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A CCS ROADMAP FOR ROMANIA

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Acknowledgments and legal disclaimer

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This publication has been prepared by the Bellona Foundation to fuel the debate in Romania on how to meet its emission and energy challenge. It is the result of one year work both in Romania as well as in-house. The Bellona Foundation would like to thank the Global CCS Institute and other sponsors of the Bellona Environmental CCS Team (BEST) for their generous support. The BEST team is led by Paal Frisvold and chaired by Frederic Hauge.

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EXECUTIVE SUMMARY

Implementing a cost effective and reliable energy system has many challenges, including energy security, technology choice, utilization of indigenous resources and transnational cooperation.

The added requirement of meeting the ever-tightening CO_2 emissions of the European Trading Scheme (ETS) adds to these challenges. Policy choices taken today will affect the development of the wider economy for at least a generation.

This report assesses these interlinking factors, and provides stakeholders with an insight into future possible liabilities, opportunities, costs and risks. The document proposes specific recommendations on how to limit such risks and secure a cost-effective energy supply for the future. The report also assesses the impact of climate change legislation on major Romanian industries, cataloguing emissions, CCS applicability and actions necessary.

The need for urgent investment in the Romanian energy sector is well-recognised. Ageing infrastructure needs to be rapidly replaced; sustained investments over the coming decades will be required to maintain capacity and meet demand growth. The possibility to repower the Romanian energy system in a sustainable way is a once in a generation opportunity. Well-informed decisions taken now could place the energy sector on a secure footing to meet the demands of this century.

Two distinct futures of the Romanian electricity production industry have been modelled until 2050. Both energy trajectories would incur large costs under the ETS predominantly due to CO_2 emissions from unabated lignite- and coal-fired power plants. Conservative estimates for operational and capital cost of CCS along with modest projections for the growth in the European Union allowances (EUA) price consistently support the potential of CCS as a cost-effective technology. CCS could limit the exposure of the Romanian energy sector to emission allowance liabilities.

The report also sets out to highlight the competitive advantages present in Romania with respect to the CCS value chain, such as the relevant technical expertise, competent operators, available infrastructure and vast CO_2 storage capacity. Commercial opportunities exist, such as using CO_2 for Enhanced Oil Recovery (EOR) offering Romania the opportunity to develop CCS capabilities while recovering a valuable resource.

Romania, possessing the highest bioenergy potential in the EU, is uniquely placed to exploit the synergies between CCS and biomass. Taking the opportunity to produce and profit from carbon negative electricity and fuels would place Romania at the forefront of the Bio-CCS industry and the fight against climate change.

The report concludes that concrete actions are required for Romania to reach its goals. The actions include ensuring the success of the Getica CCS demonstration, further characterising storage capacity, educating and preparing industrial emitters and reforming energy markets to incentivise dependable low-CO_2 generation.

1.0 BACKGROUND

International consensus, driven by the findings of the global scientific community, seeks to drastically decrease CO_2 emissions in order to avoid catastrophic and irreversible climate change. The best models currently predict that this can only be achieved by limiting global temperature increases to 2 degrees Celsius, which in turn requires keeping the concentration of CO_2 in the atmosphere below about 450 parts per million. Reaching this goal will require cutting current emissions levels by around 80%, and may even require extraction of CO_2 from the atmosphere if "safe" greenhouse gas (GHG) concentration levels are surpassed.

CO_2 Capture and Storage (CCS) offers the potential to radically reduce CO_2 emissions from large point sources such as coal- and gas-fired power plants and energy-intensive industrial facilities. In this way it can play an important role as a transition technology by securing access to more competitive sources of energy during the long transition to renewable energies.

No one technology holds the answer to achieving the necessary greenhouse gas (GHG) emission reductions or securing affordable energy. Indeed, only the use of a suite of available measures – such as enhancing energy efficiency, switching to renewable energy sources, and improving electricity grid interconnectivity, as well as deploying CCS – can help mitigate damaging climate change.

This roadmap focuses on one of these climate change mitigation technologies, namely CCS, and possible strategies for its large scale implementation in Romania. It does not address in detail other possible climate change mitigation options, such as more intensive renewable energy deployment, further energy efficiency measures, etc. These technologies need also to be examined by policy makers.

The report highlights potential major hurdles and costs of implementing CCS in Romania and proposes appropriate responses. It must be realised, however, that given the long time horizons considered there will always be a level of uncertainty associated with the results described.

CO_2 capture is a technology in which CO_2 is separated from a mixture of several different gas components, such as combustion flue gases or gases from industrial processes. Currently most modern coal power plants in the world are fitted with systems that mitigate acidification or "acid rain". These technologies separate sulphur dioxide (SO_2) and nitrous oxides (NO_x) from the flue gases prior to release into the atmosphere. These technologies are analogous to CO_2 capture in that they reduce efficiency, are capital intensive and are required to mitigate the effects of pollution. Today there are thousands of power generation plants and industrial plants worldwide emitting large volumes of CO_2 into the atmosphere. The installation of CO_2 capture technology at these point sources would drastically reduce emissions into the atmosphere. Once the CO_2 is captured it is compressed so that it becomes a dense fluid which can be efficiently transported through pipelines, in tankers, or further processed for use in industry. There is a range of CO_2 capture technologies; the optimum solution will be site specific, accounting for the combustion process, a mixture of gases, quality requirements, etc.

1.1 EU POLICIES FOR COMBATING CLIMATE CHANGE

↘ Broad climate policy objectives are enshrined in several international and European agreements. The European Union has adopted specific legislation to achieve a 20% reduction in its emissions relative to 1990 by 2020. It also has an agreed policy objective of reducing Member State CO_2 emissions by 80-95% by 2050. At the moment, the EU Emissions Trading System (ETS) is expected to be the primary tool, delivering two-thirds of the reduction target. (see box) However, additional mechanisms are also under consideration.

The ETS is a "cap-and-trade" 'system, through which qualifie industries such as electricity and many other large emitters must surrender Emission Unit Allowances (EUAs), or other emission allowances for each tonne of CO_2 emitted. Ever decreasing caps on the total number of EUAs will reduce supply over time, creating a scarcity and thus increasing cost to purchase the right to pollute. This system is economically attractive as it efficiently distributes the burden of emissions reductions. The sectors with the lowest costs of climate abatement will be incentivised to install new equipment and change practices first. Sectors with higher abatement cost will choose to emit until the cost of EUAs is a sufficient incentive to install abatement technology (Skjærseth & Wettestad, 2010). The ETS is set for trading periods and for each period the supply of EUAs is decided by the EU. The European Parliament has proposed a so-called set-aside of EUAs to raise their price.

The EU has issued several policy statements setting ambitions for CCS deployment in Europe, the most relevant being that CCS should be shown to be technically achievable and commercially viable by 2020. The European Commission Energy Roadmap 2050 has singled out CCS as one of six strategic climate and energy technologies, with CCS in widespread use by 2030 (European Commission, 2011). The EU is part funding a number of large scale demonstration projects to accelerate the development and commercialisation of the technology.

