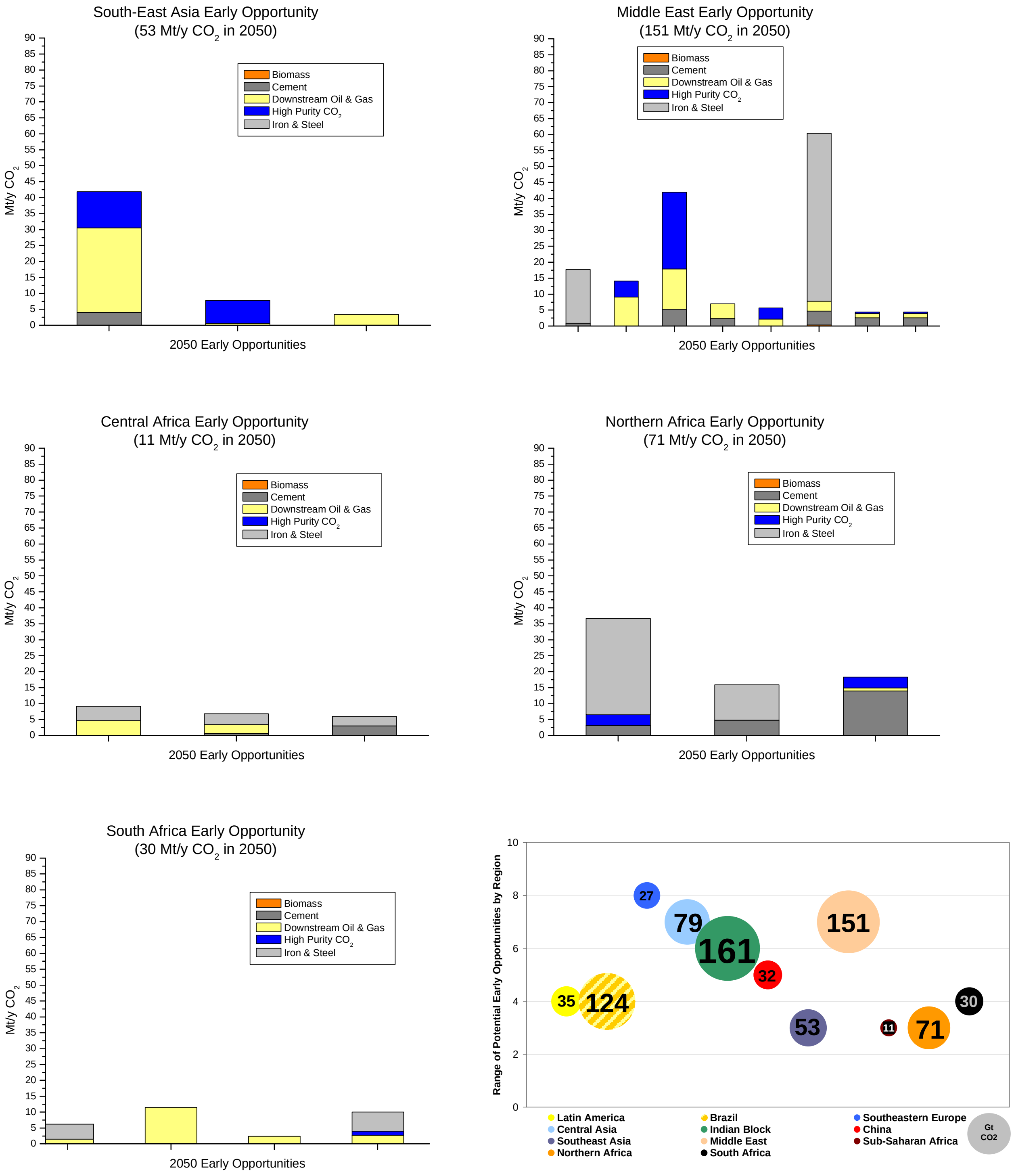


Figure 12: Estimated early CCS opportunities in 2050 synthesis for each region (priority hotspots)

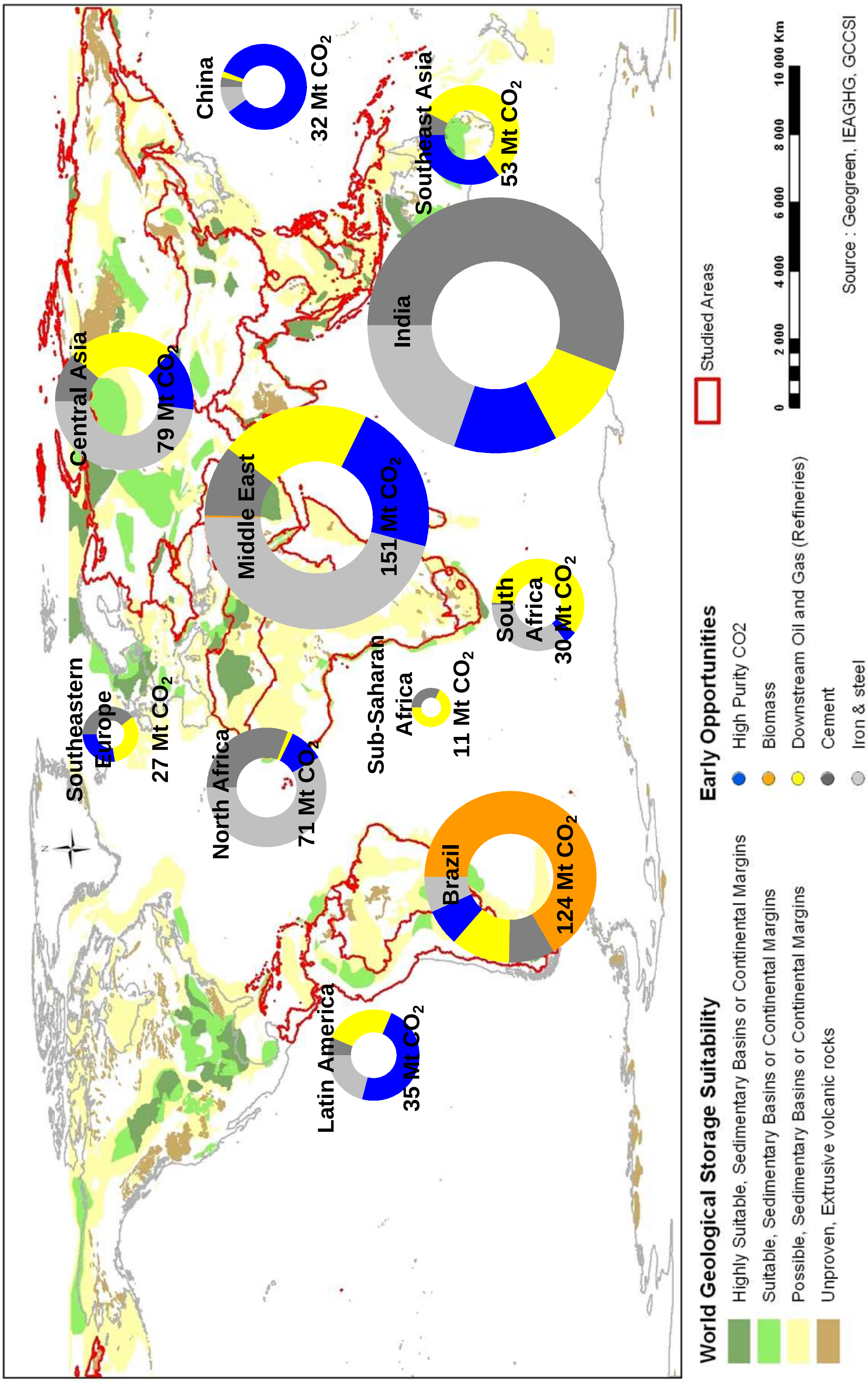


Figure 13: Estimated emissions from early CCS opportunities in 2050 for the industry sectors in the different regions of the study

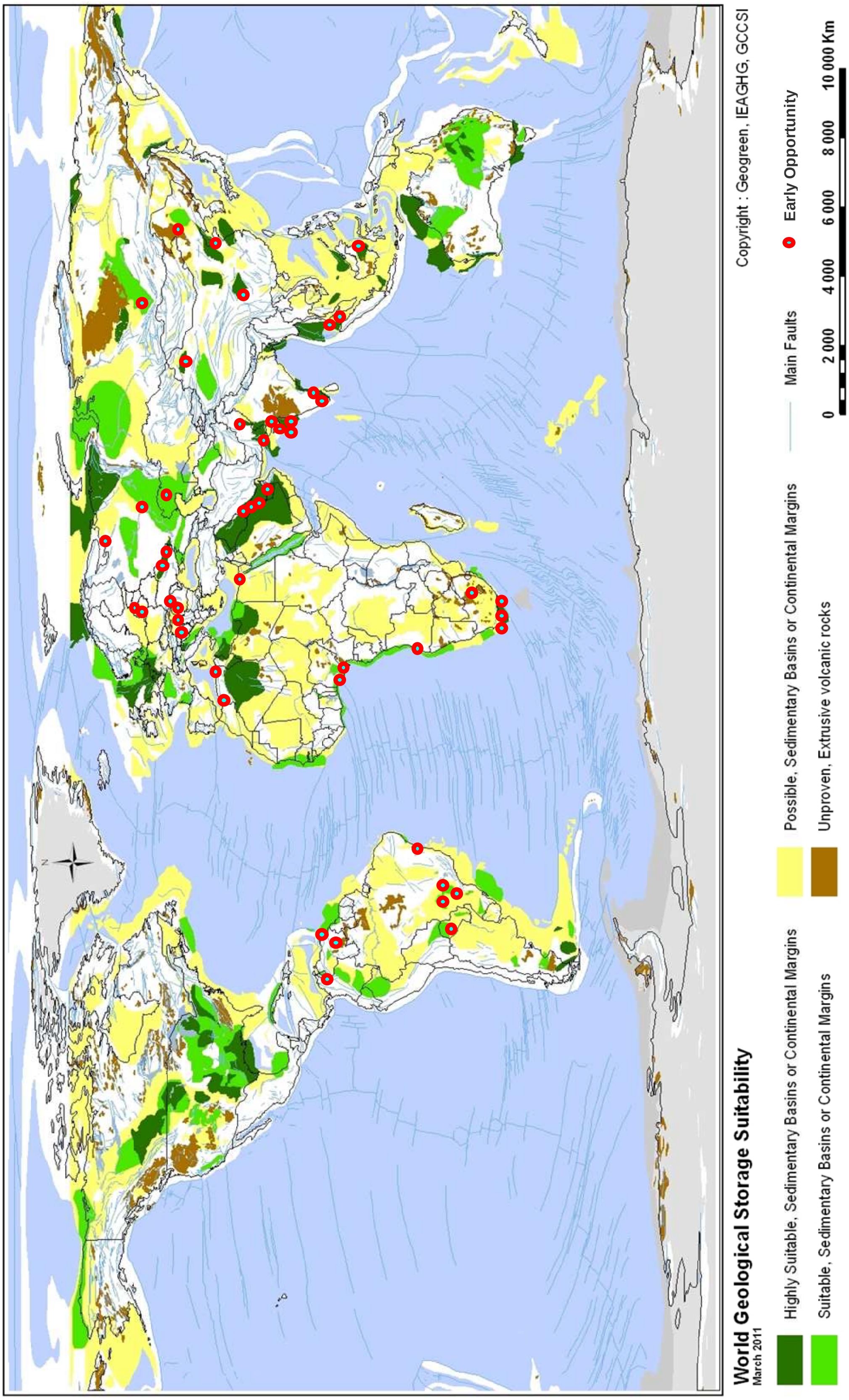


Figure 14: Estimated early CCS opportunities in 2050 for the industry sectors in the different regions of the study

4.4. LATIN AMERICA

By 2050, the percentage share of high purity CO_2 industries is expected to triple (i.e. up to 22Mt/y CO_2), which would represents roughly 12 percent of the expected total emissions for the region (see Figure 16). The share of emissions from the downstream oil and gas sector is expected to decrease to about 36 percent of the region's industrial emissions (see Figure 16) while the share from the cement sector will increase up to about 52 percent (see Figure 16). Both of these sectors are expected to almost double their CO_2 emissions, i.e. to 46Mt/y and 93Mt/y CO_2 respectively. The CO_2 emissions from all industrial sectors combined are expected to grow 93 percent, from roughly 90Mt/y CO_2 in 2007 to c.a. 180Mt/y CO_2 in 2050.

The estimated storage resources for Latin America are quite large, both in terms of oil and gas fields (i.e. 47,500Mt CO_2 – see Table 4) and deep saline formations (with highly suitable and suitable storage resources presenting roughly 35,000Mt of CO_2 capacity – see Figure 18).

For the region, most of the largest sources could be integrated into 20 hotspots (see Table 5), which would then represent 77 percent of the total industrial emissions expected in 2050 for the five sectors considered here (Figure 20).

The early opportunities identified in this study represent about 35Mt/y CO_2 (see Figure 13) from four of the hotspots (Figure 12).

The earliest opportunities are in Venezuela: near Lake Maracaibo, offshore of Carupano, and on-shore near Maturin. Other storage possibilities include oilfields existing in Columbia, Equator or Peru but these storage resources need to be confirmed.

4.5. BRAZIL

In 2050, the share of the different sectors is expected to increase and the biomass sector is expected to grow further to 43 percent of the country emissions from industry (see Figure 23). The cement sector is expected to more than double from 32 to 74Mt/y CO_2 from 2007 to 2050. The CO_2 emissions from industry are expected to grow 82 percent from c.a. 140Mt/y CO_2 in 2007 to c.a. 260Mt/y CO_2 in 2050.

The estimated storage resource is quite large both for oil and gas fields (15,400Mt CO_2, Table 7) and deep saline formations (highly suitable and suitable storage resources: c.a. 13,300Mt CO_2, Figure 25). It is noteworthy to mention that Presalt deep water oilfields[2] are not taken into account in the study. These fields may significantly change the storage capacity and enable new early opportunities from the coastal hotspots and may provide other storage or CO_2-EOR opportunities.

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[2] These fields have a high CO_2 content and Petrobras, the operator of most of these fields is planning to re-inject this CO_2 into the subsurface.

Most of the largest sources may be integrated into 15 hotspots (Figure 26) which represents 74 percent of the emissions of the industry sector in 2050. They involve all the industry sectors in the country (Figure 27).

The early opportunities identified represent about 123Mt/y CO_2 (Figure 13) and are from 4 hotspots (Figure 12).

The earliest opportunity is near Salvador considering its future growth and location with respect to onshore or even offshore oilfields. Other interesting prospects exist north-west of Sao Paulo given the nature and scale of the source linked mainly to biomass sector. Other early opportunities may arise either for onshore EOR or storage in depleted fields or with offshore storage in oilfields and Presalt deep water fields.

4.6. SOUTHEASTERN EUROPE

In 2050, the share of high CO_2 purity sector is expected to double but might represent 25 percent of the region emissions from industry (see Figure 30). The cement sector would remain the largest CO_2 emitter closely followed by the Downstream Oil and Gas sector. The CO_2 emissions from industry are expected to grow 44 percent from c.a. 55Mt/y CO_2 in 2007 to c.a. 80Mt/y CO_2 in 2050

The estimated storage resource is significant both for gas fields (12,300Mt CO_2, Table 10) and deep saline formations (highly suitable and suitable storage resources: c.a. 262000Mt CO_2, Figure 32).

Most of the largest sources may be integrated into 27 hotspots (Figure 33) which represent 92 percent of the emissions of the industry sector. They involve all the industry sectors in the region (Figure 34).

The early opportunities identified represent about 7Mt/y CO_2 (Figure 13) and are from 8 hotspots (Figure 12).

The earliest opportunity is near Tague Mures (Romania) considering its location with respect to on-shore highly suitable deep saline formations and oilfields. On the other hand, several opportunities exist in Northern Croatia for storage in gas fields and Northwestern Ukraine (near Kharkov) for storage in oilfields.

4.7. CENTRAL ASIA

In 2050, the share of downstream oil and gas sector is expected to remain constant at about 30 percent of the region emissions from industry (see Figure 37) while increasing from 43 to 63Mt/y CO_2. The other two sectors, cement and Iron & Steel, will progress on similar trends. However, the high purity CO_2 sector is expected to more than double from c.a. 17 to 43Mt/y CO_2. The CO_2

emissions from industry are expected to grow 41 percent from c.a. 147Mt/y CO_2 in 2007 to c.a. 207Mt/y CO_2 in 2050.

The estimated storage resource is quite large both for oil and gas fields (28,000Mt CO_2, Table 13) and deep saline formations (highly suitable and suitable storage resources: c.a. 33,500Mt CO_2, Figure 39).

Most of the largest sources may be integrated into 13 hotspots (Figure 40) which represent 59 percent of the emissions of the industry sector. These hotspots are mainly located in the western part of the region. They involve all the industry sectors in the region (Figure 41).

As most of the highly suitable storage is onshore (Figure 38), the industrial centers located nearby are primary candidates for the early opportunities for CCS deployment.

The early opportunities identified represent about 80Mt/y CO_2 (Figure 13) and are from 7 hotspots (Figure 12).

Several early opportunities exist in the region. In particular the hotspots with large high purity CO_2 sector near Saratov or near Orenburg for their future growths are interesting prospects.

4.8. INDIAN BLOCK

In 2050, the share of iron and steel sector is expected to represent up to 39 percent of the region emissions from industry (see Figure 44) while the cement sector is expected to be the largest CO_2 emitter, c.a. 45 percent of the region emissions from industry in 2050. The high purity CO_2 sector is also expected to increase sharply to represent about 11 percent of the region emissions from industry in 2050. These three sectors should account for about 94 percent of the region emissions from industry in 2050. The CO_2 emissions from industry are expected to grow 232 percent from c.a. 290Mt/y CO_2 in 2007 to c.a. 970Mt/y CO_2 in 2050.

The estimated storage resource is quite large for both oil and gas fields (8700Mt CO_2, Table 16) and deep saline formations (highly suitable and suitable storage resources: c.a. 58,000Mt CO_2, Figure 46).

Most of the largest sources may be integrated into 19 hotspots (Figure 47) which represents 64 percent of the emissions of the industry sector in 2007 and 73 percent of the emissions of the industry sector in 2050. They involve all the industry sectors in the region except biomass (Figure 48).

The early opportunities identified represent about 162Mt/y CO_2 (Figure 13) and from 6 hotspots (Figure 12).

The earliest opportunity is near Mumbai considering its future growth and location with respect to offshore oilfields and the existing high purity CO_2 sector. However, the available storage resources are quite limited and strong competition for storage capacity will take place. Another interesting area is near Pondicherry but additional geological characterization is required to confirm the storage capacity in deep saline formations.

4.9. CHINA

At the 2050 horizon (Figure 51), the high purity CO_2 is expected to rise sharply from 60 to 157Mt/y CO_2. The Downstream Oil and Gas sector is expected to emit about the same as the iron and steel sector, c.a. 54 and 57Mt/y CO_2 respectively. At the 2050 horizon, the CO_2 emissions from industry are expected to grow 72 percent from c.a. 170Mt/y CO_2 in 2007 to c.a. 290Mt/y CO_2 in 2050.

The estimated storage resource is quite large both for oilfields and more importantly for gas fields (14000Mt CO_2, Table 19) and deep saline formations (highly suitable and suitable storage resources: c.a. 1 460,000Mt CO_2, Figure 56).

Most of the largest sources may be integrated into 18 hotspots (Figure 54) which represents c.a. 59 percent of the CO_2 emissions of the industry sector in 2007. They involve all the industry sectors in the country (Figure 55).

The early opportunities identified represent about 32Mt/y CO_2 (Figure 13) and are from 4 hotspots (Figure 12).

In China, there are four early opportunities with significantly large (above 5Mt/y of CO_2 expected in 2050) high purity CO_2 sources. The storage resources may be oil and gas fields.
The coastal hotspots may find suitable storage resource if additional characterization and potential evaluation is performed.

The early opportunities are evenly spread on the eastern part of the country except for one in the West, near Urumqi.

4.10. SOUTHEAST ASIA

In 2050, the share of high CO_2 purity sector is expected to double reaching about 9 percent of the region emissions from industry (see Figure 58). The cement sector will however remain the largest CO_2 emitter with c.a. 185Mt/y CO_2. The CO_2 emissions from industry are expected to grow 115 percent from c.a. 150Mt/y CO_2 in 2007 to c.a. 320Mt/y CO_2 in 2050

The estimated storage resource is quite large for both oilfields and more importantly for gas fields (4,000Mt CO_2, Table 22) and deep saline formations (highly suitable and suitable storage resources: c.a. 1 125,000Mt CO_2, Figure 60).

Most of the largest sources may be integrated into 17 hotspots (Figure 61 or Table 23) which represent 88 percent of the emissions of the industry sector. They involve all the industry sectors in the country (Figure 62).

The early opportunities identified represent about 53Mt/y CO_2 (Figure 13) and are from 3 hotspots (Figure 12). As most of the highly suitable storage is offshore, the coastal hotspots are the early opportunities for CCS deployment.

The earliest opportunity is near Dungun (Malaysia) considering the CO_2 purity and location with respect to offshore highly suitable deep saline formations or oil and gas fields. A promising target is the hotspot offshore Balikpapan (Indonesia) where oilfields may be available for storage capacity or EOR when considering CO_2 volume available.

4.11. MIDDLE EAST

In 2050, the share of iron and steel sector (114Mt/y CO_2 in 2050) is expected to represent as much as the cement sector CO_2 emissions. It is expected to represent up to 34 percent of the region emissions from industry (see Figure 65). The CO_2 emissions from industry are expected to grow 160 percent from c.a. 130Mt/y CO_2 in 2007 to c.a. 330Mt/y CO_2 in 2050.

Obviously, the estimated storage resource is quite large both for oil and gas fields (211,000Mt CO_2, Table 25). Deep saline formations may also represent alternative storage resources (highly suitable and suitable storage resources: c.a. 2 300,000Mt CO_2, Figure 67).

Given the storage resource in oil and gas fields, these resources will become the main focus for CCS project in the region. Most of the largest sources may be integrated into 12 hotspots (Figure 68) which represent 81 percent of the emissions of the industry sector from the region. They involve all the industry sectors in the country (Figure 69).

The early opportunities identified represent about 150Mt/y CO_2 (Figure 13) and are from 7 hotspots (Figure 12).

The oil-rich region is a primary target for the earliest opportunities link to CO_2-EOR if the site specific studies confirm the storage capacity and the economic interest of such an injection scheme in the Middle East. Region emissions from industry sectors are largely below the huge storage resources.

Early opportunities in Abu Dhabi is already underway –Masdar CCS project - which is a large scale integration between industrial CO_2 emitters and oil and gas producer.

4.12. CENTRAL AFRICA

In 2050, the share of downstream oil and gas sector is expected to increase up to 31 percent of the region emissions from industry (see Figure 72). Meanwhile the cement sector is expected to increase to c.a. 50 percent up to 22Mt/y CO_2 in 2050. The CO_2 emissions from industry are expected to grow 89 percent from c.a. 20Mt/y CO_2 in 2007 to c.a. 43Mt/y CO_2 in 2050.

The estimated storage resource is quite large for both oilfields and more importantly for gas fields (25,000Mt CO_2, Table 28) and deep saline formations (highly suitable and suitable storage resources: c.a. 3 35,000Mt CO_2, Figure 74). There is a significant share of these storage resources that are offshore, in particular in Western Africa.

Most of the largest sources may be integrated into 5 hotspots (Figure 75 or Table 29) which represent 45 percent of the emissions of the industry sector. They involve either the cement or the downstream oil and gas sectors in the region (Figure 76). One interesting hotspot is in Biomass sector in Madagascar with no significant storage resource nearby. The other hotspots are either in Nigeria or Angola.

The early opportunities identified represent about 11Mt/y CO_2 (Figure 13) and are from 3 hotspots (Figure 12).

The earliest opportunities are in Port Harcourt (Nigeria) and near Benguela considering their future growths and locations with respect to offshore oilfields. In Central Africa, modest region emissions from industry sectors are not large enough for the large storage resources.

4.13. NORTHERN AFRICA

In 2050, the share of cement sector is expected to increase up to 77Mt/y CO_2 but the main features is the expected strong increase in emission from the iron and steel sector which is expected to increase 6 fold between 2007 and 2050 up to c.a. 41Mt/y CO_2. In 2050, cement and iron and steel sector are expected to be respectively about 62 percent and 33 percent of the region emissions from industry (see Figure 79). The CO_2 emissions from industry are expected to grow 170 percent from c.a. 46Mt/y CO_2 in 2007 to c.a. 125Mt/y CO_2 in 2050.

The estimated storage resource is quite large for both oilfields and more importantly for gas fields (29000Mt CO_2, Table 28) and deep saline formations (highly suitable and suitable storage resources: c.a. 2 003,000Mt CO_2,). In Northern Africa, most of these storage resources are onshore, except in Egypt.

Most of the largest sources may be integrated into 6 hotspots (Figure 82) which represent 85 percent of the expected emissions of the industry sector in 2050. They involve all the industry sectors in the region (Figure 83) and are mostly located near the coast line except for the Cairo area.

The early opportunities identified represent about 62Mt/y CO_2 (Figure 13) and are from 3 hotspots (Figure 13Figure 12).

The earliest opportunity is near Tripoli (Libya) considering their future growth and location with respect to offshore highly suitable deep saline formations and nearby oilfields. Another interesting area is near Algiers considering the future growth of iron and steel sector. Offshore Alexandria (Egypt) shelters some interesting early opportunities with storage in offshore gas fields. In Northern Africa, modest region emissions from industry sectors are not matching large storage resources.

4.14. SOUTH AFRICA

In 2050, the share of downstream oil and gas sector is expected to increase up to 75 percent of the country emissions from industry (see Figure 86). The CO_2 emissions from industry are expected to grow 41 percent from c.a. 90Mt/y CO_2 in 2007 to c.a. 126Mt/y CO_2 in 2050.

The estimated storage resource is negligible both for oil and gas fields. The only storage resources are in deep saline formations (highly suitable and suitable storage resources: c.a. 15, 000Mt CO_2, Figure 88). In South Africa, most of these storage resources are offshore.

As most of the highly suitable storage is offshore, the coastal hotspots are the early opportunities for CCS deployment. Most of the largest sources may be integrated into 9 hotspots (Figure 89) which represent 39 percent of the emissions of the industry sector. They involve all the industry sectors in the country (Figure 89).

The early opportunities identified represent about 30Mt/y CO_2 (Figure 13) and are from 4 hotspots (Figure 12).

The earliest opportunity is near Port Elisabeth considering its future growth and location with respect to offshore highly suitable deep saline formations along an opportunity near George. An onshore possible storage resource South of Johannesburg may be interesting if the storage capacity is confirmed.

5. CONCLUSIONS AND RECOMMENDATIONS

The results presented throughout Section 4 provide an interesting perspective on the potential for industrial CCS development in developing economies. Looking at the results from a storage capacity standpoint, it is important to bear in mind that it is assumed in this study that all potential geological storage capacity identified in the areas of interest was reserved for industrial CO_2 emissions from the five sectors used within the UNIDO study [21].

When looking at CCS development as a whole, at least 50 percent of the overall storage capacity will likely be used for power sector emissions. Furthermore, as the areas of interest considered here are by no means identical, regions where the electricity mix relies more heavily on coal will more likely need to reserve a larger portion of their overall storage resources for power sector storage projects. Beyond CCS development, there are other competing activities that could interfere with the use of the identified potential storage formations~~,~~ including natural gas storage, and waste injection. Therefore, it is difficult to know whether existing oil and gas fields could actually be sufficient to accommodate the identified emission sources as they evolve to 2050. As a result, the characterization and development of deep saline formation-based CO_2 storage options should be viewed as a priority in the context of global CCS development, especially in these developing regions, because they will most likely be needed if these recommendations for industrial CCS development are pursued.

EOR could play a significant role in several of the regions identified as containing early opportunities for industrial CCS development, especially for alleviating the high costs of early deployment. However, if CO_2-EOR development is to be considered as a storage activity, the EOR operations will need to conform to strict criteria and regulations. MMV programs will need to be designed in order to validate CO_2 injected so as to allow for policies regarding CO_2 recycling/storage accounting to be enforced. Operators should address the CO_2 recycling issue in light of the overarching goal for CO_2 to remain stored in the formations. As such, even if CO_2 is recycled during the EOR operation, the ultimate goal should be to maximize the CO_2 storage.

Given that storage development within deep saline formation takes much longer than hydrocarbon reservoirs, a potential competition for storage between emitters could occur over the more viable storage resources, given the lower costs implied. However, there exist significant potential synergies between industrial and power emission sources engaging in CCS hub development in areas where significant storage potential exists, which will allow for the costs of CO_2 transport and storage to be shared between multiple stakeholders. In addition, some local industrial operations could prove to be excellent early opportunities (e.g. due to low capture cost, availability of nearby oil or gas fields for storage or EOR). This is notably the case for natural gas processing for high CO_2 content gas fields. As the gas treatment facilities are often located next to the gas fields but far from industrial hubs, the cheap capture costs and favorable geology should allow for the development of early CCS projects in those areas.

Given the conclusions of this study, the following actions are recommended:

1. Given the significant amount of data that was found lacking for this study, numerous regional “regional CCS potential assessments” should be launched across much of the areas of interest. These studies should be government-led and should identify the regional source-to-sink matching potential, as well as underlining possible CCS deployment strategies. However, it is important that the role of industrial CO_2 sources in early opportunities for storage development is clearly recognized within these development activities. Once better geological knowledge is acquired, a Geographical Information System (GIS) should be elaborated to be coupled with decision-making tools for regional and local source-to-sink matching exercises. This GIS could also de designed to account for the topography of the region and to identify protected areas and other surface/subsurface constraints.

2. In addition to these more general development activities, specific “storage resource characterization studies” need to be launched for all of the identified storage resources in the areas of interest. Notably, deep saline formation characterization should be prioritized as hydrocarbon-bearing formations will likely prove insufficient. Deep saline formation storage takes time to be developed safely and so the storage development timelines need to be taken into account by the development activities recommended above.

3. Most importantly, a reliable revenue stream needs to be provided to early industrial CCS projects. This is the only way to ensure that early industrial opportunity projects are pursued in light of the current situation globally where there exists no price on CO_2 emissions. However, perhaps the most effective means for driving industrial CCS development within developing economies and even CCS development anywhere would be to put in place an enforceable price on emissions.

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GLOBAL INDUSTRIAL CCS TECHNOLOGY ROADMAP

APPENDICES

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A. ANALYSIS OF THE DIFFERENT REGIONS

A.1. LATIN AMERICA

The CO_2 emission reported for Latin America is illustrated in Figure 15. The industry sectors represent 54 percent of the region CO_2 emissions.

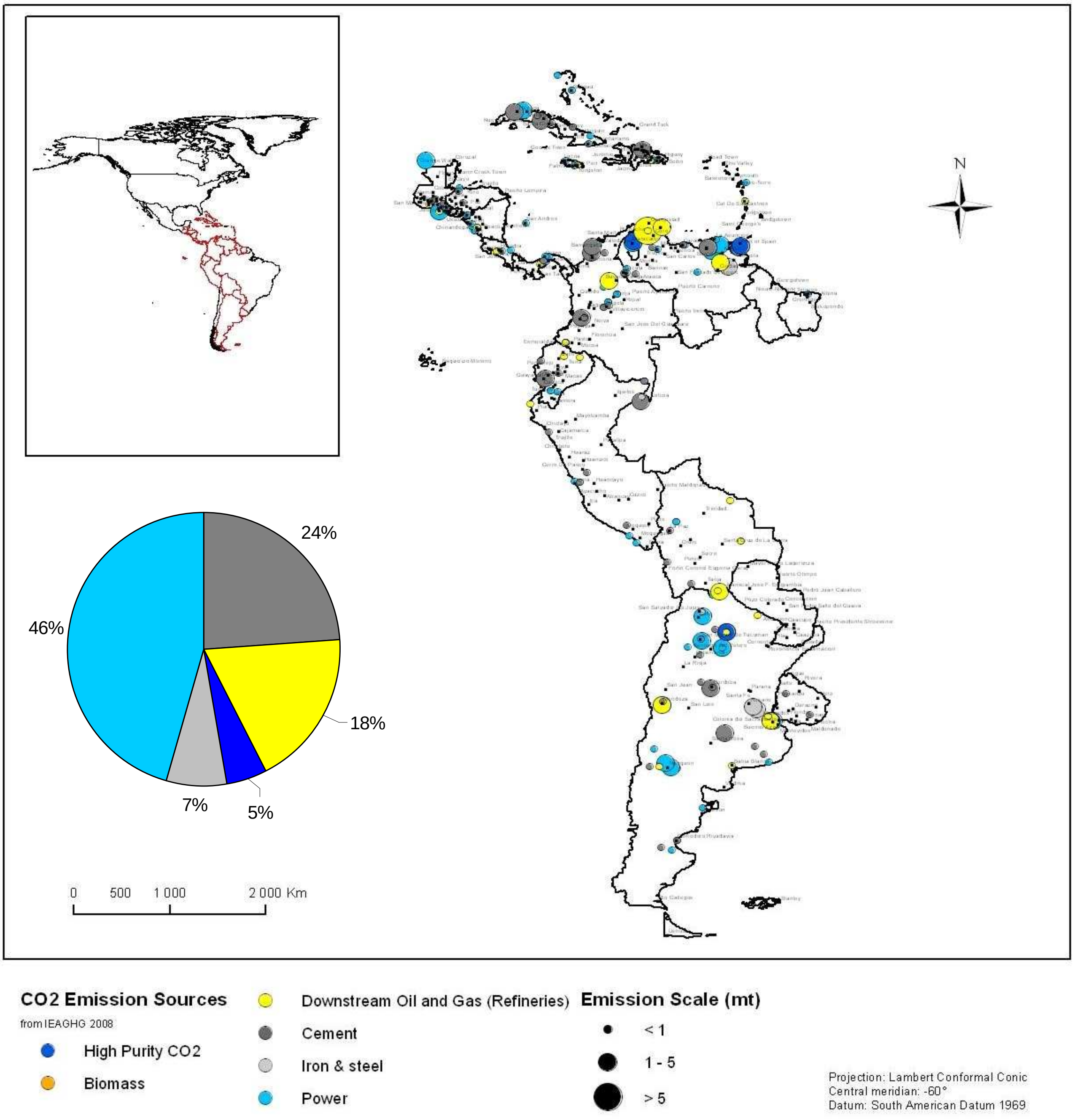


Figure 15: Annual CO_2 emissions in Latin America

A.1.1. Industrial CO_2 sources in Latin America

Emissions baseline (2007)

In Latin America, besides the power industry, the main sources of CO_2 emissions are the cement and downstream oil and gas sectors. The cement sector generates about 44 percent of the region emissions from industry, c.a. 41Mt/y CO_2 for the cement sector out of 93Mt/y CO_2 for the all industry sectors in 2007. The downstream oil and gas sector generates about 34 percent of the region emissions from industry, c.a. 31Mt/y CO_2 for the downstream oil and gas sector out of 93Mt/y CO_2 for the all industry sectors in 2007. No biofuel emission is integrated in the data base for Latin America.

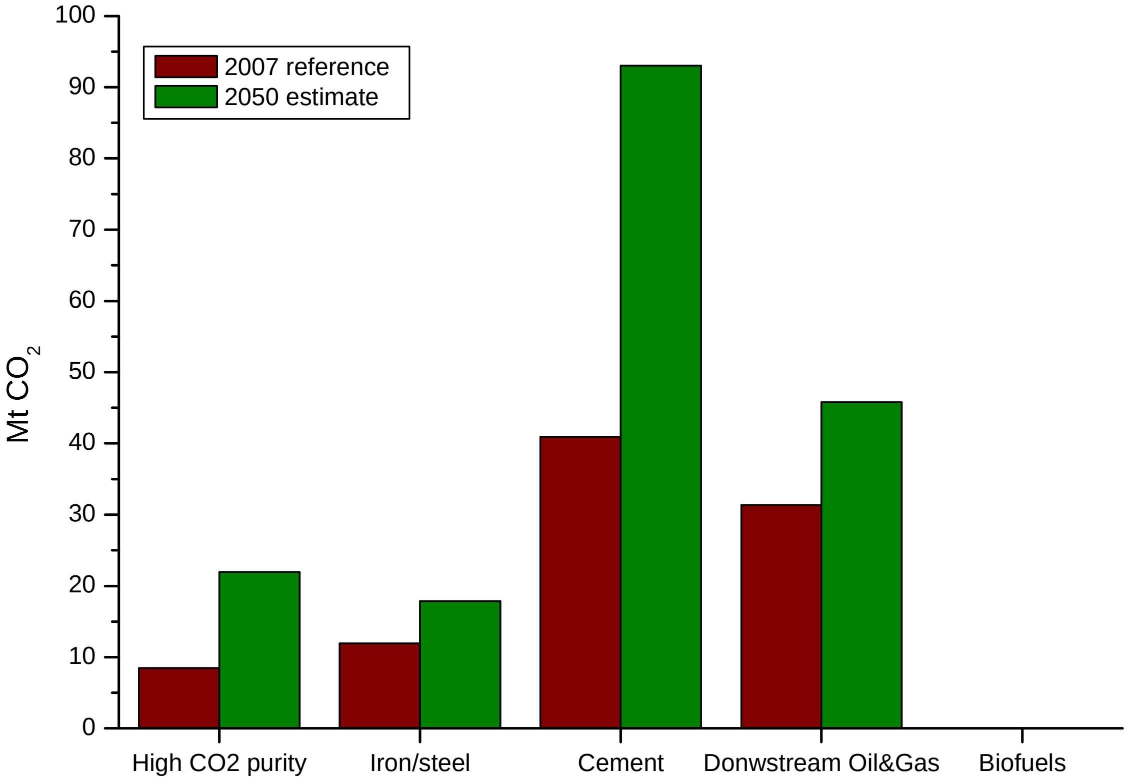


Figure 16: Annual CO_2 emissions and evolution for the industrial sectors in Latin America

Emissions evolution (by 2050)

At the 2050 horizon, all the industry sectors are expected to grow in particular the high CO_2 purity sector. The share of the downstream oil and gas sector is expected to decrease about 36 percent of the region emissions from industry (see Figure 16) while the share of the cement sector will increase up to about 52 percent of the region emissions from industry (see Figure 16). Both sectors are expected to emit almost twice as much CO_2, respectively c.a. 46Mt/y CO_2 for the downstream oil and gas sector and 93Mt/y CO_2 for the downstream oil and gas sector out of 180Mt/y CO_2 for the all industry sectors in 2050. The CO_2 emissions from industry are expected to grow 93 percent from the 2007 level: from c.a. 93 to 180Mt/y CO_2.

A.1.2. CO_2 storage resources in Latin America

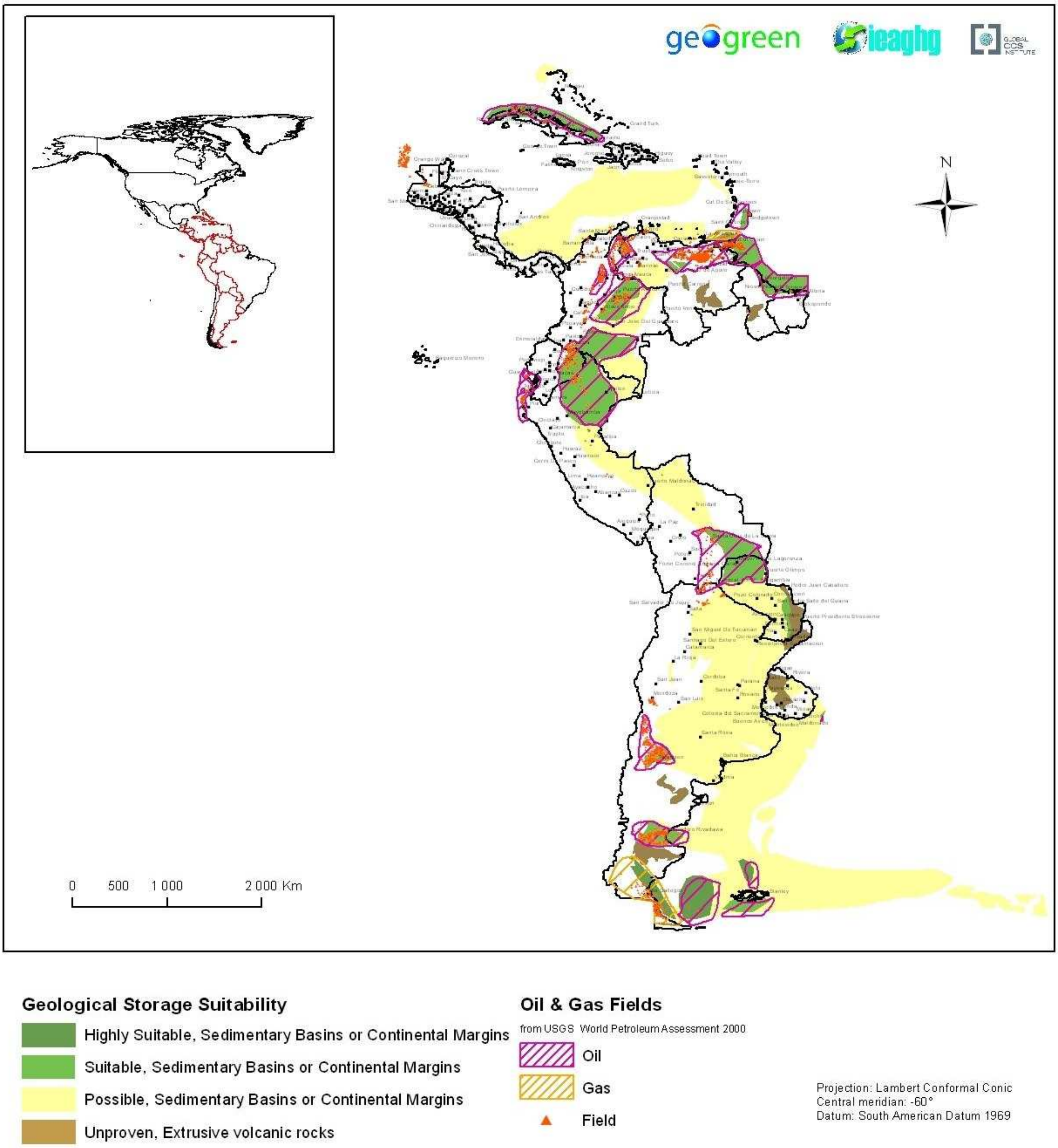


Figure 17: Storage resource in Latin America: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 18). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emission as long as the resource may be banked as storage capacity (Figure 4). Note that competition for storage resource is likely. Most of the possibly suitable storage resource is onshore, but in the southern and northern parts of the region, offshore possibilities exist.

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 18 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4)

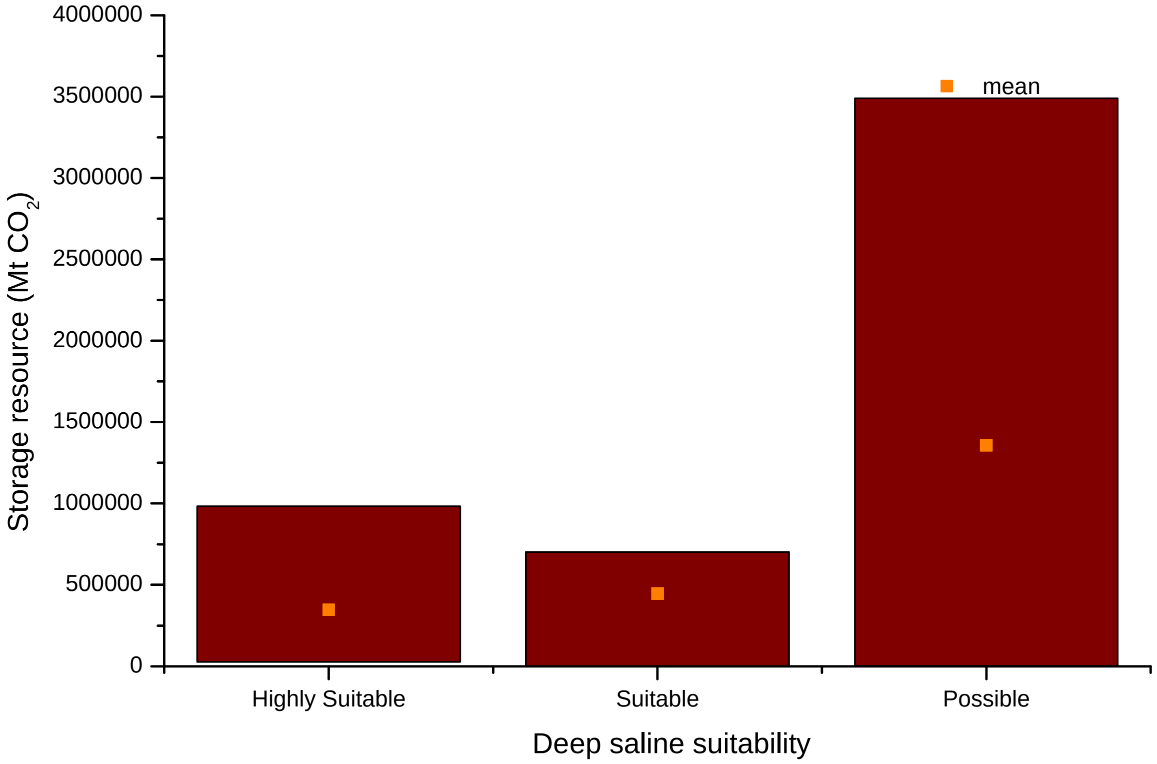


Figure 18: Estimated storage resources in deep saline formations in Latin America

Oil and Gas fields

There are significant oil and gas fields mainly onshore in Latin America mainly in Venezuela (Table 4). However some offshore oil and gas production exist mainly in Venezuela and Cuba. The storage capacity in Oil and gas fields is significant. The main constraint is the availability of the fields for storage and their suitability given the complex geological structure and long oil production history in country like Venezuela. Specific field level studies are required to firm up the storage capacity.

Table 4: Storage resource in oil and gas fields in Latin America

	Storage resource ($Mt\ CO_2$)
Oil fields	6500
Gas fields	41000
Total	**47500**

The estimated CO_2 storage potential from CO_2-EOR (Table 1) is much lower, 5 000Mt for Central and South America compared to 6500Mt using the linear estimator. Furthermore, the CO_2-EOR only considers miscible process for EOR and not the storage in depleted oil and gas fields.