The cost of unabated emissions increases with the costs of EUAs. This has a marked effect on the economics of fossil fuel-fired energy production and energy-intensive industries. As the price of EUAs climb, the cost of unabated use of fossil fuels exceeds that of applying CCS. The future price of EUAs is uncertain. Significant price volatility has been observed since the establishment of the ETS in 2005, with prices growing rapidly in 2007 and 2008 due to price increases in commodity markets, falling in mid-2008 due to the economic crisis and stabilizing in late 2009. The subsequent Euro crisis reintroduced volatility to the EUA market with prices reaching all-time lows in May 2012 (Dixson, 2011). Capital intensive investments such as in power plants and CCS technologies require high levels of certainty. Unfortunately, this is not provided by the volatile and unpredictable EUA market and results in delays in necessary investments.

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2.0 WHY CCS IN ROMANIA

Building a generation system fit for purpose is rapidly becoming ever more difficult with the necessary integration of new technologies to mitigate climate change and other pollution control measures coupled with expanding global demand and competition for ever scarcer resources. These factors and the complex interactions between them lead to a large variety of policy choices. Every nation must rigorously assess and tailor these options to their own needs and capabilities in order to achieve an optimal outcome. This report describes how Romania could build a world-leading generation system, achieving negative CO_2 emission and thus playing a major role in averting global climate change.

2.1 CURRENT ENERGY SITUATION

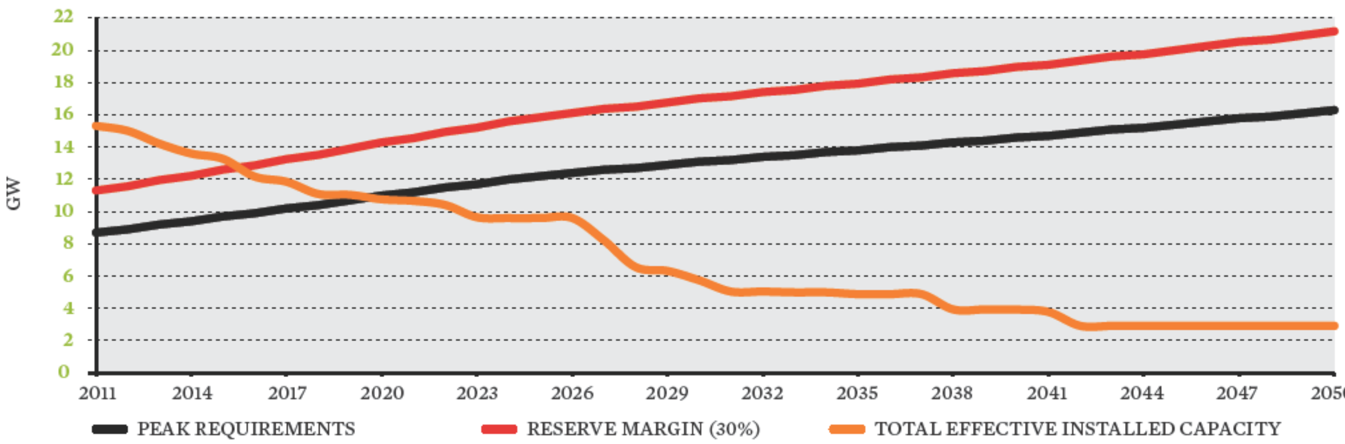
↘ Romania's abundant natural resources and low costs offer many competitive advantages. However the country's past as a centralised economy has left a legacy within the Electricity Production Industry (EPI). In the past, energy policy has been dominated by the need for security of supply and energy independence, sometimes boarding on autarky. To this end large indigenous lignite-fired power plants were preferred and, later, was the motivation for the ambitious Cernavodă nuclear energy complex (Leveque, 2010). Due to this extensive construction and prioritization of energy infrastructure coupled with relative economic decline following the fall of communism, Romania has inherited an overcapacity of generation and transmission infrastructure (Diaconu, et al., 2008).

The Romanian energy supply system is characterised by obsolete infrastructure, poor thermal energy efficiency and low productivity. High levels of uncertainty surround structural, legislative and policy goals in the short and medium term. At present there are few studies or publications that attempt to define long term strategies for the Romanian energy sector.

The need for urgent investment in the Romanian energy sector is widely recognised (Figure 2.1). Ageing infrastructure will need to be rapidly replaced and sustained investments over the coming decades will be required to maintain capacity and meet demand growth. The possibility to repower the Romanian energy system is a once in a generation opportunity; well-informed decisions now could place the energy sector on a secure footing to meet the demands of this century.

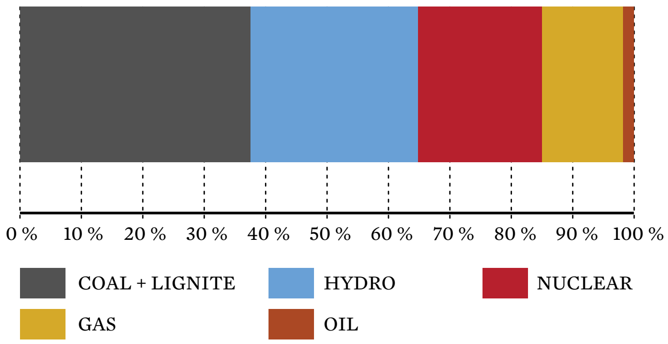
FIGURE 2.1 ROMANIAN EFFECTIVE GENERATION CAPACITY RETIREMENTS VS. FORECASTED ELECTRICITY DEMAND (ISPE, 2011)

Effective or de-rated capacity accounts for intermittent availability of hydro and wind generation (see annex I section A1.2)



In many ways Romania is in an enviable position with regard to energy. The country has access to a wealth of indigenous resources both renewable and fossil. The current electricity generating capacity is highly diverse, with hydro, nuclear, coal, lignite and gas all included in the mix (Figure 2.2). The near term will also see large wind capacity added to the energy portfolio. Present energy capacity is dominated by a large number of nominally independent state electricity companies.

FIGURE 2.2 ELECTRICITY GENERATION BY SOURCE 2009

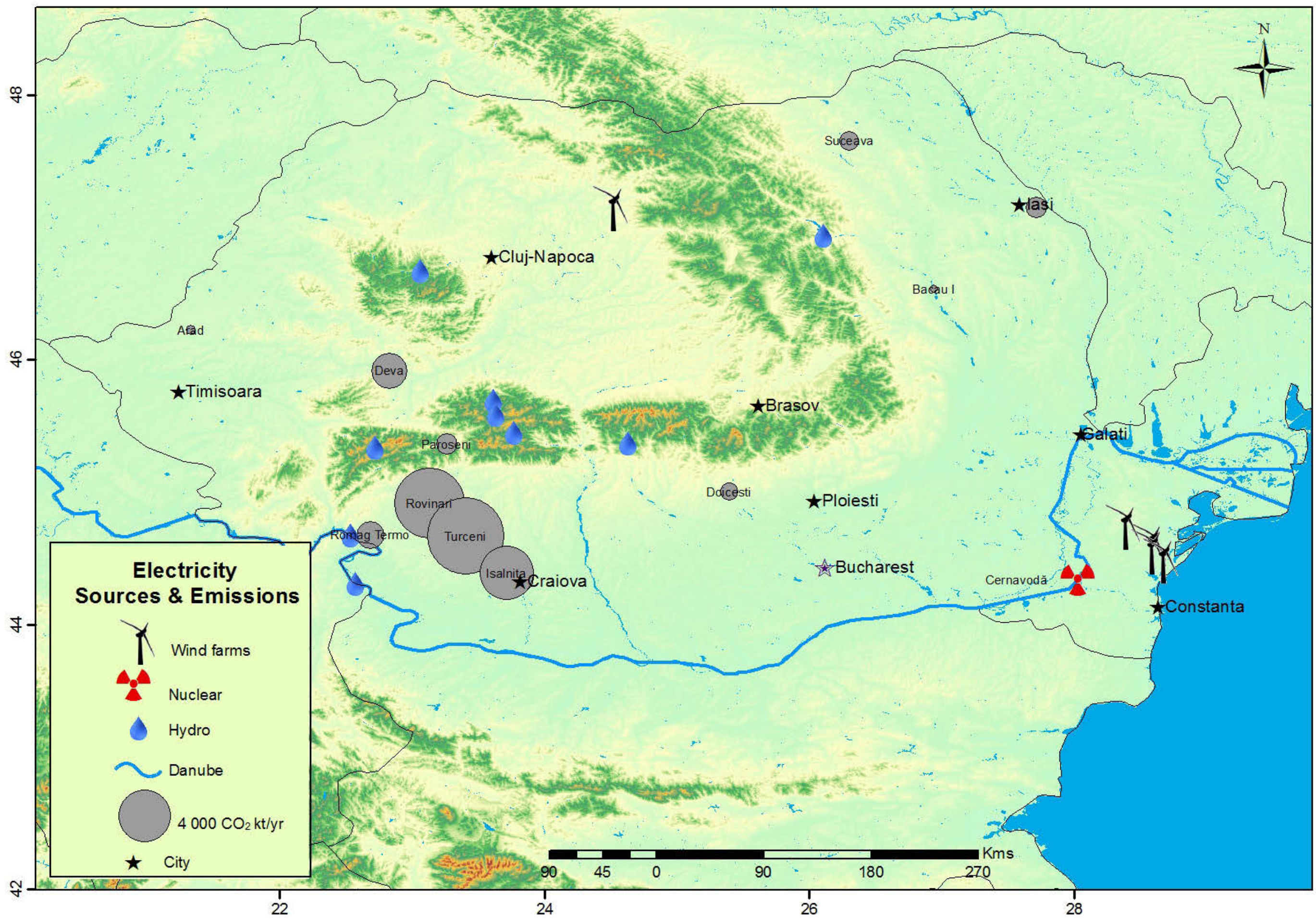


Romania has abundant hydroelectric generation, with an installed capacity of 6400 MW (Figure 2.3). Approximately 300 dams generate low marginal cost electricity. The sector is operated by the majority state-owned entity Hidroelectrica.

Nuclear generation has become an integral part of the Romanian energy strategy, with facilities operated by state owned Nuclearelectrica. Completion of the second Cernavodă reactor in 2007 increased capacity to 1400 MW and the share of output to approximately 20%.

The most significant thermal generators are the three large state-owned lignite-fuelled energy complexes: Turceni, Craiova and Rovinari. Together they have a combined capacity of 3900MW. The system also contains a large stock of small hard coal and gas thermal generating plants, much of which has modest efficiencies and currently reaching end-of operational life, with 28% to retire in the coming decade.

FIGURE 2.3 MAJOR ELECTRICITY GENERATION FACILITIES & LARGE CO_2 POINT SOURCES



2.1.1 SOURCE OF CO_2 IN GENERATION SYSTEM

CO_2 emissions from fossil generation, representing 43% of total CO_2 emissions in 2008, will need to be reduced for Romania to meet its climate obligations (The World Bank, 2011) (UNFCCC, 2010). CO_2 emissions have reduced dramatically in recent years with rationalisation of the economy, lower energy demand and the closure of inefficient outmoded industries. Similar reductions of CO_2 in the future will be harder to achieve, as the Romanian economy continues to develop and energy use increases. Romania has begun to formulate policies to achieve the required reductions. A suite of technological and societal changes will be necessary as described in the Romanian National Renewable Action Plan (2010), the Romanian Energy Strategy for the period 2007 to 2020 and Elements of energy strategy for period 2011-2035 - Strategical and objectives in the energy sector – Draft I.

Climate policy can be, and is being, used by Romanian officials as a means of modernising practices along with the economy. Romania is rapidly becoming a regional leader in tackling climate change and looking into the future for appropriate technologies to achieve these goals.

2.2 FACTORS AFFECTING FUTURE DEVELOPMENT OF THE ENERGY SECTOR

Renewing or replacing an electricity generation system, as Romania must, is a large and complex undertaking. Interlinking factors affect policy and technology choices available to central government and electricity firms. The resources available for power generation both indigenous and imported will play a primary role in determining technology choice, including the availability and price of fuels and renewable resources.

The corporate environment too will have an important effect on the eventual energy supply landscape. Companies demand a reasonable return on investments; otherwise new capacity will not be built. Electricity firms operate over long time frames and consistent policies are necessary to encourage investment in capital intensive plants. It will be necessary for Romania to reduce uncertainty with transparent and consistent policy choices, while building competitive markets to encourage inward investment. Below is a brief review of resources and infrastructure available for Romania to reach its energy and environmental goals.

2.2.1 EPI LANDSCAPE

The Romanian energy market has undergone a sustained period of reform and liberalisation from the mid-1990s. State-owned legal entities were carved from the former monopoly and generation utilities Termoelectrica, Hidroelectrica and Nuclearelectrica were created. Independent transmission and distribution companies Transelectrica and Electrica were founded. Further horizontal disintegration was achieved in 2004 with the separation of large energy complexes from the thermal generator Termoelectrica. The distribution company Electrica was also divided into eight regional energy providers with some being privatised (Vasile, 2009). Energy utilities in Romania are currently experiencing a period of legislative uncertainty. Recent government efforts to create two dominant vertically integrated generation companies have been dropped.

In the past, the tariffs and regulated prices that the generators received for energy failed to cover costs. As a result some producers such as Termoelectrica and Nuclearelectrica have accumulated significant debts (Diaconu, et al., 2011). The practise of artificial price setting needs to be reformed in order to encourage national generators to reinvest, and to incentivise inward investment. The Romanian government will continue with an energy liberalisation and privatisation programme. Stakes in state-owned power producers Hidroelectrica and Nuclearelectrica will be put up for sale in 2012. Further market liberalisation has also been proposed under draft energy legislation, removing price setting and establishing a more transparent regulatory structure (IntelliNews, 2012).