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.1.3. Qualitative source-sink matching in Latin America

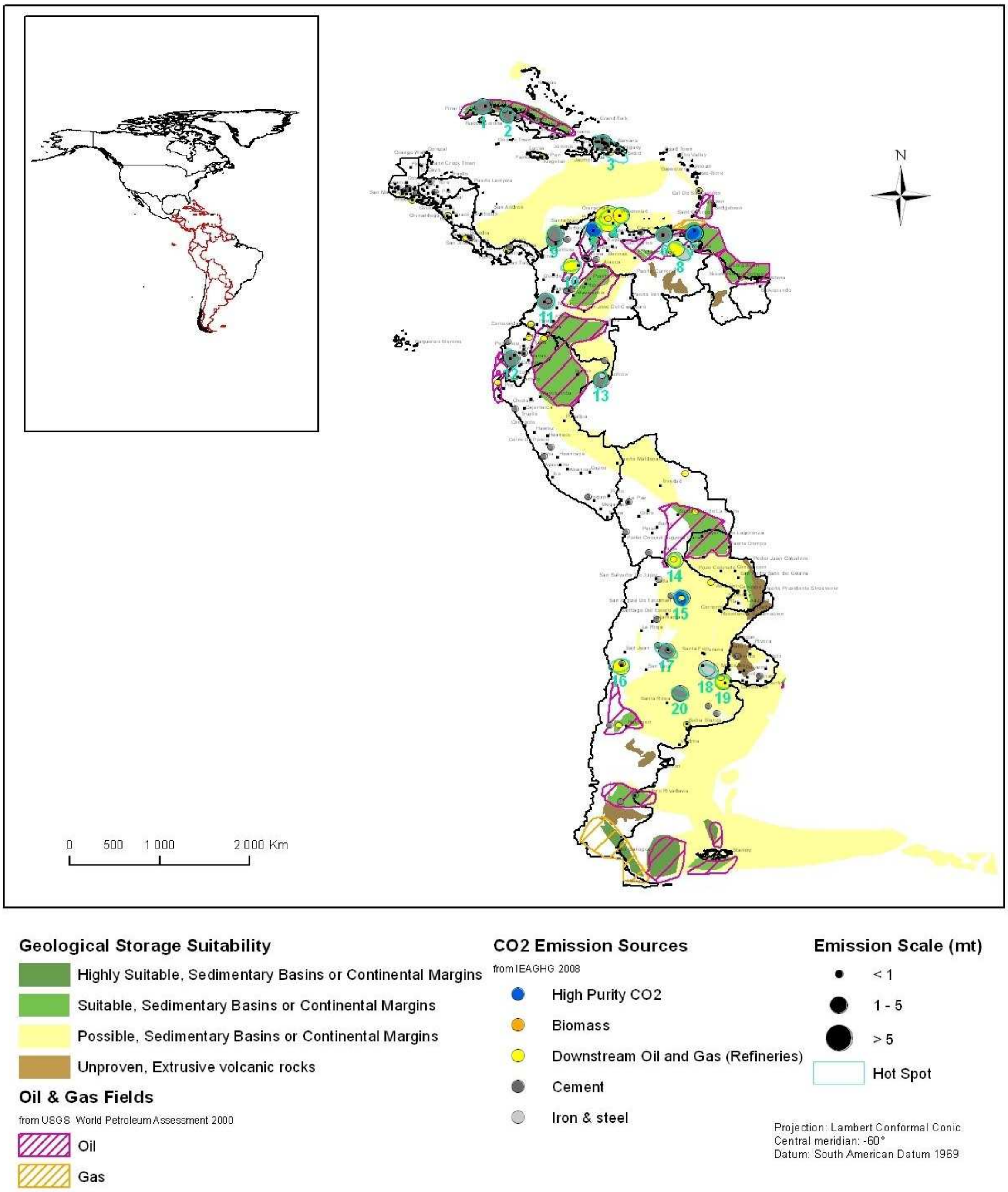


Figure 19: Storage suitability, annual CO_2 emission and hotspots in Latin America

Table 5: Identified hotspots in Latin America

hotspot		Cement		Downstream Oil and Gas		High Purity CO2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	1	1.07	0	0.00	0	0.0	0	0.00	1	1.1
	2	2	1.75	1	0.73	0	0.0	0	0.00	3	2.5
	3	2	1.85	2	0.47	0	0.0	0	0.00	4	2.3
	4	1	0.68	4	12.07	0	0.0	0	0.00	5	12.8
	5	1	0.53	1	0.10	1	1.3	0	0.00	3	1.9
	6	1	2.21	1	1.88	0	0.0	0	0.00	2	4.1
	7	1	0.47	1	1.54	2	5.2	0	0.00	4	7.2
	8	0	0.00	2	2.19	0	0.0	1	4.86	3	7.0
	9	4	3.50	0	0.00	0	0.0	0	0.00	4	3.5
	10	1	0.10	1	1.97	0	0.0	0	0.00	2	2.1
	11	3	2.97	0	0.00	0	0.0	0	0.00	3	3.0
	12	2	1.26	0	0.00	0	0.0	0	0.00	2	1.3
	13	1	1.74	0	0.00	0	0.0	1	0.57	2	2.3
	14	0	0.00	2	2.13	0	0.0	0	0.00	2	2.1
	15	0	0.00	1	0.28	1	1.5	0	0.00	2	1.8
	16	1	0.44	1	1.16	0	0.0	0	0.00	2	1.6
	17	3	2.15	0	0.00	0	0.0	0	0.00	3	2.2
	18	0	0.00	0	0.00	0	0.0	2	5.43	2	5.4
	19	0	0.00	2	1.91	0	0.0	1	0.83	3	2.7
	20	2	2.00	0	0.00	0	0.0	0	0.00	2	2.0
2050	1	1	2.43	0	0.00	0	0.00	0	0.00	1	2.4
	2	2	3.98	1	1.07	0	0.00	0	0.00	3	5.0
	3	2	4.20	2	0.69	0	0.00	0	0.00	4	4.9
	4	1	1.55	4	17.62	0	0.00	0	0.00	5	19.2
	5	1	1.21	1	0.15	1	3.33	0	0.00	3	4.7
	6	1	5.02	1	2.74	0	0.00	0	0.00	2	7.8
	7	1	1.06	1	2.25	2	13.39	0	0.00	4	16.7
	8	0	0.00	2	3.19	0	0.00	1	7.29	3	10.5
	9	4	7.94	0	0.00	0	0.00	0	0.00	4	7.9
	10	1	0.23	1	2.88	0	0.00	0	0.00	2	3.1
	11	3	6.74	0	0.00	0	0.00	0	0.00	3	6.7
	12	2	2.86	0	0.00	0	0.00	0	0.00	2	2.9
	13	1	3.95	0	0.00	0	0.00	1	0.85	2	4.8
	14	0	0.00	2	3.11	0	0.00	0	0.00	2	3.1
	15	0	0.00	1	0.41	1	3.85	0	0.00	2	4.3
	16	1	1.00	1	1.69	0	0.00	0	0.00	2	2.7
	17	3	4.89	0	0.00	0	0.00	0	0.00	3	4.9
	18	0	0.00	0	0.00	0	0.00	2	8.14	2	8.1
	19	0	0.00	2	2.78	0	0.00	1	1.24	3	4.0
	20	2	4.55	0	0.00	0	0.00	0	0.00	2	4.5

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 20 hotspots (Table 5) which represents 77 percent of the expected emission of the industry sectors in 2050. They involve all the industry sectors of the region (Figure 20).The main hotspots are numbers 3, 4, 7 and 8 for their emitted CO_2. However, the high purity CO_2 sources exist mainly in hotspot number 7 and 15 (see Figure 20). The iron and steel sector is only significant in the hotspots 8 and 18.

The expected growths of the hotspots are highlighted in Figure 21) The number 4 and 7 are expected to grow significantly (Figure 21).

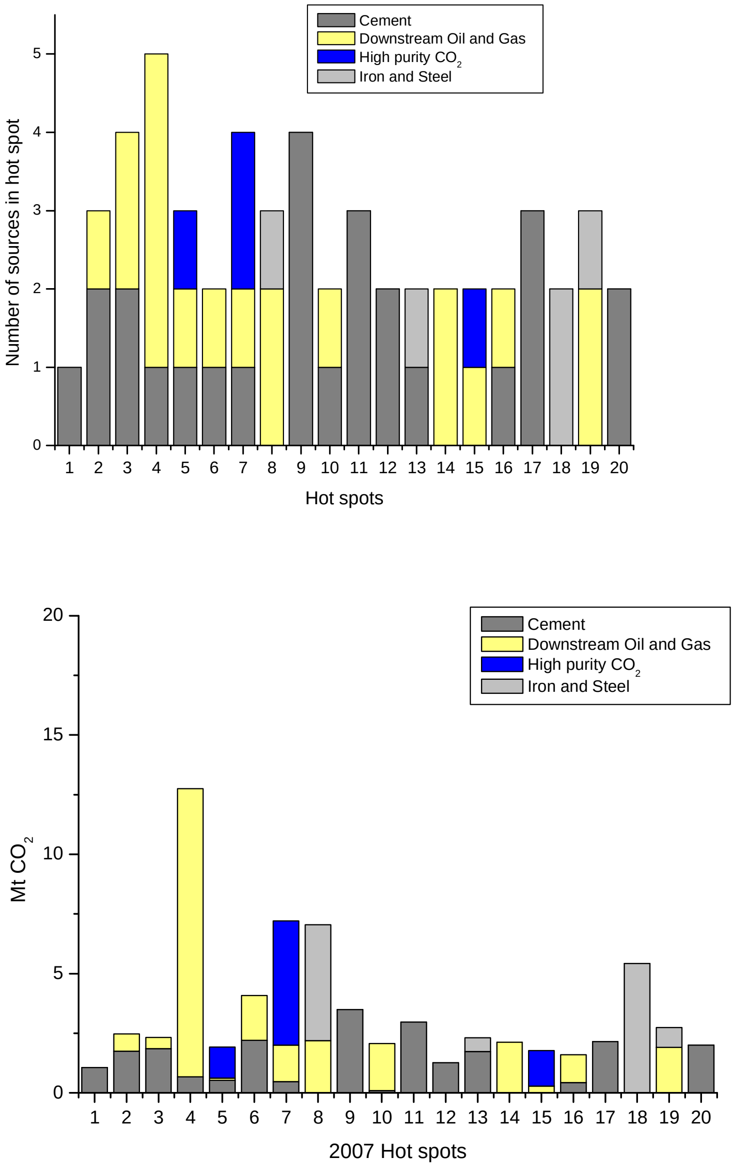


Figure 20: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Latin America

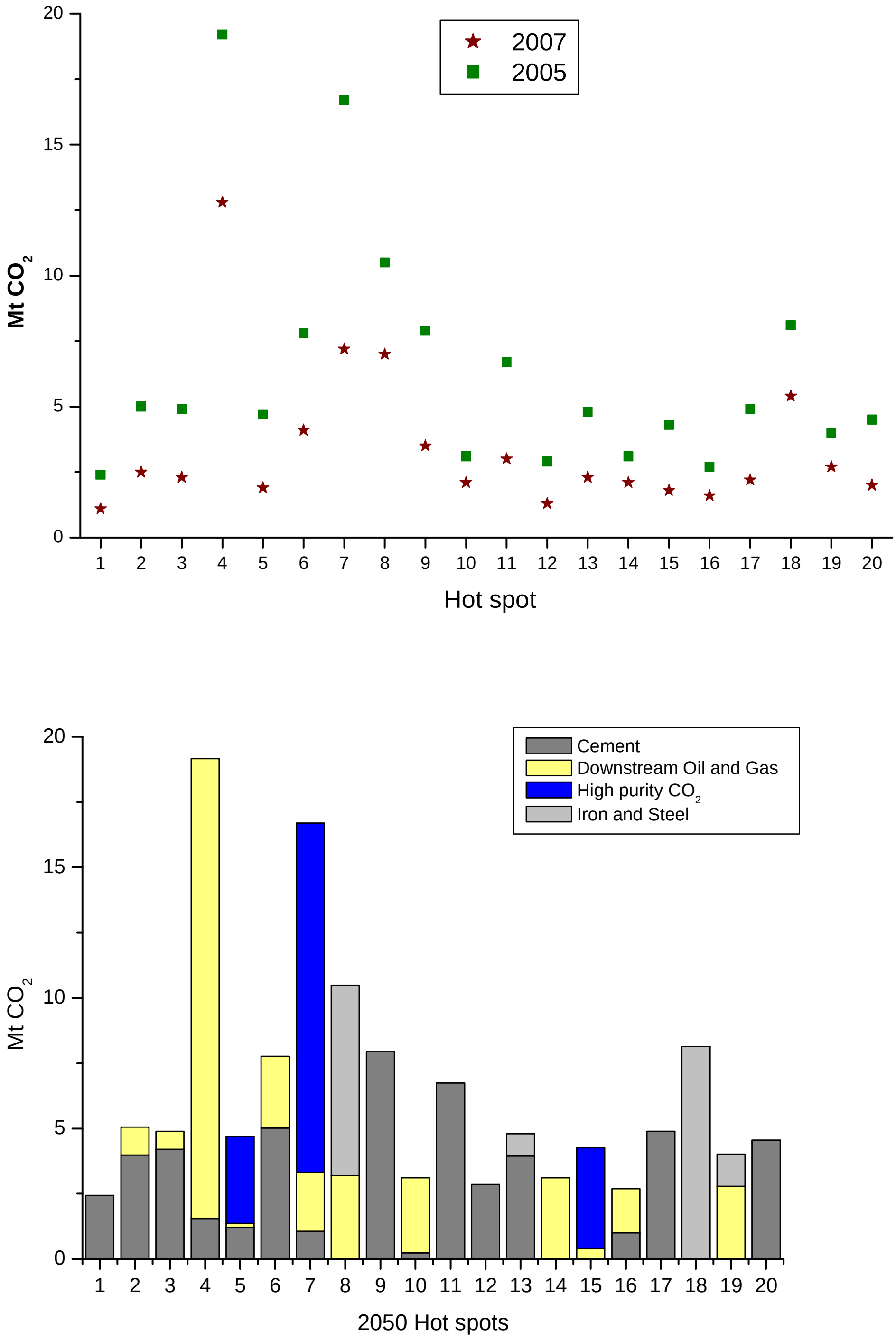


Figure 21: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Latin America

Early opportunities

The obvious early opportunities are the hotspots 5, 7 and 8 for storage of High purity CO_2 sources in oilfields and potential CO2-EOR. An equally interesting hotspot is number 14 which could also find storage resource in oilfields but across the border which may be a pitfall. A series of interesting hotspot might emerge as early opportunities if the oilfields are available as storage capacity which needs to be confirmed through field specific studies.

The hotspot number 4, the largest in the region, may be able to find storage capacity if offshore deep saline formation suitability is confirmed through geologic characterization. A group of hotspots 17 to 20 are interesting if onshore deep saline formation suitability is confirmed through geologic characterization.

The other hotspot might emerge as later on opportunities if the further characterization is carried out. Table 6 summarizes the proposed early opportunities which account for 19 percent of the region expected emissions from industry at about 35Mt/y of CO_2.

Table 6: Qualitative source sink matching on the CO_2 source for Latin America

hotspot number	**Early Opportunities**	
	number of sources	**annual emission (Mt/y CO_2)**
5	3	5
7	4	17
8	3	10
14	2	3
Total	**12**	**35**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in Latin America a competitive characterization should be initiated for the Oil and gas field and for the deep saline formation. In particular site specific studies must be performed to evaluate the storage capacity given the complex geological structure in the region. In addition, the benefits from CO_2-EOR must be carefully verified to ensure the opportunities for hotspots 10, 11, 12, 13. The transport network should also be of concern in some part of the region because of geographical constraints such as mountain ranges and urban areas (beyond the scope of the study).

A.1.4. Synthesis and recommendations for Latin America

The earliest opportunities are in Venezuela: hotspot 5 near Lake Maracaibo, hotspot 7 offshore Carupano and on-shore with hotspot 8 near Maturin.

Other storage possibilities in oilfields exist in Colombia, Equator or Peru which storage resources must be confirmed.

In the future, the competition for storage capacity is obvious not only with power industry but also with oil and gas production sectors given the location and geography of the region. Deep saline formations represent attractive alternatives but the storage resource must also be confirmed
Addition site specifics must be carried out for storage capacity and transport facilities assessment.

A.2. BRAZIL

The CO_2 emission reported for Brazil is illustrated in Figure 22. The industry sectors represent 74 percent of the country CO_2 emissions. The CO_2 emissions in Brazil are dominated by biomass sectors.

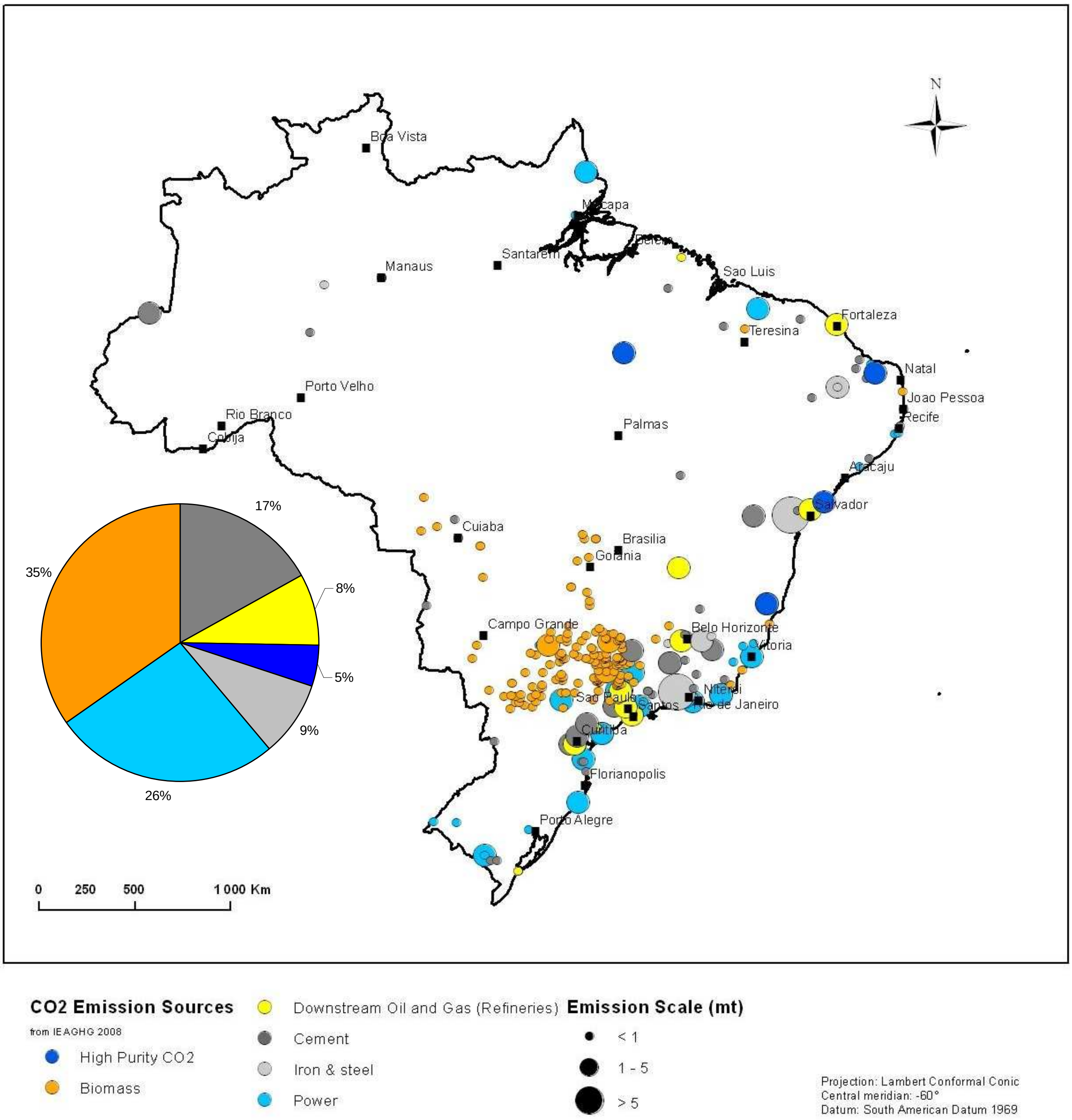


Figure 22: Annual CO_2 emissions in Brazil

A.2.1. Industrial CO_2 sources in Brazil

Emissions baseline (2007)

In Brazil, the main source of CO_2 emission is from Biomass with c.a. 35 percent of the country CO_2 emissions (Figure 22) while the power industry represents 26 percent of the country CO_2 emissions. The other sectors, i.e. cement and downstream oil and gas, represent respectively 17 and 8 percent of the country CO_2 emissions.

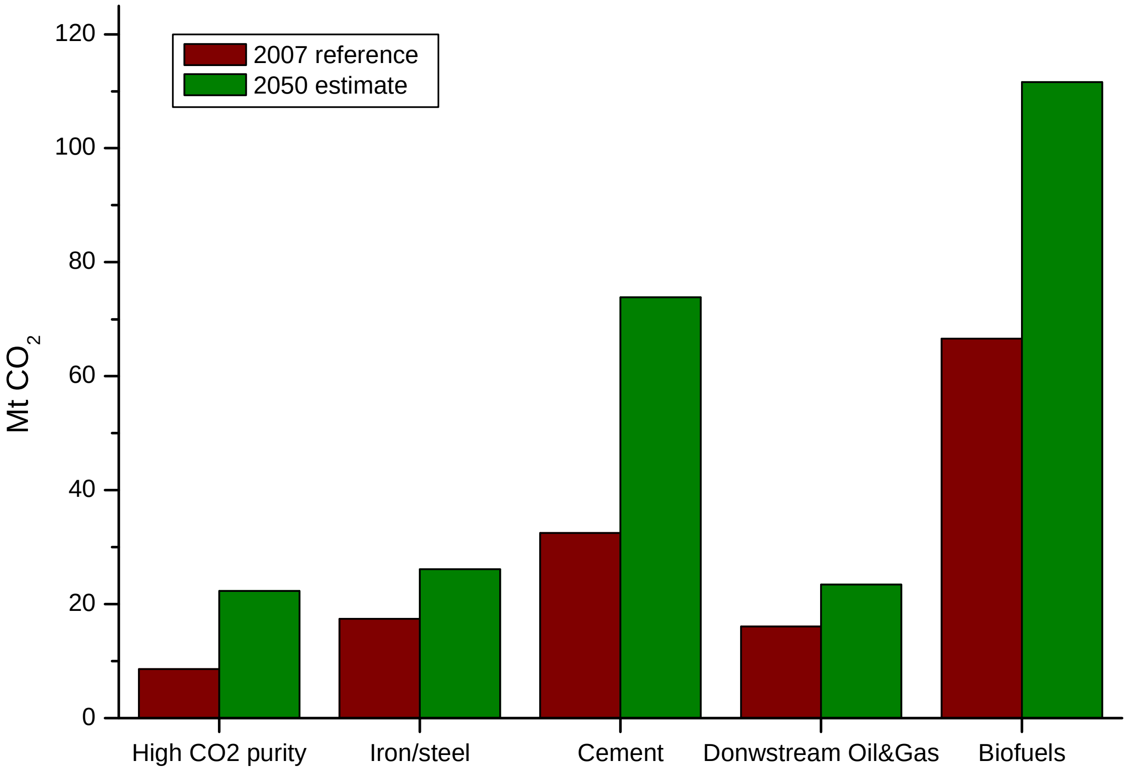


Figure 23: Annual CO_2 emissions and evolution for the industrial sectors in Brazil

Emissions evolution (by 2050)

At the 2050 horizon, the share of the different sectors will increase and the biofuel sector is expected to grow further to 43 percent of the country emissions from industry (see Figure 23). The cement sector is expected to grow significantly up to c.a. 74Mt/y CO_2. The CO_2 emissions from industry are expected to grow 82 percent from the 2007 level: from c.a. 140 to 260Mt/y CO_2.

A.2.2. CO_2 storage resources in Brazil

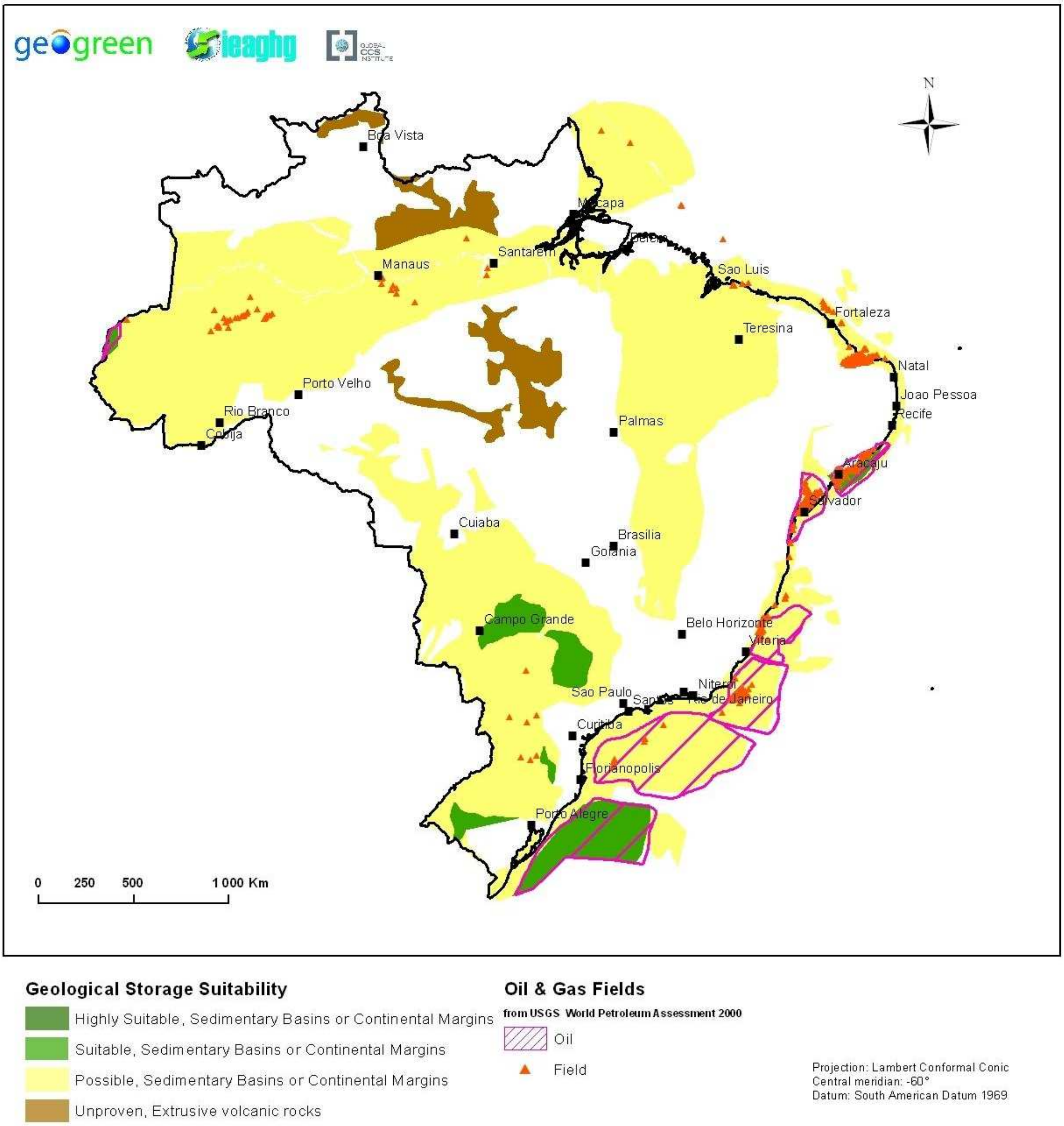


Figure 24: Storage resource in Brazil: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 7 or Figure 25). No highly suitable deep saline formation was identified even in recent work [20]. The suitable areas for storage resource are located onshore in the south eastern part of the county. However, when considering the early opportunities or even the opportunities, there is potentially enough suitable storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4).

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 25 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

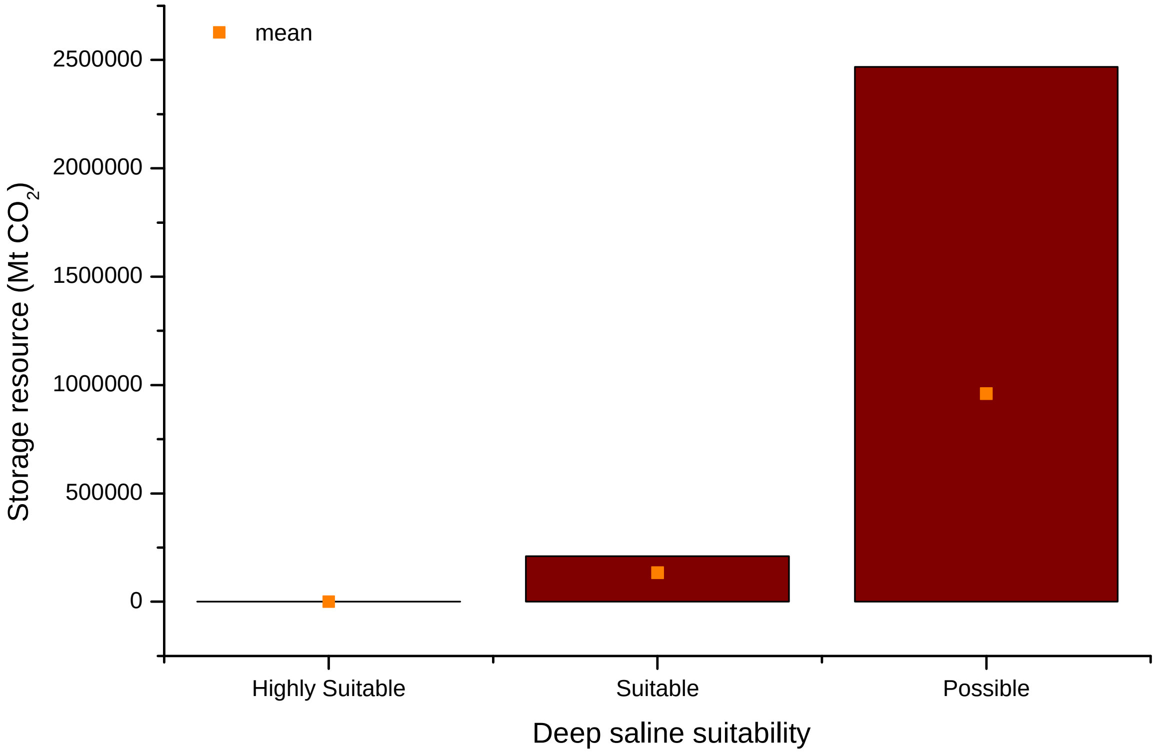


Figure 25: Estimated storage resources in deep saline formations in Brazil

Oil and gas fields

There are significant oil and gas fields onshore but mainly offshore in Brazil. The storage capacity in Oil and gas fields is significant. The main constraint is the availability of the fields for storage. Specific field level studies are required to firm up the storage capacity.

Table 7: Storage resource in oil and gas fields in Brazil

	Storage resource (Mt CO_2)
Oil fields	2700
Gas fields	12700
Total	**15400**

The estimated CO_2 storage potential from CO_2-EOR (Table 1) and the linear estimator do not include the presalt play offshore Brazil which could significantly improve the storage potential and CO_2-EOR potential. One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

It is noteworthy to mention that Presalt deep water oilfields are not taken into account.

A.2.3. Qualitative source-sink matching in Brazil

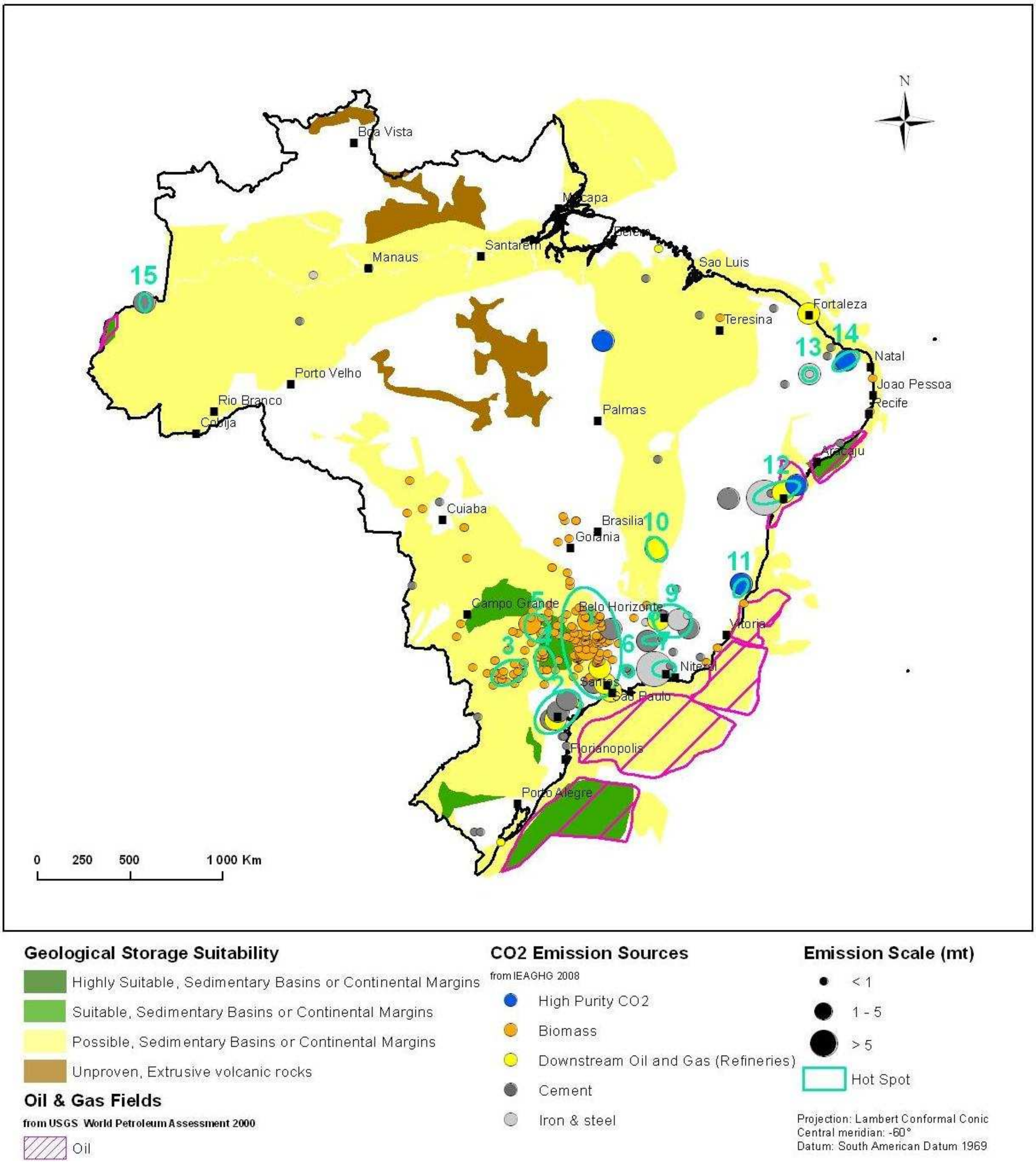


Figure 26: Storage suitability, annual CO_2 emissions and hotspots in Brazil

Table 8: Identified hotspots in Brazil

hotspot		Biomass		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	101	40.83	4	4.56	3	6.59	2	0.4	0	0.00	110	52.4
	2	0	0.00	5	6.62	2	2.10	0	0.0	0	0.00	7	8.7
	3	16	4.34	0	0.00	0	0.00	1	0.1	0	0.00	17	4.5
	4	10	3.86	0	0.00	0	0.00	0	0.0	0	0.00	10	3.9
	5	11	4.50	0	0.00	0	0.00	1	0.3	0	0.00	12	4.8
	6	0	0.00	4	2.31	0	0.00	0	0.0	0	0.00	4	2.3
	7	0	0.00	2	1.13	0	0.00	0	32.0	2	5.82	4	38.9
	8	0	0.00	3	3.25	0	0.00	0	0.0	0	0.00	3	3.3
	9	1	0.11	3	3.57	1	1.35	0	0.0	2	2.16	7	7.2
	10	0	0.00	0	0.00	1	1.69	0	0.0	0	0.00	1	1.7
	11	1	0.10	0	0.00	0	0.00	2	2.2	0	0.00	3	2.3
	12	0	0.00	1	0.16	1	2.73	2	2.7	1	5.43	5	11.1
	13	0	0.00	0	0.00	0	0.00	0	0.0	2	2.71	2	2.7
	14	0	0.00	1	0.90	0	0.00	1	2.4	0	0.00	2	3.3
	15	0	0.00	1	1.74	0	0.00	0	0.0	0	0.00	1	1.7
2050	1	101	68.39	4	10.37	3	9.63	2	0.97	0	0.00	110	89.3
	2	0	0.00	5	15.05	2	3.06	0	0.00	0	0.00	7	18.1
	3	16	7.28	0	0.00	0	0.00	1	0.29	0	0.00	17	7.6
	4	10	6.47	0	0.00	0	0.00	0	0.00	0	0.00	10	6.5
	5	11	7.53	0	0.00	0	0.00	1	0.67	0	0.00	12	8.2
	6	0	0.00	4	5.25	0	0.00	0	0.00	0	0.00	4	5.3
	7	0	0.00	2	2.56	0	0.00	0	82.83	2	8.72	4	94.1
	8	0	0.00	3	7.40	0	0.00	0	0.00	0	0.00	3	7.4
	9	1	0.19	3	8.11	1	1.97	0	0.00	2	3.24	7	13.5
	10	0	0.00	0	0.00	1	2.47	0	0.00	0	0.00	1	2.5
	11	1	0.18	0	0.00	0	0.00	2	5.66	0	0.00	3	5.8
	12	0	0.00	1	0.37	1	3.99	2	7.10	1	8.14	5	19.6
	13	0	0.00	0	0.00	0	0.00	0	0.00	2	4.07	2	4.1
	14	0	0.00	1	2.04	0	0.00	1	6.29	0	0.00	2	8.3
	15	0	0.00	1	3.95	0	0.00	0	0.00	0	0.00	1	3.9

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 15 hotspots (Figure 26) which represents 74 percent of the emissions of the industry sector in 2050. They involve all the industry sectors in the country (Figure 27). As illustrated in Figure 27 or Table 8, the hotspot number 1 is non-typical as it involves a large number of sources (101) emitting on average 0.5Mt/y CO2. There expected growth is highlighted in Figure 28. Besides the hotspot number 1, the number 7 and 12 are expected to grow significantly (Figure 28). Only 3 hotspots involved high purity CO2 sources, number 1, 3, 5.

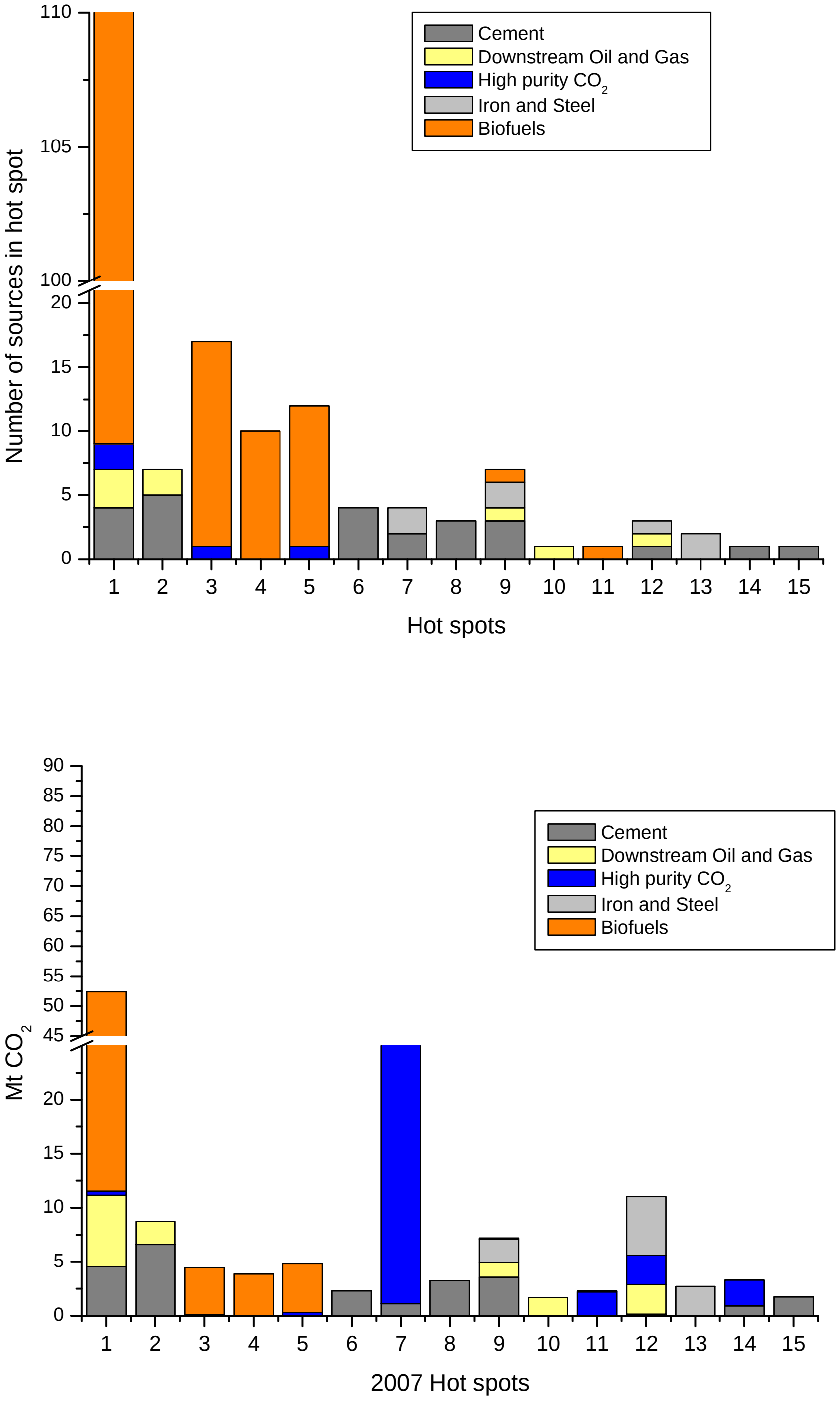
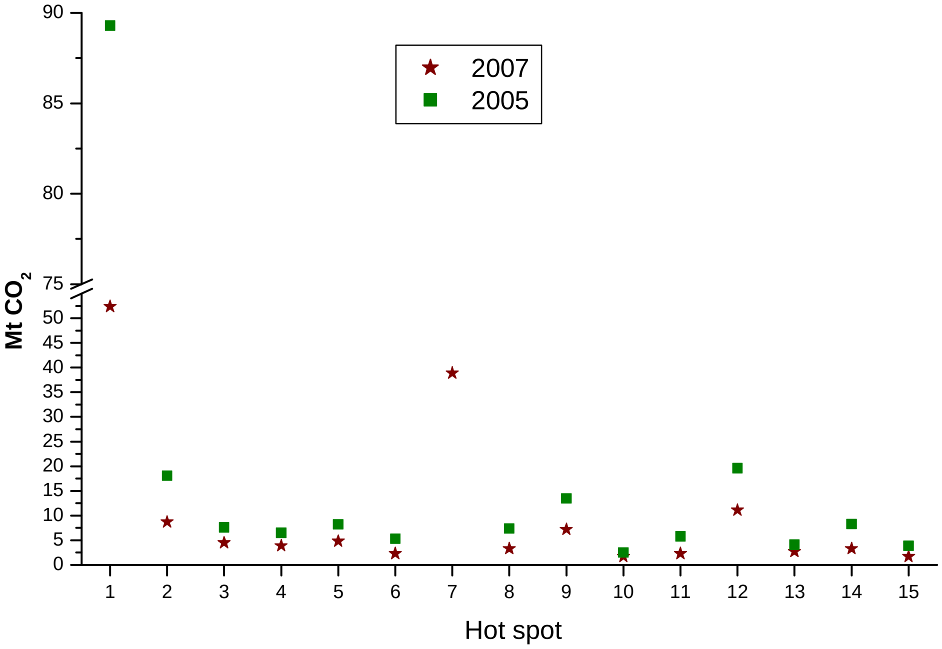


Figure 27: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Brazil



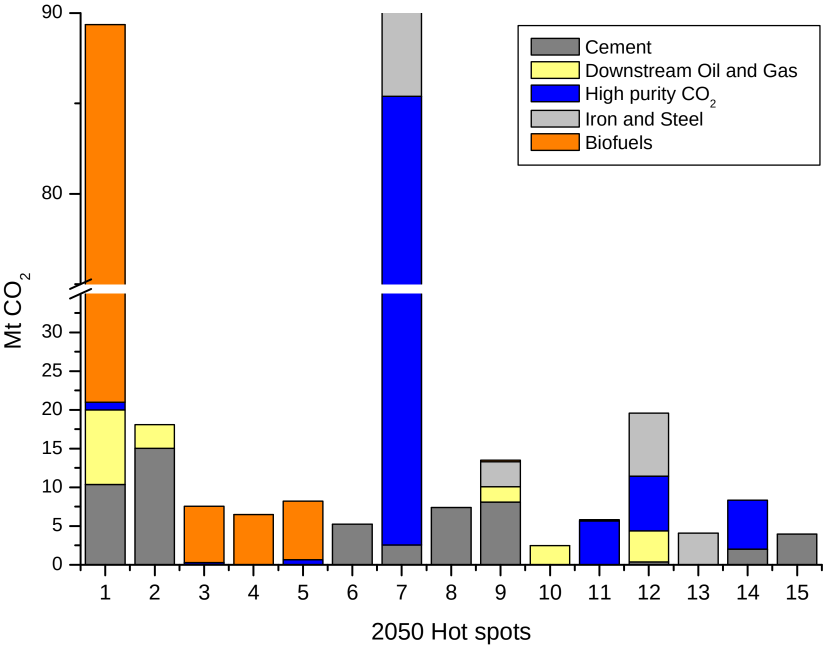


Figure 28: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Brazil

Early opportunities

The obvious large hotspot number 1 (Table 9), is over a suitable storage resource onshore and is an early opportunity for CCS as the source are from the biomass or high purity CO_2 sectors. Other early opportunities are with hotspot number 4 and 5 which may be targeting the same storage resource as number 1. Both hotspot 4 and 5 emits over 5Mt/y of CO_2 from about ten sources overwhelmingly from biomass.

A potentially interesting hotspot is number 12 (near Salvador) where CO_2-EOR is already taking place [18]. Further increase in CO_2 EOR may be considered if the transportation infrastructures are developed.

As most of the oil and gas fields are offshore (Figure 24), the coastal hotspot are opportunities for CCS deployment in particular hotspot numbered 2, 7, 10, 11 and 14 as long as the Offshore Deep saline formation suitability is confirmed through geologic characterization. Some significant offshore storage may be available in the offshore pre-salt play (upstream oil and gas processing) which is beyond the scope of the current study (focusing only on the downstream oil and gas sector).