2.2.2 LIGNITE + COAL

Indigenous reserves of coal and lignite in Romania are large but only a portion may be economically competitive with international sources (EuroCoal, 2011). The Romanian coal industry has undergone extensive change over the last two decades. The workforce in the industry declined from 100,000 to some 20,000 now, producing periods of labour unrest (S.R.L, 2010). After 2018, EU regulations prohibit subsidies to loss-making mining operations. This will accelerate rationalisation of the Romanian coal and lignite industry with the result that much of the remaining hard coal sector expected to close in the coming years. The continued use of lignite and, with it, generation from the "energy complexes" will require further mine closures, investment in modern mining equipment and a marked improvement in productivity. Current goverment forecasts predict lignite extraction rates of 20 to 25 Mt/yr to be sustainable, though marginal, this is lower than the 27 Mt/yr produced in 2010 (EuroCoal, 2011). However at forecasted extraction rates these viable reserves will be consumed in approximately 40 years.

Lignite-fired generating plants currently receive indirect cross subsidies from more profitable sectors of the generating system. This situation is rationalised as necessary for security of supply and for social protection. The use of lignite to some extent is not in doubt under current Romanian energy strategies. Extensive upgrades have already begun or are planned at units to remediate for emissions such as SO_2 and NO_x, extending the life of these CO_2 intensive plants. Further major retrofits are planned to extend the operational life of the lignite-fired "energy complexes" until the late 2020s.

2.2.3 FOSSIL GAS

Due to increasing demand and stagnating domestic production, Romania now imports over a third of its fossil gas needs, almost exclusively from Russia. The indigenous production of gas is set to continue for many years and new offshore discoveries should help to maintain and even increase production (Petroleum Club of Romania, 2011). Sterling Resources estimate that 600 billion cubic meters of recoverable fossil gas may be present. However the importance of these finds should not be overestimated as they are not sufficient to cover growing national demand and significant net imports will still be required. Only if consumption is maintained at current levels will Romania have sufficient domestic supplies to meet national demand (Beacom, 2011).

Romania contains an extensive gas pipeline network, both for domestic gas production and for the transit of international gas supplies with a total network length of 13,110 km. Currently the Isaccea pipeline provides Russian gas via the Ukraine, and while

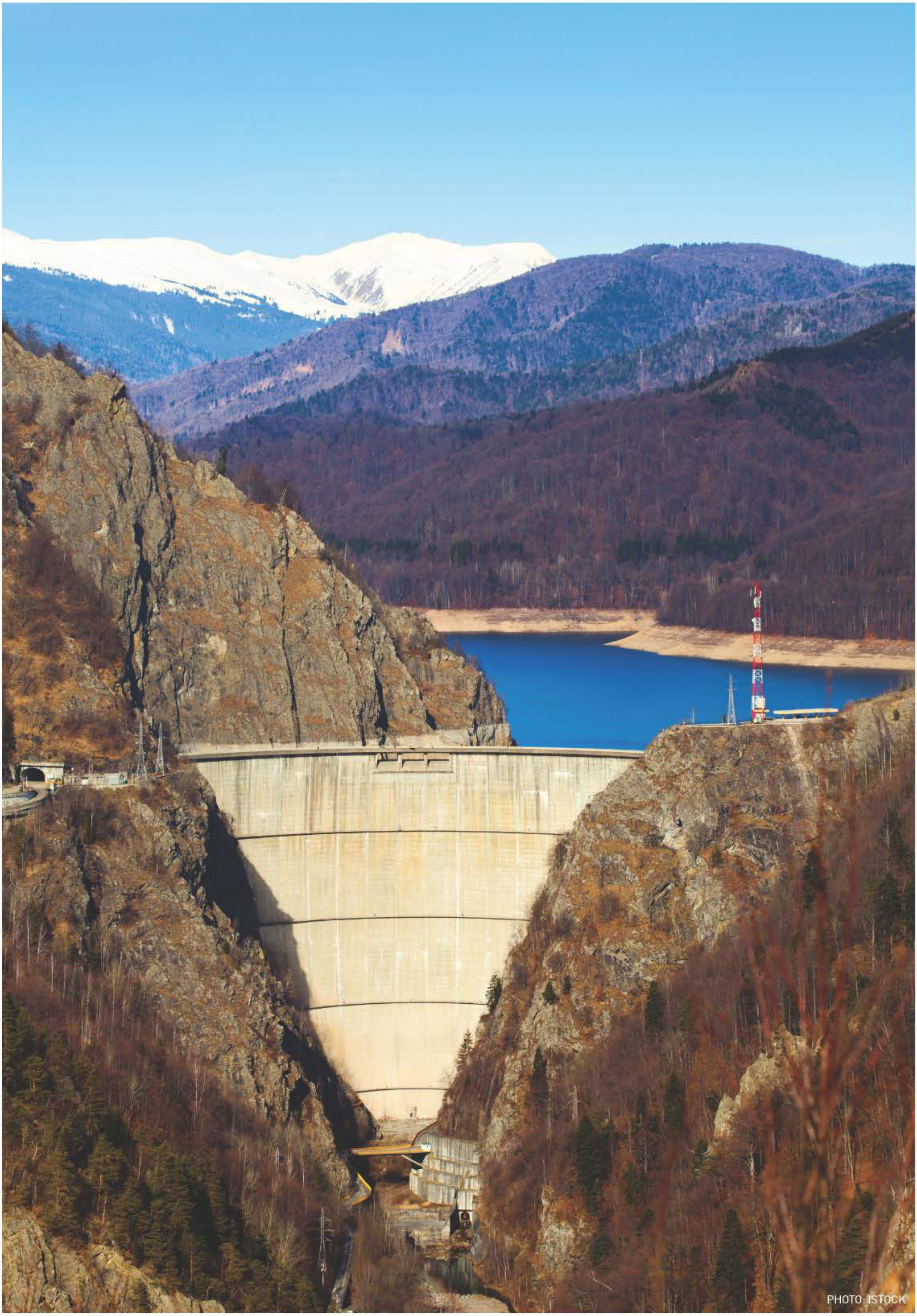


PHOTO: ISTOCK

the Arad pipeline only allows for the import of gas from Hungary, this interconnector is currently being upgraded to allow the possible export of Romanian gas to Hungary.

The proposed development of two large transnational pipelines supplying gas from the Caucasus and Russia to central Europe would, if constructed, play a major role in the future energy options available to policy makers. The European Commission-backed Nabucco pipeline or southern gas corridor plans to transport natural gas from the Caucasus to central Europe, bypassing Russia and the Ukraine. Transgaz, the Romanian state-owned pipeline operator, is a partner in Nabucco, and the pipeline, if constructed, would pass directly through Romanian territory (Transgaz, 2011). Progress to date has been slow, and available quantities of gas to supply Nabucco may not come on line quickly enough, putting the entire project in jeopardy. The rival Russian backed pipeline "South Stream" would also provide a large source of gas to the region; however this would be sourced from Russia, generally seen as an unreliable energy partner in the region. It is also likely that if Nabucco fails, Gazprom, the Russian gas major, could drop South Stream in place of more cost effective pipeline expansion in northern Europe (Pflüger, 2012).