The other hotspots might emerge as later on if the further characterization is carried out. Table 9 summarizes the proposed early opportunities which account for 48 percent of the country emissions from industry at about 123Mt/y of CO_2.

An interesting possibility may exist in the northwestern part of Brazil where hotspot 15, one large cement factory expected to emit over 1Mt/y of CO_2 in 2050 may use the onshore oilfield at the Brazilian western border.

Table 9: Qualitative source sink matching in 2050 on the CO_2 sources in Brazil

hotspot number	**Early Opportunity**	
	number of sources	annual emission (Mt/y CO_2)
1	110	89
4	10	6
5	12	8
12	5	20
Total	**137**	**123**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in Brazil for storage in deep saline formation, a competitive characterization should be initiated to confirm the storage capacity for the onshore formation. However, early opportunities may be either for onshore EOR or storage in depleted fields or with offshore storage in oilfields and presalt plays.

A.2.4. Synthesis and recommendations for Brazil

The earliest opportunity is the hotspot 12 (near Salvador) considering its future growth and location with respect to onshore or even offshore oilfields. Other interesting prospects (hotspots 1 4 and 5) exist north-west of Sao Paulo given the nature and scale of the source linked mainly to biomass sector.

Local opportunities may arise if CO_2 transportation and storage capacity/availability is confirmed at the north-western border of Brazil.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.

A.3. SOUTHEASTERN EUROPE

The CO_2 emissions reported for Southeastern Europe is illustrated in Figure 29. The industry sectors represent 29 percent of the region's CO_2 emissions.

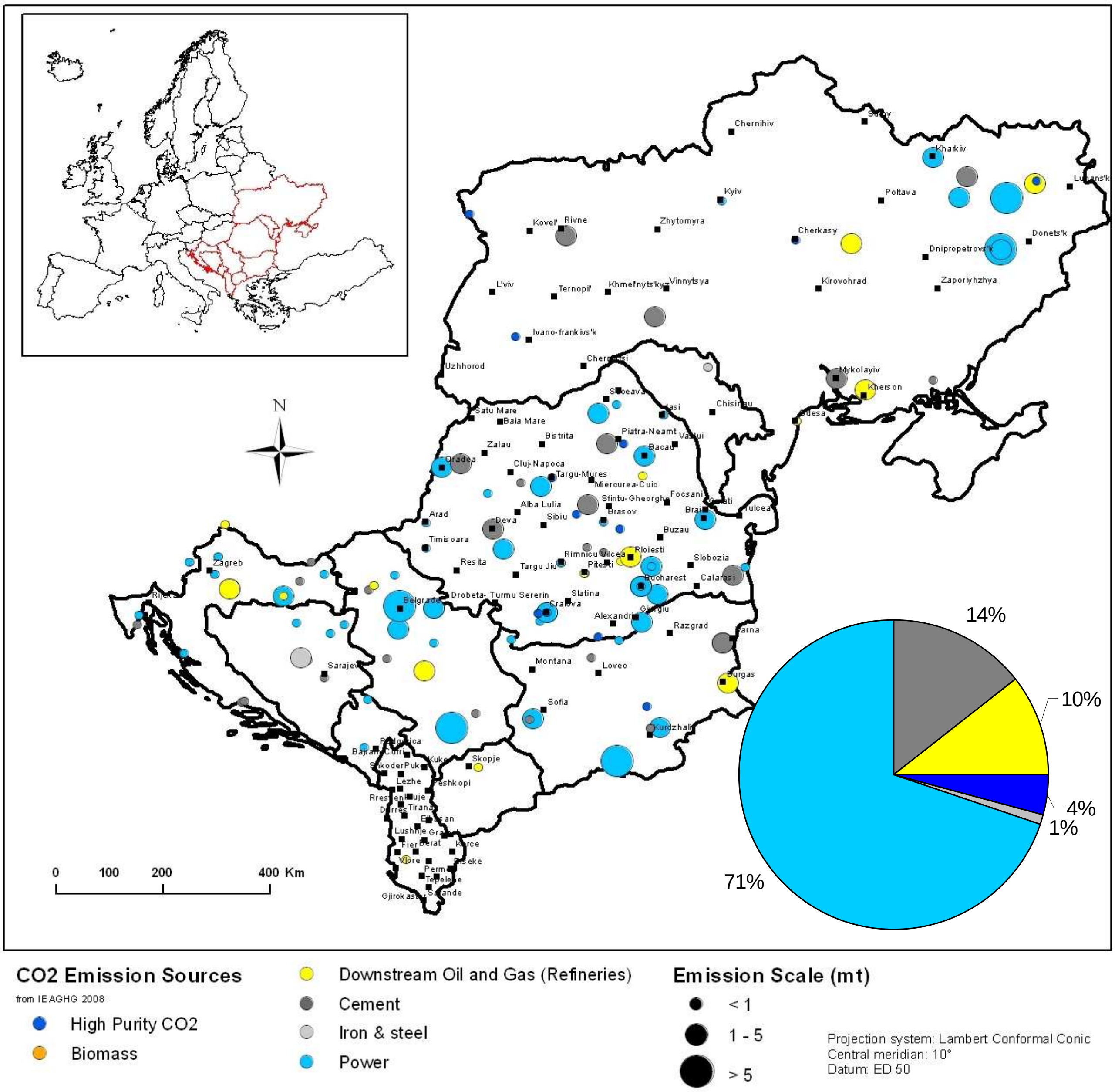


Figure 29: Annual CO_2 emissions in Southeastern Europe

A.3.1. Industrial CO_2 sources in Southeastern Europe

Emissions baseline (2007)

In Southeastern Europe, besides the power industry, the main source of CO_2 emissions is from the cement sector. The cement sector generates about 48 percent of the region emissions from industry, c.a. 26Mt/y CO_2 for the cement sector out of 55Mt/y CO_2 for the all industry sectors in 2007. No biofuel emissions are integrated in the data base for Southeastern Europe.

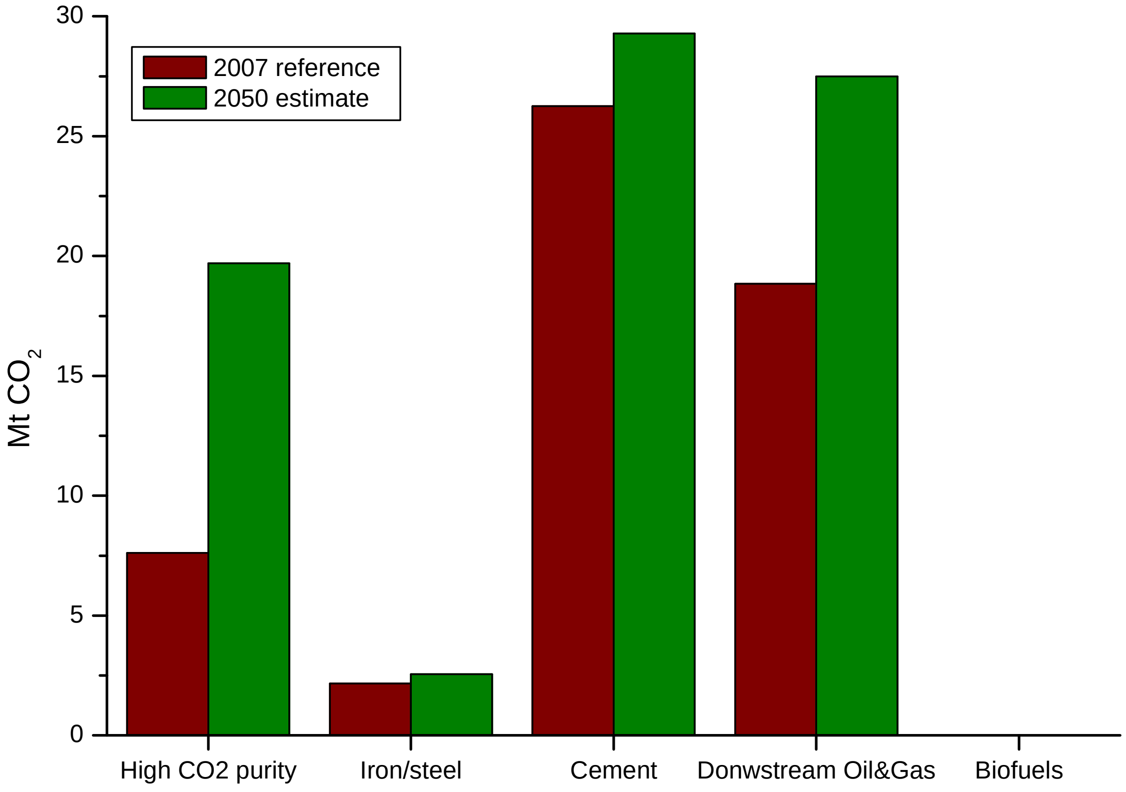


Figure 30: Annual CO_2 emissions and evolution for the industrial sectors in Southeastern Europe

Emissions evolution (by 2050)

At the 2050 horizon, the share of high CO_2 purity sector is expected to double but will represent 25 percent of the region emissions from industry (see Figure 30). The cement sector will however remain the largest CO_2 emitter closely followed by the Downstream Oil and Gas sector. The CO_2 emissions from industry are expected to grow 44 percent from the 2007 level: from c.a. 55 to 80Mt/y CO_2.

A.3.2. CO$_2$ storage resources in Southeastern Europe

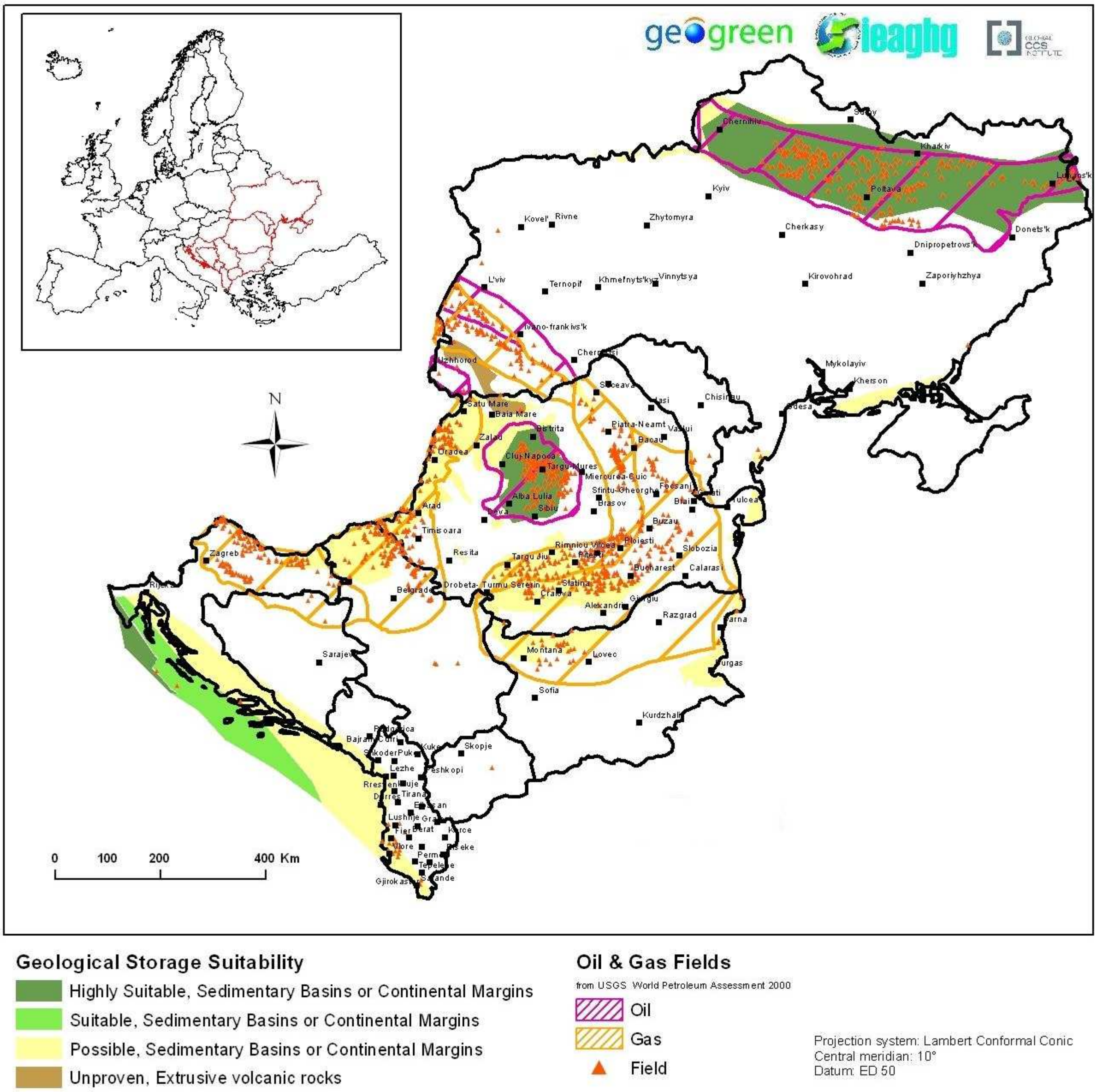


Figure 31: Storage resource in South–East Europe: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formations may be estimated (see Figure 32). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4). Note that competition for storage resource is likely.

One shall note that the deep saline formation storage resource estimates are associated with large uncertainties as illustrated by the bar in Figure 32 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

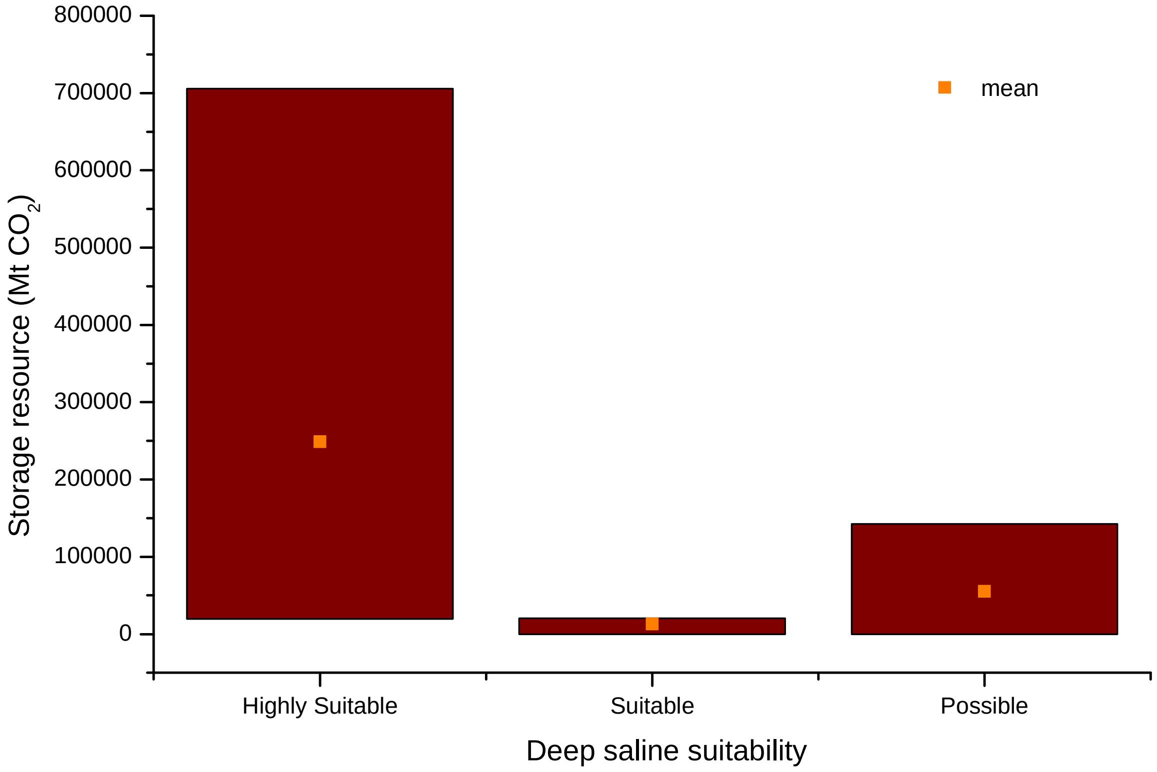


Figure 32: Estimated storage resources in deep saline formations in Southeastern Europe

Oil and gas fields

Large storage resources may be identified onshore in the Eastern part of the region. The main storage resource is estimated to be in the gas field. The storage capacity in oilfields is modest, 575Mt of CO_2. The main constraint is the availability of the fields for storage given the long oil production of some part of the region, e.g. Romania, Ukraine or Croatia. Specific field level studies are required to firm up the storage capacity.

Table 10 Storage resource in oil and gas fields in Southeastern Europe

	Storage resource (Mt CO_2)
Oil fields	575
Gas fields	12260
Total	12835

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.3.3. Qualitative source-sink matching in Southeastern Europe

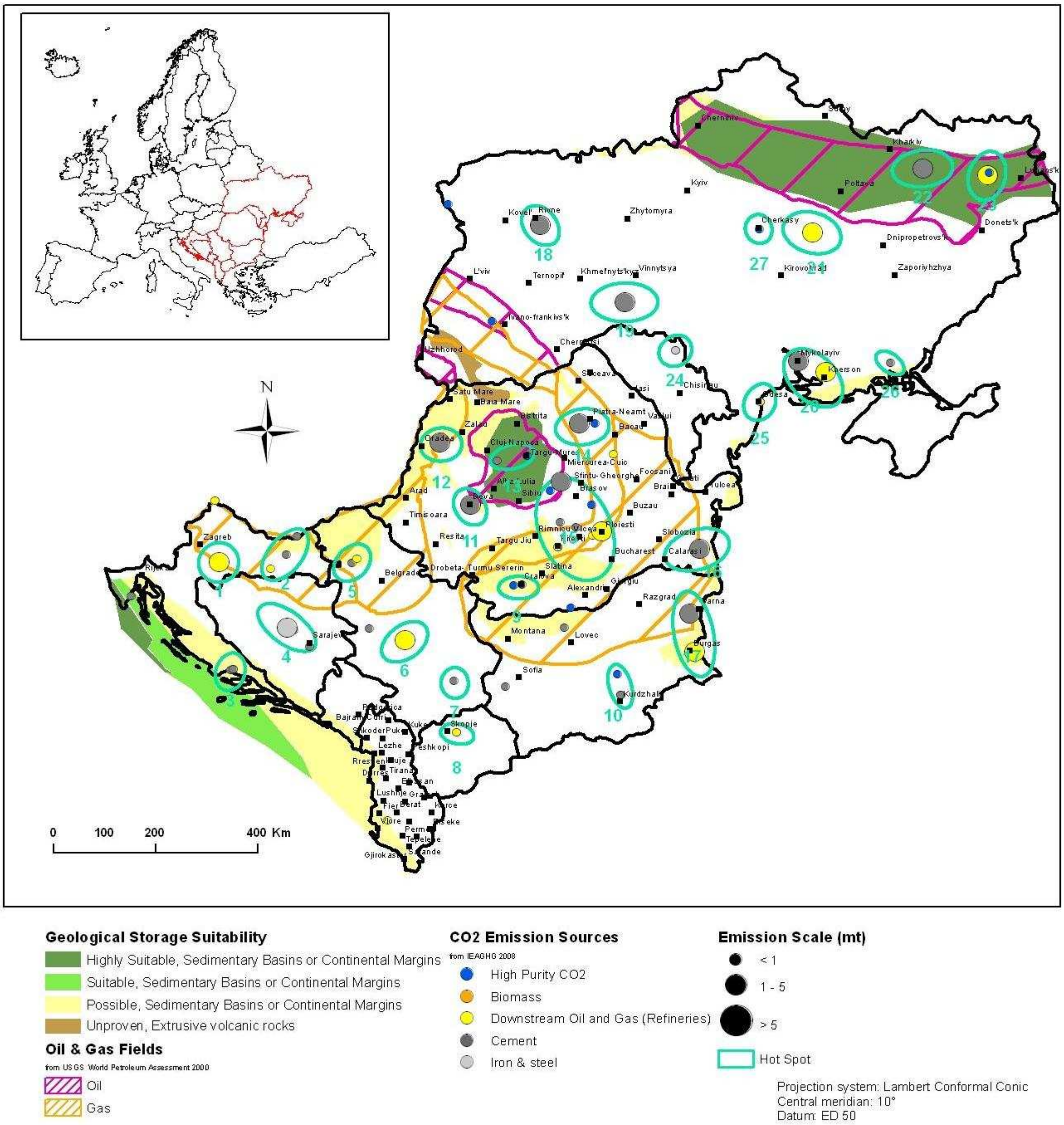


Figure 33: Storage suitability, annual CO_2 emissions and hotspots in Southeastern Europe

Table 11: Identified hotspots in Southeastern Europe

hotspot		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	0	0.00	1	1.38	0	0.0	1	n.a.	2	1.4
	2	2	0.93	1	0.88	0	0.0	0	0.00	3	1.8
	3	3	1.19	0	0.00	0	0.0	1	n.a.	4	1.2
	4	2	0.47	0	0.00	0	0.0	1	2.04	3	2.5
	5	1	0.86	1	0.58	0	0.0	0	0.00	2	1.4
	6	0	0.00	1	1.03	0	0.0	0	0.00	1	1.0
	7	1	0.79	0	0.00	0	0.0	0	0.00	1	0.8
	8	1	0.43	1	0.49	0	0.0	2	n.a.	4	0.9
	9	0	0.00	0	0.00	2	0.8	0	0.00	2	0.8
	10	1	0.31	0	0.00	2	0.7	0	0.00	3	1.0
	11	1	1.06	0	0.00	0	0.0	2	n.a.	3	1.1
	12	1	1.51	0	0.00	0	0.0	0	0.00	1	1.5
	13	1	0.55	0	0.00	1	0.7	1	n.a.	3	1.2
	14	1	1.08	0	0.00	1	0.4	0	0.00	2	1.4
	15	3	2.77	5	2.61	4	1.5	0	0.00	12	6.9
	16	1	1.41	0	0.00	0	0.0	0	0.00	1	1.4
	17	1	1.48	1	1.11	1	0.9	0	0.00	3	3.5
	18	1	1.46	0	0.00	0	0.0	0	0.00	1	1.5
	19	1	2.55	0	0.00	0	0.0	0	0.00	1	2.5
	20	1	2.19	1	2.27	0	0.0	0	0.00	2	4.5
	21	0	0.00	1	3.48	0	0.0	0	0.00	1	3.5
	22	1	2.50	0	0.00	0	0.0	0	0.00	1	2.5
	23	0	0.00	1	3.08	2	0.9	0	0.00	3	4.0
	24	1	0.61	0	0.00	0	0.0	1	0.12	2	0.7
	25	1	0.22	1	0.75	0	0.0	0	0.00	2	1.0
	26	1	0.64	0	0.00	0	0.0	0	0.00	1	0.6
2050	1	0	0.00	1	2.02	0	0.00	1	n.a.	2	2.0
	2	2	1.04	1	1.29	0	0.00	0	0.00	3	2.3
	3	3	1.32	0	0.00	0	0.00	1	n.a.	4	1.3
	4	2	0.52	0	0.00	0	0.00	1	2.41	3	2.9
	5	1	0.96	1	0.85	0	0.00	0	0.00	2	1.8
	6	0	0.00	1	1.50	0	0.00	0	0.00	1	1.5
	7	1	0.88	0	0.00	0	0.00	0	0.00	1	0.9
	8	1	0.48	1	0.72	0	0.00	2	n.a.	4	1.2
	9	0	0.00	0	0.00	2	1.95	0	0.00	2	1.9
	10	1	0.35	0	0.00	2	1.72	0	0.00	3	2.1
	11	1	1.18	0	0.00	0	0.00	2	n.a.	3	1.2
	12	1	1.68	0	0.00	0	0.00	0	0.00	1	1.7
	13	1	0.61	0	0.00	1	1.70	1	n.a.	3	2.3
	14	1	1.21	0	0.00	1	0.93	0	0.00	2	2.1
	15	3	3.09	5	3.81	4	3.93	0	0.00	12	10.8
	16	1	1.57	0	0.00	0	0.00	0	0.00	1	1.6
	17	1	1.66	1	1.62	1	2.37	0	0.00	3	5.6

	18	1	1.63	0	0.00	0	0.00	0	0.00	1	1.6
	19	1	2.84	0	0.00	0	0.00	0	0.00	1	2.8
	20	1	2.44	1	3.32	0	0.00	0	0.00	2	5.8
	21	0	0.00	1	5.08	0	0.00	0	0.00	1	5.1
	22	1	2.79	0	0.00	0	0.00	0	0.00	1	2.8
	23	0	0.00	1	4.50	2	2.45	0	0.00	3	7.0
	24	1	0.68	0	0.00	0	0.00	1	0.15	2	0.8
	25	1	0.24	1	1.10	0	0.00	0	0.00	2	1.3
	26	1	0.72	0	0.00	0	0.00	0	0.00	1	0.7
	27	0	0.00	0	0.00	1	1.61	0	0.00	1	1.6

Source: 2007 emissions from IEAGHG
n.a. = not available

Hotspots

Most of the largest sources may be grouped into 27 hotspots (Figure 33 or Table 11) which represent 92 percent of the emissions of the industry sector. They involve all the industry sectors in the region (Figure 34). Their expected growth between 2007 and 2050 is highlighted in Figure 35. The numbers 15 and 17 are expected to grow significantly (Figure 35).

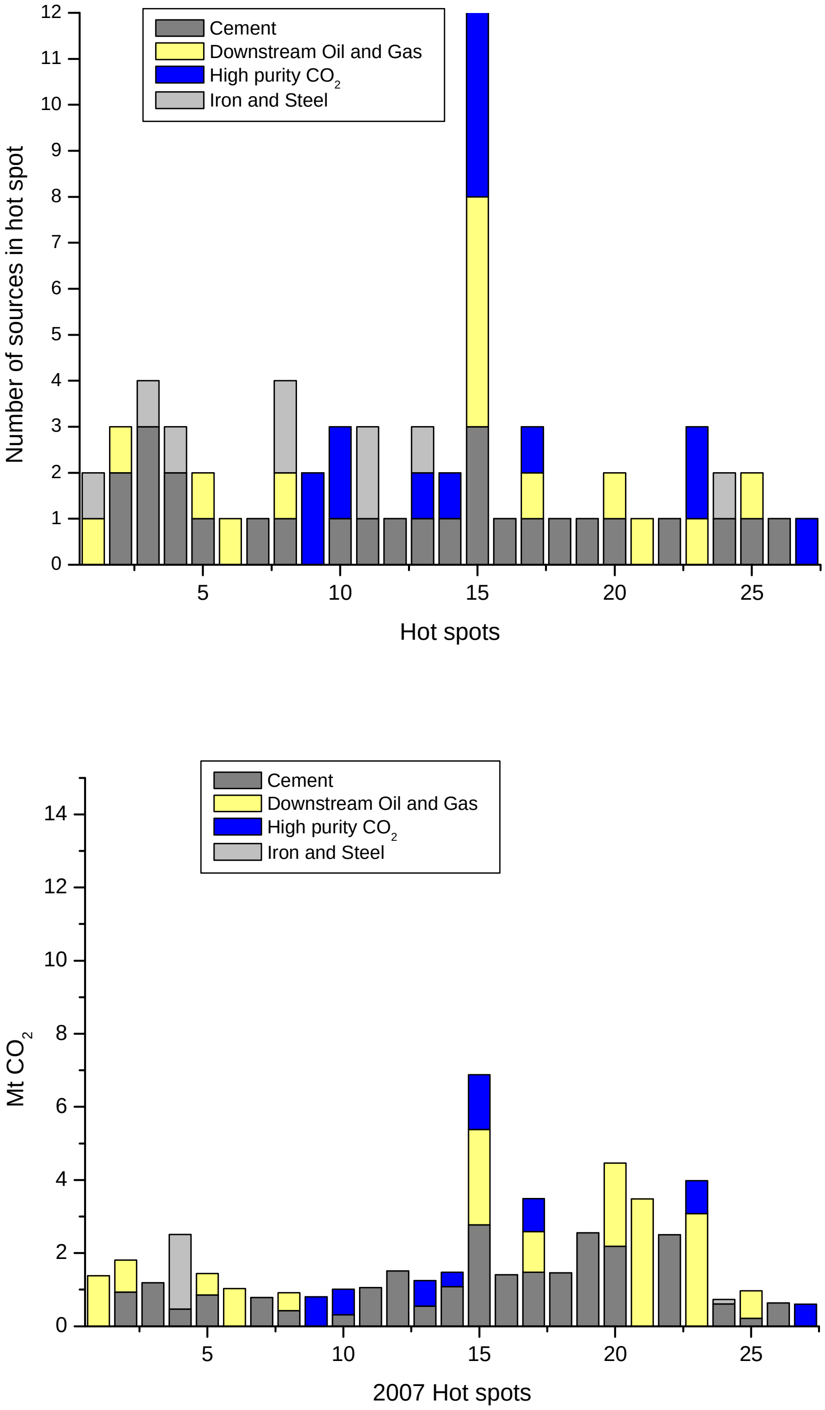


Figure 34: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Southeastern Europe

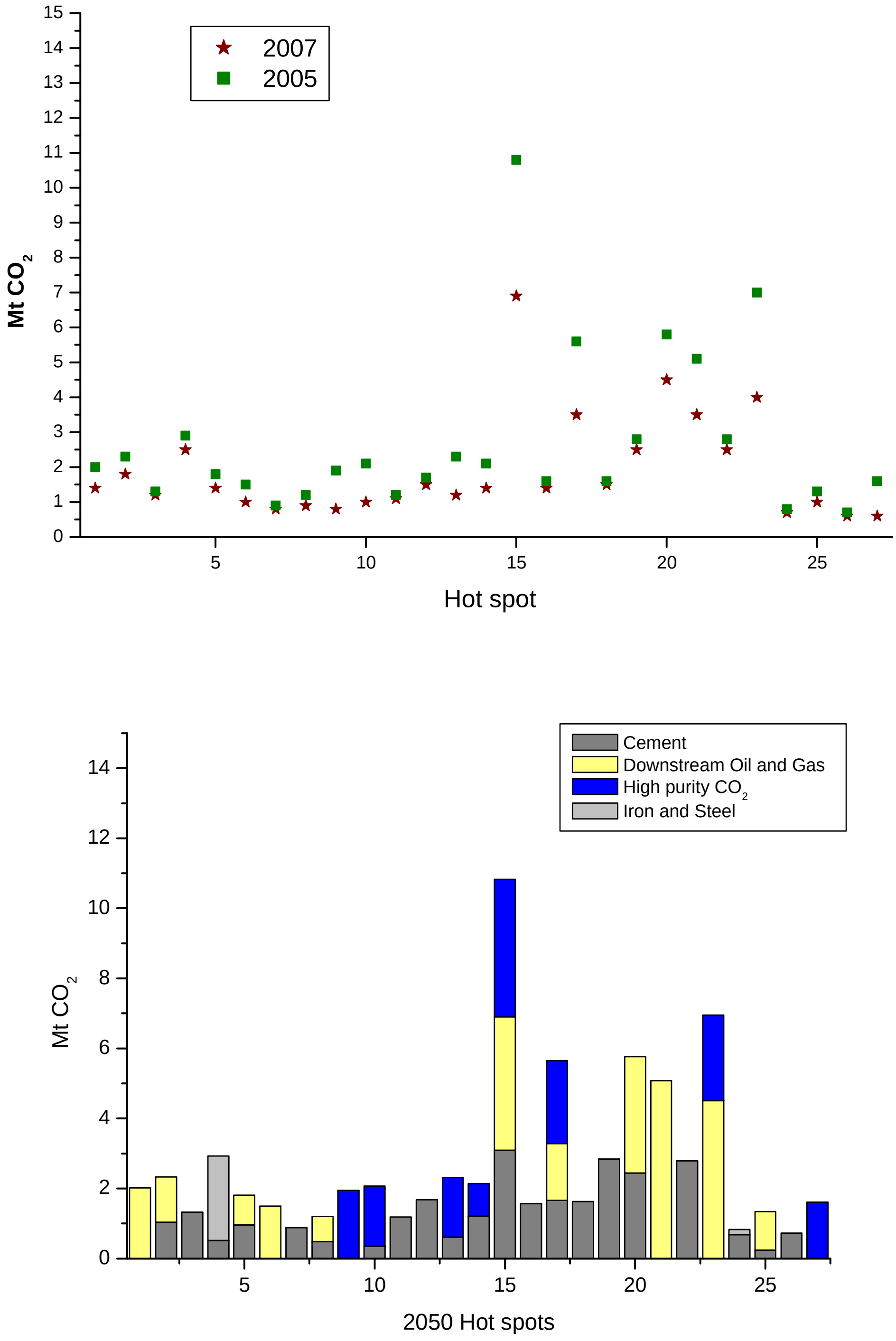


Figure 35: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Southeastern Europe

Early opportunities

As most of the highly suitable storage is onshore (Figure 33), the only early opportunity offshore is hotspot number 3 but its storage resource in deep saline formation suitability need to be confirmed through geologic characterization. Most of the early opportunities will be in gas fields except for hotspot number 13 which will be in oilfields. Specific field level studies are required to firm up the storage capacity.

Table 12 summarizes the proposed early opportunities in 2050 which account for 34 percent of the region emissions from industry at about 30Mt/y of CO_2.

Table 12: Qualitative source sink matching on the CO_2 sources in 2050 in Southeastern Europe

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
2	3	2
3	4	1
5	2	2
13	3	2
14	2	2
15	12	11
22	1	3
23	3	7
Total	**30**	**30**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in Southeastern Europe, a competitive characterization should be initiated for the Oil and gas field but more importantly for the deep saline formation. The storage capacity of the oil and gas fields needs to be confirmed by site specific studies if the fields are available.

A.3.4. Synthesis and recommendations for Southeastern Europe

The earliest opportunity is the hotspot 3 (near Tague Mures) considering its location with respect to on-shore highly suitable storage, oilfields. To enable the early opportunity in the central part of Romania a transport network and a competitive characterization for the deep saline formations should be initiated. On the other hand, several opportunities exist in Northern Croatia, hotspot 2 and 5 for storage in gas fields. Additional early opportunities exit in Northwestern Ukraine, south-east of Kharkov and close to Chuhuiv.

However, competition for storage capacity is likely in the future given the location and share of CO_2 emissions from the power industry.

A.4. CENTRAL ASIA

The CO_2 emissions reported for Central Asia is illustrated in Figure 36. The industry sectors represent 24 percent of the region CO_2 emissions.

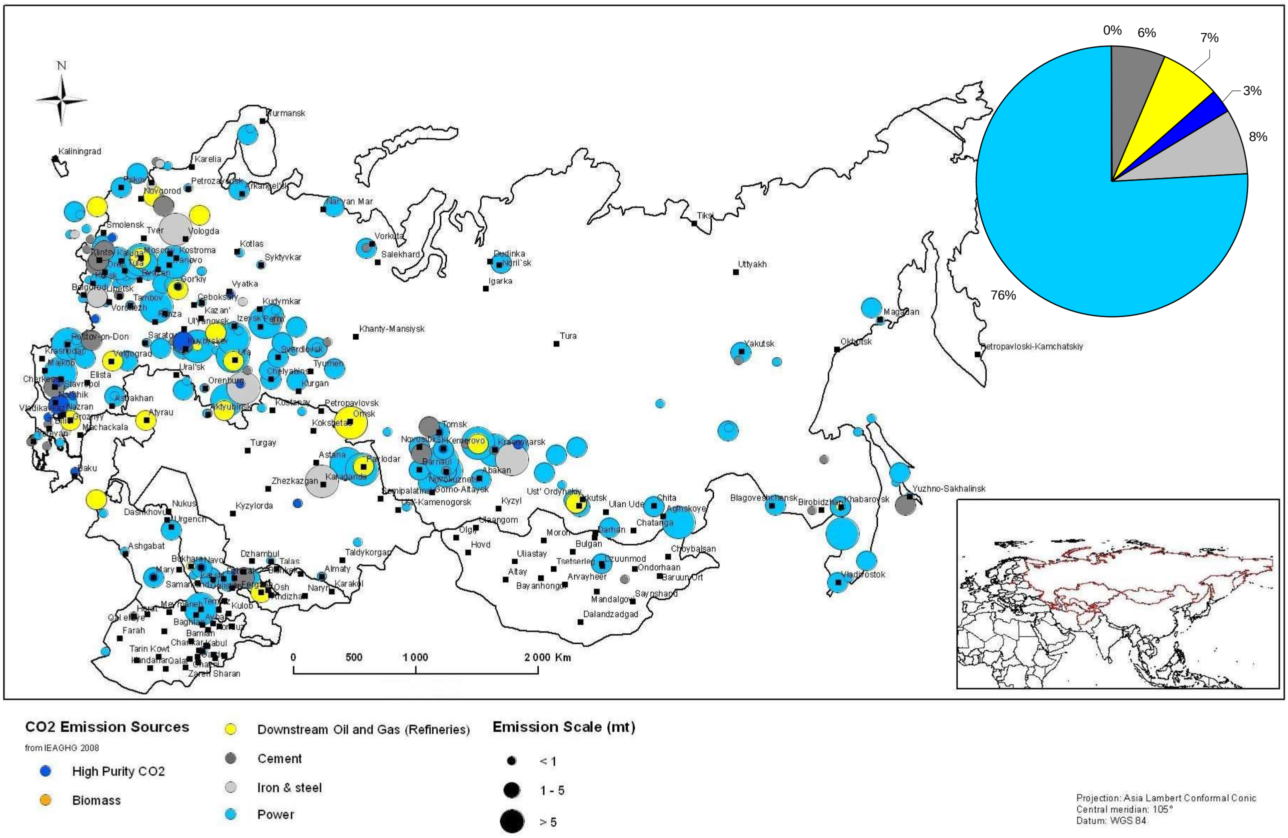


Figure 36: Annual CO_2 emissions in Central Asia

A.4.1. Industrial CO_2 sources in Central Asia

Emissions baseline (2007)

In Central Asia, besides the power industry, the three industrial sectors have about the same CO_2 emissions: downstream oil and gas, cement and Iron & Steel. The downstream oil and gas sector generates about 29 percent of the region emissions from industry, c.a. 43Mt/y CO_2 for the downstream oil and gas sector, 39Mt/y CO_2 for the cement sector and 48Mt/y CO_2 for the iron and steel sector out of 147Mt/y CO_2 for the all industry sectors in 2007. No biofuel emission is integrated in the data base for Central Asia.

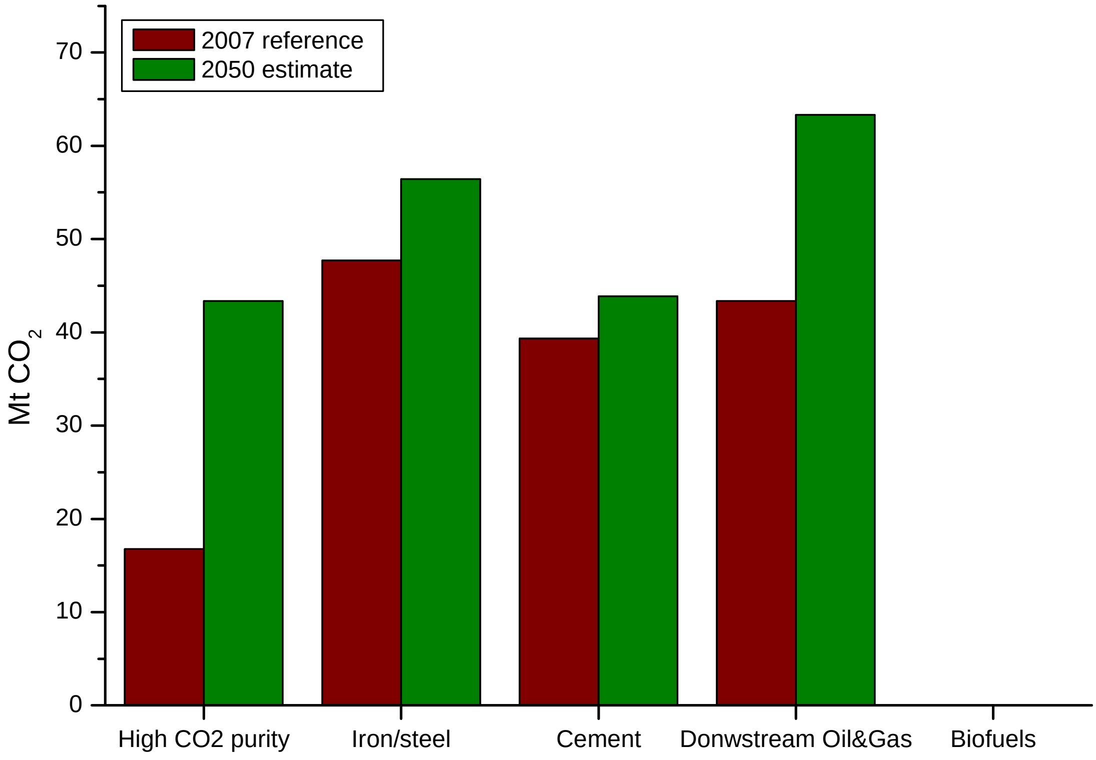


Figure 37: Annual CO_2 emissions and evolution for the industrial sectors in Central Asia

Emissions evolution (by 2050)

At the 2050 horizon, the share of downstream oil and gas sector is expected to remain constant at about 31 percent of the region emissions from industry (see Figure 37). However, the CO_2 emissions from the downstream oil and gas sector will increase from 43 to 63Mt/y CO_2. The other two sectors, cement and Iron & Steel, will progress on similar trends. However, the high purity CO_2 sector is expected to more than double from c.a. 17 to 43Mt/y CO_2.

The CO_2 emissions from industry are expected to grow 41 percent from the 2007 level: from c.a. 147 to 207Mt/y CO_2.

A.4.2. CO$_2$ storage resources in Central Asia

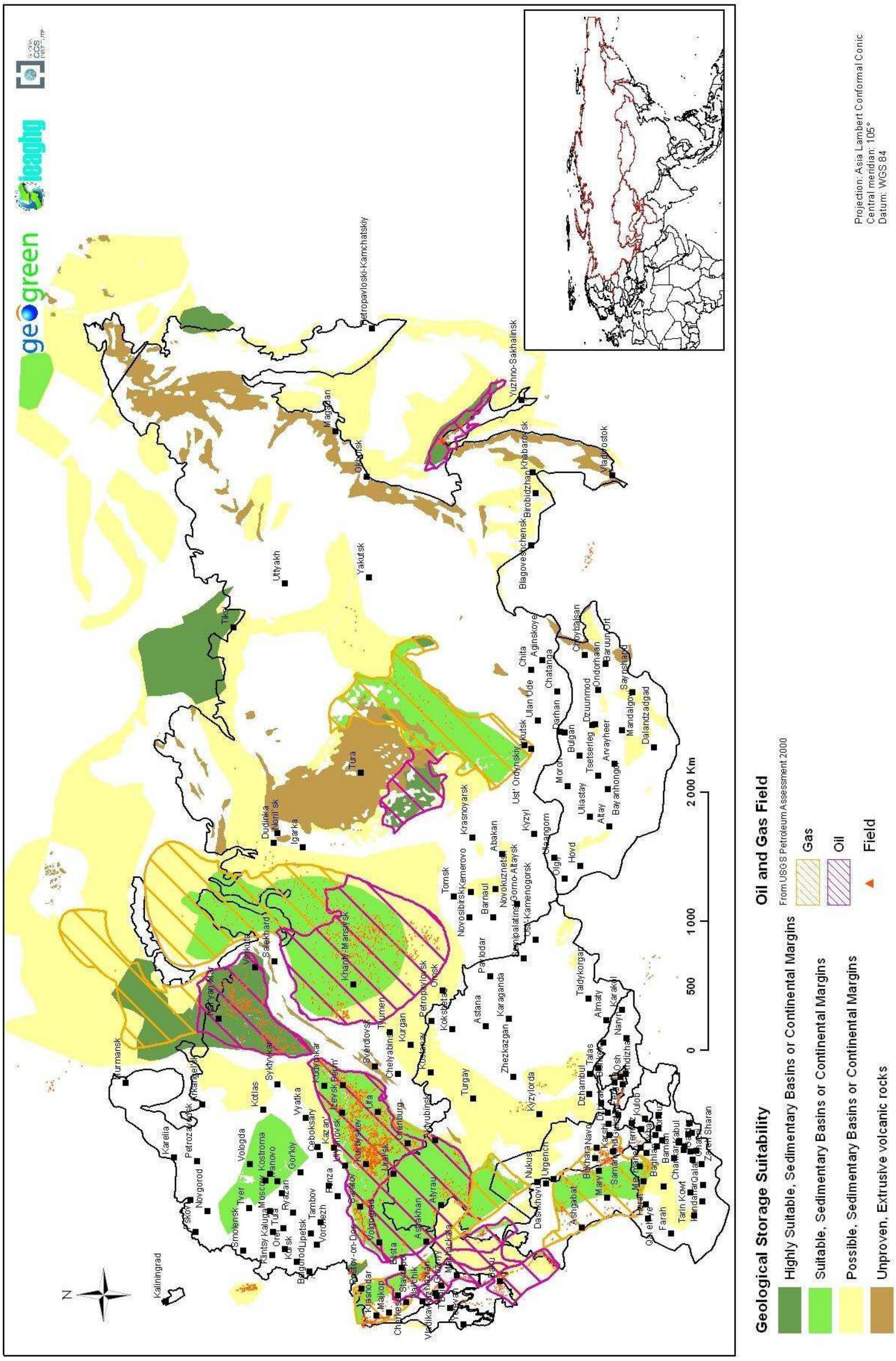


Figure 38: Storage resource in Central Asia: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 39). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (see Figure 4). Note that competition for storage resource is likely.

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 39 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

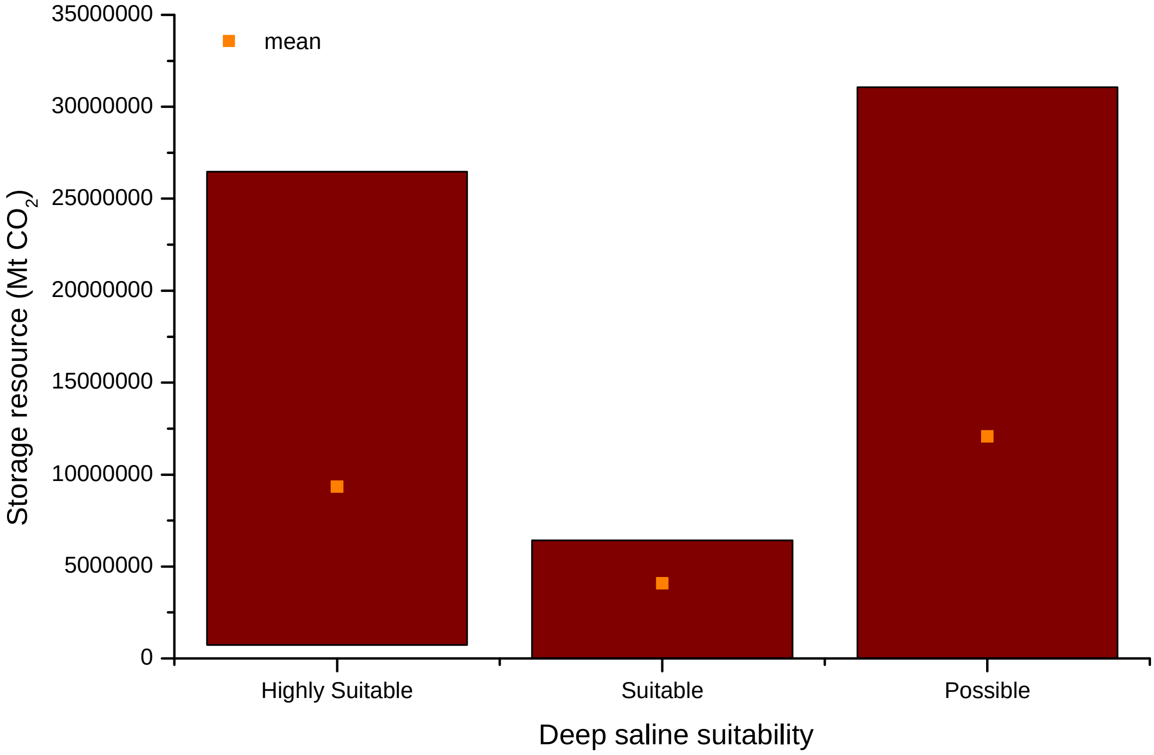


Figure 39: Estimated storage resources in deep saline formations in Central Asia

Oil and gas fields

Storage resource may be identified onshore and offshore (Northern and Eastern Siberia). The main storage resource is estimated to be in the gas fields. The storage capacity in oilfields is very large as well, c.a. 8100Mt of CO_2 (see Table 13). The main constraint is the availability of the fields for storage given the long oil production of some part of the region, e.g. Georgia, Azerbaijan or Russia. Specific field level studies are required to firm up the storage capacity.

Table 13: Storage resource in oil and gas fields in Central Asia

Storage resource (Mt CO_2)	
Oil fields	8110
Gas fields	272100
Total	**280210**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.4.3. Qualitative source-sink matching in Central Asia

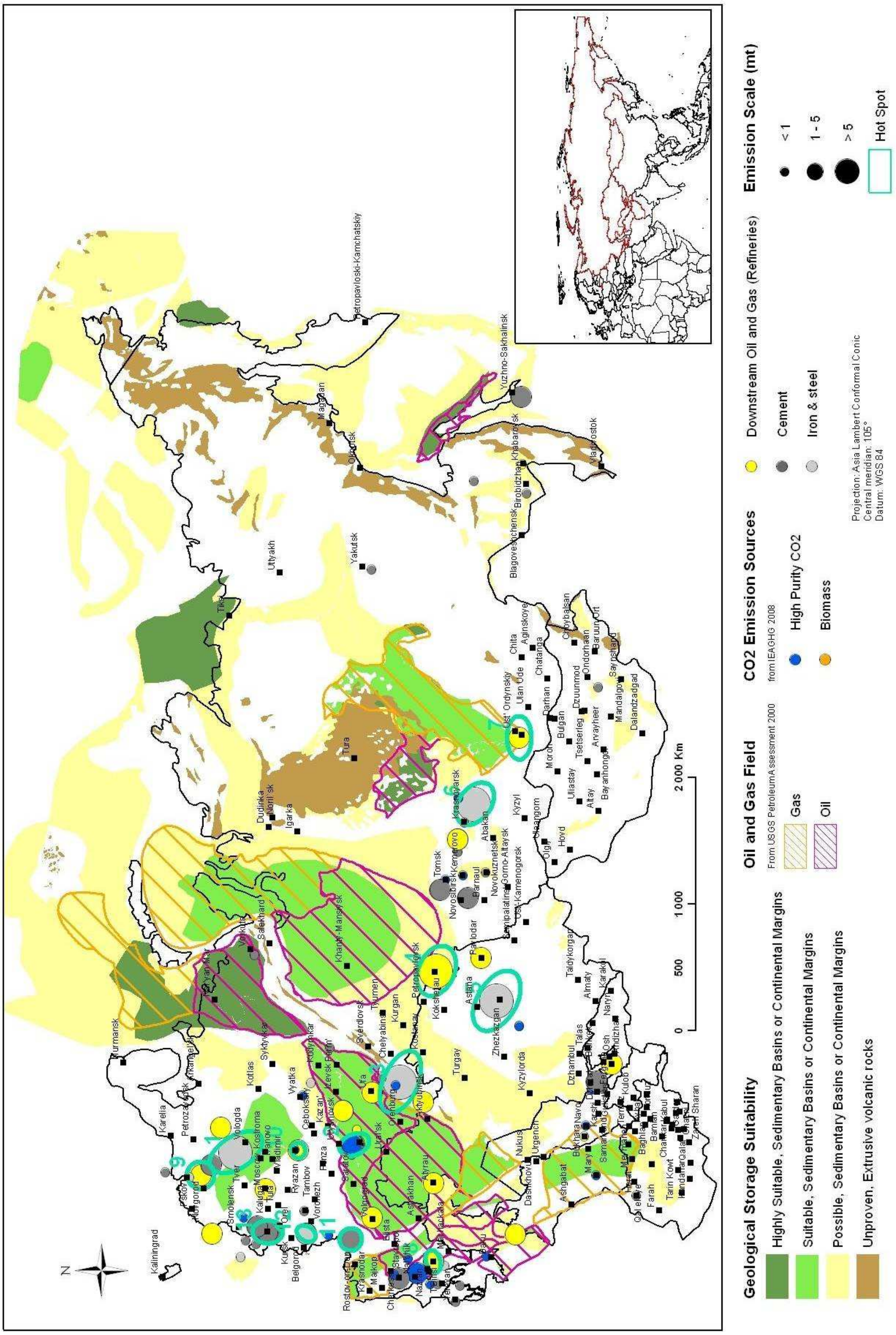


Figure 40: Storage suitability, annual CO_2 emissions and hotspots in Central Asia

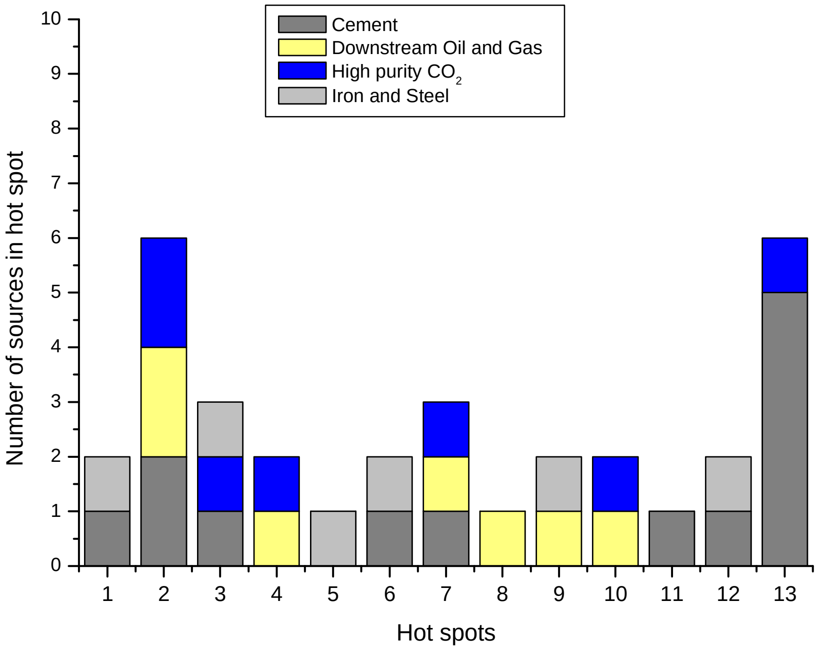
Table 14: Identified hotspots in Central Asia

hotspot		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	1	2.99	0	0.00	0	0.00	1	12.33	2	15.3
	2	2	1.76	2	1.52	2	2.18	0	0.00	6	5.5
	3	1	0.59	0	0.00	1	0.91	1	19.79	3	21.3
	4	0	0.00	1	5.46	1	0.32	0	0.00	2	5.8
	5	0	0.00	0	0.00	0	0.00	1	7.12	1	7.1
	6	1	0.93	0	0.00	0	0.00	1	5.09	2	6.0
	7	1	0.96	1	4.25	1	0.77	0	0.00	3	6.0
	8	0	0.00	1	3.75	0	0.00	0	0.00	1	3.8
	9	0	0.00	1	3.73	0	0.00	1	0.34	2	4.1
	10	0	0.00	1	4.22	1	0.69	0	0.00	2	4.9
	11	1	1.91	0	0.00	0	0.00	0	0.00	1	1.9
	12	1	2.58	0	0.00	0	0.00	1	2.04	2	4.6
	13	5	6.64	0	0.00	1	0.22	0	0.00	6	6.9
2050	1	1	3.33	0	0.00	0	0.00	1	14.58	2	17.9
	2	2	1.97	2	2.22	2	5.63	0	0.00	6	9.8
	3	1	0.65	0	0.00	1	2.37	1	23.41	3	26.4
	4	0	0.00	1	7.96	1	0.83	0	0.00	2	8.8
	5	0	0.00	0	0.00	0	0.00	1	8.43	1	8.4
	6	1	1.03	0	0.00	0	0.00	1	6.02	2	7.1
	7	1	1.07	1	6.20	1	1.98	0	0.00	3	9.2
	8	0	0.00	1	5.48	0	0.00	0	0.00	1	5.5
	9	0	0.00	1	5.45	0	0.00	1	0.40	2	5.9
	10	0	0.00	1	6.16	1	1.77	0	0.00	2	7.9
	11	1	2.13	0	0.00	0	0.00	0	0.00	1	2.1
	12	1	2.88	0	0.00	0	0.00	1	2.41	2	5.3
	13	5	7.41	0	0.00	1	0.57	0	0.00	6	8.0

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 13 hotspots (Figure 40 or Table 14) which represent 59 percent of the emissions of the industry sector. These hotspot are mainly located in the western part of the region. They involve all the industry sectors in the region (Figure 41). There expected growth is highlighted in Figure 42. The number 2, 3 and 7 are expected to grow significantly (Figure 42). Each of the hotspot identified is expected to emit more than 2Mt/y CO_2 in 2050 (Figure 42).



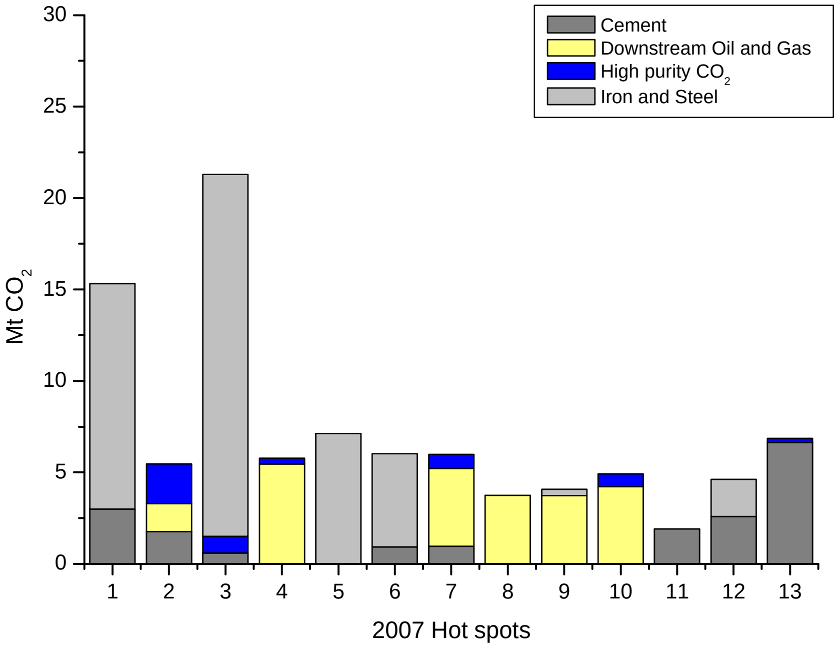
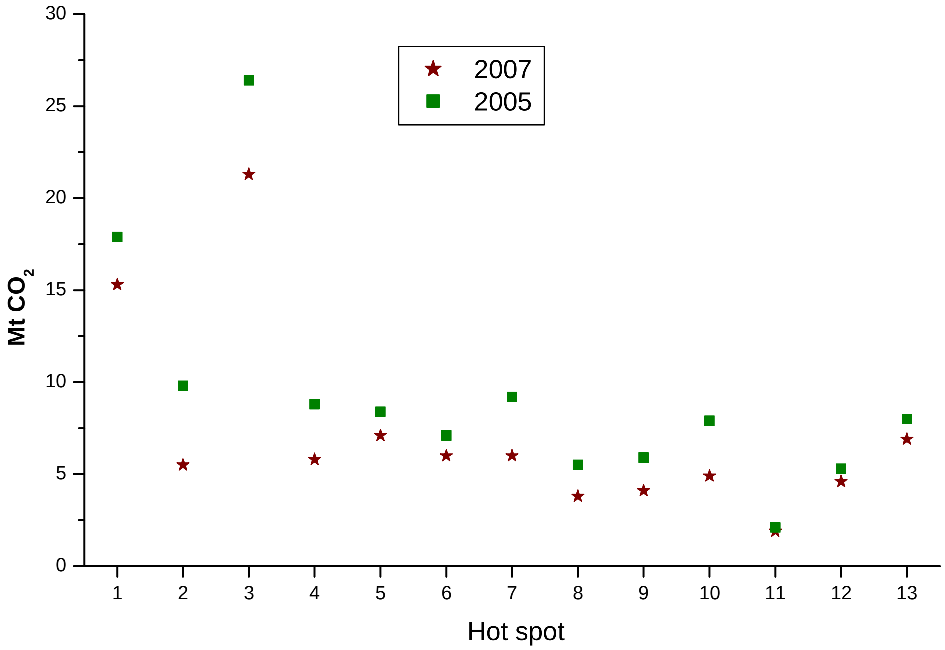


Figure 41: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Central Asia



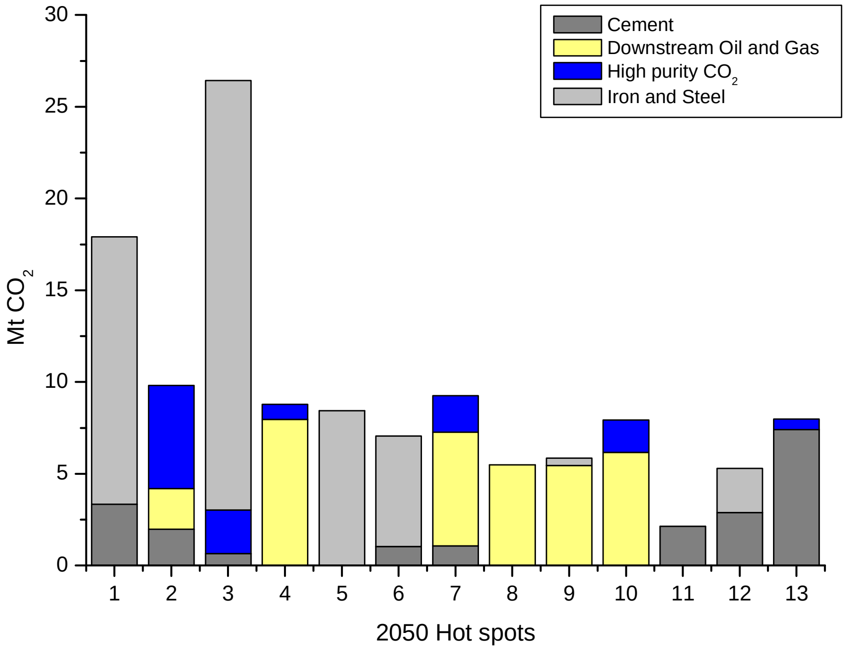


Figure 42: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Central Asia

Early opportunities

As most of the highly suitable storage is onshore (Figure 38), the industrial centers located nearby are primary candidate for the early opportunities for CCS deployment in particular hotspots numbered 1, 2, 3, 7, 8 and 10. All of these hotspot will have significant high purity CO_2 sector in 2050. They target both highly suitable storage resource (Figure 40) and oilfields. The deep saline formation storage resource must be confirmed through geologic characterization to ensure storage capacity. The other hotspots might emerge is number 4 in Kazakhstan, at the border with Russia which is near the Russian oilfields but cross-border transport of CO_2 may be a pitfall. Table 15 summarizes the proposed early opportunities which account for 38 percent of the region emissions from industry at about 79Mt/y of CO_2 in 2050.

Table 15: Qualitative source sink matching on the CO_2 sources in Central Asia

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
1	2	18
2	6	10
3	3	26
7	3	9
8	1	6
10	2	8
11	1	2
Total	**18**	**79**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in Central Asia a competitive characterization should be initiated for the oil and gas field. However, access to storage resource may be facing competition from oil and gas production.

A.4.4. Synthesis and recommendations for Central Asia

Several early opportunities exist in the region. In particular the hotspot with large high purity CO_2 sector such as 2 (near Saratov) or number 3 (near Orenburg) for its future growth are interesting prospects.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.

A.5. THE INDIAN BLOCK

The CO_2 emissions reported for India is illustrated in Figure 43. The industry sectors represent 17 percent of the region CO_2 emissions in 2007.

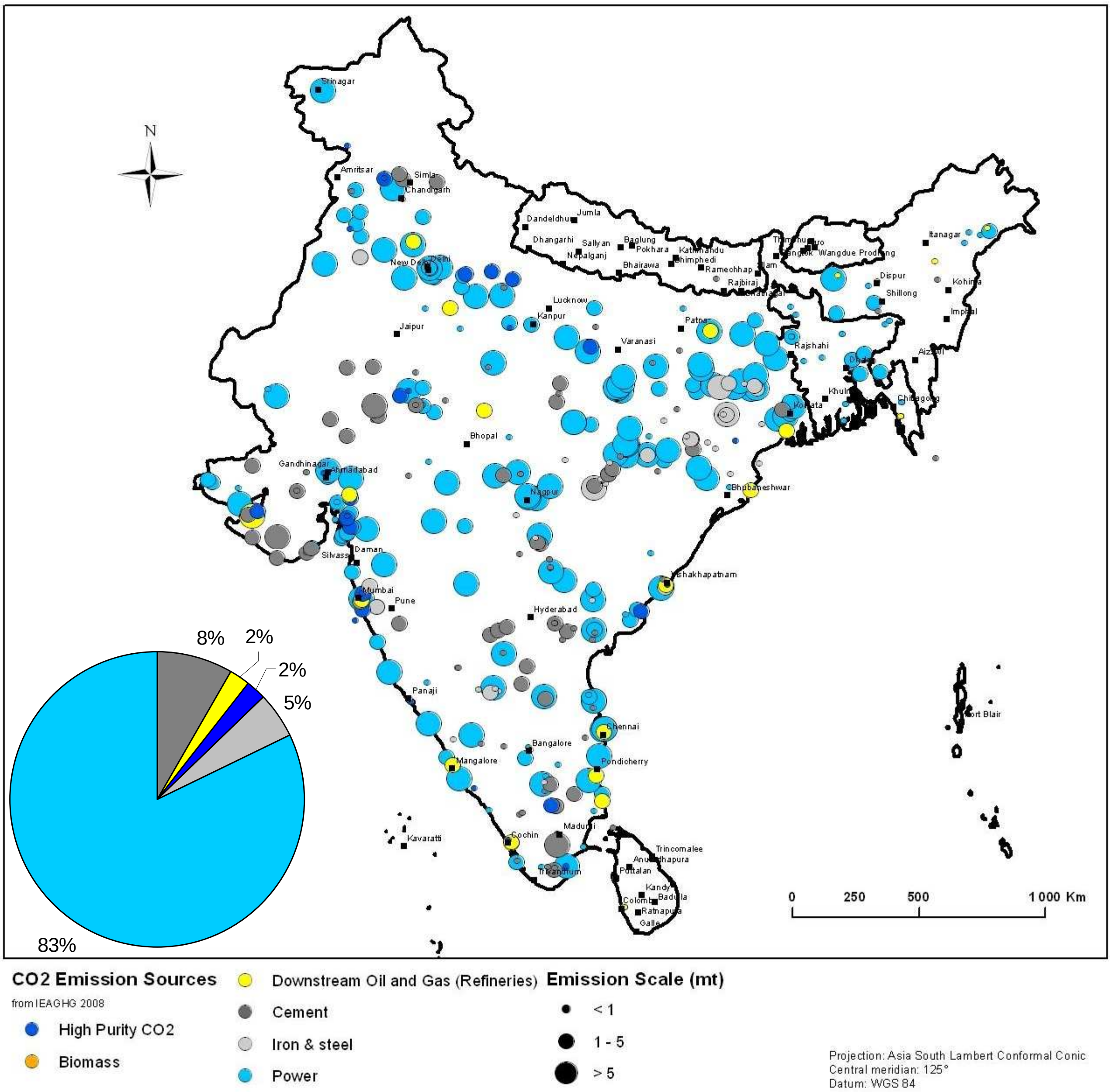


Figure 43: Annual CO_2 emissions in the Indian Block

A.5.1. Industrial CO_2 sources in the Indian Block

Emissions baseline (2007)

In The Indian Block, besides the power industry, the main source of CO_2 emissions is from the iron and steel sector. The cement sector generates about 46 percent of the region emissions from industry, c.a. 135Mt/y CO_2 for the cement sector out of 290Mt/y CO_2 for the all industry sectors in 2007.

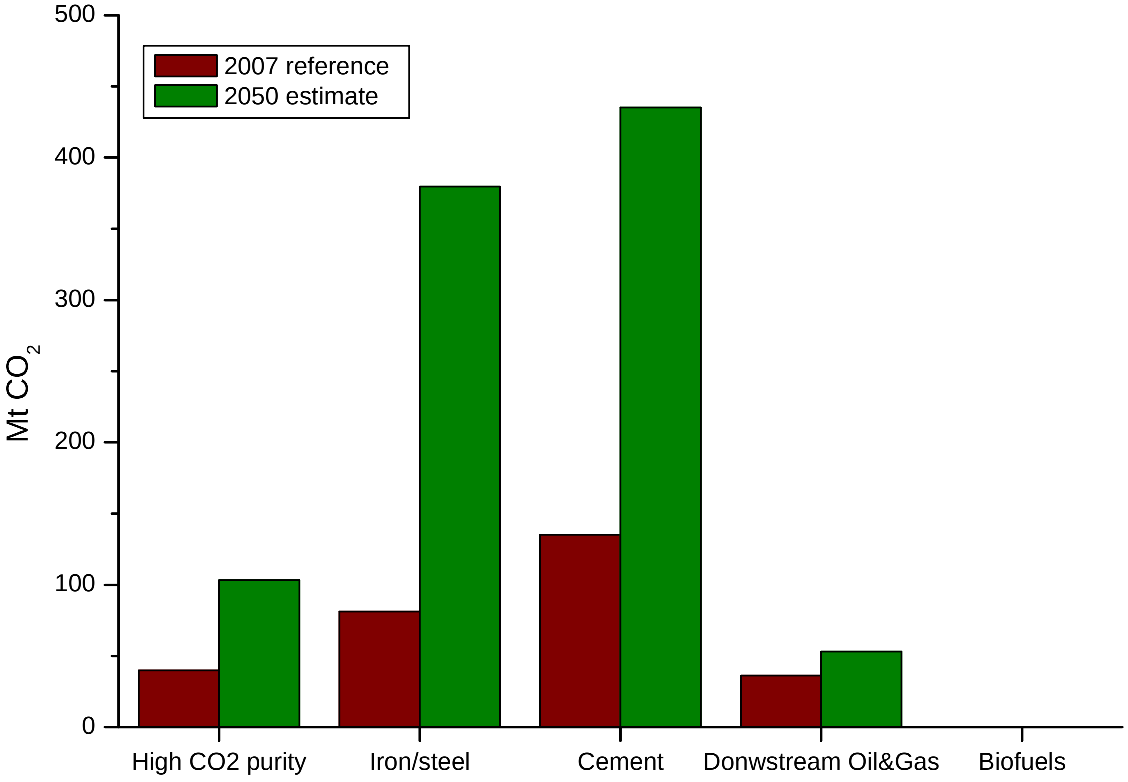


Figure 44: Annual CO_2 emissions and evolution for the industrial sectors in The Indian Block

Emissions evolution (by 2050)

At the 2050 horizon, the share of iron and steel sector is expected to increase up to 39 percent of the region emissions from industry (see Figure 44) while the cement sector is expected to remain the largest CO_2 emitter, c.a. 45 percent of the region emissions from industry in 2050. These two sectors are expected to strongly increase between 2007 and 2050. The high purity CO_2 sector is also expected to increase sharply to represent about 15 percent of the region emissions from industry in 2050. These three sectors should account for about 94 percent of the region emissions from industry in 2050. The CO_2 emissions from industry are expected to grow 232 percent from the 2007 level: from c.a. 290 to 970Mt/y CO_2.

A.5.2. CO_2 storage resources in the Indian Block

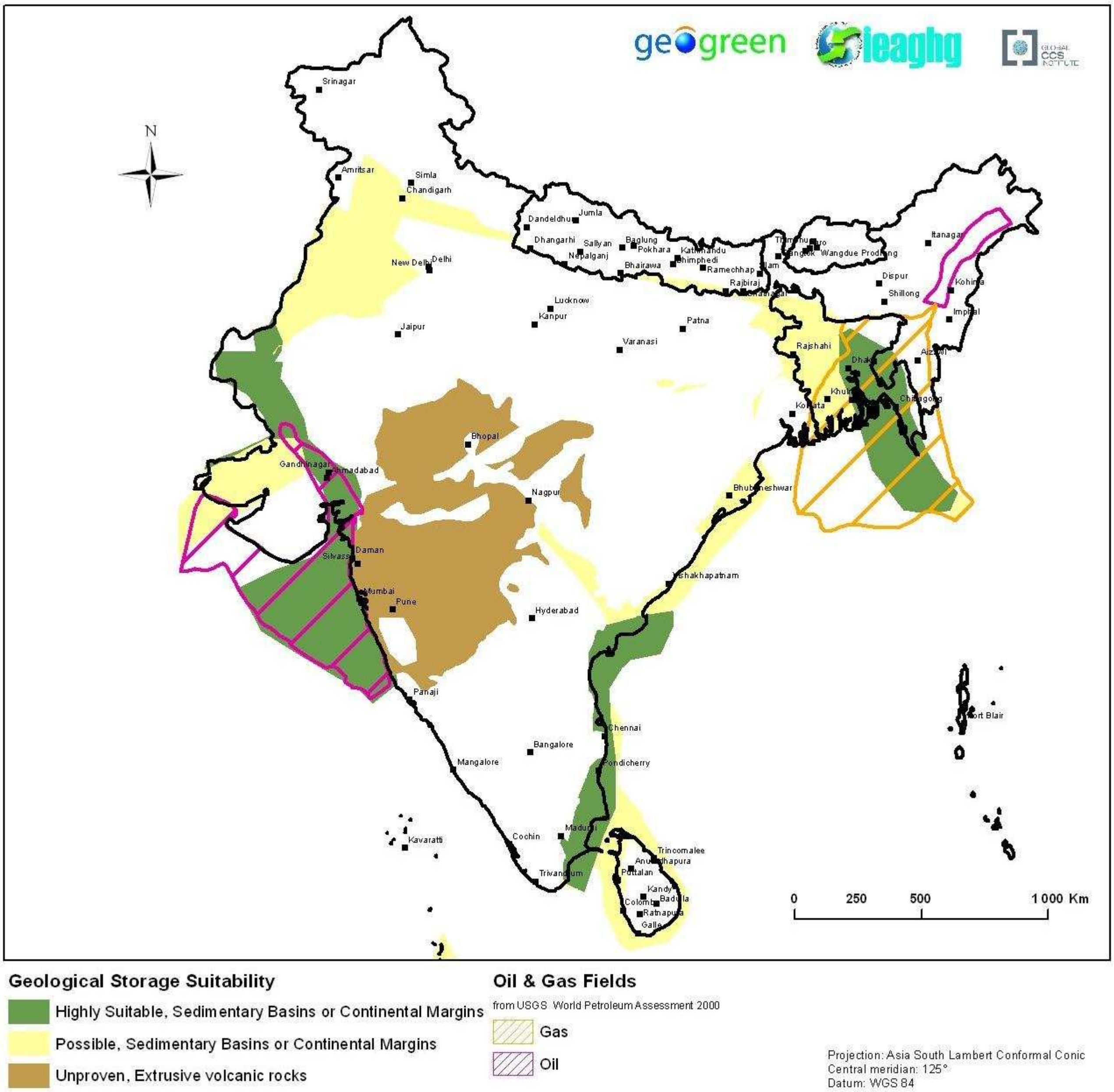


Figure 45: Storage resource in The Indian Block: deep saline formations and oil and gas fields

<u>**Deep saline formations**</u>

The available storage resource in deep saline formation may be estimated (see Figure 46). When considering the early opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (see Figure 4). Note that competition for storage resource is likely. Further more the storage resource is unevenly distributed throughout the Indian Block. Highly suitable storage resources lie mainly offshore or on the coastal plains (see Figure 45). Inland the storage resources need to be confirmed through characterization in the western and eastern boundary of India.

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 46 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

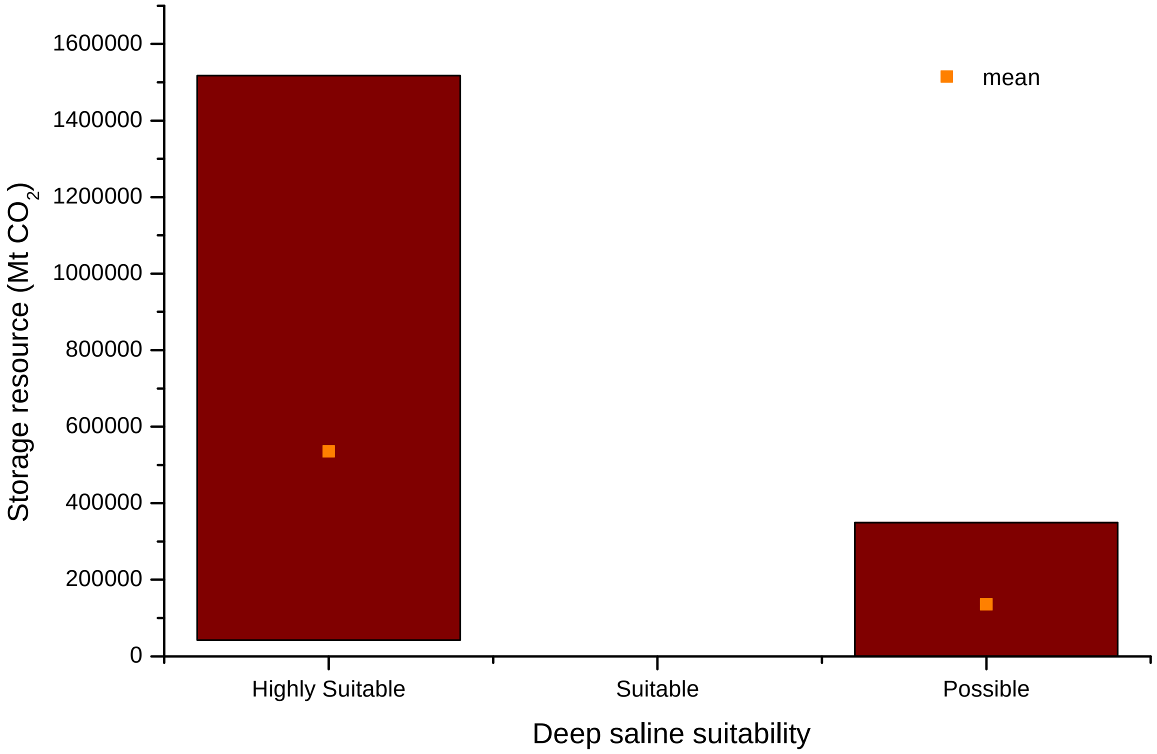


Figure 46: Estimated storage resources in deep saline formations in the Indian Block

Oil and gas fields

Limited oilfield storage resources (see Table 16) exists offshore of western India (see Figure 45) The estimated storage resource in gas fields is significant (see Table 16) given the extension of these fields in the eastern part of India and Bangladesh. Specific field level studies are required to firm up the storage capacity.

Table 16: Storage resource in oil and gas fields in the Indian Block

	Storage resource (Mt CO_2)
Oil fields	393
Gas fields	8300
Total	**8693**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.5.3. Qualitative source-sink matching in the Indian Block

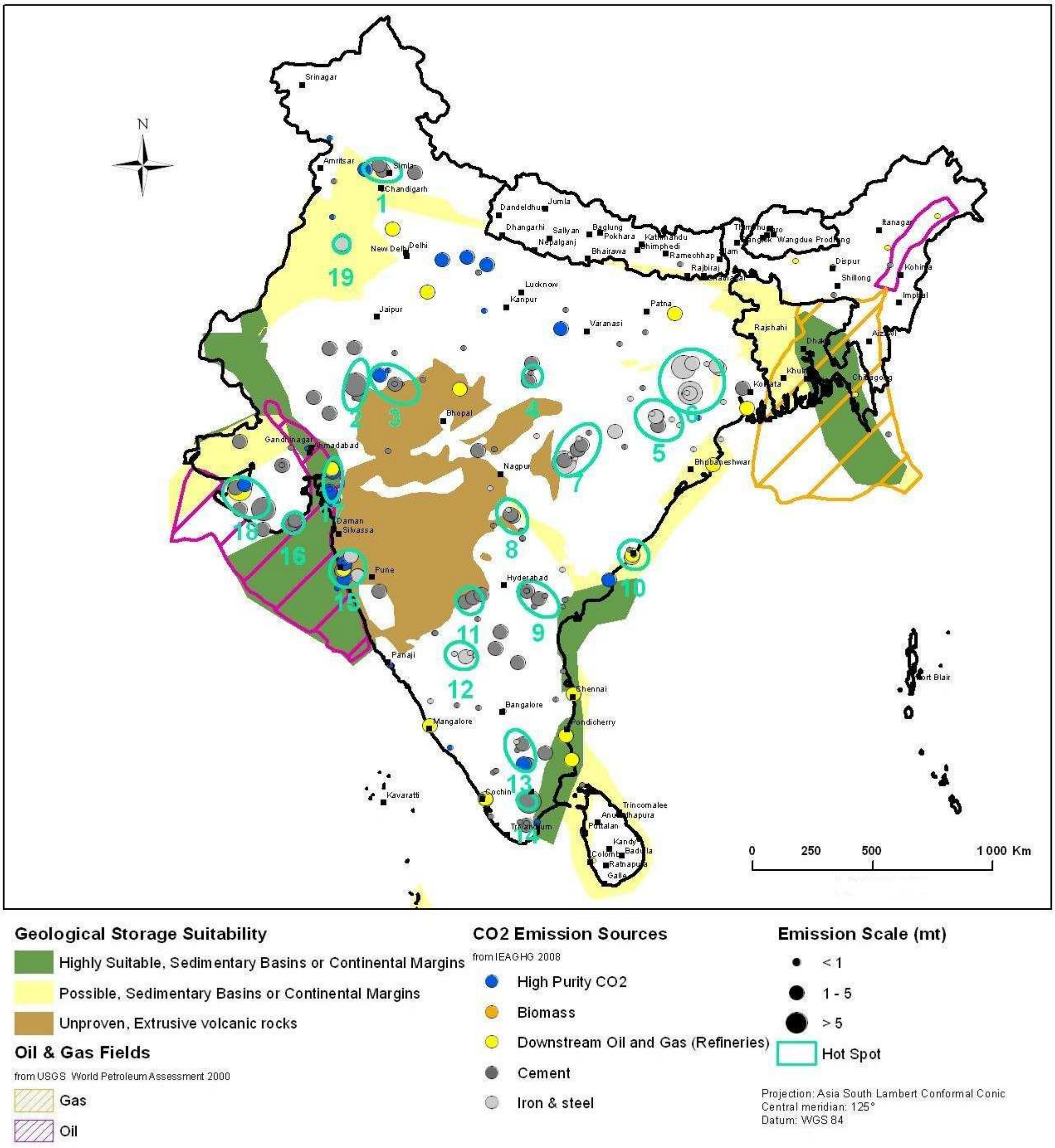


Figure 47: Storage suitability, annual CO_2 emissions and hotspots in the Indian Block

Table 17: Identified hotspots in the Indian Block

hotspot		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	2	6.94	0	0.00	1	3.5	0	0.00	3	10.4
	2	4	10.31	0	0.00	0	0.0	0	0.00	4	10.3
	3	2	2.09	0	0.00	1	2.3	0	0.00	3	4.4
	4	1	0.77	0	0.00	0	0.0	0	0.00	1	0.8
	5	2	1.92	0	0.00	1	0.2	5	7.84	8	9.9
	6	2	0.93	0	0.00	0	0.0	9	35.41	11	36.3
	7	7	9.16	0	0.00	0	0.0	5	11.96	12	21.1
	8	5	8.30	0	0.00	0	0.0	1	0.25	6	8.6
	9	11	6.76	0	0.00	0	0.0	0	0.00	11	6.8
	10	1	0.25	1	1.81	0	0.0	1	2.73	3	4.8
	11	2	5.48	0	0.00	0	0.0	0	0.00	2	5.5
	12	0	0.00	0	0.00	0	0.0	6	6.79	6	6.8
	13	4	7.22	0	0.00	1	1.1	2	0.97	7	9.3
	14	1	5.18	0	0.00	0	0.0	0	0.00	1	5.2
	15	1	1.11	1	2.60	7	5.1	3	5.88	12	14.7
	16	3	5.91	0	0.00	0	0.0	0	0.00	3	5.9
	17	0	0.00	1	2.97	3	1.8	0	0.00	4	4.8
	18	4	8.51	1	7.16	0	0.0	0	0.00	4	15.7
	19	0	0.00	0	0.00	3	2.2	1	2.26	4	4.5
2050	1	2	22.36	0	0.00	1	9.03	0	0.00	3	31.4
	2	4	33.21	0	0.00	0	0.00	0	0.00	4	33.2
	3	2	6.74	0	0.00	1	5.90	0	0.00	3	12.6
	4	1	2.48	0	0.00	0	0.00	0	0.00	1	2.5
	5	2	6.20	0	0.00	1	0.42	5	36.61	8	43.2
	6	2	2.99	0	0.00	0	0.00	9	165.29	11	168.3
	7	7	29.51	0	0.00	0	0.00	5	55.82	12	85.3
	8	5	26.76	0	0.00	0	0.00	1	1.16	6	27.9
	9	11	21.80	0	0.00	0	0.00	0	0.00	11	21.8
	10	1	0.80	1	2.64	0	0.00	1	12.76	3	16.2
	11	2	17.66	0	0.00	0	0.00	0	0.00	2	17.7
	12	0	0.00	0	0.00	0	0.00	6	31.71	6	31.7
	13	4	23.27	0	0.00	1	2.96	2	4.53	7	30.8
	14	1	16.70	0	0.00	0	0.00	0	0.00	1	16.7
	15	1	3.57	1	3.80	7	13.27	3	27.43	12	48.1
	16	3	19.05	0	0.00	0	0.00	0	0.00	3	19.1
	17	0	0.00	1	4.34	3	4.65	0	0.00	4	9.0
	18	4	27.43	1	10.45	0	0.00	0	0.00	5	37.9
	19	0	0.00	0	0.00	3	5.67	1	10.56	4	16.2

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 19 hotspots (Figure 47) which represents 64 percent of the emissions of the industry sector in 2007 and 73 percent of the emissions of the industry sector in 2050. They involve all the industry sectors in the region except biomass (Figure 48). There expected growth is highlighted in Figure 49. The number 5, 6, 7 and 15 are expected to grow significantly (Figure 49). The number 6 increase is linked to the important expected increase of the iron and steel sectors of the Indian Block (almost 5 fold between 2007 and 2050).

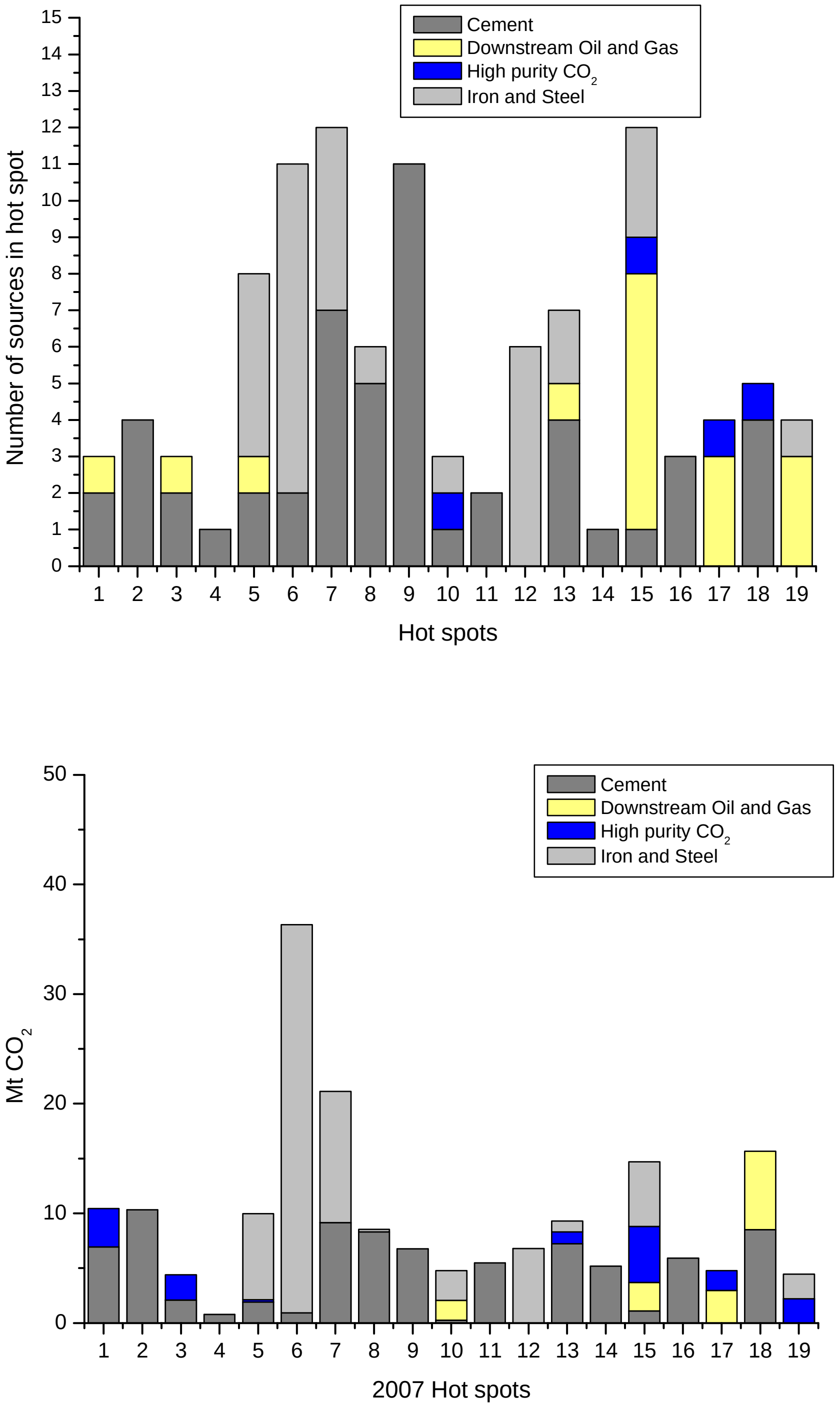


Figure 48: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in the Indian Block

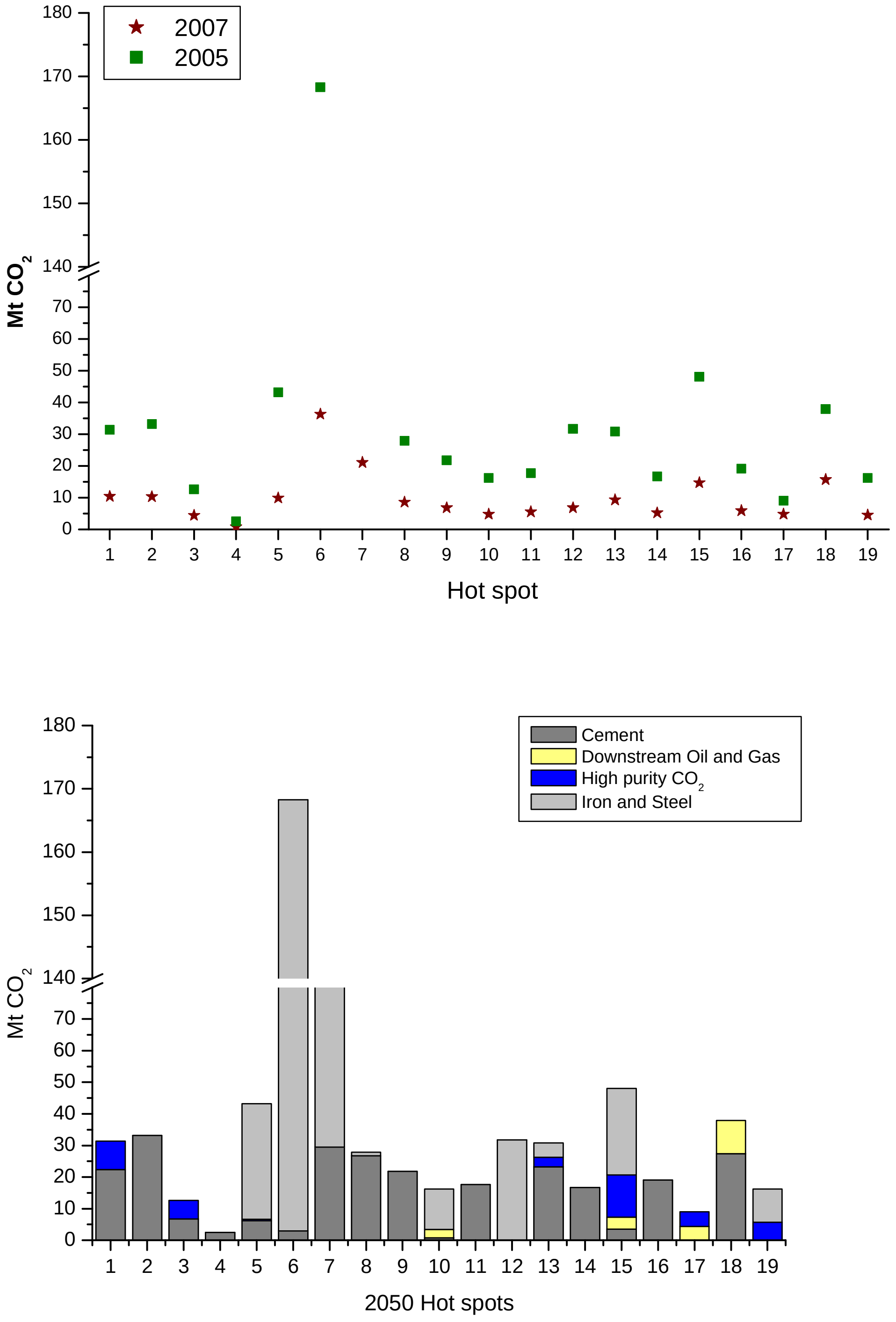


Figure 49: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in the Indian Block

Early opportunities

As most of the highly suitable storage is offshore (Figure 47), the coastal hotspot are therefore the early opportunities for CCS deployment in particular hotspot numbered 14, 15, 16, 17, and 18 as long as the storage resource are confirmed through geologic characterization for the coastal (offshore and onshore) Deep saline formation along the southeastern Indian coast. Another attractive for early opportunities lies in the north western offshore area where oilfield may enable the First-Of-A-Kind project. However, the limited storage resource indicate that alternative storage solution will be required if all emissions from the hotspots 15, 16, 17, to 18 was targeting the same area. Therefore, it is obvious that competition for the storage space from the industry and power sectors will take place in this area if CCS is implemented.