2.2.4 RENEWABLE ENERGY SOURCES (RES)

The energy strategy in Romania from 2007 to 2020 calls for RES to supply 35% of generation by 2015 and 38% by 2020. The majority of this share would be met in the near future by the significant hydro capacity already installed, modestly expanded by the construction of new capacity. Beyond that, much of new RES capacity could be provided through Romania's significant wind power resource potential of around 14,000 MW (Mediafax, 2007), with the Dobrogea region on the Black Sea coast having the second largest wind potential in Europe. Beginning from an almost non-existent base, wind generation has expanded rapidly due to very favourable support policies (Teckenburg, et al., 2011). Romania currently boasts Europe's largest operating onshore wind farm. Solar energy will also play a role in the future electricity generation, especially in the Dobrogea region and along the Black Sea coast. Romania has implemented a regulatory framework supporting renewable generation with access guarantees and a green certificate market with mandatory quotas. Quotas will reach 14% in 2013 and are anticipated to rise by 1 percentage point every year, reaching 20% in 2020 (ABB, 2011).

2.2.5 ENERGY EFFICIENCY IN THE ELECTRICITY SECTOR

The European Commission "Energy Roadmap 2050" describes energy efficiency as a crucial link in meeting climate targets (European Commission, 2011). Romania has achieved significant energy efficiency gains in the previous two decades. Primary energy intensity decreased at the rate of 4.4%p.a. over the period. Implementation of energy efficiency measures in industry along with the rationalisation of communist-era industries have led to the bulk of efficiency gains (ABB, 2011). Over the same period, the electricity production sector has had some noticeable increase in efficiency, primarily due to the increased utilisation of hydro power and the commissioning of two modern nuclear reactors. Further efficiency gains should be realised as older plants are retired. However, today, primary energy intensity in Romania is still considerably higher than the EU average. Romania's national energy efficiency action plan sets an energy intensity reduction target of 40% by 2015 (ABB, 2011). However even with these ambitious efficiency targets overall electricity demand is forecast to rise over the first half of the century due to economic expansion.

2.2.6 THE GRID

The Romanian electricity grid is operated by Transelectrica. The system has many interconnections to neighbouring states, with Romania exporting approximately 10% of its electricity production. In times of high demand and low electricity production, such as in the 2003 drought, Romania played an important role in balancing electricity grids in the region (Emerging Markets Group, 2005). Current government objectives along with reinforced interconnections with neighbours such as Hungary and Serbia allow for continued export. The planned construction of a subsea interconnector between Romania and Turkey, where electricity demand is rising rapidly, will provide further avenues for electricity export. The establishment in 2010 of a common regional energy exchange strengthened Romania's ambitions to become a regional energy hub.

At present the grid is limiting the integration of Romania's wind resource, and can only receive 4,000 MW of decentralised intermittent renewable sources. This is reflected in the current national energy strategy, which expects installed wind capacity to grow rapidly in the near future and then stagnate as the grid reaches capacity.

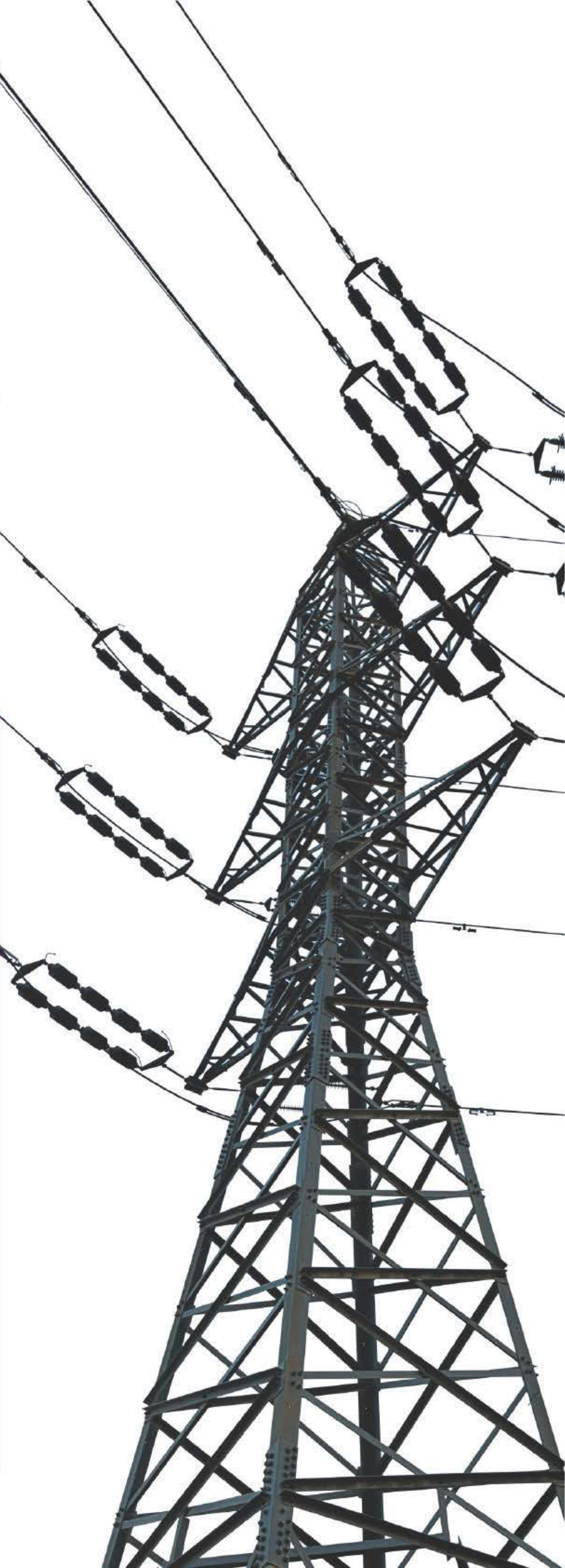
2.2.7 GOVERNMENTAL LIMITATION IN ROMANIA

In spite of all Romania's natural and human capital strengths, many hurdles will still need to be overcome in its development into a modern European economy. These obstacles range from infrastructural, procedural, capital, bureaucratic and excessively influential interest groups. Overcoming these issues will require a concerted effort on behalf of the political elite to improve productivity and enact consistent policies. The effective use of available EU funds is a boon for the economy and if managed correctly could attract vital foreign capital. Corruption is still present in Romania, adversely affecting some decision making. The 2011 progress report from the European Commission did not reflect favourably on government performance, highlighting failures to reduce corruption and secure high-level convictions (European Commission, 2011). Procedural inefficacies and complex governmental structures also hamper Romania's development. EU funds give Romania an unprecedented opportunity to accelerate economic and social development. Since accession, the EU has made €19 billion available to Romania in the form of regional development and cohesion funds. However as of mid-2011 the utilisation of such funds has been poor, with an absorption rate of only 3.7%, far behind accession partner Bulgaria (EUbusiness, 2011).