Other opportunities might emerge but will require geological characterization to confirm the storage resource (hotspots 1 and 19) or large scale transport network for hot post 6 and 7 to reach the eastern favorable storage area.

Table 18 summarizes the proposed early opportunities which account for 16 percent of the region emissions from industry at about 162Mt/y of CO_2 expected in 2050.

Table 18: Qualitative source sink matching on the CO_2 sources in the Indian Block

hotspot number	Early Opportunity	
	number of sources	Annual emission (Mt/y CO_2)
13	7	31
14	1	17
15	12	48
16	3	19
17	4	9
18	5	38
Total	**32**	**162**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in the Indian Block a competitive characterization should be initiated for the deep saline formation on the coastal storage resource in southeast India. The attractive north-western area (Figure 47) may not only rely on Oil field but need confirmation through geological characterization of any deep saline formations. The best opportunity lie in the east part of India but will require, except for the gas fields, addition characterization and CO_2 transport network to link the large industrial hotspot, west of Kolkata, with the storage resource in Bangladesh. This solution will imply trans-border CO_2 transport which may be a difficult pitfall.

A.5.4. Synthesis and recommendations for the Indian Block

The earliest opportunity is the hotspot 15 (near Mumbai) considering its future growth and location with respect to offshore oilfields and the existing high purity CO_2 sector. However, the available storage resource is quite limited and strong competition for storage capacity will take place. Another interesting area is on the southeast coast of India but additional geological characterization is required to confirm the storage capacity in deep saline formations. At the 2050 horizon, to ensure storage capacity, the large potential of eastern India and Bangladesh must be confirmed.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.

A.6. CHINA

The CO_2 emissions reported for China is illustrated in Figure 50). The industry sectors represent 9 percent of the country CO_2 emissions in 2007.

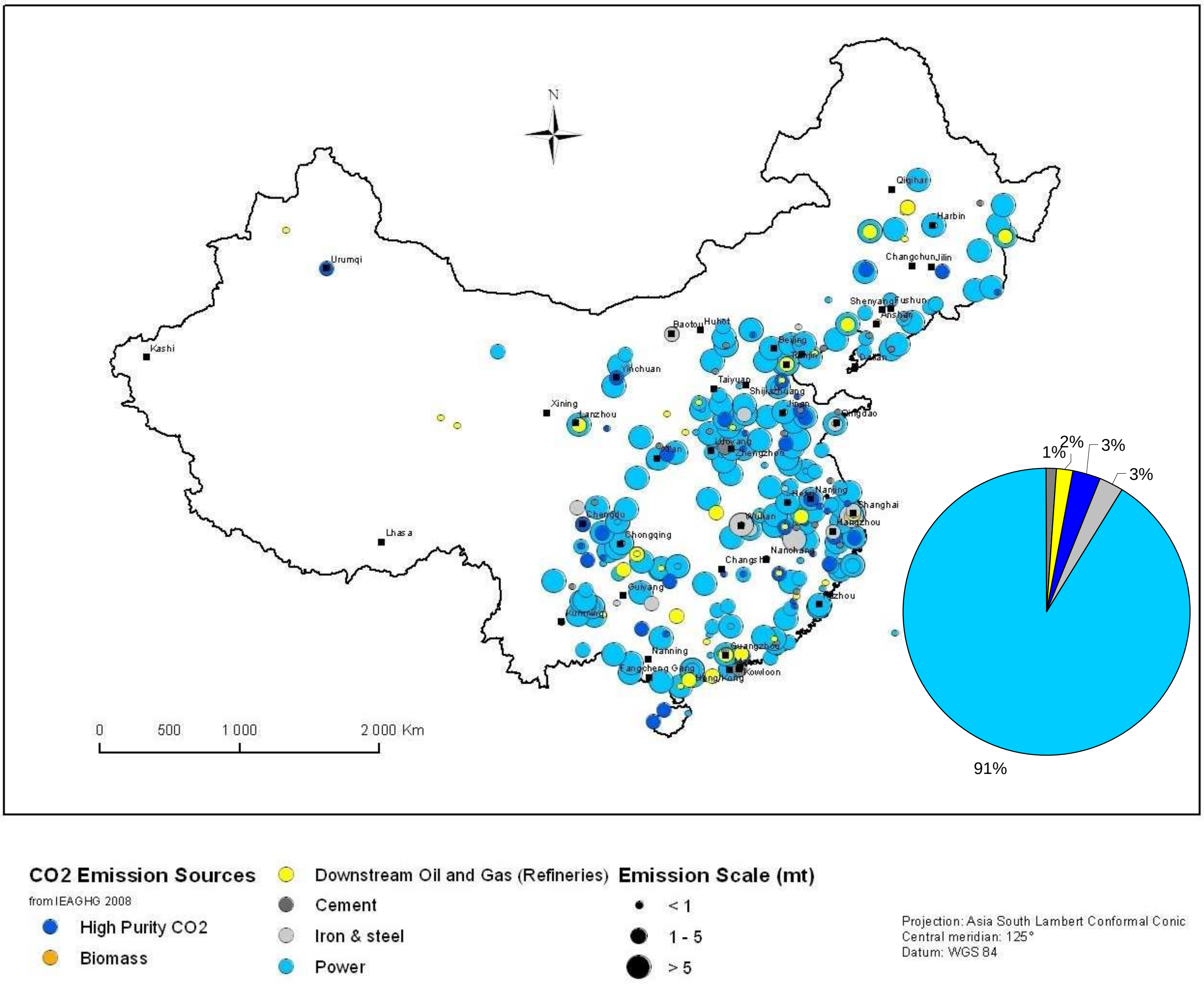


Figure 50: Annual CO_2 emissions in China

A.6.1. Industrial CO_2 sources in China

Emissions baseline (2007)

In China, besides the power industry, the main source of CO_2 emissions is from high purity CO_2, c.a. 60Mt/y CO_2 for the high purity CO_2sector out of 170Mt/y CO_2 for the all industry sectors in 2007 (Figure 51). However, iron and steel sector has similar CO_2 emissions c.a. 52Mt/y CO_2. When combined these tow sectors generates about 66 percent of the country emissions from industry.

However, the 2007 emissions need to be updated when considering the current economic growth of China.

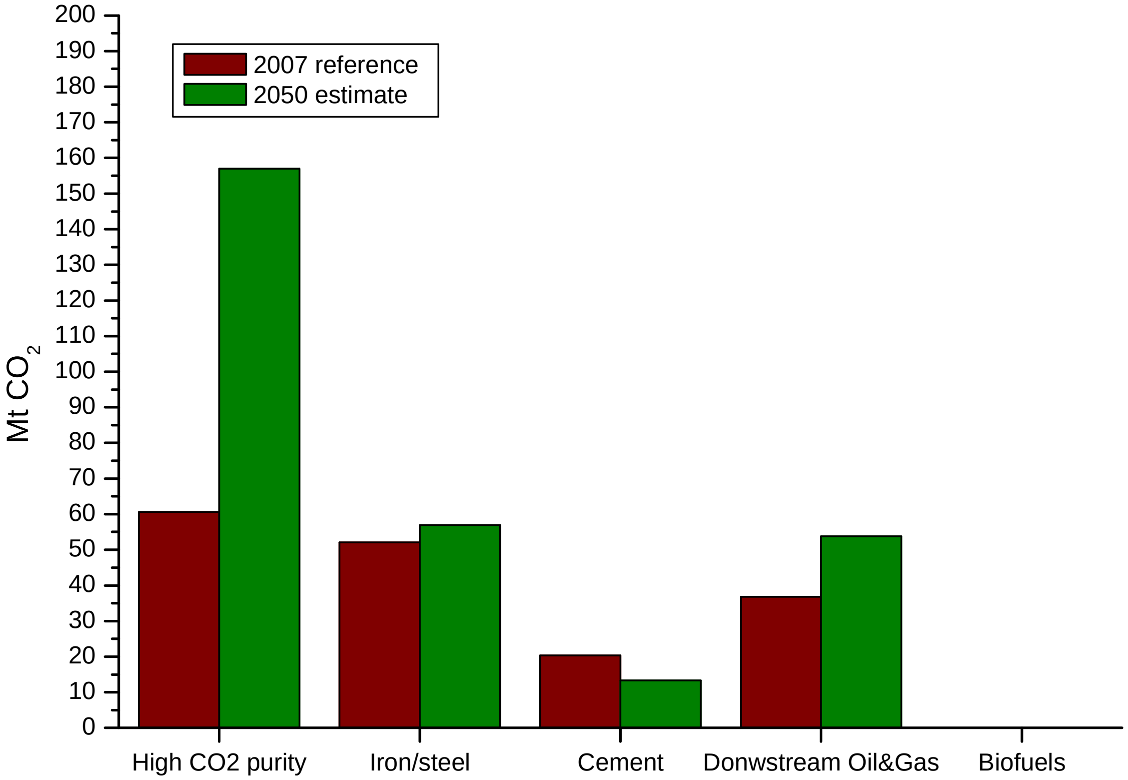


Figure 51: Annual CO_2 emissions and evolution for the industrial sectors in China

Emissions evolution (by 2050)

At the 2050 horizon (Figure 51), the high purity CO_2 is expected to rise sharply from 60 to 157Mt/y CO_2. The Downstream Oil and Gas sector is expected to significantly to emit about the same as the iron and steel sector, c.a. 54 and 57Mt/y CO_2 respectively. At the 2050 horizon, the CO_2

emissions from industry are expected to grow 65 percent from the 2007 level: from c.a. 170 to 280Mt/y CO_2.

A.6.2. CO_2 storage resources in China

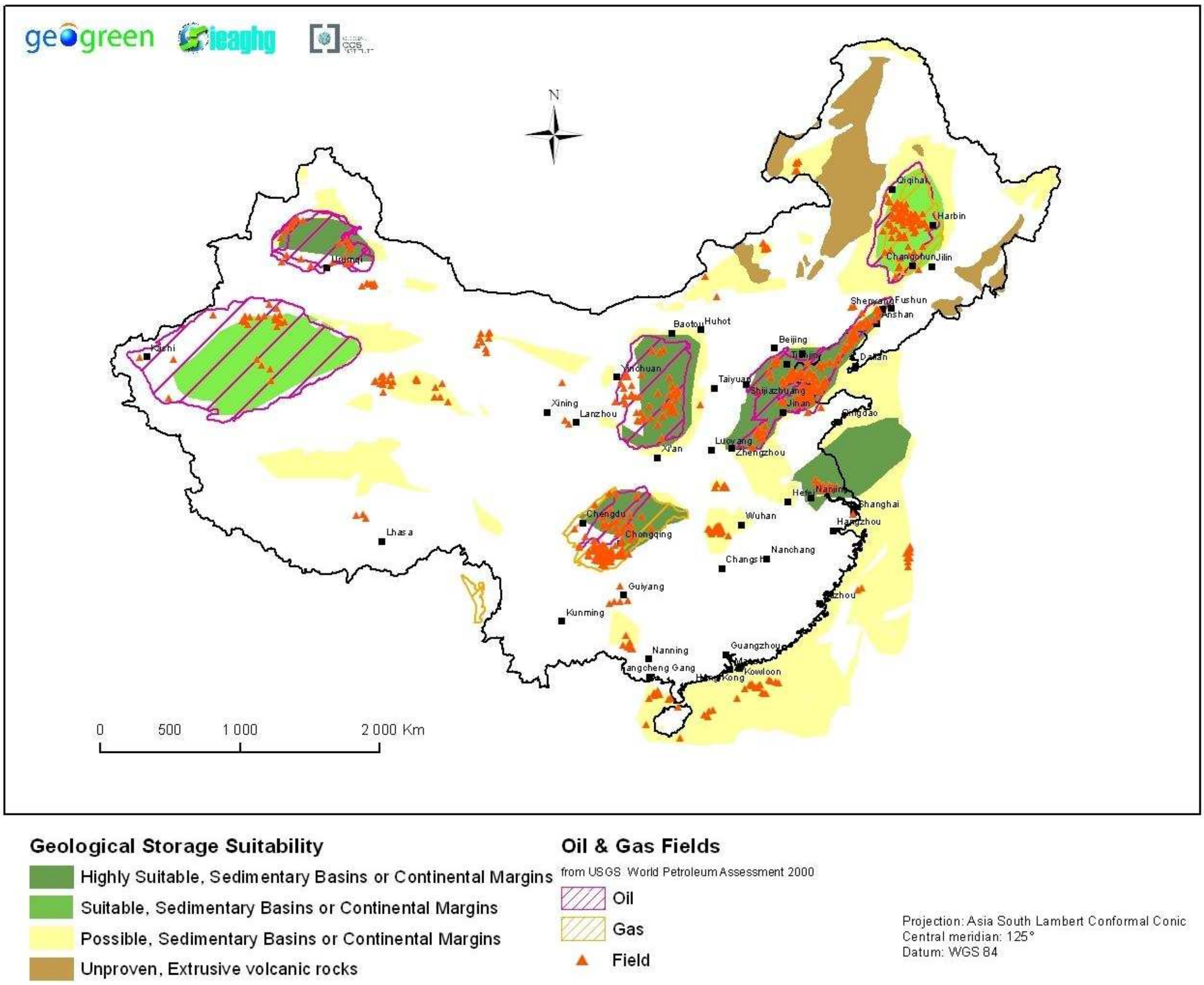


Figure 52: Storage resource in China: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource may be estimated (see Figure 7). When considering the early opportunities or even the opportunities, there is potentially enough storage resource (Figure 53) for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4). However, most of the deep saline formation storage resources are in the same basin as the Oil and gas fields. To enable the full storage potential of deep saline formation additional characterization study must confirm the storage capacity. Note that competition for storage resource is likely with Oil and Gas production or storage.

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 53 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

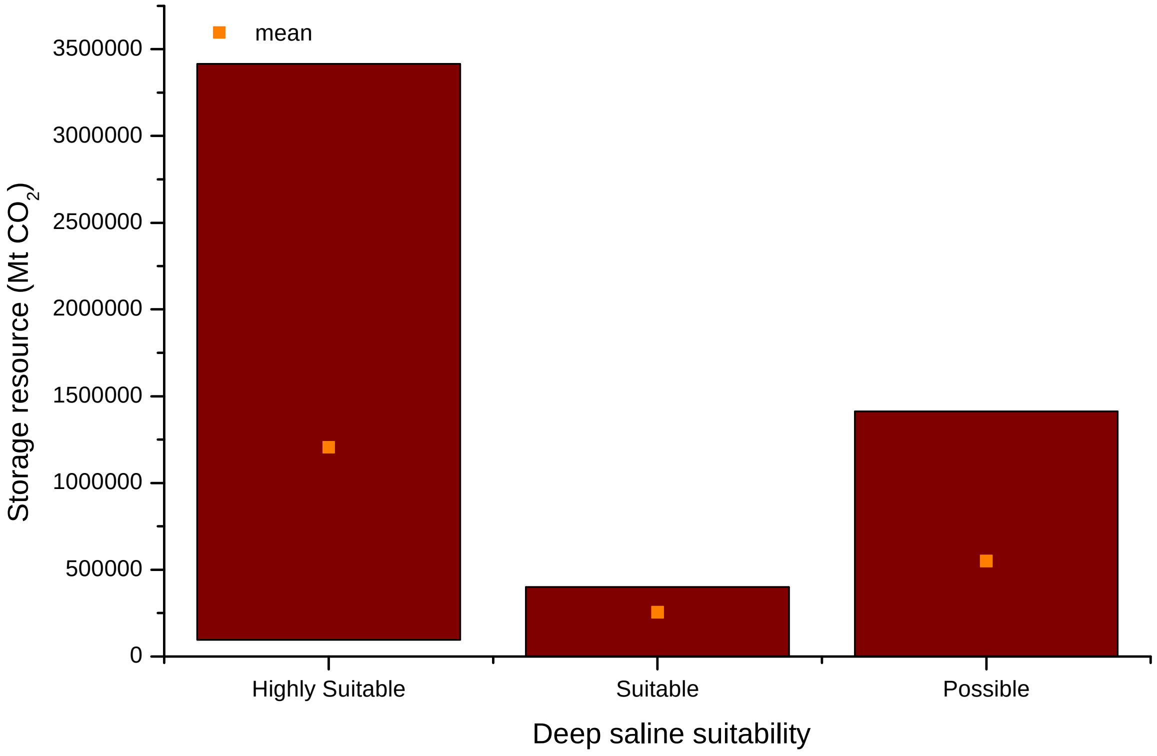


Figure 53: Estimated storage resources in deep saline formations in China

Oil and gas fields

Important oil and gas fields exist onshore and also offshore in China. The (characterized) storage resource in oil and gas fields in China is estimated in Table 19. Specific field level studies are required to firm up the storage capacity.

Table 19: Storage resource in oil and gas fields in China

	Storage resource (Mt CO_2)
Oil fields	1800
Gas fields	12245
Total	**14045**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.6.3. Qualitative source-sink matching in China

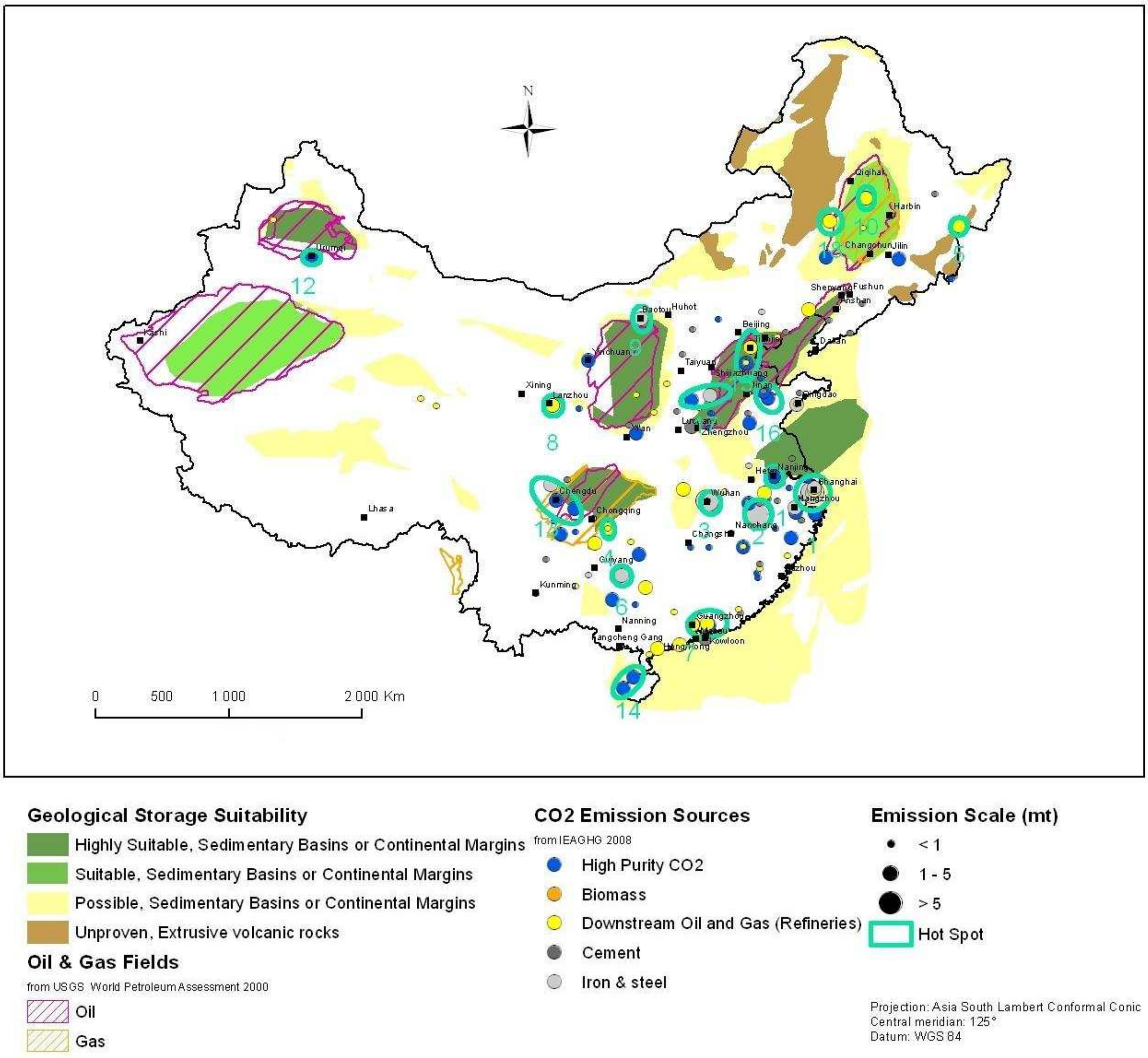


Figure 54: Storage suitability, annual CO_2 emissions and hotspots in China

Table 20: Identified hotspots in China

hotspot		Cement		Downstream Oil and Gas (Refineries)		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	1	0.24	1	1.02	4	4.1	3	14.59	9	20.0
	2	1	0.92	0	0.00	0	0.0	1	9.73	2	10.6
	3	0	0.00	1	0.48	0	0.0	2	10.18	3	10.7
	4	2	1.39	2	2.34	1	1.6	0	0.00	5	5.4
	5	1	0.48	1	1.03	3	4.0	0	0.00	5	5.5
	6	0	0.00	0	0.00	0	0.0	1	3.39	1	3.4
	7	1	0.29	2	2.01	4	3.7	1	1.13	8	7.2
	8	0	0.00	1	1.26	2	2.1	0	0.00	3	3.4
	9	0	0.00	0	0.00	0	0.0	1	3.05	1	3.1
	10	0	0.00	2	2.32	1	1.2	0	0.00	3	3.5
	11	2	1.59	0	0.00	2	2.5	0	0.00	4	4.1
	12	0	0.00	1	0.48	1	2.2	0	0.00	2	2.7
	13	0	0.00	0	0.00	2	2.9	2	2.94	4	5.9
	14	0	0.00	0	0.00	2	2.3	0	0.00	2	2.3
	15	2	1.49	2	1.35	2	1.5	0	0.00	6	4.3
	16	1	0.13	0	0.00	2	2.6	0	0.00	3	2.8
	17	0	0.00	0	0.00	1	1.2	1	1.41	2	2.6
	18	1	0.44	1	1.78	1	0.3	0	0.00	3	2.5
2050	1	1	0.16	1	1.50	4	10.62	3	15.94	9	28.2
	2	1	0.60	0	0.00	0	0.00	1	10.63	2	11.2
	3	0	0.00	1	0.71	0	0.00	2	11.12	3	11.8
	4	2	0.92	2	3.41	1	4.22	0	0.00	5	8.5
	5	1	0.31	1	1.51	3	10.40	0	0.00	5	12.2
	6	0	0.00	0	0.00	0	0.00	1	3.71	1	3.7
	7	1	0.19	2	2.94	4	9.63	1	1.24	8	14.0
	8	0	0.00	1	1.84	2	5.55	0	0.00	3	7.4
	9	0	0.00	0	0.00	0	0.00	1	3.34	1	3.3
	10	0	0.00	2	3.39	1	2.98	0	0.00	3	6.4
	11	2	1.05	0	0.00	2	6.51	0	0.00	4	7.6
	12	0	0.00	1	0.71	1	5.66	0	0.00	2	6.4
	13	0	0.00	0	0.00	2	7.62	2	3.21	4	10.8
	14	0	0.00	0	0.00	2	5.84	0	0.00	2	5.8
	15	2	0.98	2	1.98	2	3.81	0	0.00	6	6.8
	16	1	0.08	0	0.00	2	6.85	0	0.00	3	6.9
	17	0	0.00	0	0.00	1	2.98	1	1.54	2	4.5
	18	1	0.29	1	2.59	1	0.68	0	0.00	3	3.6

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 18 hotspots (Figure 54) which represents c.a. 59 percent of the CO_2 emissions of the industry sector in 2007. They involve all the industry sectors in the country (Figure 55). There expected growth is highlighted in Figure 56. The number 1, 5, 7 and 13 are expected to grow significantly (Figure 56).

The number 1, 5, 7, 8, 11, 12, 13, 14 and 16 are expected to be the largest CO_2 emissions (above 5Mt/y CO_2) in 2050 from the high purity CO_2 sector as shown in Figure 56.

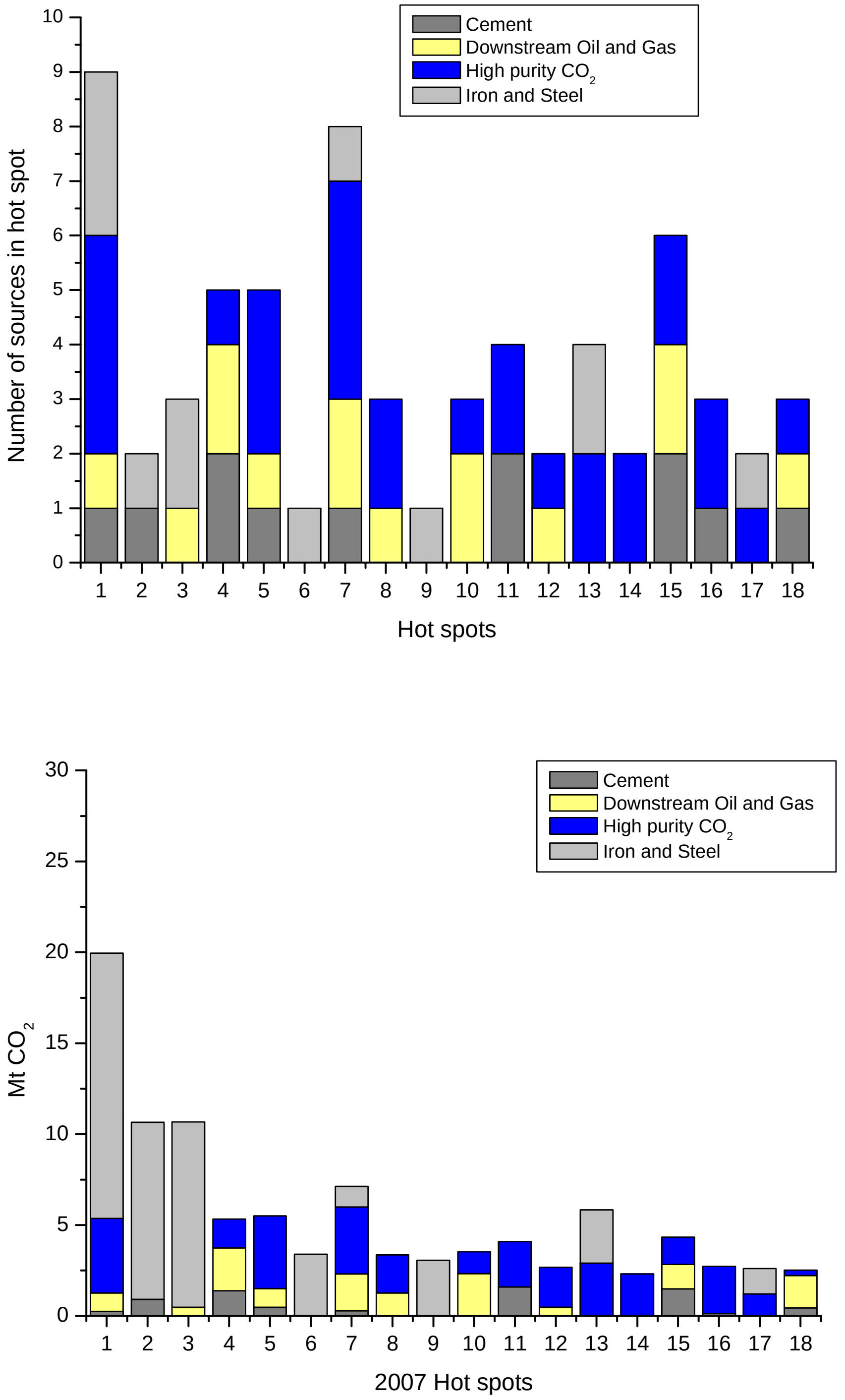
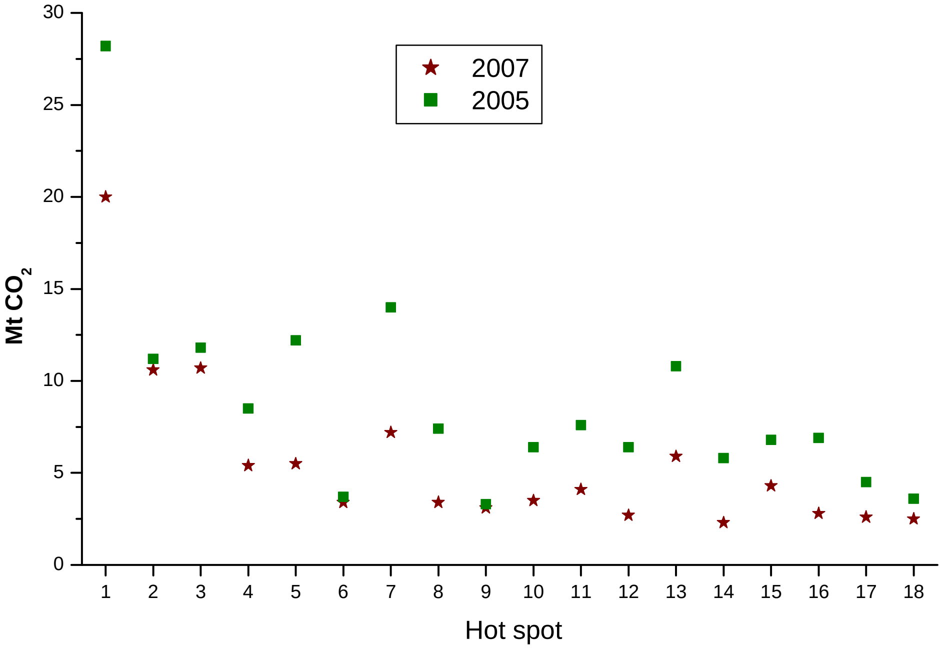


Figure 55: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in China



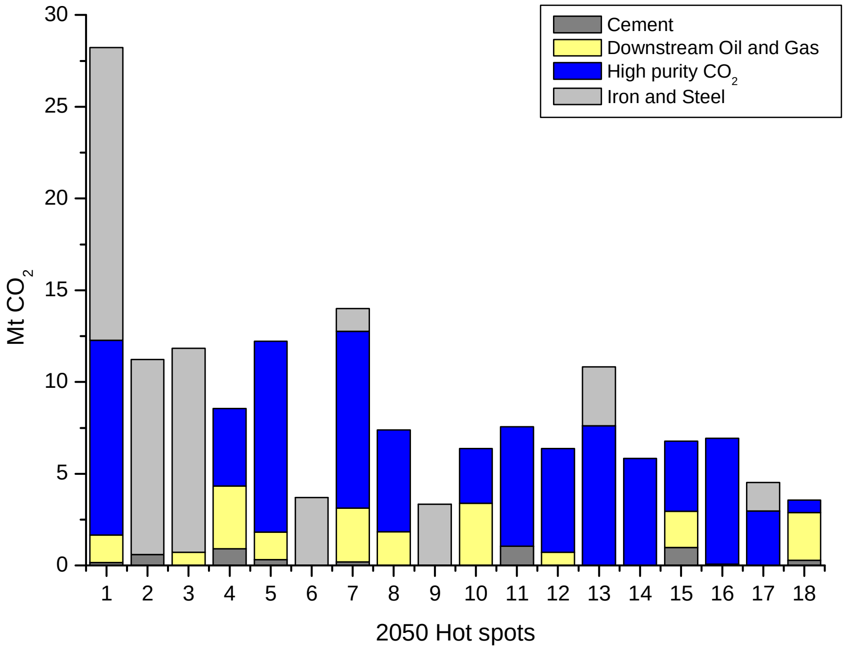


Figure 56: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in China

Early opportunities

The hotspot 11, 12, 13 and 16 are early opportunities as the large high purity CO_2 source are nearby Oil and gas fields or highly suitable storage resource. Some hotspot, 7 and 14, on the south eastern coast are potentially good candidate if the offshore storage resource is confirmed.

Linked to oil and gas fields with potentially a good storage capacity, the hotspot, 9, 10, 15, 17 and 18 are mainly Downstream Oil and Gas or Iron and steel sectors which might be interesting early opportunities if the CO_2 stream is compatible with the oil operation for EOR purposes or if the fields may be used as CO_2 storage.

Table 21: Qualitative source sink matching in 2050 on the CO2 sources in China

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
11	4	8
12	2	6
13	4	11
16	3	7
Total	**13**	**32**

Bottlenecks

To enable the development of CCS projects from industry in China, a competitive characterization should be initiated for the Oil and gas fields to ensure compatibility between the CO_2 storage objective and oil production as most of the early opportunities may be linked to oil production. On the southeast coast offshore storage either in deep saline formation or oil and gas field may be possible but additional characterization is required. As most of the industrial centers are on the eastern part of China, it is interesting to note that to some extent most of the hotspot could find suitable storage possibility when considered independently from power emission. There is a potentially interesting early opportunity in the north-western part of China where a high purity CO_2 sources are closed to highly suitable storage resource and oil and gas fields.

A.6.4. Synthesis and recommendations for China

In China, there are four early opportunities with significantly large (above 5 Mt/y of CO_2 expected in 2050) high purity CO_2 sources. The storage resources may be oil and gas fields.
The coastal hotspot may find suitable storage resource if additional characterization and potential evaluation is performed.

The early opportunities are evenly spread on the eastern part of the country except for one in the west, near Urumqi.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.

A.7. SOUTHEAST ASIA

The CO_2 emissions reported for Southeast Asia is illustrated in Figure 57. The industry sectors represent 47 percent of the region CO_2 emissions

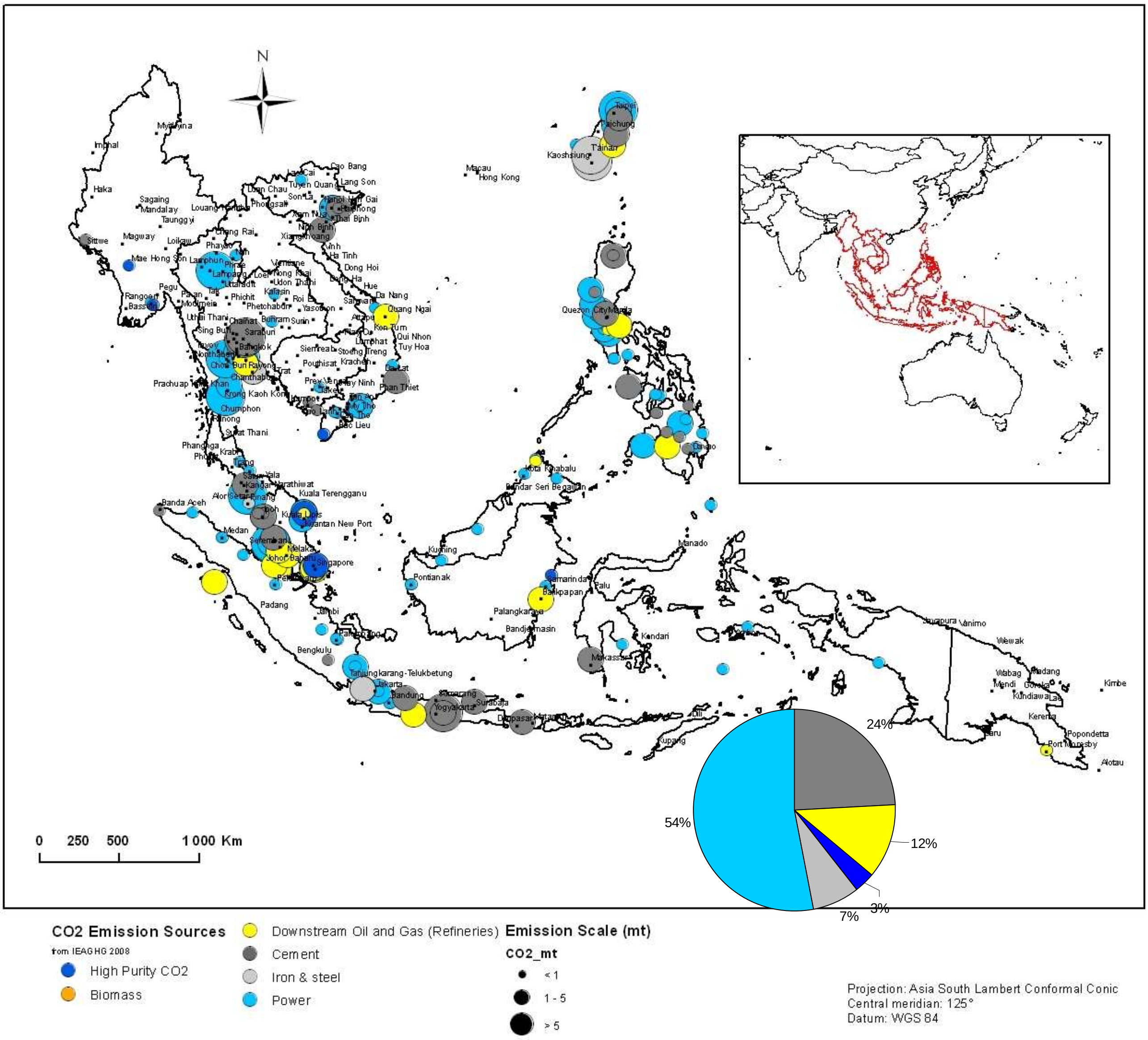


Figure 57: Annual CO_2 emissions in Southeast Asia

A.7.1. Industrial CO_2 sources in Southeast Asia

Emissions baseline (2007)

In Southeast Asia, besides the power industry, the main source of CO_2 emissions is from the cement sector (Figure 58). The cement sector generates about 57 percent of the region emissions from industry, c.a. 78Mt/y CO_2 for the cement sector out of 150Mt/y CO_2 for the all industry sectors in 2007. No biofuel emission is integrated in the data base for Southeast Asia.

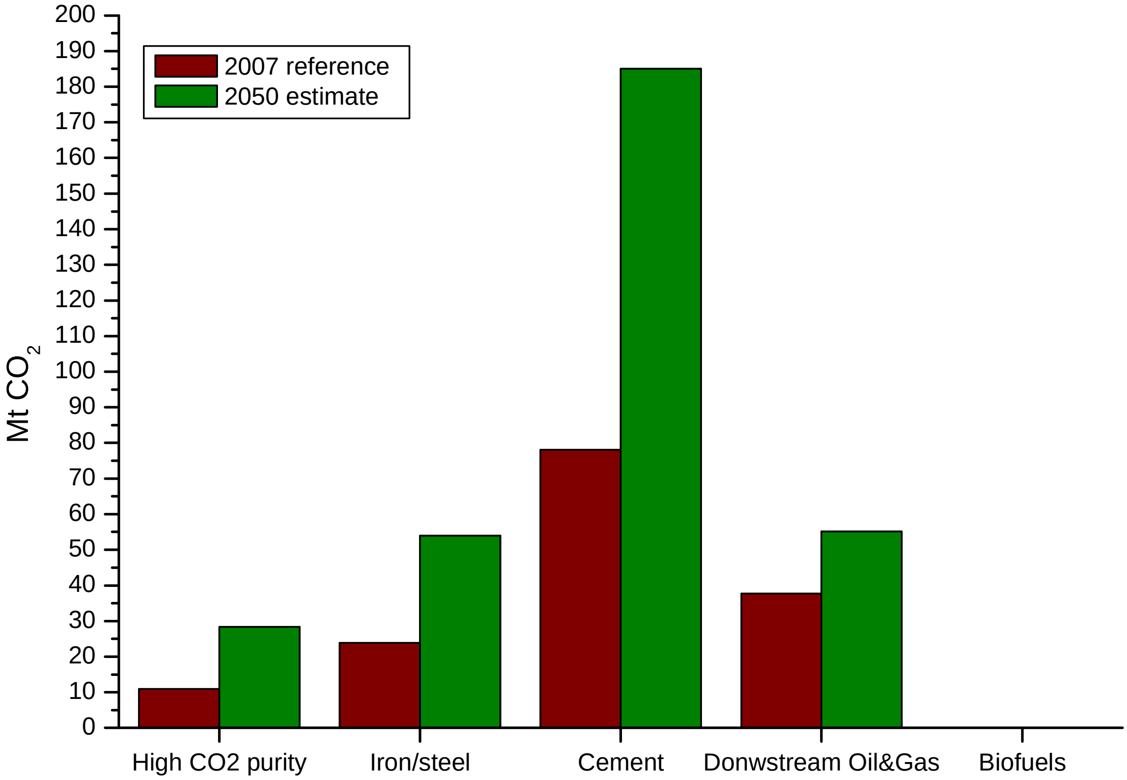


Figure 58: Annual CO_2 emissions and evolution for the industrial sectors in Southeast Asia

Emissions evolution (by 2050)

At the 2050 horizon, the share of high CO_2 purity sector is expected to double but will only represent 9 percent of the region emissions from industry (see Figure 58). The cement sector will however remain the largest CO_2 emitter with c.a. 185Mt/y CO_2 out of c.a. 320Mt/y CO_2 for the whole industry in the region. The CO_2 emissions from industry are expected to grow 115 percent from the 2007 level: from c.a. 150 to 320Mt/y CO_2.

A.7.2. CO_2 storage resources in Southeast Asia

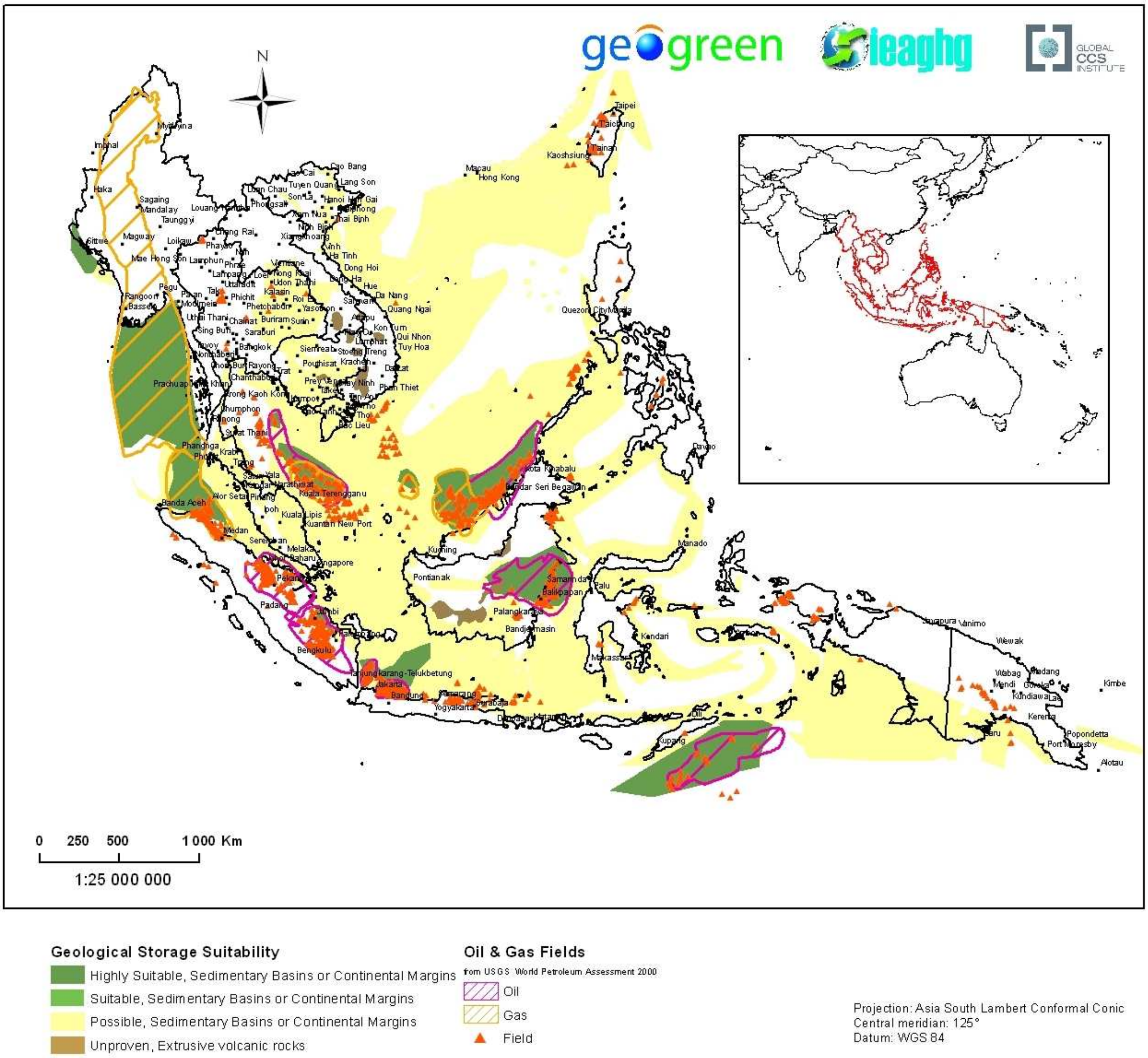


Figure 59: Storage resource in South–East Asia: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 60). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4). Note that competition for storage resource is likely.

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 60 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

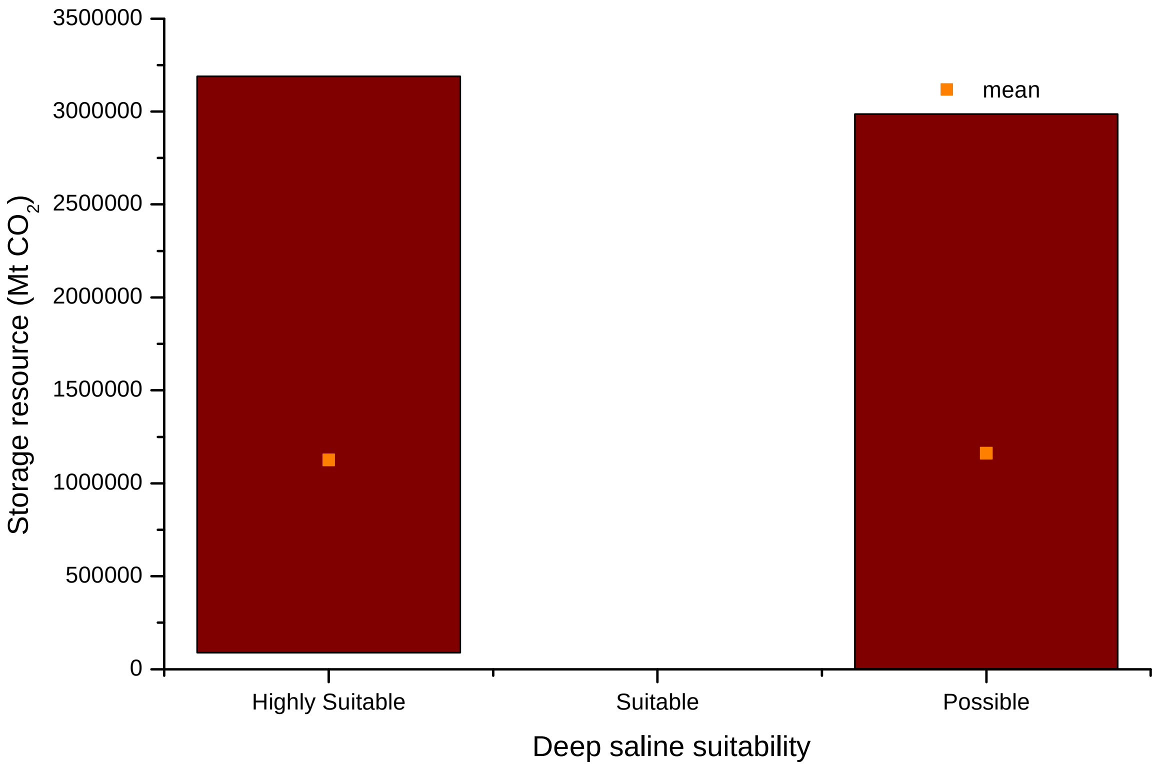


Figure 60: Estimated storage resources in deep saline formations in Southeast Asia

Oil and gas fields

Limited storage resource may be identified onshore or on the coast line. The main storage resource is estimated to be in the gas field. The storage capacity in Oil fields is large as well, c.a. 1400Mt of CO_2. The main constraint is the availability of the fields for storage given the long oil production of some part of the region, e.g. Malaysia. Specific field level studies are required to firm up the storage capacity.

Table 22: Storage resource in oil and gas fields in Southeast Asia

	Storage resource (Mt CO_2)
Oil fields	1400
Gas fields	38100
Total	**39500**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.7.3. Qualitative source-sink matching in Southeast Asia

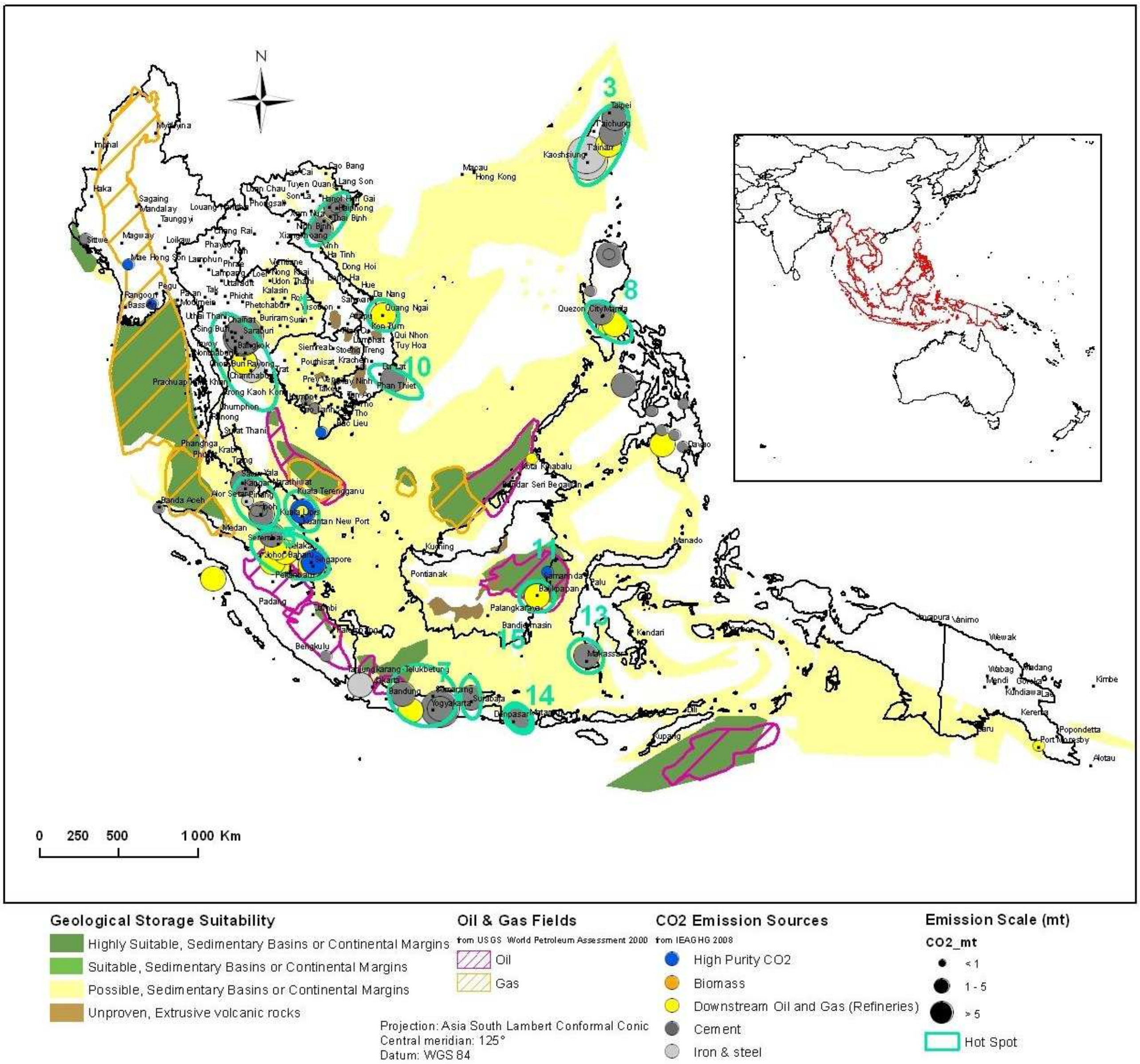


Figure 61: Storage suitability, annual CO_2 emissions and hotspots in Southeast Asia

Table 23: Identified hotspots in Southeast Asia

hotspot		Cement		Downstream Oil and Gas		High Purity CO$_2$		Iron & steel		**Total**	
		number of sources	emission (Mt CO$_2$)	number of sources	emission (Mt CO$_2$)	number of sources	emission (Mt CO$_2$)	number of sources	emission (Mt CO$_2$)	number of sources	emission (Mt CO$_2$)
2007	1	6	27.50	2	3.62	0	0.0	2	2.83	10	33.9
	2	3	2.55	0	0.00	0	0.0	0	0.00	3	2.5
	3	4	9.90	2	3.01	0	0.0	2	17.53	8	30.4
	4	4	4.22	0	0.00	0	0.0	2	0.69	6	4.9
	5	1	1.73	11	18.11	4	4.4	0	0.00	16	24.3
	6	0	0.00	1	0.39	3	2.8	0	0.00	4	3.2
	7	4	9.78	1	3.35	0	0.0	0	0.00	5	13.1
	8	5	2.43	2	2.54	1	0.8	0	0.00	8	5.8
	9	0	0.00	1	1.25	0	0.0	0	0.00	1	1.3
	10	1	1.34	0	0.00	0	0.0	0	0.00	1	1.3
	11	0	0.00	1	2.32	0	0.0	0	0.00	1	2.3
	12	1	2.75	0	0.00	0	0.0	0	0.00	1	2.8
	13	1	2.69	0	0.00	0	0.0	0	0.00	1	2.7
	14	1	2.75	0	0.00	0	0.0	0	0.00	1	2.8
	15	1	3.33	0	0.00	0	0.0	0	0.00	1	3.3
2050	1	6	65.17	2	5.29	0	0.00	2	6.39	10	76.8
	2	3	6.04	0	0.00	0	0.00	0	0.00	3	6.0
	3	4	23.46	2	4.39	0	0.00	2	39.63	8	67.5
	4	4	10.01	0	0.00	0	0.00	2	1.56	6	11.6
	5	1	4.10	11	26.44	4	11.43	0	0.00	16	42.0
	6	0	0.00	1	0.56	3	7.18	0	0.00	4	7.7
	7	4	23.16	1	4.89	0	0.00	0	0.00	5	28.1
	8	5	5.76	2	3.71	1	2.07	0	0.00	8	11.5
	9	0	0.00	1	1.83	0	0.00	0	0.00	1	1.8
	10	1	3.19	0	0.00	0	0.00	0	0.00	1	3.2
	11	0	0.00	1	3.39	0	0.00	0	0.00	1	3.4
	12	1	6.53	0	0.00	0	0.00	0	0.00	1	6.5
	13	1	6.36	0	0.00	0	0.00	0	0.00	1	6.4
	14	1	6.53	0	0.00	0	0.00	0	0.00	1	6.5
	15	1	7.89	0	0.00	0	0.00	0	0.00	1	7.9

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 17 hotspots (Figure 61 orTable 23) which represent 88 percent of the emissions of the industry sector. They involve all the industry sectors in the country (Figure 62). There expected growth is highlighted in Figure 63. The number 1, 3 and 5 are expected to grow significantly (Figure 63). Hotspot number 1 and 15 are important as hotspot number 1 is the largest in 2007 and expected to be the second largest in 2050 (Figure 63).
Several large emission sources are also interesting hotspots, numbers 6, 7 and 8.

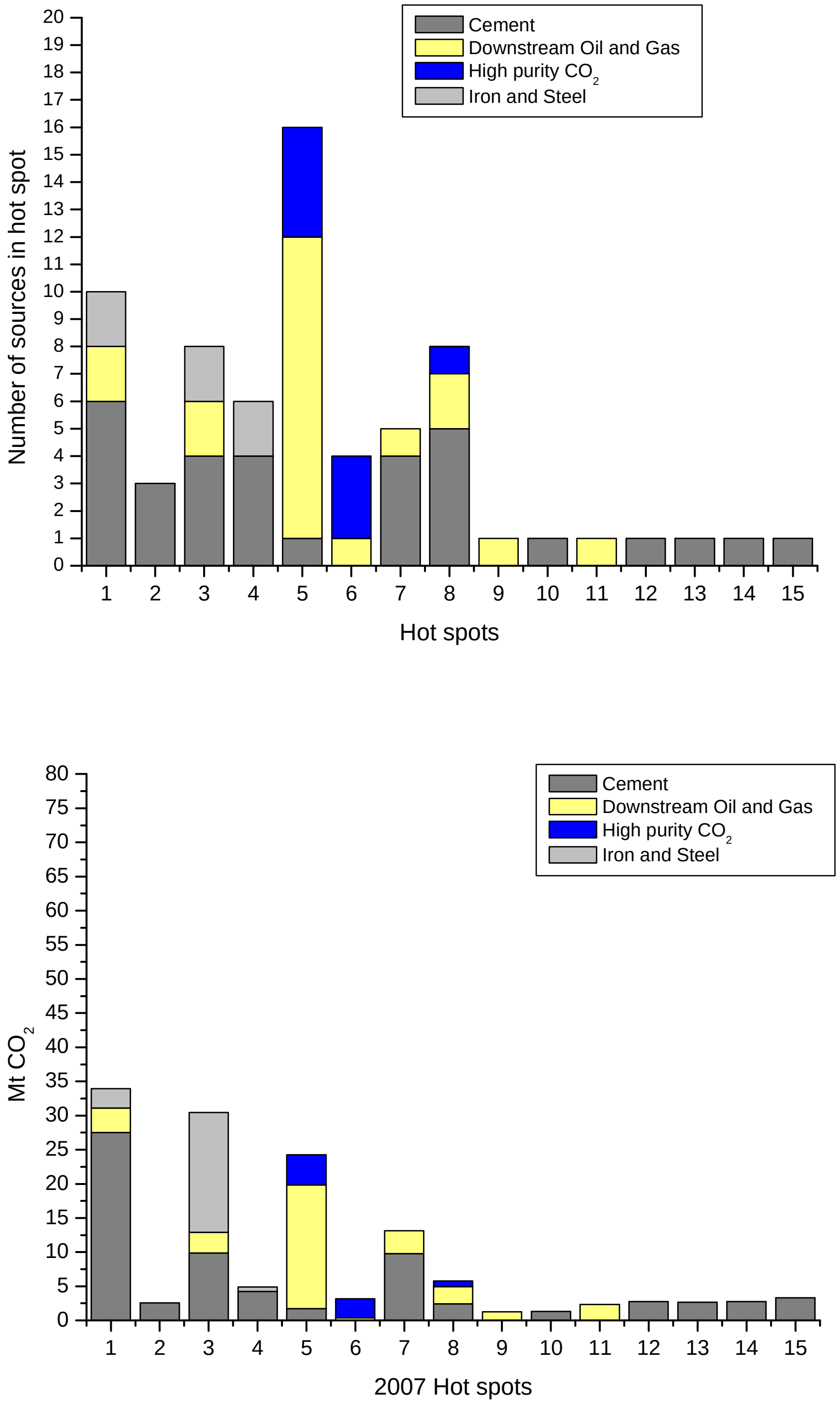


Figure 62: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Southeast Asia

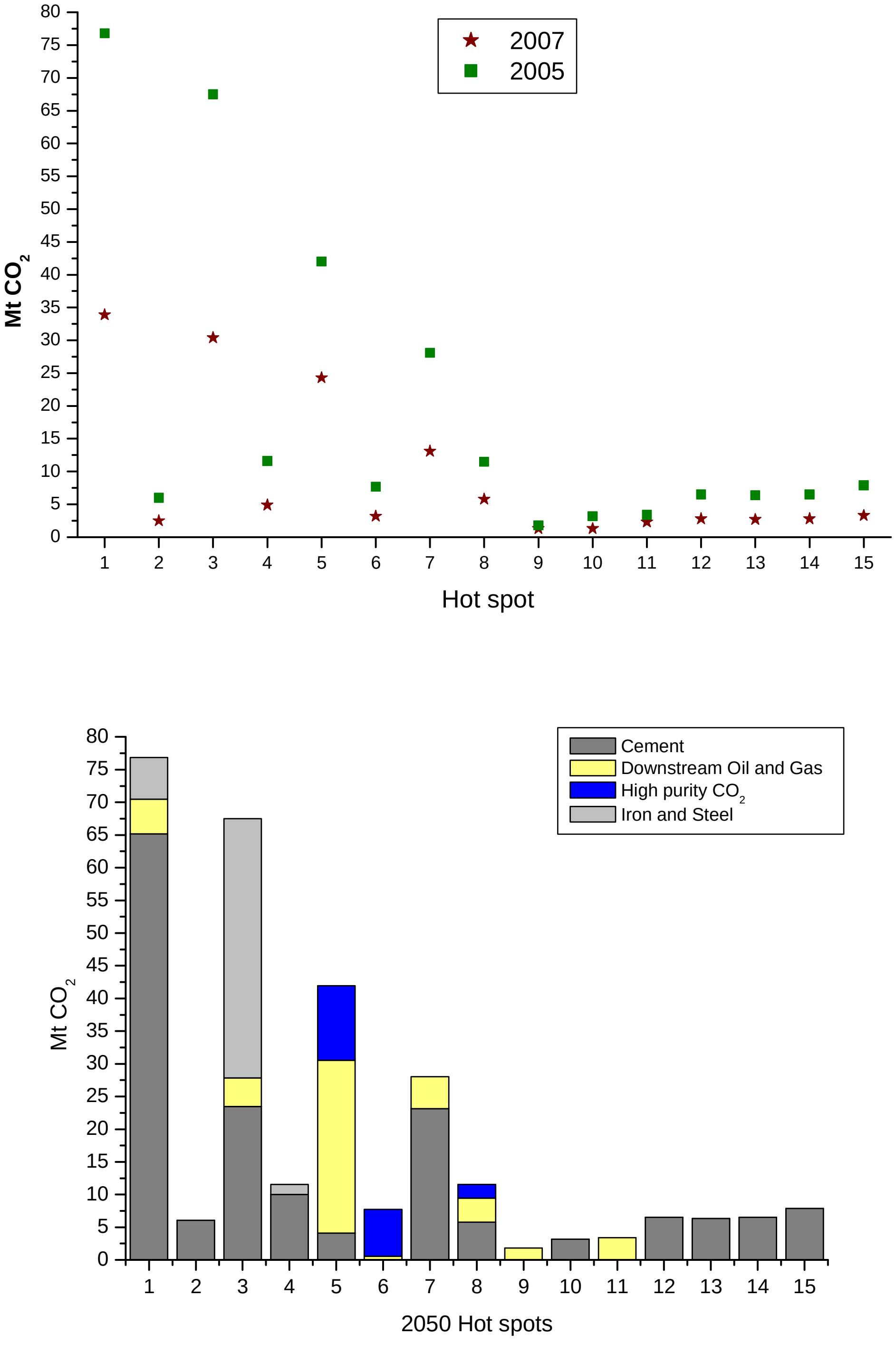


Figure 63: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Southeast Asia

Early opportunities

As most of the highly suitable storage is offshore (Figure 59), the coastal hotspots are the early opportunities for CCS deployment in particular hotspot numbered 5, 6 and 11 as long as the Offshore Deep saline formation suitability is confirmed through geologic characterization. The interesting emission sources are the hotspot 5 and 6 for their high purity CO_2 sectors. The other hotspot might emerge as later on opportunities if the further characterization is carried out. Table 24 summarizes the proposed early opportunities which account for 16 percent of the region emissions from industry at about 53Mt/y of CO_2 in 2050.

Table 24: Qualitative source sink matching on the CO_2 sources in Southeast Asia

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
5	16	42
6	4	8
11	1	3
Total	**21**	**53**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in Southeast Asia, a competitive characterization should be initiated for the Oil and gas fields but also for the deep saline formation. Each of the identified storage resource need site specific study to unlash the storage capacity.

A.7.4. Synthesis and recommendations for Southeast Asia

The earliest opportunity is the hotspot 6 (near Dungun, Malaysia) considering the CO_2 purity and location with respect to offshore highly suitable deep saline formations or oil and gas fields. A promising target is hotspot 11 (offshore Balikpapan, Indonesia) where oilfields may be available for storage capacity or EOR when considering CO_2 volume available. Obviously, hotspot 5 (near Singapore) with offshore saline aquifer is an attractive early opportunity as long as the collection network and cross-border CO_2 stream issues are solved.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.

A.8. THE MIDDLE EAST

The CO_2 emissions reported for the Middle East is illustrated in Figure 64. The industry sectors represent 36 percent of the region CO_2 emissions.

In the emission database, it seems the emission of a lot of the power plants in Pakistan seem doubtful as they are surprisingly large.

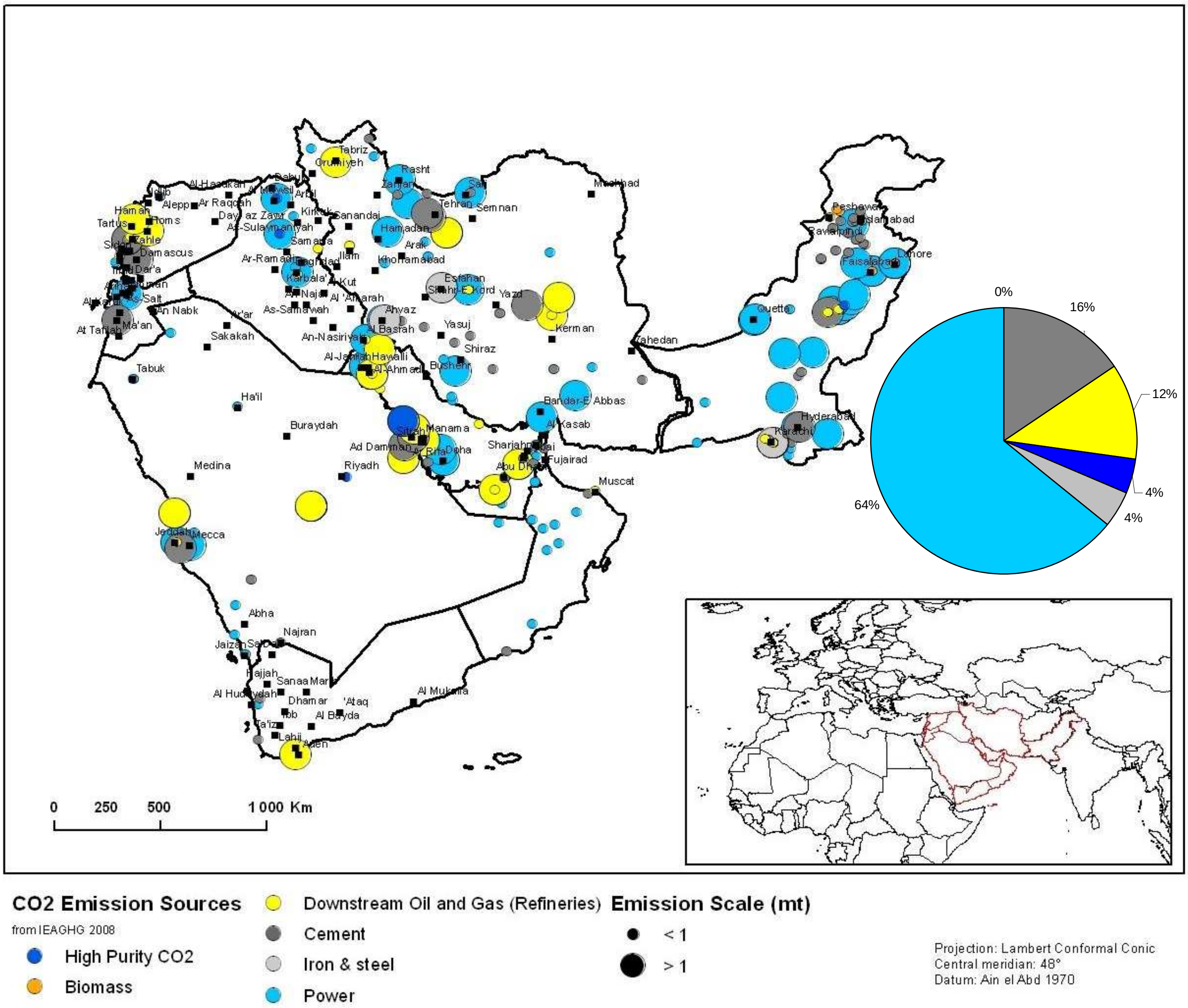


Figure 64: Annual CO_2 emissions in the Middle East

A.8.1. Industrial CO_2 sources in the Middle East

Emissions baseline (2007)

In the Middle East, besides the power industry, the main source of CO_2 emissions is from the cement sector ahead of the downstream oil and gas sector. The cement sector generates about 43 percent of the region emissions from industry while the downstream oil and gas sector generates about 33 percent. These two sectors emit respectively c.a. 55 and 42Mt/y CO_2 out of 128Mt/y CO_2 for the all industry sectors in 2007. Limited biofuel emission, 0.3Mt/y CO_2, is integrated in the data base for the Middle East.

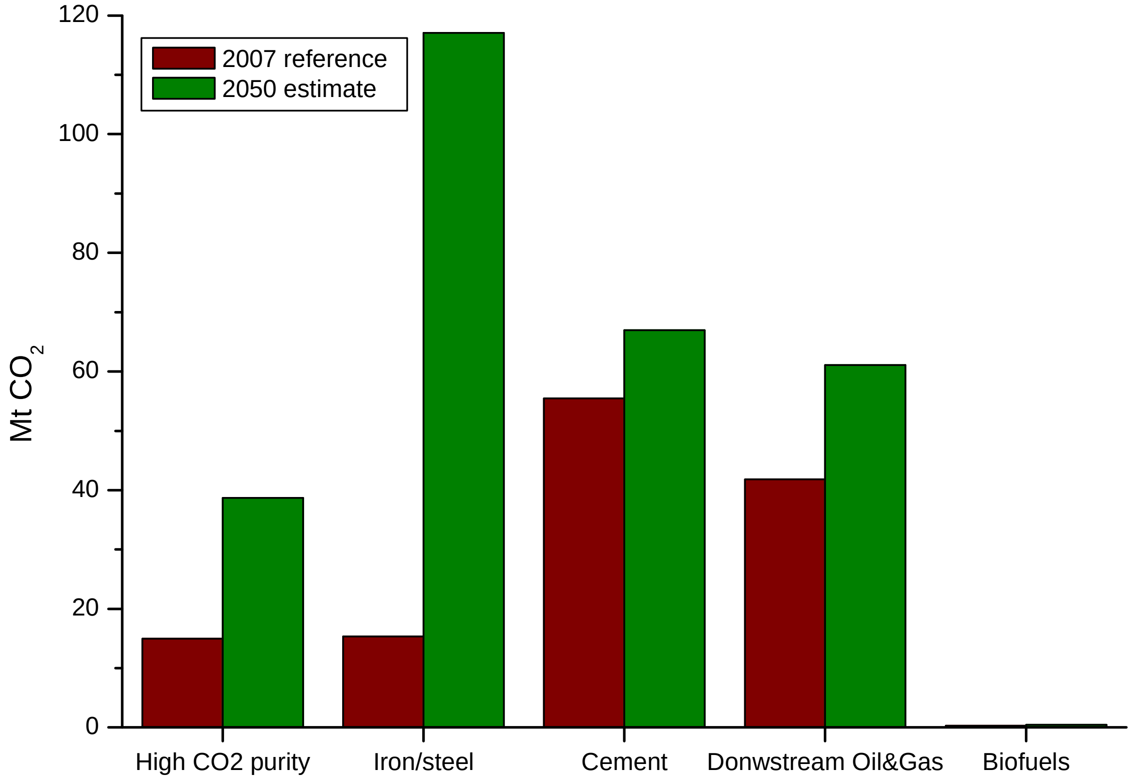


Figure 65: Annual CO_2 emissions and evolution for the industrial sectors in the Middle East

Emissions evolution (by 2050)

At the 2050 horizon, the share of iron and steel sector is expected to increase sharply to represent up to 34 percent of the region emissions from industry (see Figure 65). The Iron and Steel sector is expected to strongly increase from c.a. 15Mt/y CO_2 in 2007 to about 114Mt/y CO_2 in 2050. Meanwhile the cement sector is expected to double from 55Mt/y CO_2 in 2007 to 117Mt/y CO_2 in 2050. The CO_2 emissions from industry are expected to grow 160 percent from the 2007 level: from c.a. 130 to 330Mt/y CO_2.

A.8.2. CO_2 storage resources in the Middle East

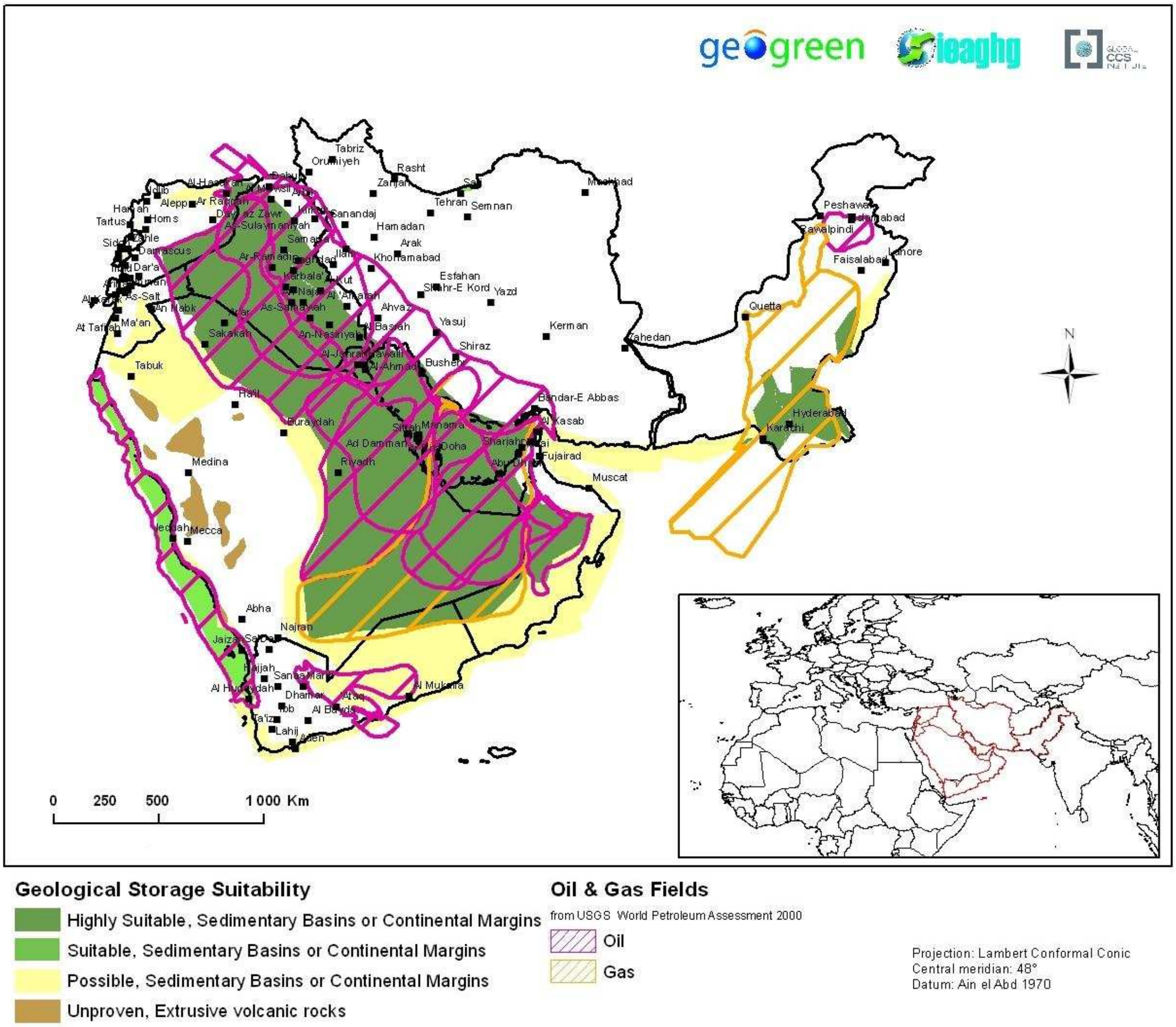


Figure 66: Storage resource in the Middle East: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 67). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4).

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 67 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

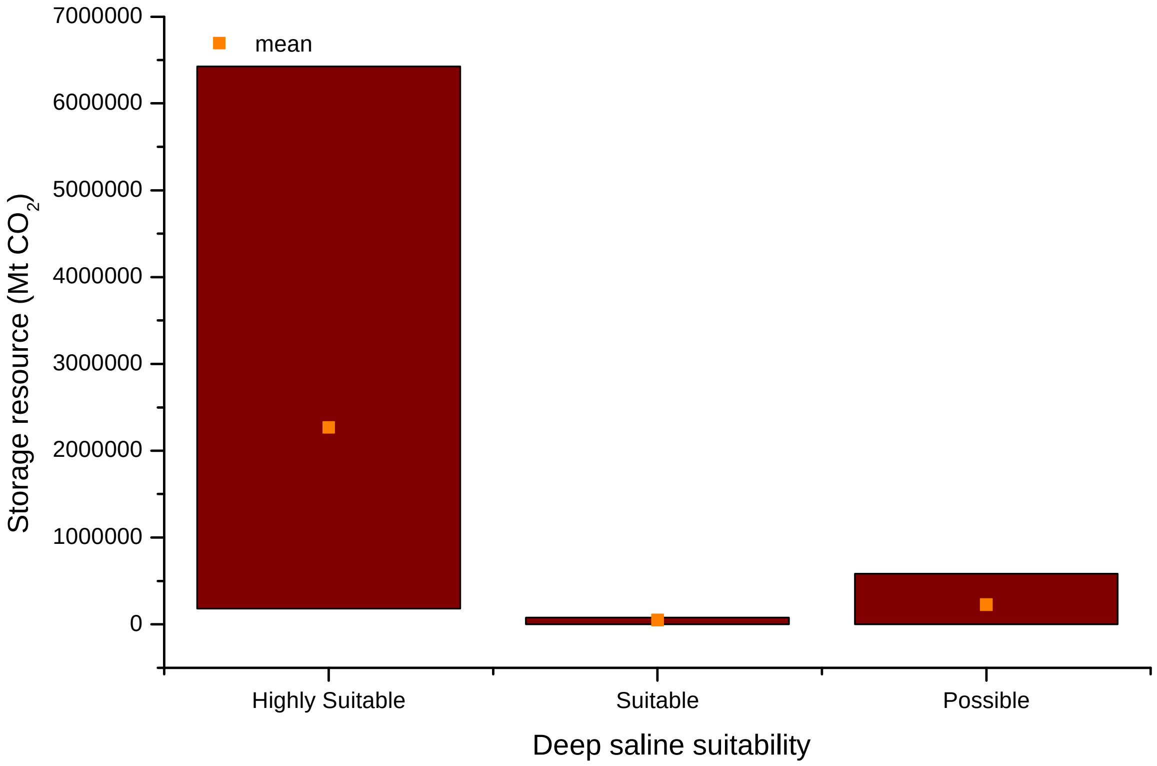


Figure 67: Estimated storage resources in deep saline formations in the Middle East

Oil and gas fields

Large storage resource may be identified onshore or offshore in the region. The main storage resource is estimated to be in the gas field. The storage capacity in Oil fields is quite large as well, c.a. 38700Mt of CO_2. The main constraint is the availability of the fields for storage given the long oil production of the region. Specific field level studies are required to firm up the storage capacity.

Table 25: Storage resource in oil and gas fields in the Middle East

	Storage resource (Mt CO_2)
Oil fields	38700
Gas fields	173100
Total	**211800**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.8.3. Qualitative source-sink matching in the Middle East

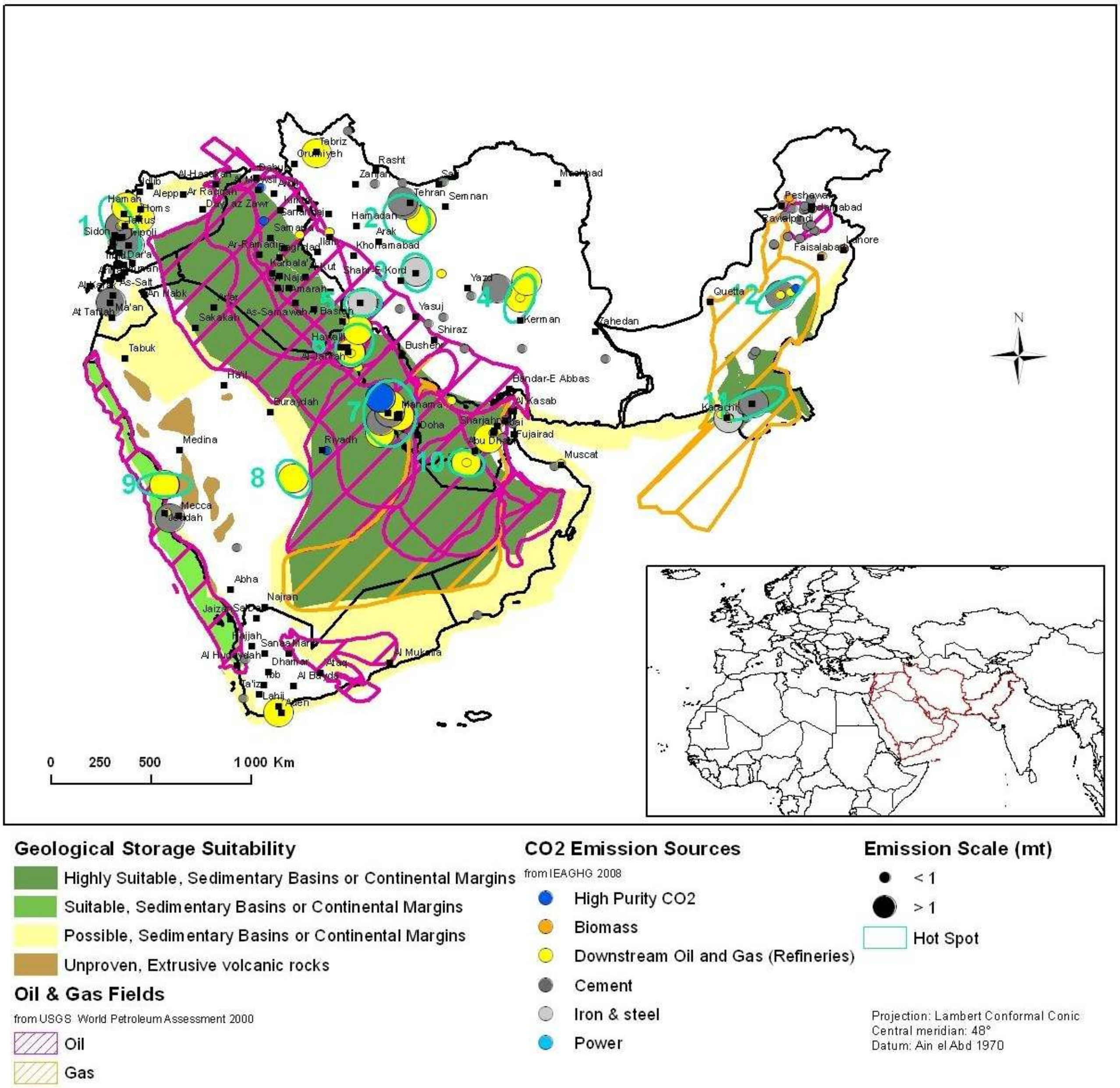


Figure 68: Storage suitability, annual CO_2 emissions and hotspots in the Middle East

Table 26: Identified hotspots in the Middle East

hotspot		Biomass		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	annual emission (Mt CO_2)	number of sources	annual emission (Mt CO_2)	number of sources	annual emission (Mt CO_2)	number of sources	annual emission (Mt CO_2)	number of sources	annual emission (Mt CO_2)	number of sources	annual emission (Mt CO_2)
2007	1	0	0	10	6.42986	2	0.361238	0	0	0	0	12	6.8
	2	0	0.00	4	5.83	2	2.34	0	0.00	0	0.00	6	8.2
	3	0	0.00	0	0.00	0	0.00	0	0.00	2	5.99	2	6.0
	4	0	0.00	1	0.78	4	4.32	1	0.56	0	0.00	6	5.7
	5	0	0.00	1	0.75	0	0.00	0	0.00	1	2.26	2	3.0
	6	0	0.00	0	0.00	3	6.24	2	1.93	0	0.00	5	8.2
	7	0	0.00	4	4.39	4	8.60	3	9.26	0	0.00	11	22.2
	8	0	0.00	1	1.98	2	1.56	0	0.00	0	0.00	3	3.5
	9	0	0.00	1	1.97	1	3.13	0	0.00	0	0.00	2	5.1
	10	0	0.00	0	0.00	2	1.54	1	1.37	0	0.00	3	2.9
	11	7	0.18	11	3.64	4	2.12	0	0.00	2	7.10	24	13.0
	12	0	0.00	2	2.13	2	0.88	1	0.21	0	0.00	5	3.2
2050	1	0	0.00	10	13.57	2	0.53	0	0.00	0	0.00	12	14.1
	2	0	0.00	4	12.31	2	3.42	0	0.00	0	0.00	6	15.7
	3	0	0.00	0	0.00	0	0.00	0	0.00	2	44.43	2	44.4
	4	0	0.00	1	1.65	4	6.30	1	1.46	0	0.00	6	9.4
	5	0	0.00	1	1.58	0	0.00	0	0.00	1	16.76	2	18.3
	6	0	0.00	0	0.00	3	9.12	2	5.00	0	0.00	5	14.1
	7	0	0.00	4	9.26	4	12.56	3	23.96	0	0.00	11	45.8
	8	0	0.00	1	4.18	2	2.28	0	0.00	0	0.00	3	6.5
	9	0	0.00	1	4.15	1	4.57	0	0.00	0	0.00	2	8.7
	10	0	0.00	0	0.00	2	2.25	1	3.55	0	0.00	3	5.8
	11	7	0.30	11	7.68	4	3.09	0	0.00	2	52.59	24	63.7
	12	0	0.00	2	4.49	2	1.28	1	0.54	0	0.00	5	6.3

Source: 2007 emissions from IEAGHG

Hotspots

Given the storage resource in oil and gas fields, these resources will be the main focus for CCS project in the region.

Most of the largest sources may be integrated into 12 hotspots (Figure 68 or Table 26) which represent 81 percent of the emissions of the industry sector from the region. They involve all the industry sectors in the country (Figure 69). There expected growth is highlighted in Figure 70. The number 3, 7 and 11 are expected to grow significantly (Figure 70). The biomass represents a tiny fraction of the region CO_2 emissions or expected emission in 2050.

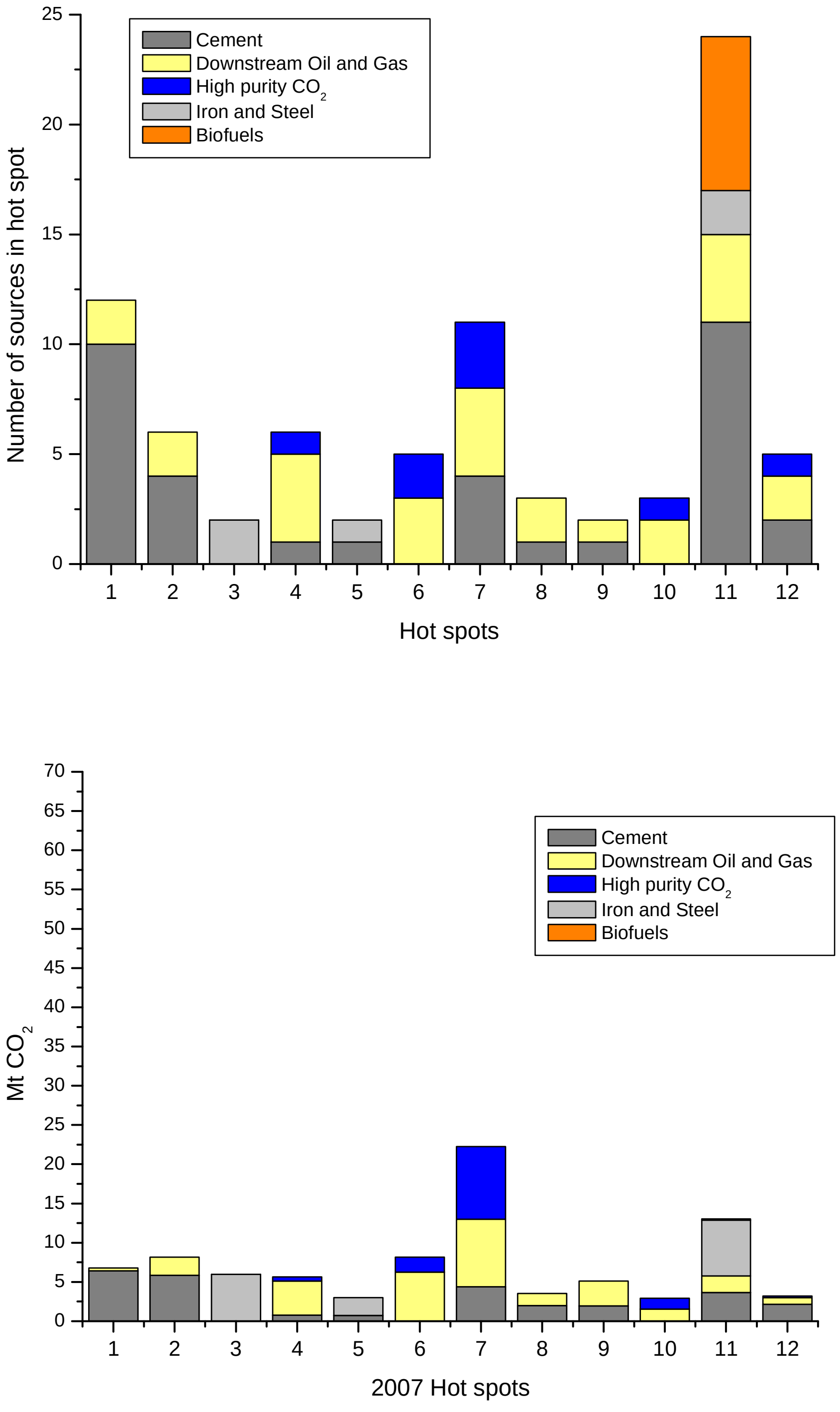
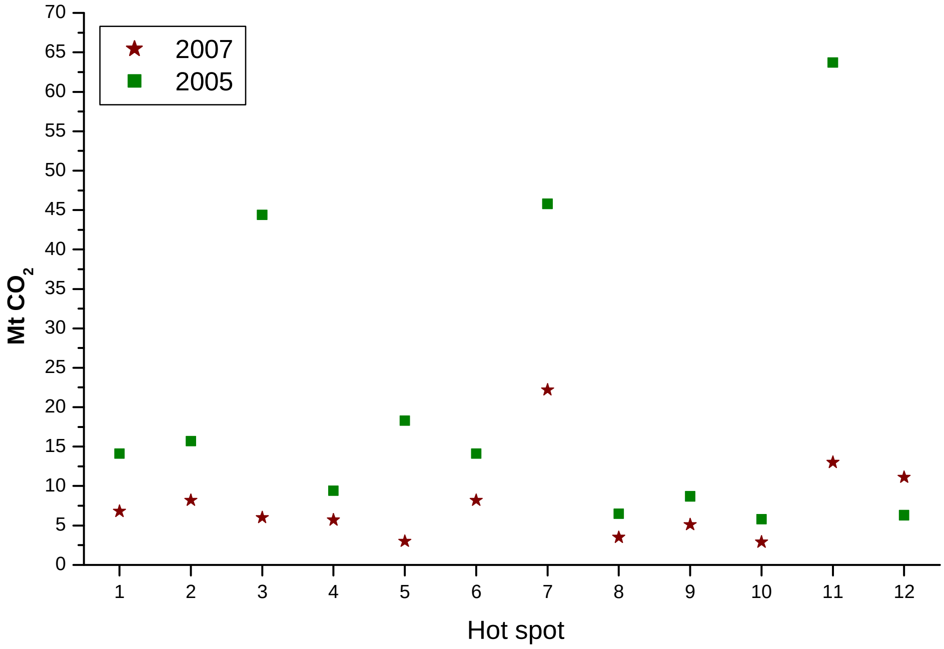


Figure 69: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in the Middle East



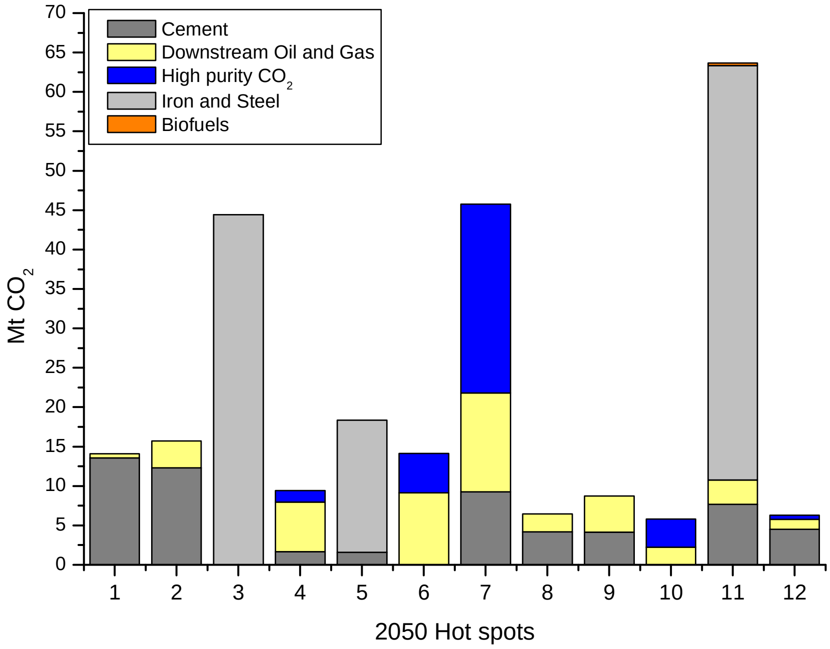


Figure 70: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in the Middle East

Early opportunities

As most of the highly suitable storage covers the oil basin of the region (Figure 68), the early opportunities are obviously the hotspot with the largest high purity CO_2 sector such as hotspot 6, 7, and 10. Their emissions may be use for CO_2-EOR if the field level studies confirm the potential. Other early opportunities will still be associated with storage or CO_2-EOR in oilfields around hotspot 5 and 9 given their location. Finally, link to storage resource in gas field, hotspot number 1à and 11 are early opportunities as well (Figure 68). Should additional storage be confirmed e.g. deep saline formation, hotspot 8 may become at a later stage and opportunity.