2.3 PRIMARY ACTORS AND STAKEHOLDERS FOR CCS

The Romanian government has sought to use climate change goals as a mechanism for capacity building at an institutional level, proactively seeking EU funds for technology demonstrations. The National Reform Programme 2011-2020 highlights CCS as a key area of research and development. The National Programme for

Carbon Capture and Storage seeks to develop the technology, reducing cost and paving the way for its implementation. Initiatives such as the "Action Plan to implement a Demonstration Project regarding Carbon Capture and Storage in Romania" has established the steps necessary to develop a CCS project in Romania, recruiting national and private bodies with the relevant skills. Romanian stakeholders participate in many European technology networks to advance CCS. Institute for Studies and Power Engineering (ISPE) and The National Institute for Research and Development in Geology (GeoEcoMar) have represented Romania in ZEP (Zero Emission Platform), CO_2Net, ENeRG, and Fossil Energy Coalition (FENCO ERA). The country has leveraged EU R&D projects, with ISPE and GeoEcoMar as active members of many projects such as EU GeoCapacity (Assessing European Capacity for Geological Storage of Carbon Dioxide) CO_2 NetEast (CO_2 capture and storage networking extension to new member states) and CASTOR.



INDUSTRY ACTORS, THE FOLLOWING COMPANIES ARE INVOLVED WITH DEMONSTRATION PROJECTS OR HAVE INTERESTS IN CCS

CORPORATE

- Romgaz – Largest natural gas producer and operator of underground storage facilities
- Petrom – Largest oil production firm in Romania
- Transgaz – State owned operator of gas transmission system
- Transelectrica – Electricity transmission system operator
- Termoelectrica – Operator of thermal power plants
- C.EN Turceni – Operator of Turceni energy complex

RESEARCH & TECHNICAL INSTITUTES

- ISPE "Institute for Studies and Power Engineering"
- GeoEcoMar "The National Institute for Research and Development in Geology"
- IPCUP Ploiesti "National Research and Development Institute for Oilfield Equipment"
- COMOTI "The Scientific Research and Engineering Centre for Aircraft Engines"
- ICEMENERG "Energy Research and Modernization Institute"
- ENERO "Centre for Promotion of Clean and Efficient Energy in Romania"
- University Politehnica of Bucharest – Research into power system CCS
- NHN EcoInvest – Environmental audits and impact assessments
- Romelectro – Vendor of power plant equipment

NGOS

- CO2 Club – Public outreach involving companies with an interest to promote CCS
- Terra Millennium III – NGO with an interest in electricity sector and climate change
- The National Centre for Sustainable evelopment – Develops proposals for sustainable development

3.0 SECURING ENERGY

3.1 DEMONSTRATION PROJECTS

In 2007, the European Commission began to create an economic and legal framework to support flagship demonstration CCS power plant projects. These demonstration projects aim to show the potential of CO_2 capture and storage while testing the technology at scale, gaining valuable know-how, reducing capital costs through technological and operational learning and reducing risk through gained experience. The European Commission has committed to financially support first of a kind CCS demonstration projects through the "NER300" initiative, which dedicates the revenues of 300 million EUAs from the New Entrant Reserve.

The demonstration programme provides Romania with the ideal opportunity to work with EU support to develop a first-generation commercial CCS facility. This would enhance Romania's institutional capacity, placing the country at the centre of a critical Pan-European project. Raising the profile of Romanian technological expertise and administrative capacity would also help the nation develop further the investor confidence necessary to facilitate wide-scale CCS deployment into the future.

3.1.1 GETICA CCS DEMO PROJECT

The Romanian government has already recognized the potential importance of the demonstration programme, and has positioned itself at the forefront of the NER300 program. The Getica CCS project has been proposed as a flagship European demonstration project, demonstrating capture transport and the permanent storage of 1.5 million tonnes of CO_2 pro annum. The project has received official support from the Prime Minister, with coordination by the Ministry of Economy, Trade and Business (MECMA) and support from the Global CCS Institute. It is hoped that 50% of the cost of the Getica project will be financed through the NER300. The European Commission and investors have made it clear that financial support from national governments will be indispensable, in addition to those resources available through EU grant mechanisms and the European Investment Bank (EIB). To further support the demonstration project, from 2013 onward Member States will be able to use ETS income to support CCS demonstration projects.

This first Romanian demonstration CCS facility is proposed to be retro-fitted to the 330MW lignite-fired power unit no. 6, owned by the Turceni Energy Complex. The CO_2 capture facility is to be based on post-combustion capture technology, removing CO_2 from the flue gases using the chilled ammonia process. Captured CO_2 would be transported via pipeline to a deep saline storage site within 50 km of the power plant. GeoEcoMar along with international subsurface services firm Schlumberger are currently carrying out work to characterise a suitable site. A project company and a steering group has been established with a consortium of state-owned companies. These included Turceni Energy Complex, the operators of the power plant, Transgaz, the future operators of a CO_2 transport network and Romgaz, the future operator of CO_2 injection and storage (Getica CCS, 2011). The Turceni power plant is located in the south-west of Romania, an area that is considered the most industrialized region, responsible for approximately 40 percent of the total emissions of CO_2 at the national level. This places the Getica project at the heart of a future possible CCS hub, with further application of CCS to other regional power generators and industry leveraging the skills and infrastructure developed during the NER300 programme.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3.2 STORAGE

↘ CO_2 can be safely stored in a dense liquid state deep in the subsurface. Similar mechanisms that trap and preserve hydrocarbons such as oil and gas will immobilise CO_2 and prevent its escape to the atmosphere. CO_2 will be compressed at the point of capture to a supercritical fluid for transport and injection. This minimises the size of the transport pipeline necessary while maximising the available storage space. Only deep storage sites below 800m are considered for storage, below this depth the weight of rock or overburden above will keep the CO_2 pressurised and so remaining in a supercritical state.

Injected CO_2 it is a buoyant liquid and over time will attempt to migrate, much like oil and gas in the subsurface do. Due to this the prospective selection of a storage site must be thoroughly carried out. Structures and barriers are necessary to prevent the flow of CO_2 upwards; these are generally mudstones and are known as cap rocks. When these cap rocks are present in structures that form natural traps we may safely store CO_2. Over a long time, chemical reactions and physical process will permanently immobilise the CO_2, trapping it in new minerals or dissolving it into deep salty brines.

↘ 3.2.1 POTENTIAL STORAGE SITES

Studies indicate that Romania has the potential to store very large volumes of CO_2 in onshore geological reservoirs. GeoEcoMar working in EU programs such as CO_2GeoNet, EU GeoCapacity and CGS Europe has begun to assess the potential of CO_2 storage in Romania. Possible CO_2 storage formations such as saline formations and depleted oil fields are widely distributed throughout the country. Potential storage rocks run in a large arc to the east of the Carpathians, proximal to large point source emitters, such as the CO_2-intensive lignite energy complexes in the south. Significant storage potential is also present in the central Carpathians and the western edge of the country (Figure 3.1). Existing fossil gas pipeline networks already provide corridors and access to many candidate CO_2 storage sites (Figure 3.2)*. Current estimates of onshore storage potential vary significantly. Figures released under the EU GeoCapacity project of 7.5 Gt (billion tonnes) in saline formations and 490 Mt (million tonnes) in depleted oil and gas reservoirs are modest in comparison to the 18Gt in saline formations and 4Gt in depleted oil and gas reservoirs estimated by GeoEcoMar (Vangkilde, et al., 2009). Even a fraction of the most conservative estimates of onshore CO_2 storage potential is far larger than emissions from CCS applicable sources for many decades. Due to this abundance of capacity, discovering and assessing suitable storage sites may be less costly than in other European countries. A breakdown of the estimates of the storage potential in saline aquifers is given in Table 3.1.