Table 27 summarizes the proposed early opportunities which account for 46 percent of the region emissions from industry at about 151Mt/y of CO_2.

Table 27: Qualitative source sink matching in 2050 on the CO_2 sources in the Middle East

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
5	2	18
6	5	14
7	11	42
9	2	7
10	3	6
11	24	60
12	5	4
Total	**52**	**151**

Bottlenecks

To enable the development of the CCS projects in the Middle East, site specific EOR study must be carried out and discussion between the industry sector and oil and gas production must be initiated such as the on-going Masdar CCS initiative in the United Arab Emirates.

A.8.4. Synthesis and recommendations for the Middle East

The oil-rich region is a primary target for the earliest opportunities link to CO_2-EOR if the site specific studies confirm the storage capacity and the economic interest of such an injection scheme in the Middle East.

Early opportunities in Abu Dhabi is already underway (hotspot 7 – Masdar CCS project) which is a large scale integration between industrial CO_2 emitters and oil and gas producer.
However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry and the region may evolve towards a storing place once the oil production ceased.

A.9. CENTRAL AFRICA

The CO_2 emissions reported for Central Africa is illustrated in Figure 71. The industry sectors represent 51 percent of the region CO_2 emissions

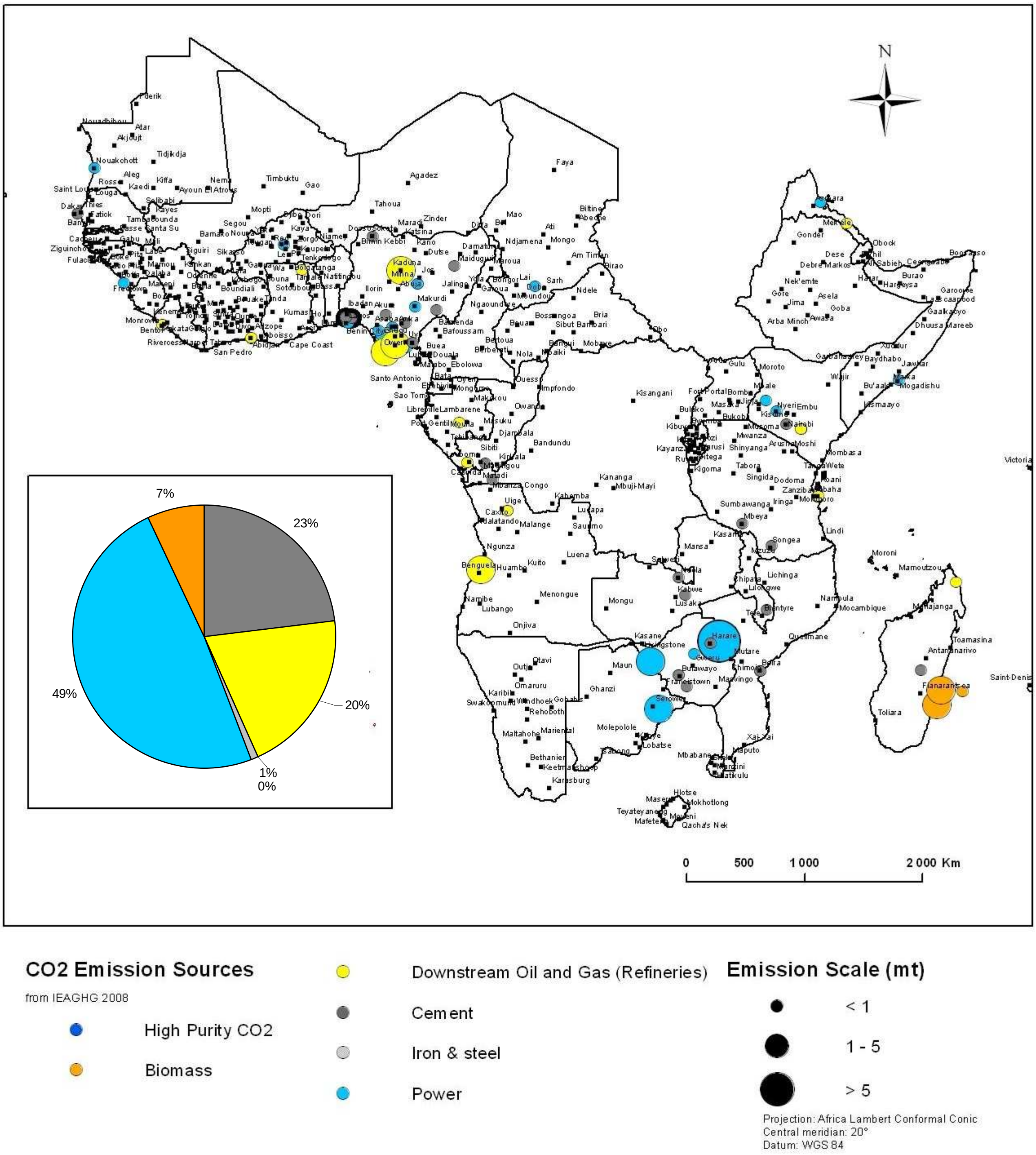


Figure 71: Annual CO_2 emissions in Central Africa

A.9.1. Industrial CO_2 sources in Central Africa

Emissions baseline (2007)

In Central Africa, besides the power industry, the main sources of CO_2 emissions are from the downstream oil and gas and cement sectors. The downstream oil and gas sector generates about 20 percent of the region emissions from industry while the cement sector represents 23 percent of the region emissions from industry, c.a. respectively 9 and 10Mt/y CO_2 for the two sectors out of 23Mt/y CO_2 for the all industry sectors in 2007. The emission from the biomass sector exist are significant with emissions of about 3Mt/y CO_2 for Central Africa all located in Madagascar.

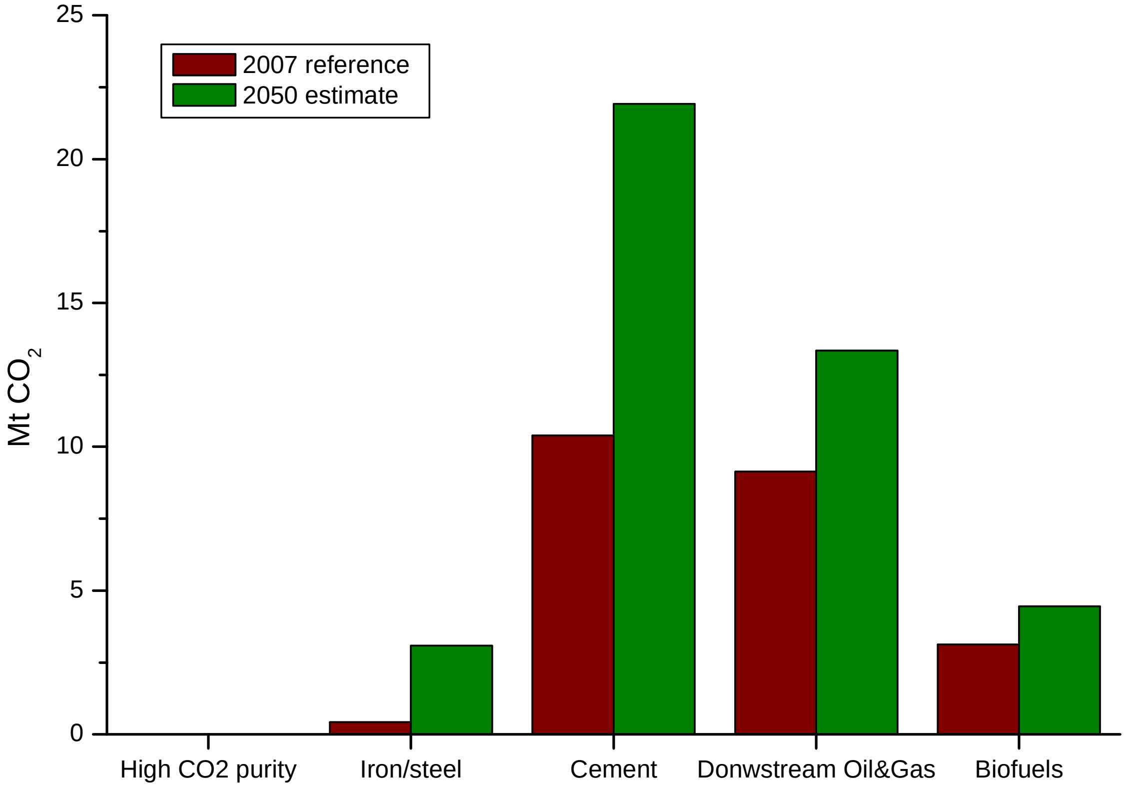


Figure 72: Annual CO_2 emissions and evolution for the industrial sectors in Central Africa

Emissions evolution (by 2050)

At the 2050 horizon, the share of downstream oil and gas sector is expected to increase up to 31 percent of the region emissions from industry (see Figure 72). The cement sector on the other hand is expected to increase to c.a. 50 percent of the CO_2 emissions from industry up to 22Mt/y CO_2 in 2050. The CO_2 emissions from industry are expected to grow 89 percent from the 2007 level: from c.a. 20 to 43Mt/y CO_2.

A.9.2. CO_2 storage resources in Central Africa

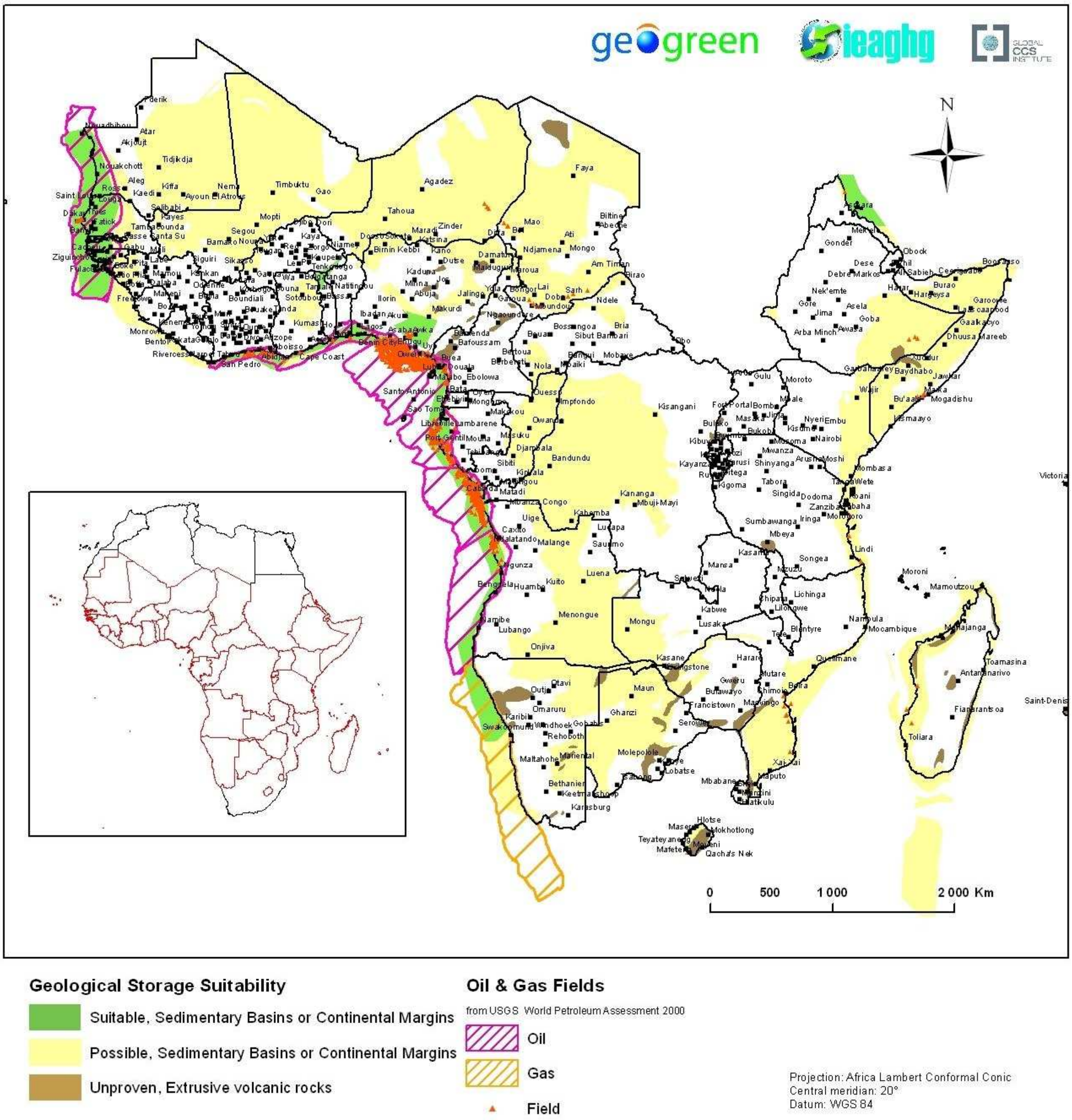


Figure 73: Storage resource in Central Africa: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 74). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4). There is a large uncertainty associated with these numbers as illustrated in Figure 74.

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 74 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

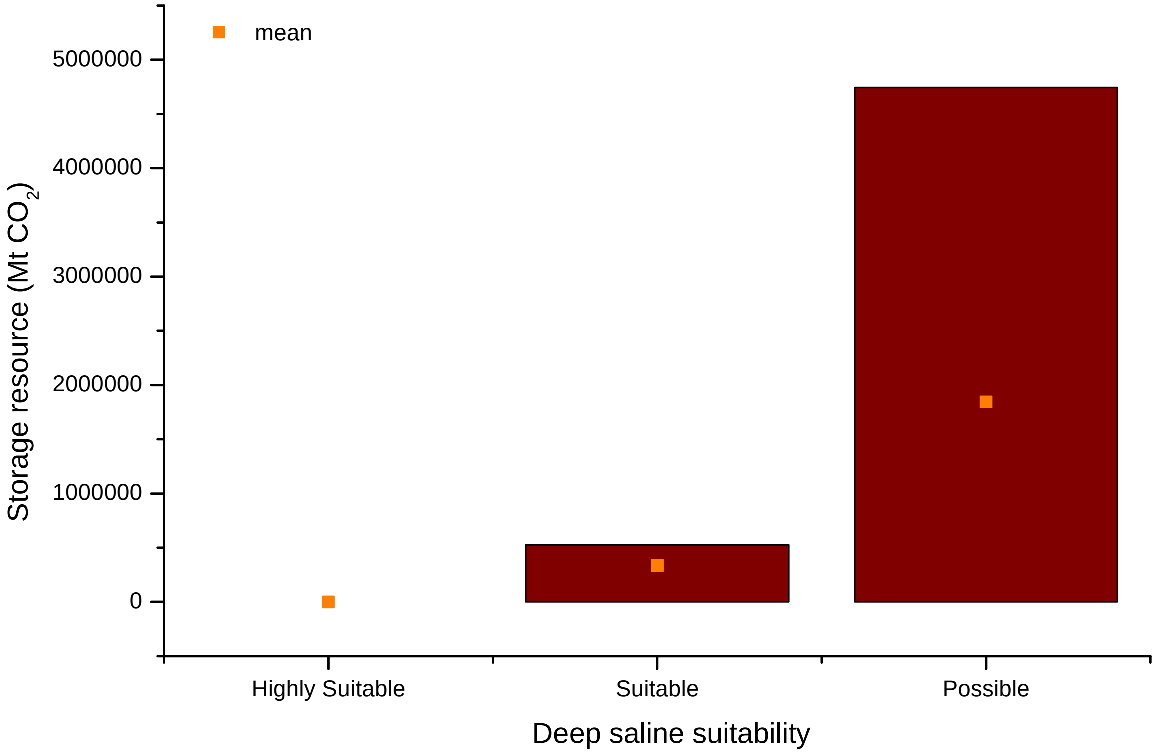


Figure 74: Estimated storage resources in deep saline formations in Central Africa

Oil and gas fields

The major storage resource is estimated to be in the gas field. The storage capacity in oilfields is large as well, c.a. 4800Mt of CO_2. The main constraint is the availability of the fields for storage given the long oil production of some part of the region, e.g. Angola, Gabon, Nigeria. Specific field level studies are required to firm up the storage capacity.

Table 28: Storage resource in oil and gas fields in Central Africa

	Storage resource (Mt CO_2)
Oil fields	4800
Gas fields	20100
Total	**24900**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.9.3. Qualitative source-sink matching in Central Africa

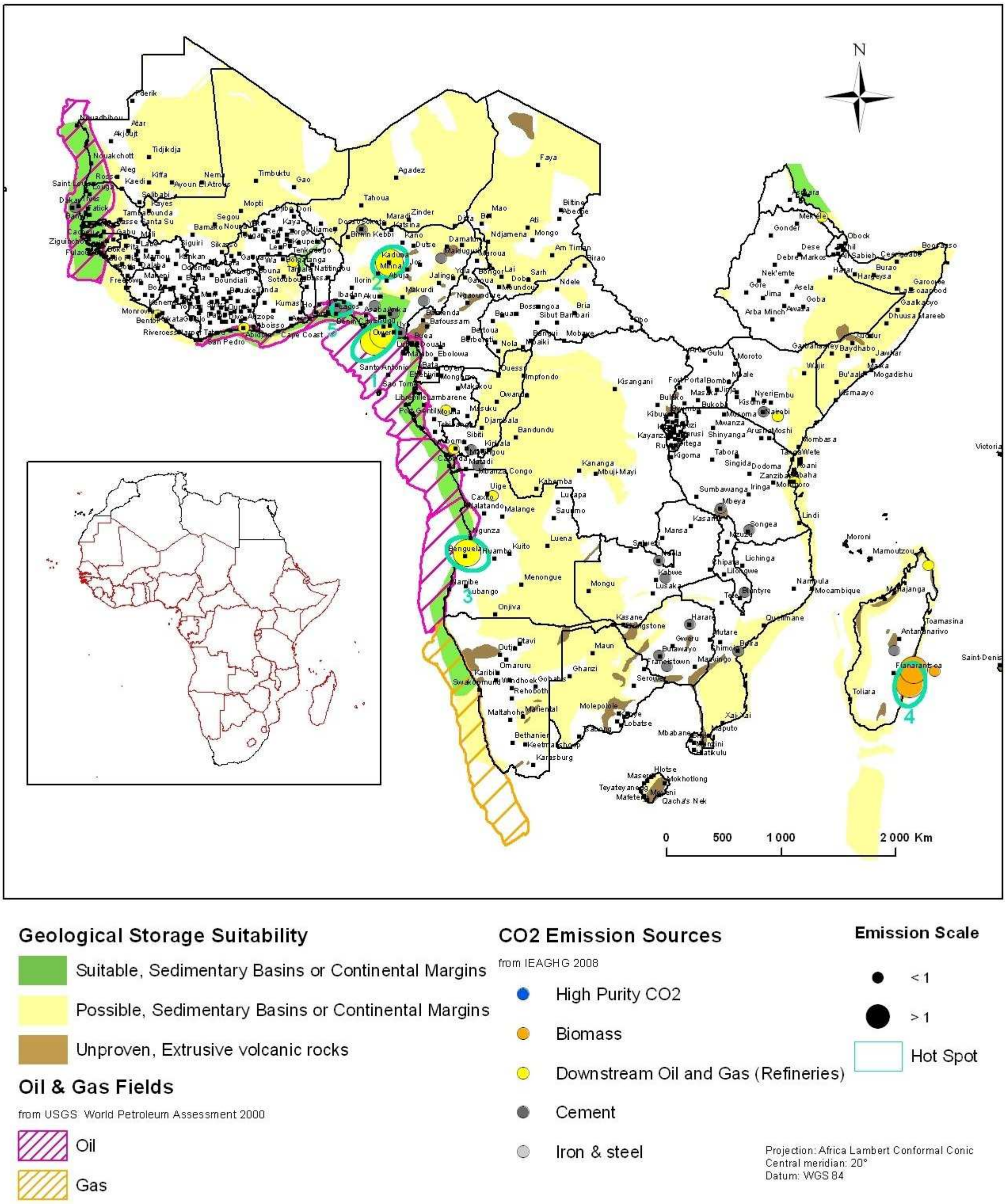


Figure 75: Storage suitability, annual CO_2 emissions and hotspots in Central Africa

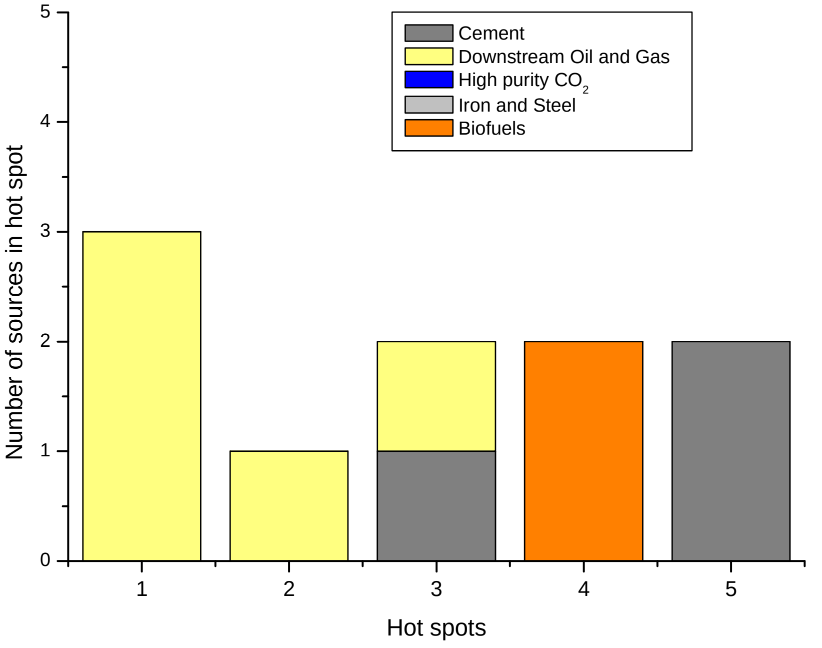
Table 29: Identified hotspots in Central Africa

hotspot		Biomass		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	0	0.00	0	0.00	3	3.17	0	0.0	0	0.00	3	3.2
	2	0	0.00	0	0.00	1	1.06	0	0.0	0	0.00	1	1.1
	3	0	0.00	1	0.27	1	1.93	0	0.0	0	0.00	2	2.2
	4	2	2.92	0	0.00	0	0.00	0	0.0	0	0.00	2	2.9
	15	0	0.00	2	1.40	0	0.00	0	0.0	0	0.00	2	1.4
2050	1	0	0.00	0	0.00	3	4.62	0	0.00	0	0.00	3	4.6
	2	0	0.00	0	0.00	1	1.55	0	0.00	0	0.00	1	1.5
	3	0	0.00	1	0.57	1	2.81	0	0.00	0	0.00	2	3.4
	4	2	4.90	0	0.00	0	0.00	0	0.00	0	0.00	2	4.9
	15	0	0.00	2	2.95	0	0.00	0	0.00	0	0.00	2	3.0

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 5 hotspots (Figure 75 or Table 29) which represent 45 percent of the emissions of the industry sector. They involve either the cement or the downstream oil and gas sectors from the industry sectors in the region (Figure 76). One interesting hotspot is in Biomass sector in Madagascar. The other hotspots are either in Nigeria or Angola. There expected growth is highlighted in Figure 77. The number 1, 3 and 4 are expected to grow significantly (Figure 77).



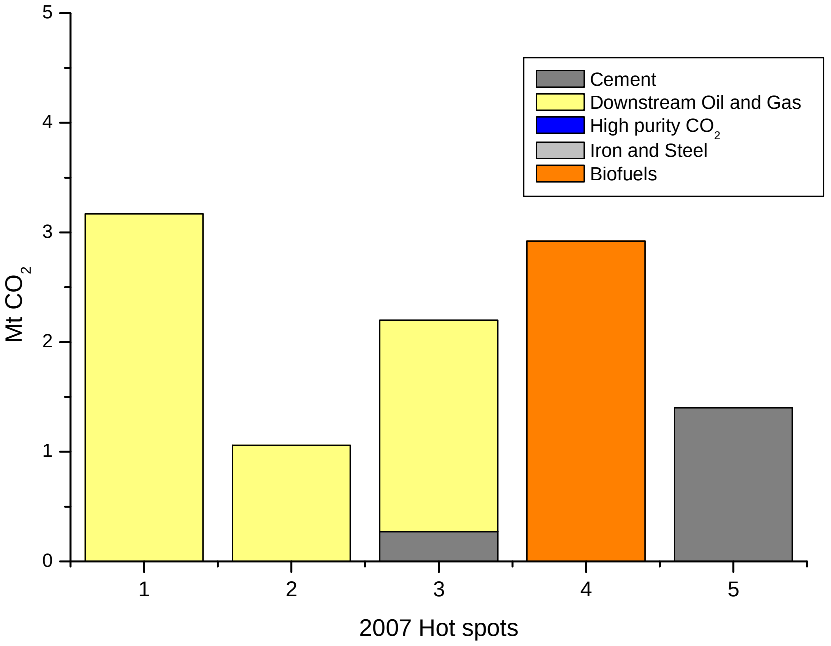
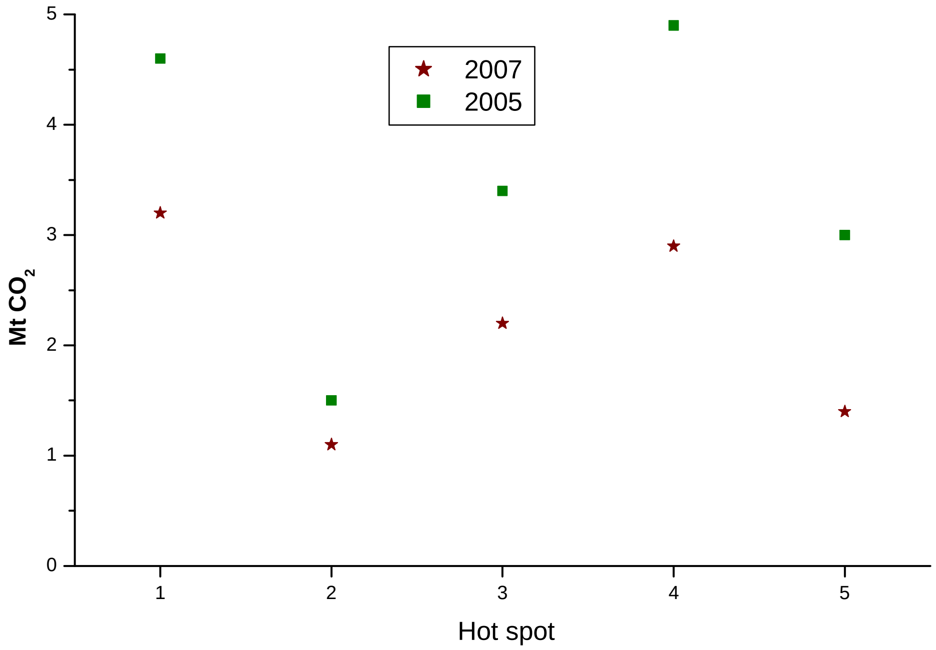


Figure 76: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Central Africa



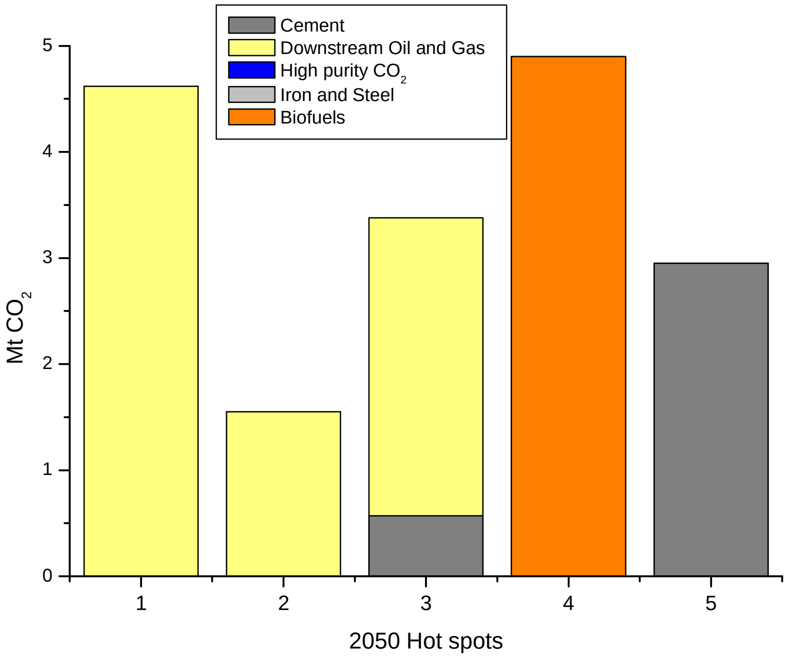


Figure 77: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Central Africa

Early opportunities

As most of the highly suitable storage is offshore (Figure 75), the coastal hotspots are the early opportunities for CCS deployment in particular hotspot numbered 1, 3 and 5 as long as the offshore oilfields are available either for CO_2-EOR or storage.

The other hotspot 2 might emerge as later on opportunities if the further characterization is carried out for the onshore deep saline formation to confirm its suitability through geologic characterization. Table 30 summarizes the proposed early opportunities in 2050 which account for 25 percent of the region emissions from industry at about 10Mt/y of CO_2.

Table 30: Qualitative source sink matching on the CO_2 sources in Central Africa

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
1	3	5
3	2	3
5	2	2
Total	**7**	**10**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in Central Africa access to offshore oilfields is the preferred path given the location of the hotspots along the coast in oil producing region like Angola and Nigeria. However, site specific studies must be undertaken to ensure efficiency of the EOR process.

A.9.4. Synthesis and recommendations for Central Africa

The earliest opportunity is the hotspot 1 (near Port Harcourt, Nigeria) and hotspot number 3 (near Benguela) considering its future growth and location with respect to offshore highly suitable storage link to the offshore oilfields.

Site specific studies must be undertaken to ensure efficiency of the EOR process and storage opportunity in 2050.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.

A.10. NORTHERN AFRICA

The CO_2 emissions reported for South Africa is illustrated in Figure 78. The industry sectors represent 50 percent of the region CO_2 emissions

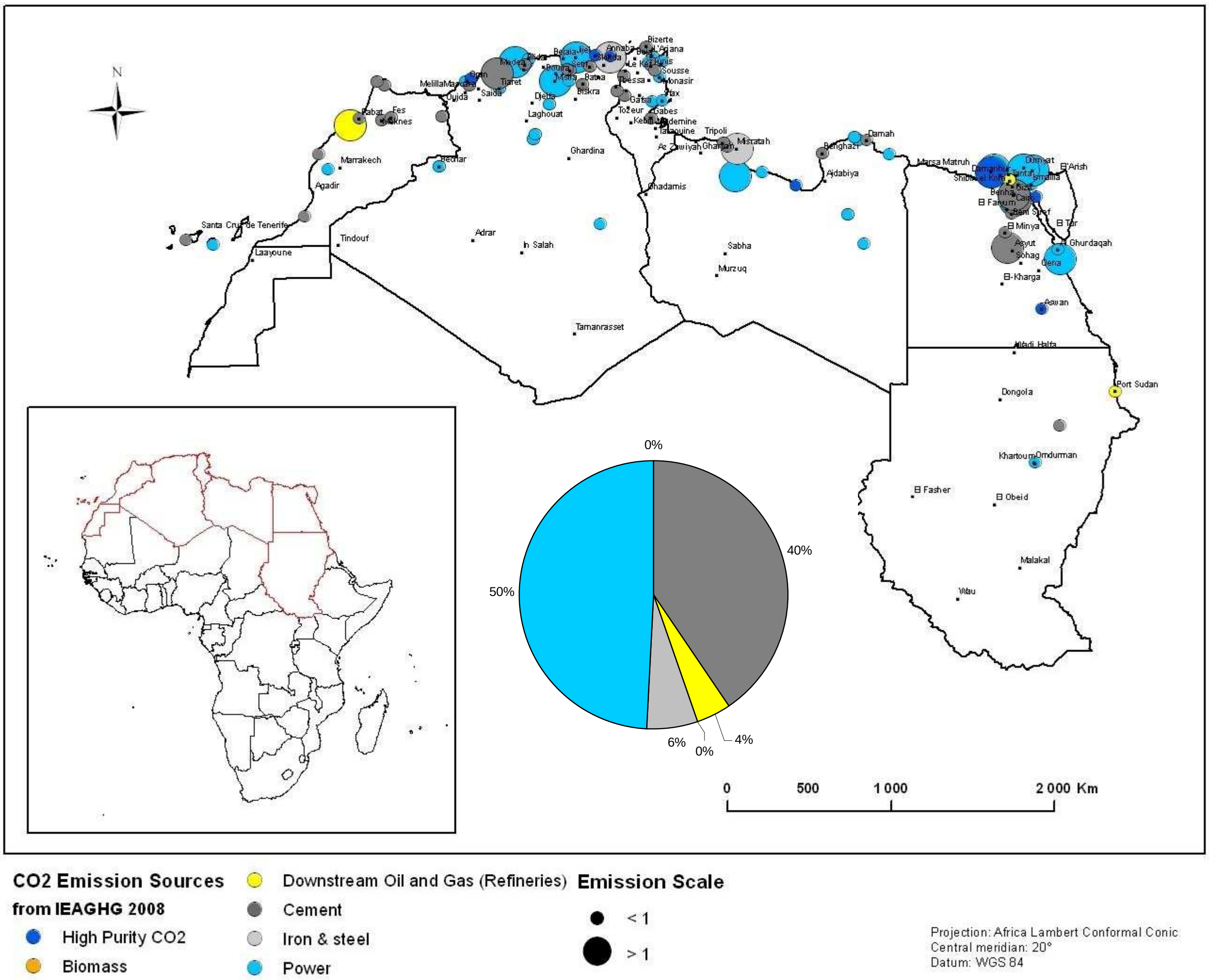


Figure 78: Annual CO_2 emissions in Northern Africa

A.10.1. Industrial CO_2 sources in Northern Africa

Emissions baseline (2007)

In Northern Africa, besides the power industry, the main source of CO_2 emissions is from the cement sector. The cement sector generates about 80 percent of the region emissions from industry, c.a. 37Mt/y CO_2 for the cement sector out of 47Mt/y CO_2 for the all industry sectors in 2007. No biofuel emission is integrated in the data base for Northern Africa.

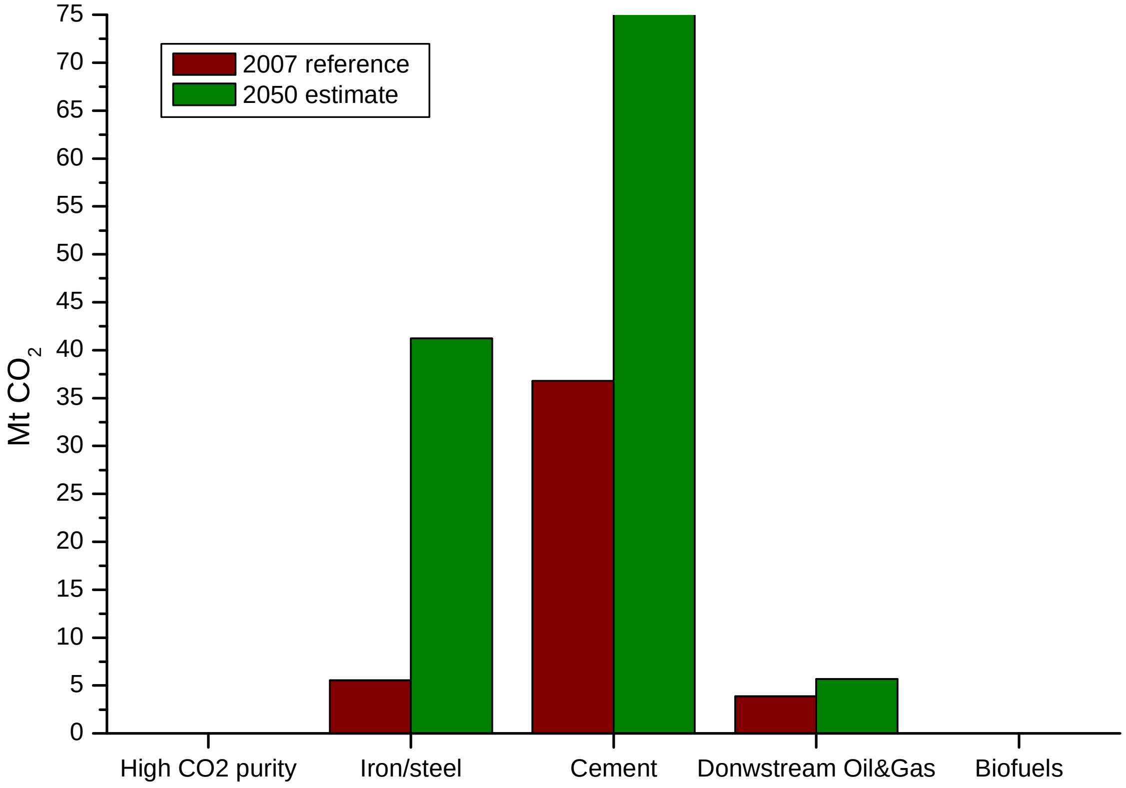


Figure 79: Annual CO_2 emissions and evolution for the industrial sectors in Northern Africa

Emissions evolution (by 2050)

At the 2050 horizon, the share of cement sector is expected to increase up to 78Mt/y CO_2 but the main features is the expected strong increase in emission from the iron and steel sector which is expected to increase 6 fold between 2007 and 2050 levels up to c.a. 41Mt/y CO_2 . In 2050, cement and iron and steel sector are expected to be respectively about 62 and 33 percent of the region emissions from industry (see Figure 79). The CO_2 emissions from industry are expected to grow 170 percent from the 2007 level: from c.a. 46 to 125Mt/y CO_2.

A.10.2. CO_2 storage resources in Northern Africa

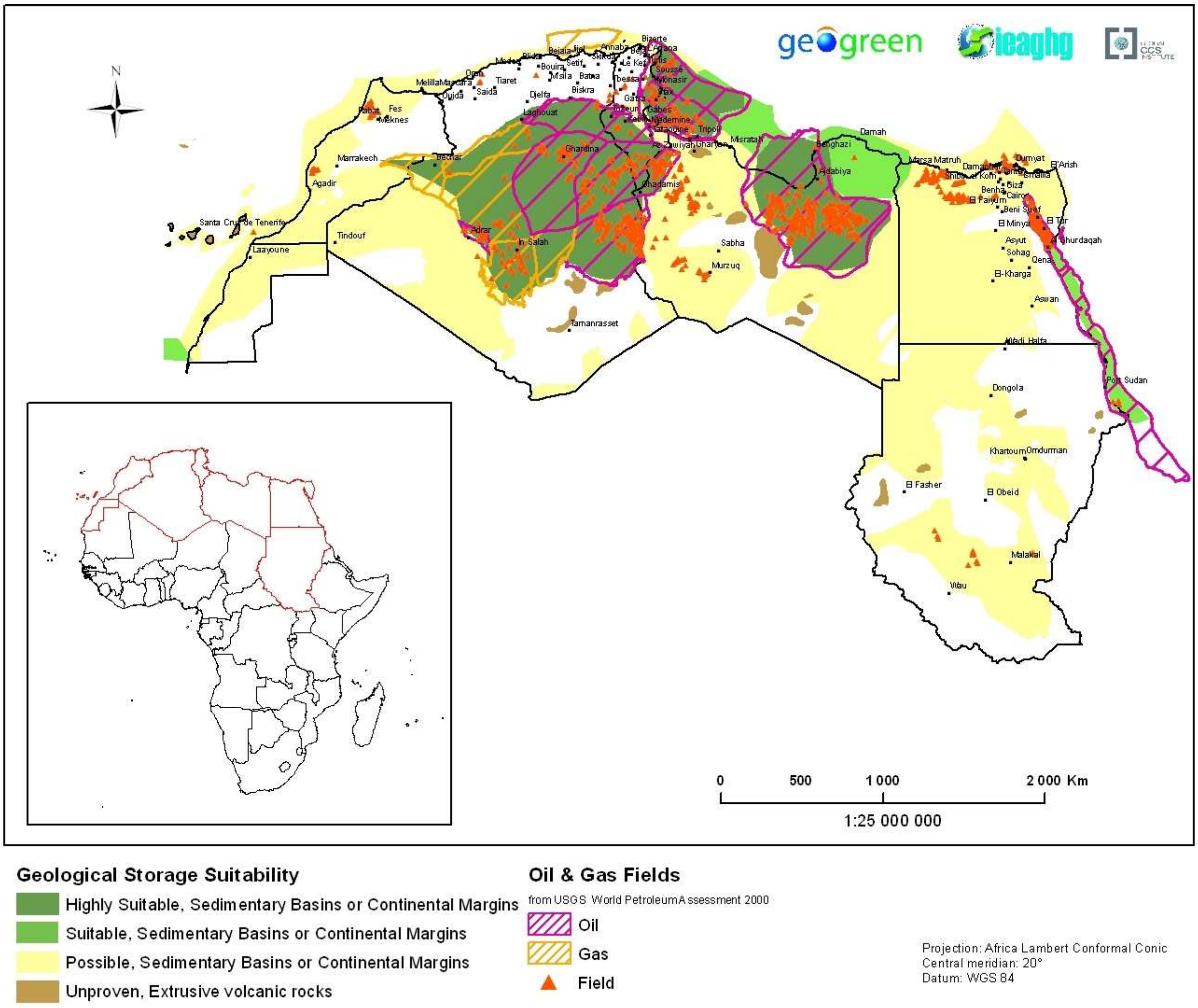


Figure 80: Storage resource in Northern Africa: deep saline formations and oil and gas fields

Deep saline formations

The available storage resource in deep saline formation may be estimated (see Figure 81). When considering the early opportunities or even the opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4).

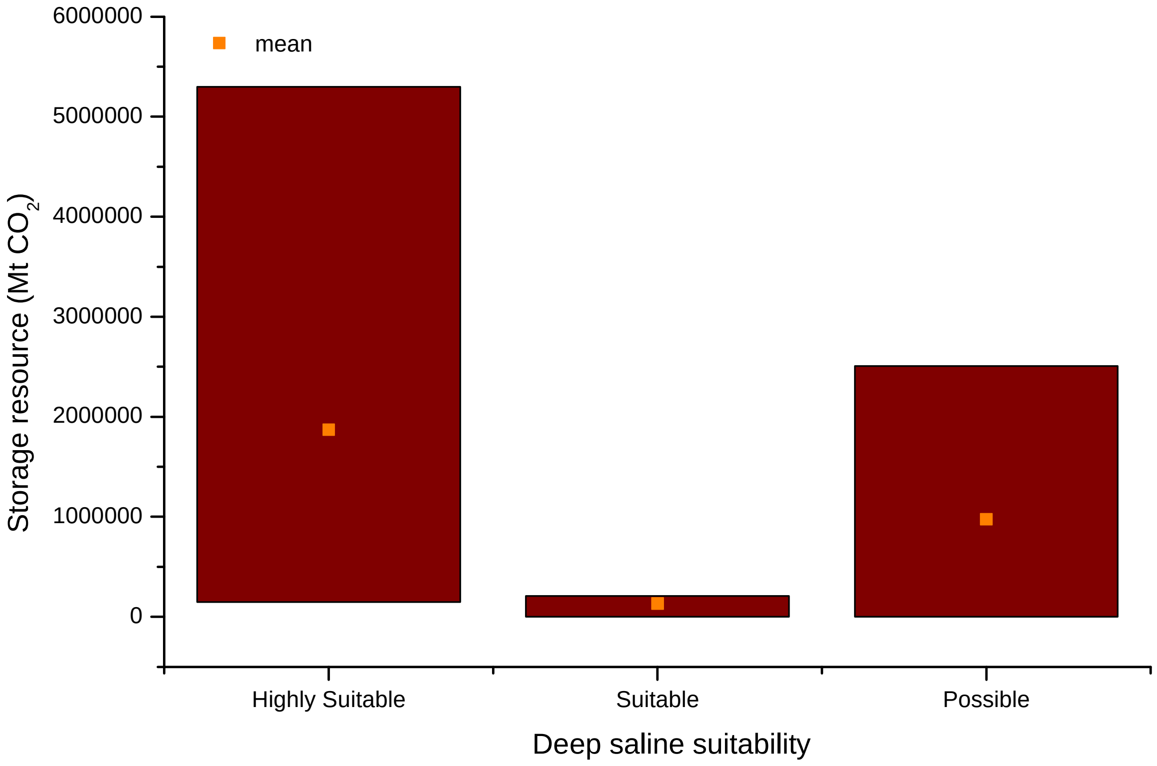


Figure 81: Estimated storage resources in deep saline formations in Northern Africa

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 81 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

Oil and gas fields

The major storage resource is estimated to be in the gas field. The storage capacity in oilfields is large as well, c.a. 4000Mt of CO_2. Most of the storage resource is onshore. The main constraint is the availability of the fields for storage given the long oil production history of some part of the region, e.g. Algeria, Libya. Specific field level studies are required to firm up the storage capacity.

Table 31: Storage resource in oil and gas fields in Northern Africa

	Storage resource (Mt CO_2)
Oil fields	4000
Gas fields	25000
Total	**29000**

One shall note that the oil and gas field storage resources estimates are associated with large uncertainties and required detail reservoir study to estimate the effective storage resources and practical storage capacity (see Figure 4).

A.10.3. Qualitative source-sink matching in Northern Africa

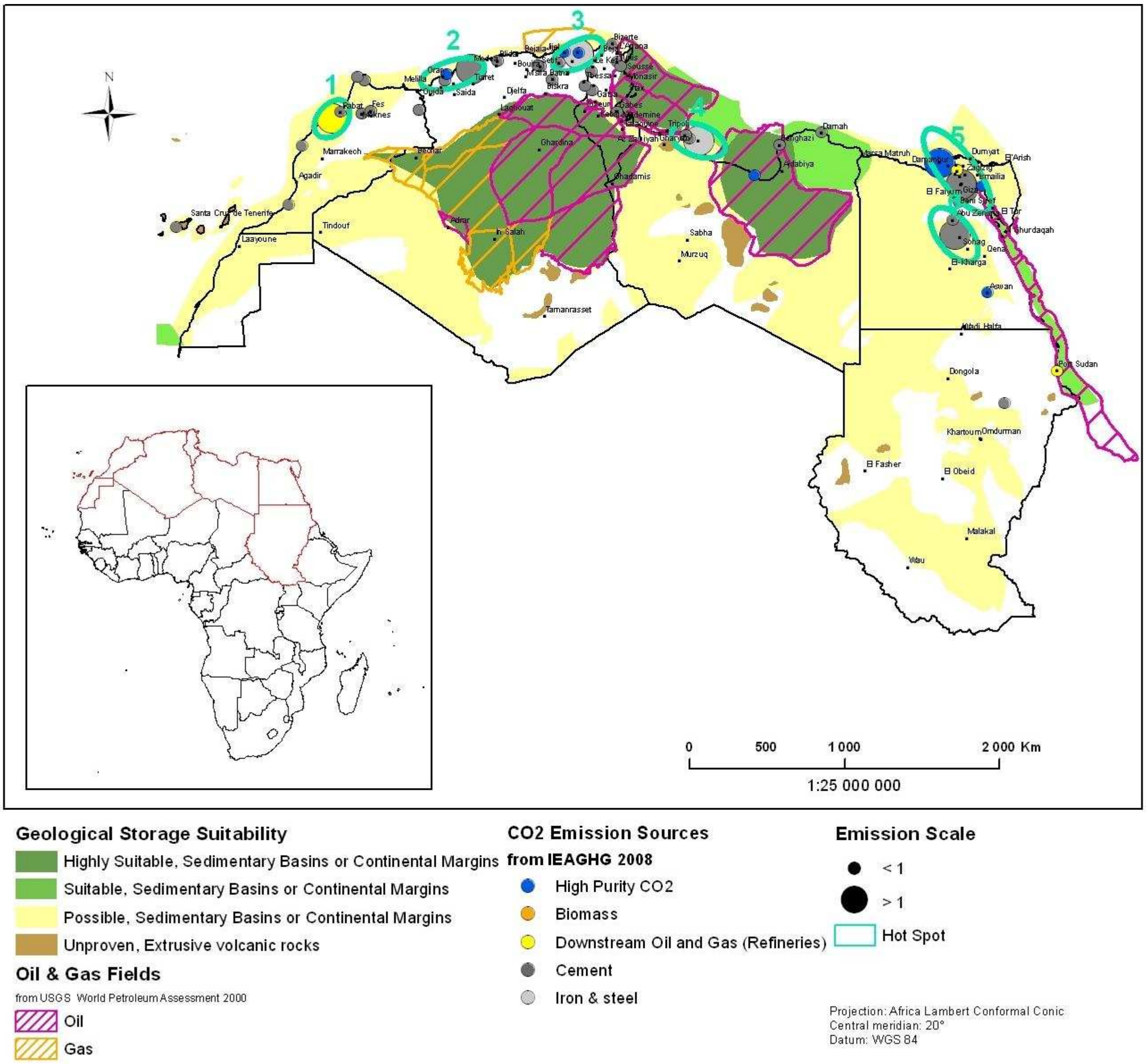


Figure 82: Storage suitability, annual CO_2 emissions and hotspots in Northern Africa

Table 32: Identified hotspots in Northern Africa

hotspot		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	1	0.36	4	3.02	0	0.0	0	0.00	5	3.4
	2	4	4.10	0	0.00	2	1.4	0	0.00	6	5.5
	3	2	1.45	0	0.00	4	1.3	2	4.07	8	6.9
	4	3	2.26	0	0.00	0	0.0	1	1.49	4	3.8
	5	3	6.61	2	0.67	2	1.3	0	0.00	7	8.6
	6	2	2.55	0	0.00	0	0.0	0	0.00	2	2.6
2050	1	1	0.76	4	4.41	0	0.00	0	0.00	5	5.2
	2	4	8.65	0	0.00	2	3.74	0	0.00	6	12.4
	3	2	3.06	0	0.00	4	3.45	2	30.18	8	36.7
	4	3	4.77	0	0.00	0	0.00	1	11.06	4	15.8
	5	3	13.94	2	0.98	2	3.37	0	0.00	7	18.3
	6	2	5.38	0	0.00	0	0.00	0	0.00	2	5.4

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 6 hotspots (Figure 82 or Table 32) which represent 85 percent of the expected emissions of the industry sector in 2050. They involve all the industry sectors in the region (Figure 83). There expected growth is highlighted in Figure 84.The number 3 is expected to grow significantly (Figure 84) as the iron and steel sector is expected to increase 6 fold in the region[15].

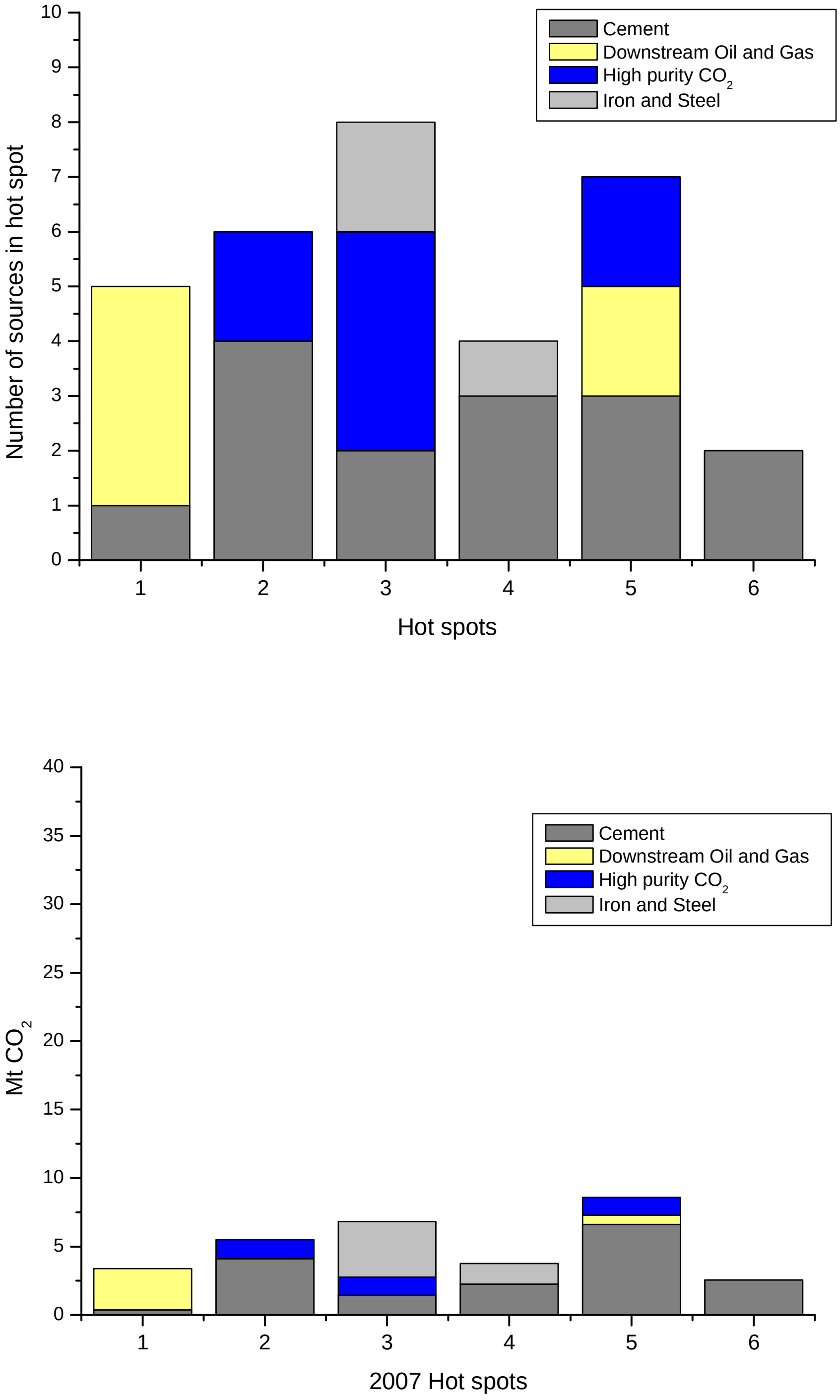
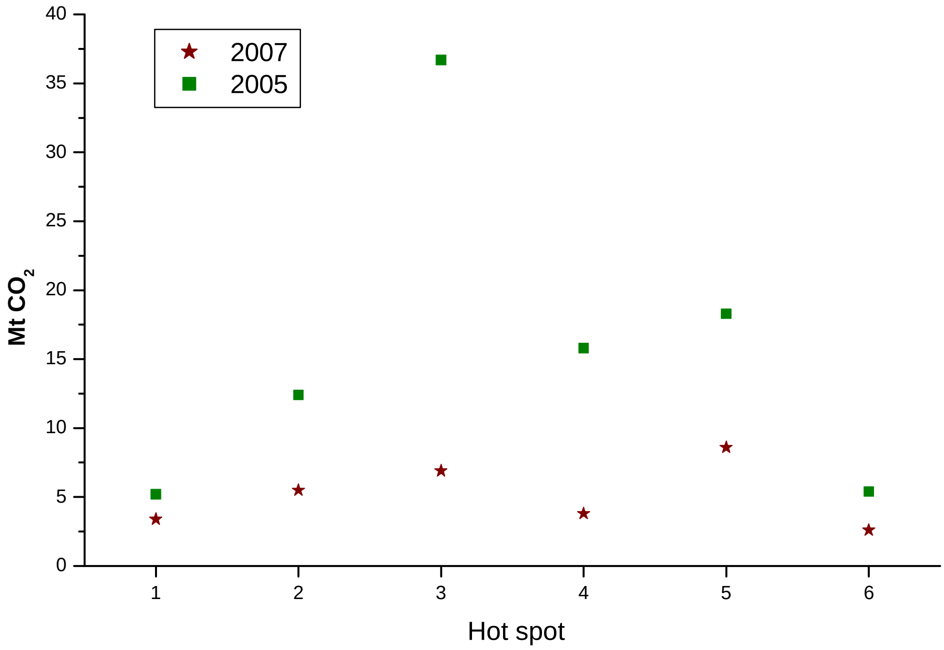


Figure 83: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in Northern Africa



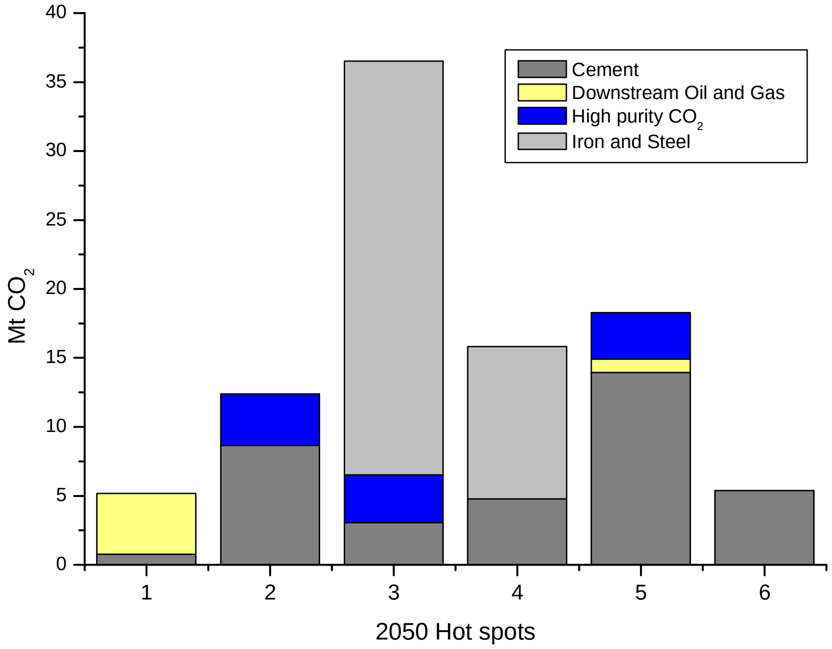


Figure 84: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in Northern Africa

Early opportunities

As most of the hotspot are located on the coast line and most of the oil and gas fields are inland, there is a hiatus between CO_2 emission and storage resource in the region (Figure 82). Early opportunities are with hotspot numbers 3 and 5 for storage either in offshore gas fields or in deep saline formation if suitability is confirmed through geologic characterization. The hotspot number 4 is also a very interest prospect in terms of geographical location, storage possibility (suitable to highly suitable storage resource and eventually storage in oilfields with prospect of EOR if site specific studies confirm this potential. The other hotspots might emerge as later on opportunities if the further characterization is carried out. Table 33 summarizes the proposed early opportunities in 2050 which account for 57 percent of the region emissions from industry at about 71Mt/y of CO_2.

Table 33: Qualitative source sink matching on the CO_2 sources in Northern Africa

hotspot number	Early Opportunity	
	number of sources	annual emission (Mt/y CO_2)
3	8	37
4	4	16
5	7	18
Total	**19**	**71**

Bottlenecks

To enable the development of the projects in Northern Africa a competitive characterization should be initiated for the Oil and gas field but more importantly for the deep saline formation as they are best located with respect to emission hotspot.

A.10.4. Synthesis and recommendations for Northern Africa

The earliest opportunity is the hotspot 4 (near Tripoli, Libya) considering their future growth and location with respect to offshore highly suitable deep saline formations and nearby oilfields. Another interesting area is near Algiers (hotspot number 2) considering the future growth of particular for iron and steel sector and its location close to gas fields. Offshore from Alexandria, Egypt there exist some interesting early opportunities with storage in offshore gas fields.

To further develop the deep saline formation storage resource, geological characterization should be promoted.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry and oil and gas production in the region.

A.11. SOUTH AFRICA

The CO_2 emissions reported for South Africa is illustrated in Figure 85. The industry sectors represent 26 percent of the country CO_2 emissions in 2007.

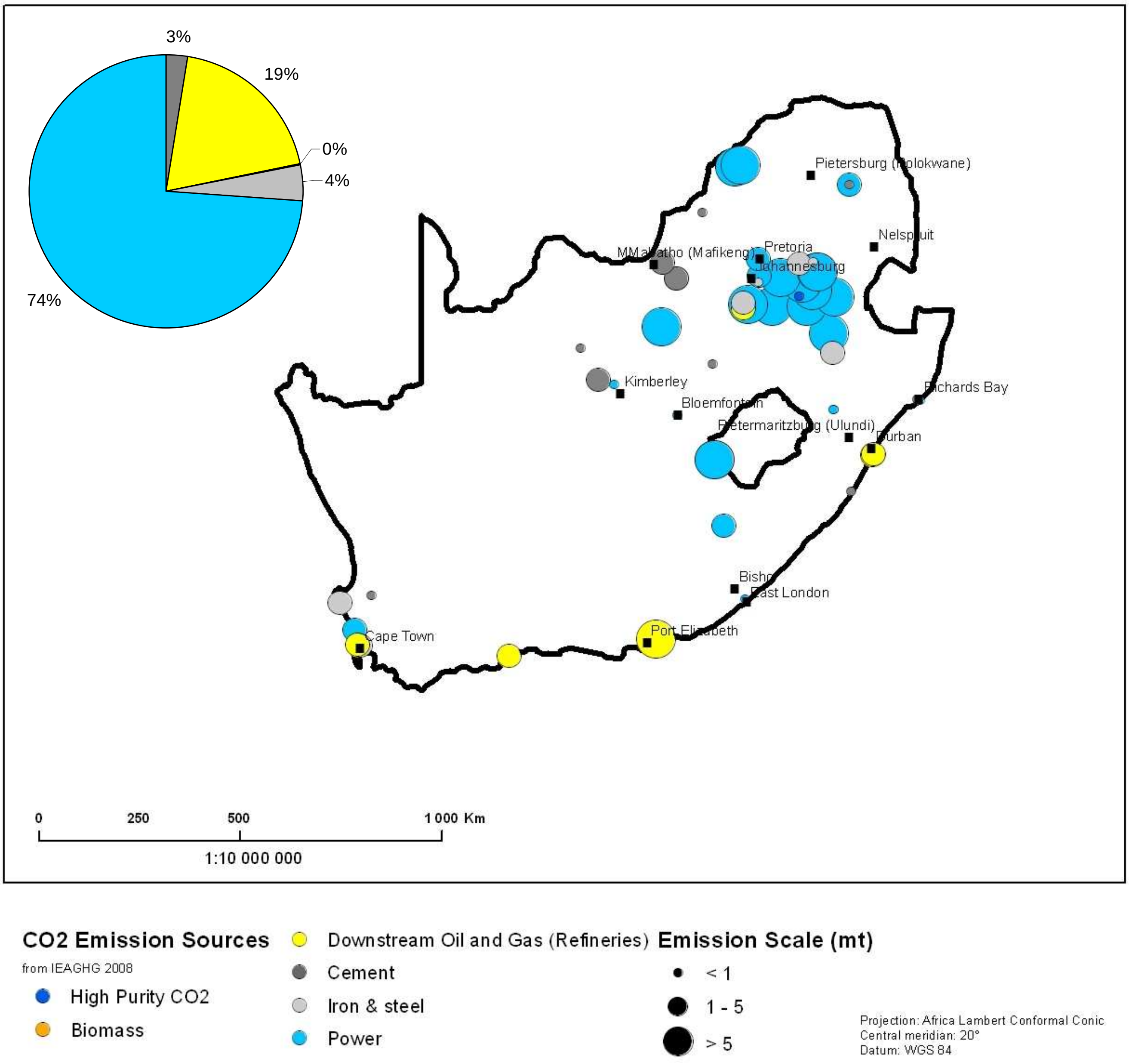


Figure 85: Annual CO_2 emissions in South Africa

A.11.1. Industrial CO_2 sources in South Africa

Emissions baseline (2007)

In South Africa, besides the power industry, the main source of CO_2 emissions is from the downstream oil and gas. The downstream oil and gas sector generates about 73 percent of the country emissions from industry, c.a. 66Mt/y CO_2 for the downstream oil and gas sector out of 90Mt/y CO_2 for the all industry sectors in 2007. The significant share of downstream oil and gas sector is linked to CTL operations. No biofuel emission is integrated in the data base for South Africa.

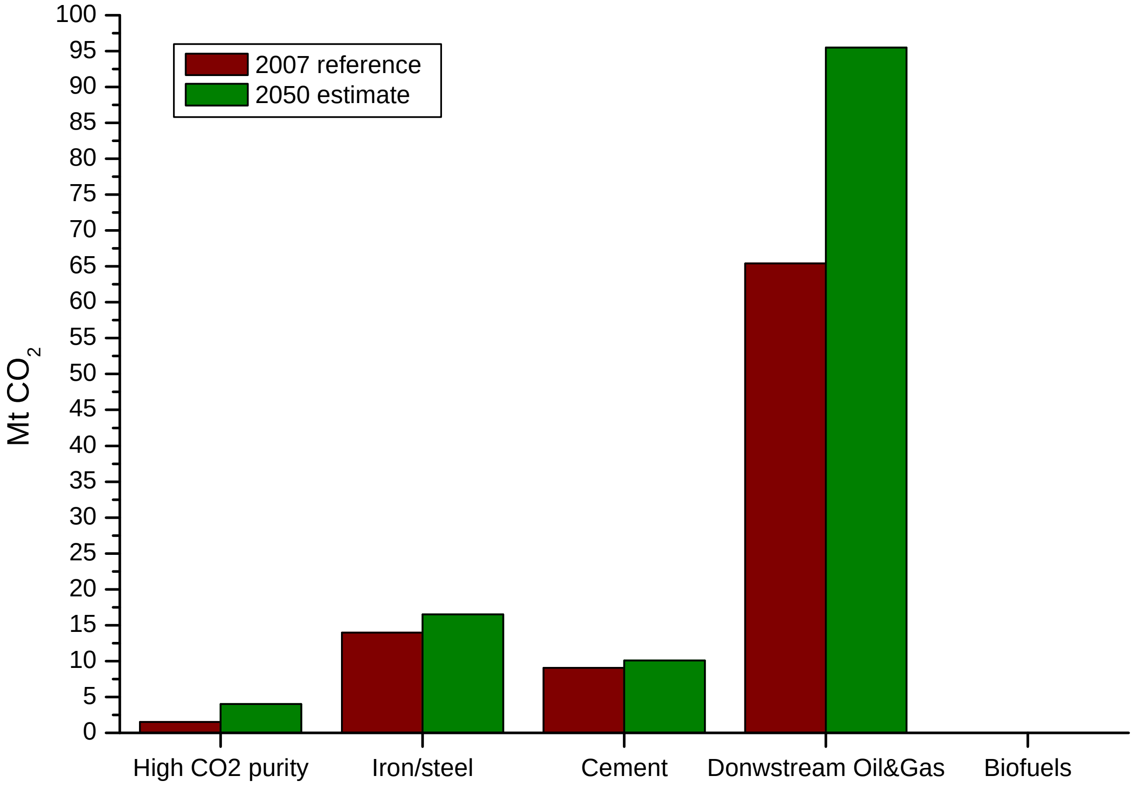


Figure 86: Annual CO_2 emissions and evolution for the industrial sectors in South Africa

Emissions evolution (by 2050)

At the 2050 horizon, the share of downstream oil and gas sector is expected to increase up to 75 percent of the country emissions from industry (see Figure 86). The CO_2 emissions from industry are expected to grow 40 percent from the 2007 level: from c.a. 90 to 126Mt/y CO_2

A.11.2. CO_2 storage resources in South Africa

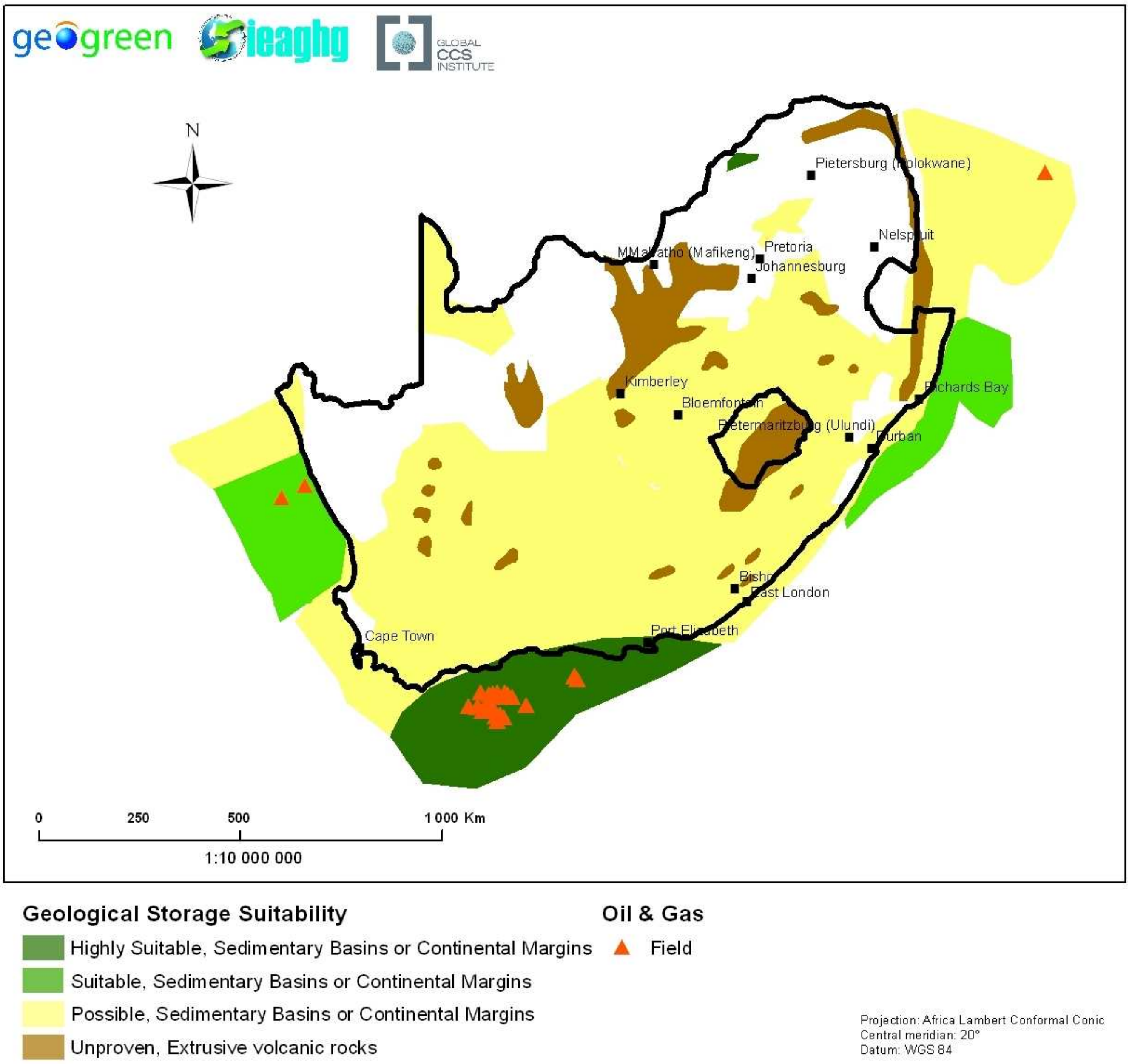


Figure 87: Storage resource in South Africa: deep saline formations and oil and gas fields

<u>Deep saline formations</u>

The available storage resource in deep saline formation was recently estimated [3] or may be estimated (see Figure 7 or Figure 88). When considering the early opportunities, there is potentially enough storage resource for several centuries of emissions as long as the resource may be banked as storage capacity (Figure 4). Note that competition for storage resource is likely and storage resource computation are highly uncertain. Most of the highly suitable storage resource lies offshore.

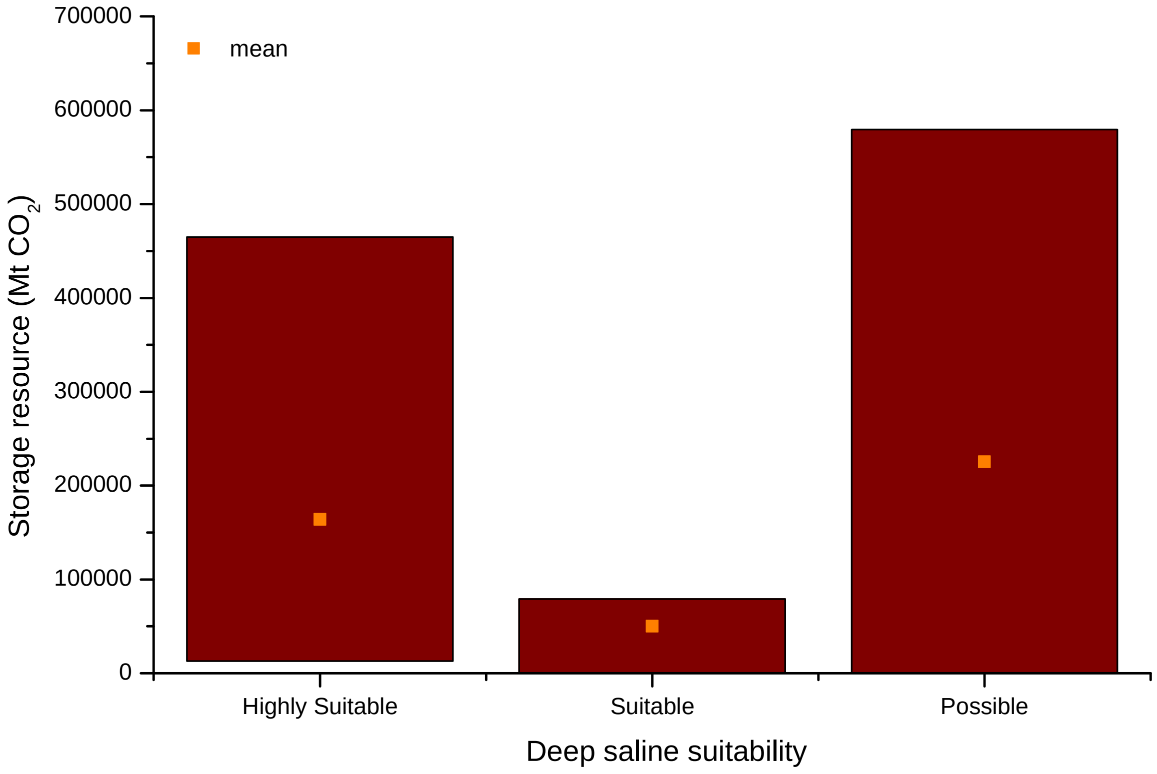


Figure 88: Estimated storage resources in deep saline formations in South Africa

One shall note that the deep saline formation storage resources estimates are associated with large uncertainties as illustrated by the bar in Figure 81 and required detail geosciences study to estimate the effective storage resources and practical storage capacity (see Figure 4).

Oil and gas fields

No significant oil and gas field exist onshore in South Africa. The storage capacity is Oil and Gas field is relatively small and was recently estimated at about 77Mt/y of CO_2.

A.11.3. Qualitative source-sink matching in South Africa

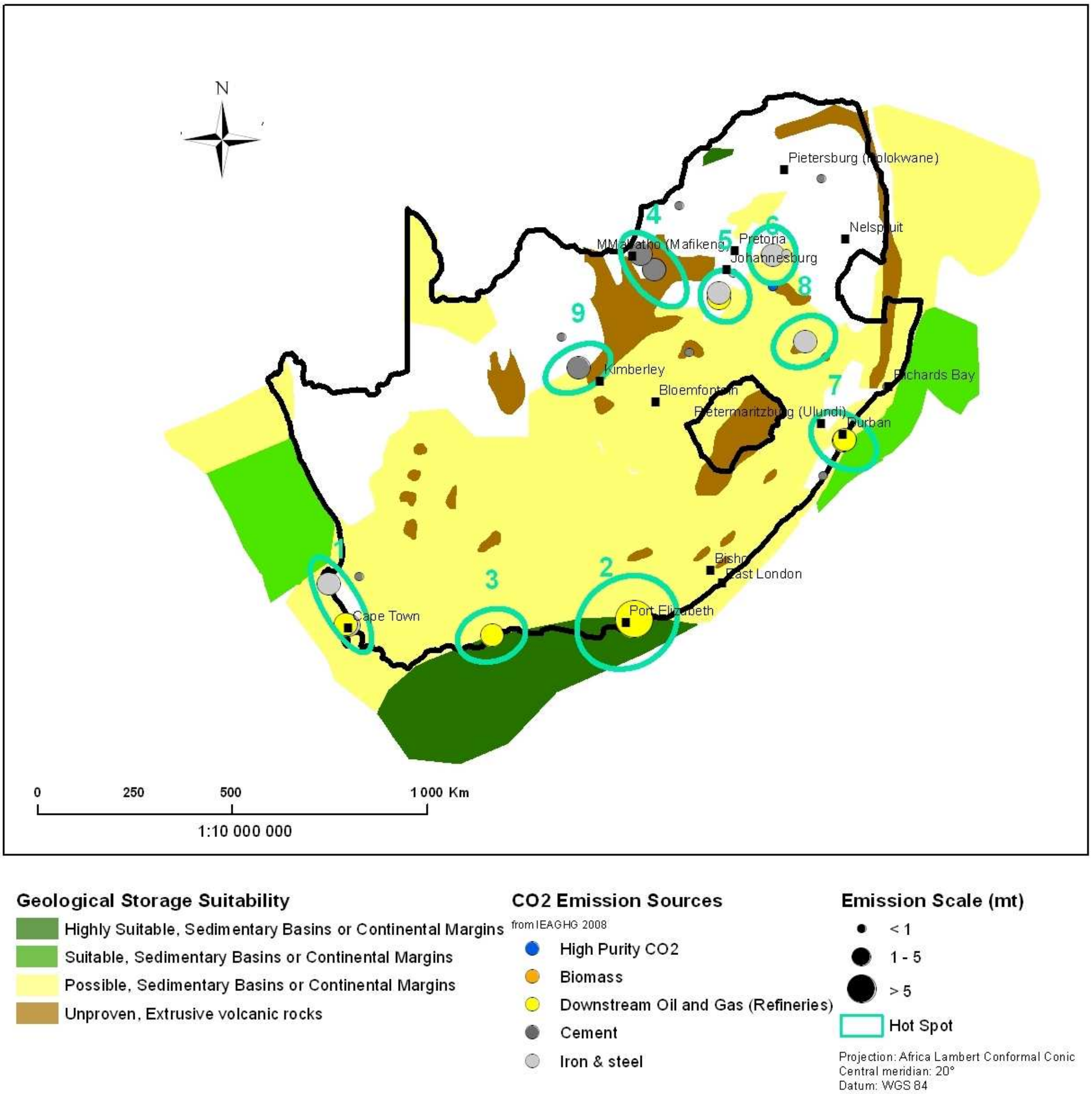


Figure 89: Storage suitability, annual CO_2 emissions and hotspots in South Africa

Table 34: Identified hotspots in South Africa

hotspot		Cement		Downstream Oil and Gas		High Purity CO_2		Iron & steel		**Total**	
		number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)	number of sources	emission (Mt CO_2)
2007	1	0	0.00	1	1.06	0	0.0	2	3.95	3	5.0
	2	1	0.21	1	7.77	0	0.0	0	0.00	2	8.0
	3	0	0.00	1	1.64	0	0.0	0	0.00	1	1.6
	4	3	4.34	0	0.00	0	0.0	0	0.00	3	4.3
	5	0	0.00	2	1.85	2	0.5	2	5.09	6	7.5
	6	0	0.00	0	0.00	0	0.0	2	2.50	2	2.5
	7	0	0.00	2	2.59	0	0.0	0	0.00	2	2.6
	8	0	0.00	0	0.00	0	0.0	1	2.41	1	2.4
	9	1	1.42	0	0.00	0	0.0	0	0.00	1	1.4
2050	1	0	0.00	1	1.55	0	0.00	2	4.68	3	6.2
	2	1	0.23	1	11.34	0	0.00	0	0.00	2	11.6
	3	0	0.00	1	2.39	0	0.00	0	0.00	1	2.4
	4	3	4.84	0	0.00	0	0.00	0	0.00	3	4.8
	5	0	0.00	2	2.71	2	1.34	2	6.02	6	10.1
	6	0	0.00	0	0.00	0	0.00	2	2.96	2	3.0
	7	0	0.00	2	3.78	0	0.00	0	0.00	2	3.8
	8	0	0.00	0	0.00	0	0.00	1	2.85	1	2.9
	9	1	1.58	0	0.00	0	0.00	0	0.00	1	1.6

Source: 2007 emissions from IEAGHG

Hotspots

Most of the largest sources may be integrated into 9 hotspots (Figure 89 and Table 34) which represent 39 percent of the emissions of the industry sector. They involve all the industry sectors in the country (Figure 90). There expected growth is highlighted in Figure 91. The number 2 and 5 are expected to grow significantly (Figure 91).

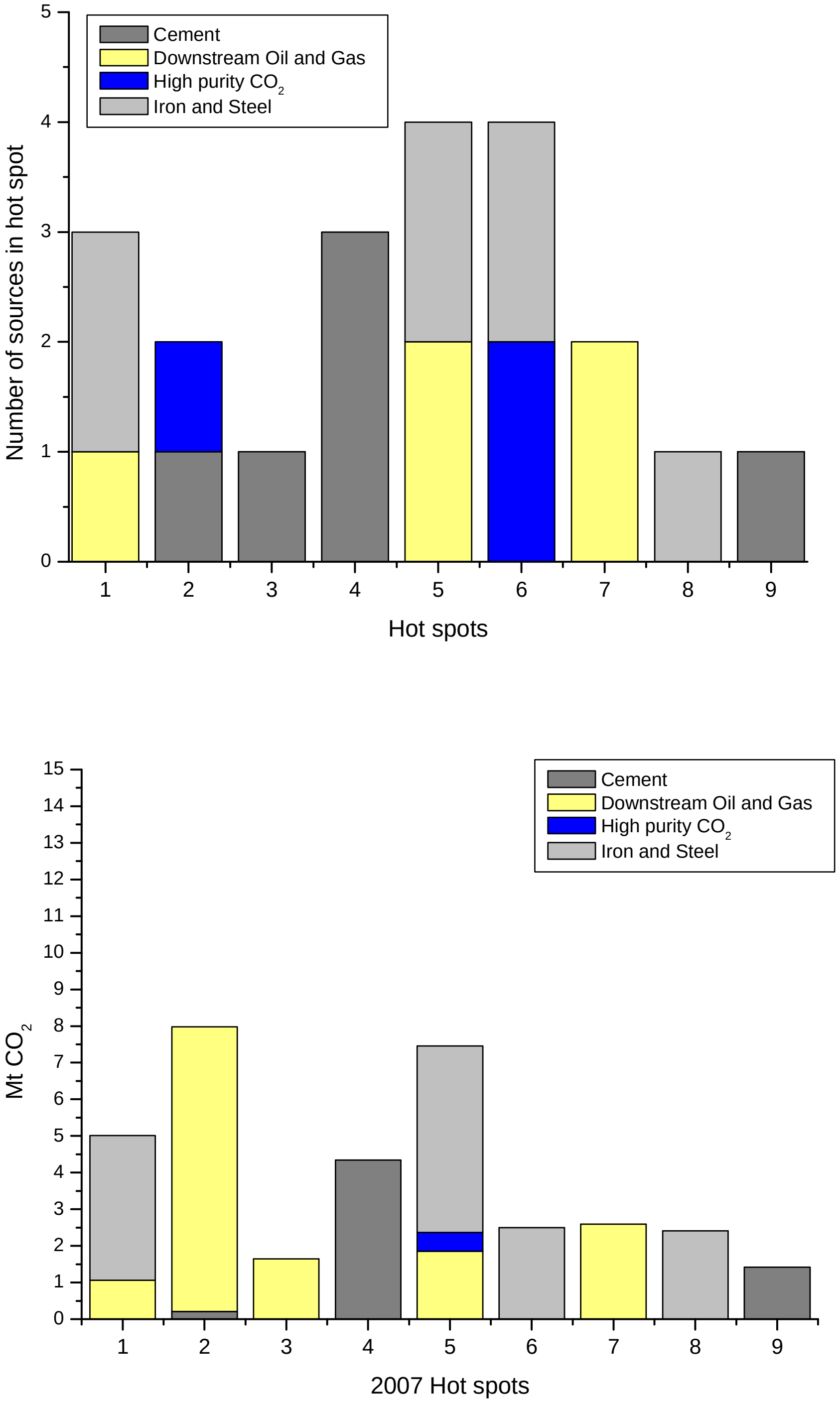


Figure 90: Number of sources (top) and annual CO_2 emissions (bottom) in the 2007 hotspots in South Africa

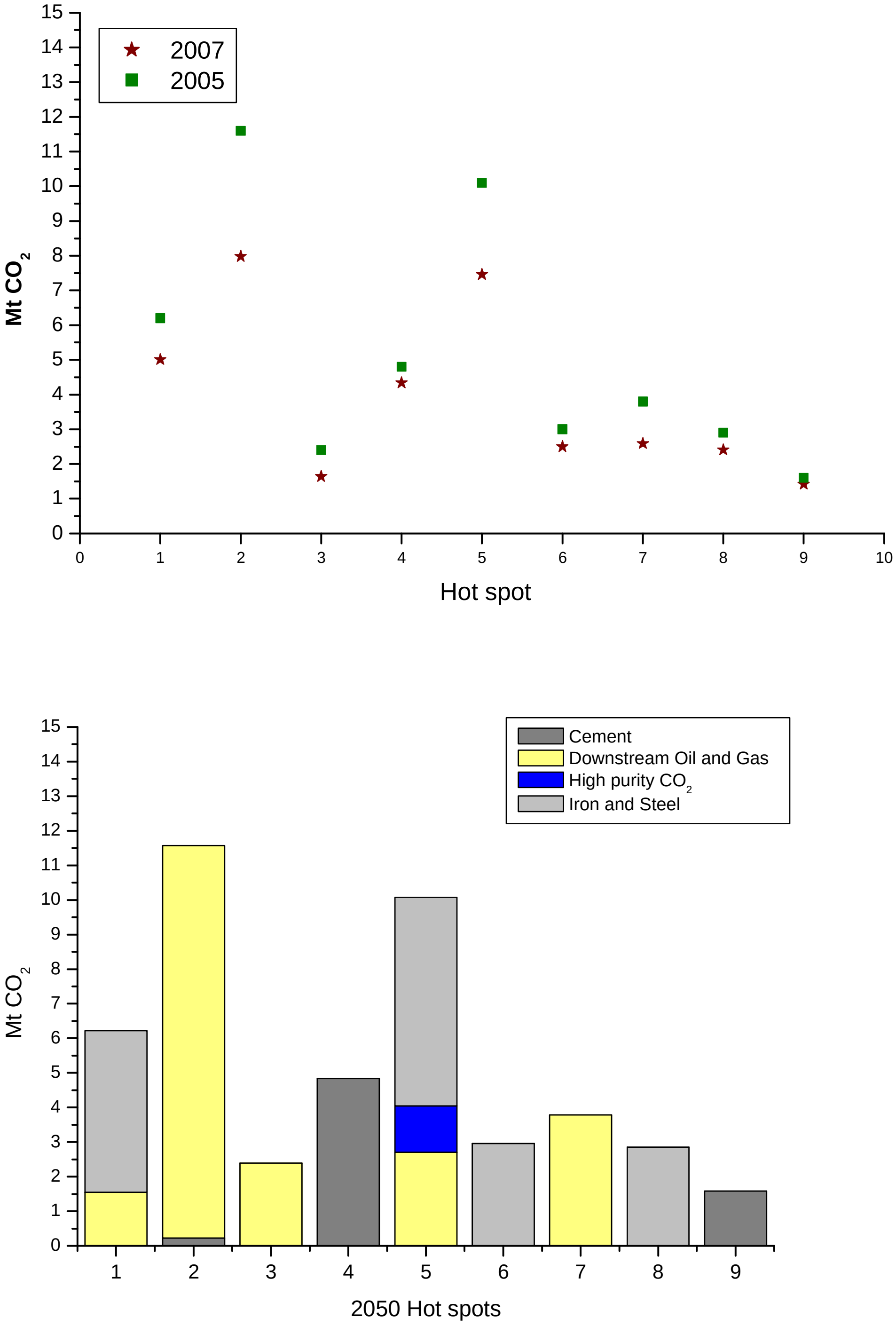


Figure 91: Estimated evolutions towards 2050 of the annual CO_2 emissions from industry sectors in the hotspots in South Africa

Early opportunities

As most of the highly suitable storage is offshore (Figure 87), the coastal hotspots are the earliest opportunities for CCS deployment in particular hotspot numbered 1, 2 and 3 as long as the Offshore Deep saline formation suitability is confirmed through geologic characterization. The hotspot 5 is the only one with high purity CO_2 sources and the second largest in the country. The storage possibilities are only onshore and must be confirmed to ensure CCS development. This hotspot may be developed from the high purity sources (0.5Mt/y CO_2 in 2007 - Table 34).

The other hotspots might emerge as later on opportunities if the further characterization is carried out.

Table 35 summarizes the proposed early opportunities in 2050 which account for 24 percent of the country emissions from industry at about 30Mt/y of CO_2.

Table 35: Qualitative source sink matching on the CO_2 sources in South Africa

Hot Spot number	**Early Opportunity**	
	number of sources	**Annual emission (Mt/y CO_2)**
1	3	6
2	2	12
3	1	2
5	*6*	*10*
Total	**12**	**30**

Bottlenecks

To enable the development of the First-Of-A-Kind projects in South Africa a competitive characterization should be initiated for the Oil and gas field but more importantly for the deep saline formation.

Each hotspot is characterized by several sources and therefore different CO_2 qualities that must be combined for the storage.

A.11.4. Synthesis and recommendations for South Africa

The earliest opportunity is the hotspot 2 (near Port Elisabeth) considering its future growth and location with respect to offshore highly suitable deep saline formations along with hotspot number 3 (near George). The onshore possible storage is South of Johannesburg is the storage capacity is confirmed.

However, competition for storage capacity is obvious in the future given the location and share of CO_2 emissions from the power industry.