* A more detailed account of Romanian geology and structures suitable for CO_2 storage are given in Appendix II.

FIGURE 3.1 POTENTIAL CO_2 STORAGE FORMATIONS IN ROMANIA

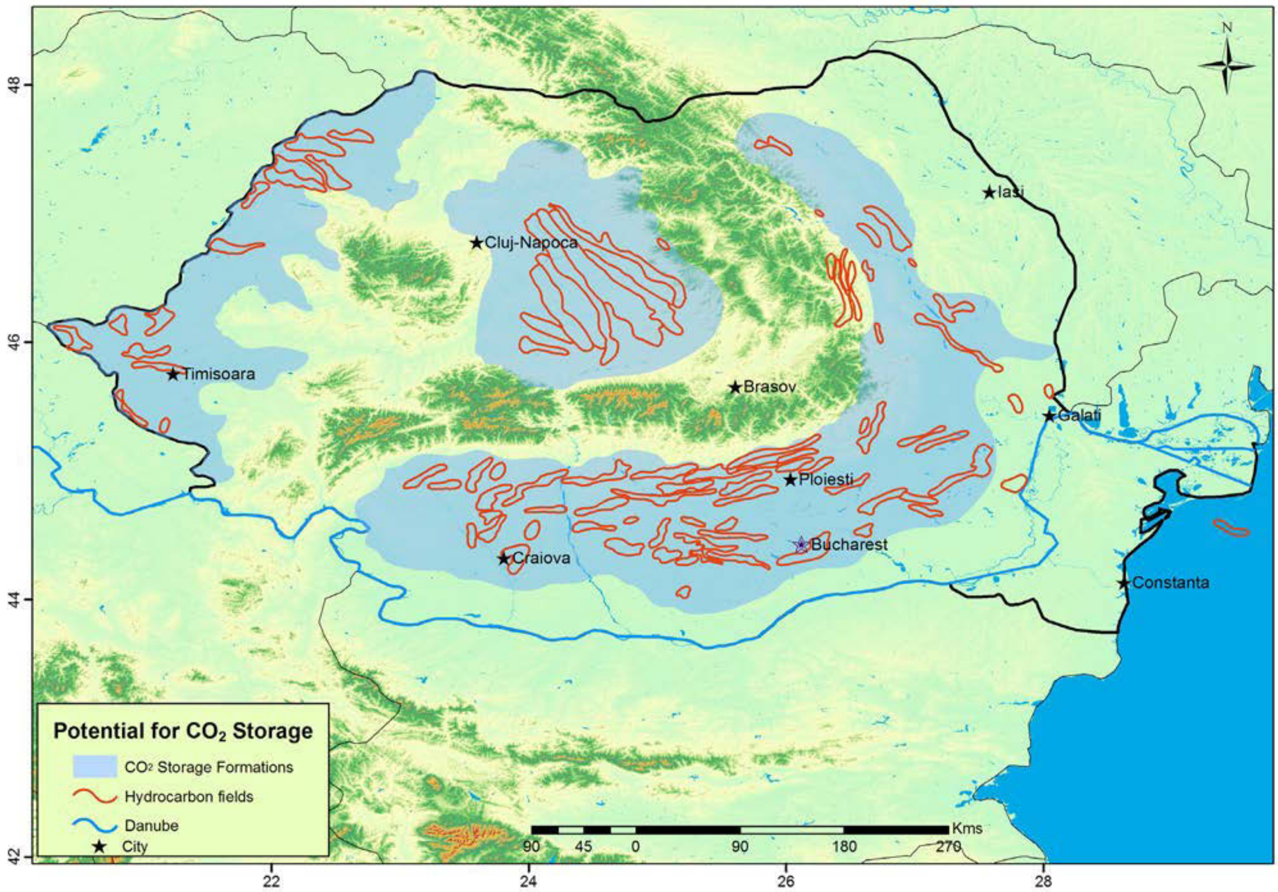
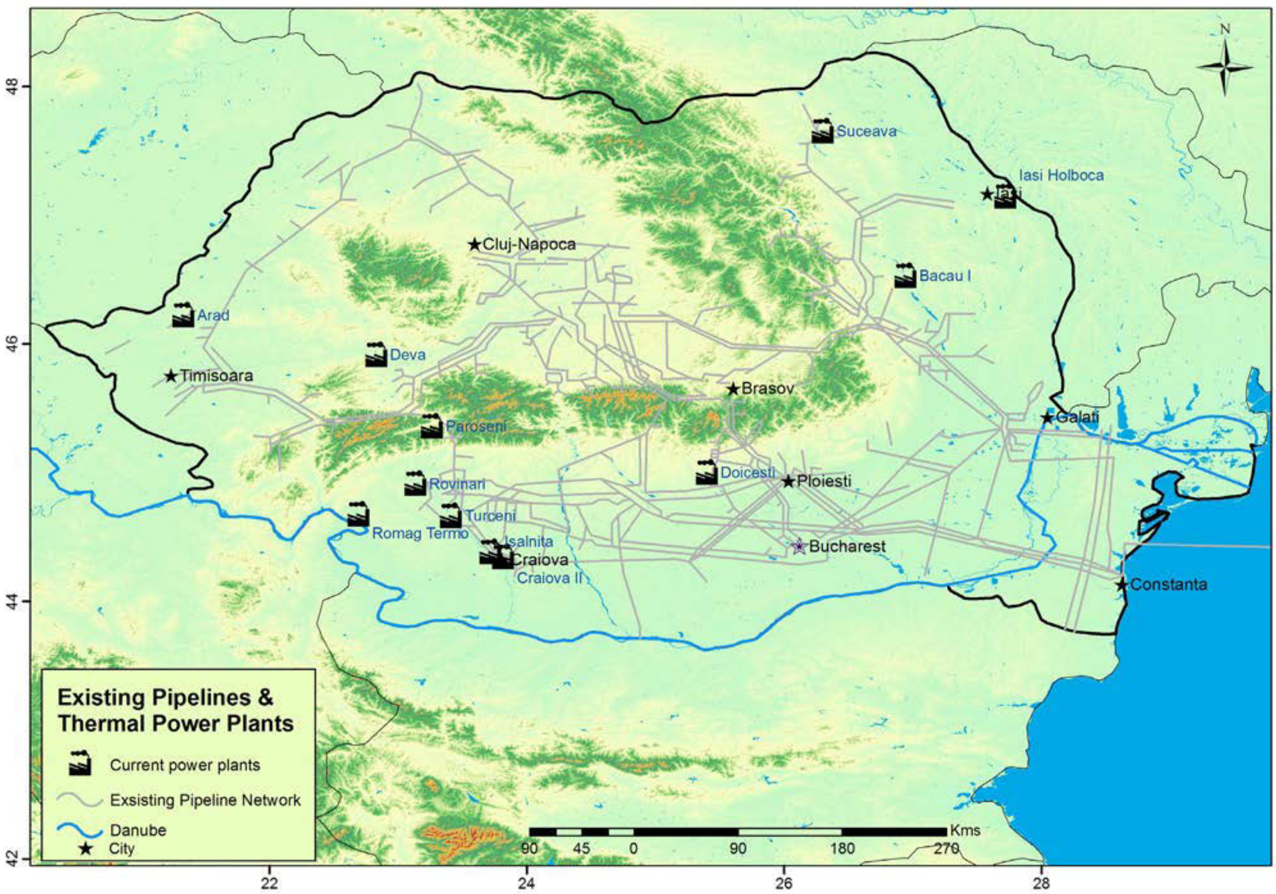


FIGURE 3.2 EXISTING FOSSIL GAS PIPELINES & THERMAL POWER PLANTS



* Saline formations are attractive for CO_2 storage as these potentially offer very large volumes for CO_2 storage. However as there has been no economic incentive to explore, categorise and assess these formations, current knowledge is usually limited. It is possible to produce regional storage estimates with existing data and reasonable assumptions, outlining gross storage potential. It is necessary to note that these figures are estimates and further site specific investigations will be needed to asses in detail the injectivity, heterogeneity and most critically the presence of an adequate cap rock to guarantee CO_2 storage.
Preliminary calculations of the CO_2 storage capacity in a saline formation uses a volumetric equation recommended by many institutions and authors (Equation 3.1) (RCSP, 2006, Bachu, 2007, university of Edinburgh etc):
Equation 3.1 CO_2 Storage Potential
$G_{CO2} = A.h.\varphi.\rho\ E$
Where GCO_2 (Mt) –Storage capacity;
A (Sq. km) – Area that defines the region being assessed;
h (km) – Gross thickness of the saline formation (s);
φ (%) – Average porosity of entire saline formation(s) over thickness h;
ρ (Mt/Sq.km) – Density of CO_2 evaluated at pressure and temperature that represents anticipated storage conditions;
E (%) – CO_2 Storage Efficiency Factor that reflects, among others, the total pore volume that is filled with carbon dioxide.

TABLE 3.1 ESTIMATED CO_2 STORAGE POTENTIAL OF DEEP SALINE AQUIFERS

The Romanian sedimentary basins containing saline formations with potential for CO_2 storage have been assessed in four large zones (Moesian platform and S. Carpathians foredeep, Moldavian platform and Eastern Carpathian foredeep, Transylvanian basin and Pannonian basin).

Structure/Zone	Lithology	Top Depth (m)	Total Area (10^6 m2)	Thickness of aquifer (m)	Effective Porosity	CO_2 density (t/ m^3)	Permeability (mD)	Storage efficiency factor	Total estimated CO_2 storage Capacity (Mt)
Moesian Platform and South Carpathians Foredeep	Limestones, arenitic rocks and sandstones	800, 2600, 3200,	38	70	20	0.65	400-1000, 500-600, 40-700	0.04	5200
Moldavian Platform and East Carpathians Foredeep	Sandstones and limestone	1420, 1000	24	50	20	0.65	0.3-160	0.04	2500
Transylvanian Depression	Sands	1000	22	200	20	0.60	-	0.04	8800
Pannonian Depression	Silty sands	1200	15	70	20	0.60	-	0.04	2100
Total estimated CO_2 storage capacity in deep saline aquifers (Mt)									**18 600**

3.2.2 CO_2 STORAGE IN DEPLETED OIL & GAS RESERVOIRS

Romania has the longest documented history of hydrocarbon production in Europe and was an early leader in the application of geophysical methods for exploration and field development. Romania was the first oil province to commercially exploit its resource, with oil production beginning in 1857 at a rate of 225 tonnes a year. By 1900, Romania was the third largest oil producer in the world with a production of 300 thousand tonnes a year. To date over 23300 wells have been drilled in Romania, discovering 19.2 billion barrels of oil-in-place and 671 billion cubic meters (Bcm) of gas-in-place, located in 473 oil and 201 gas reservoirs. Hydrocarbon production reached a peak in the mid-1970s and has declined substantially since, to approximately 117 thousand barrels a day.

Today Romania is a mature oil province with approximately 40% of oil production obtained by secondary technologies such as water and air flooding. The mature nature of the Romania hydrocarbon sector provides synergies with a developing CCS industry; depleted or declining hydrocarbon fields offer well-characterised and secure CO_2 storage sites. These sites have long operational experience, extensive data and the possibility to reuse existing infrastructure such as injection wells. Geological structures that have trapped and preserved the hydrocarbons could also trap CO_2 in the subsurface*.

3.2.3 EOR POSSIBILITIES IN ROMANIA

CO_2 from anthropogenic sources is not simply a waste product that must be safely disposed of; the gas has a number of properties that can make it an economic resource, especially for use in the oil and gas sector. CO_2 is an ideal fluid to maintain hydrocarbon formation pressure, as well as improving the mobility of the oil through the permeable formation, resulting in the extraction of oil or gas beyond what would traditionally be recovered. Enhanced oil recovery (EOR) using CO_2 has been extensively demonstrated, having an active and profitable history in neighbouring Hungary and, in particular, in the U.S.A. Studies indicate that incremental oil recovery of 3-19% is achievable by CO_2 EOR, dependent on the lithologies and heterogeneity of the producing reservoir (Ferguson, 2009; Aam, 2010; Richards, 2011).

The application of EOR and CCS has many co-benefits. Oil field operators, along with the State, could see an increase in revenues due to extra oil production. EOR could incentivise the early adoption of CCS by providing a revenue stream, while also stimulating the construction of CCS infrastructure such as pipelines. Romania has a vast resource of aging fields that may benefit from EOR; extra oil production achieved during the permanent geological storage of CO_2 would provide rents, reducing costs and financial risks of deploying CCS. Romania has some of the most favourable conditions in Europe to implement CO_2 EOR. Unlike other European oil provinces such as the North Sea, where any future EOR operations will be offshore, most of Romania's exploited hydrocarbon resources are onshore, resulting in lower exploration and exploitation costs, lower financial risks and higher returns. EOR using the CO_2 recovered by capture at power plants could result in a significant extension of the lifetime of declining fields and produce important economic benefit. This is especially true when considering the geographical proximity of the major emitters such as the lignite-fired power plants to depleted hydrocarbon fields in the the Moesian platform.

The future of Romanian hydrocarbon production has already begun; Petrom, a Romanian subsidiary of OMV, an Austrian oil firm, has developed an EOR project at the Turnu field in the west of the country. The project consist of production of mixed gases, which are separated at a surface facility with the natural gas sold to market and the CO_2 reinjected back into a deeper reservoir to maintain formation pressure and enhance oil recovery (Coca, 2008). Successful implementation of the Turnu project could permanently sequester approximately 5 million tonnes CO_2 over a 10 year period. The company has also committed itself to unlocking the substantial potential of its mature Romanian assets, the

* Estimates of CO_2 storage capacity in depleted reservoirs may be calculated in two ways, either by a similar volumetric equation or by a production-based equation if acceptable records of the volume of hydrocarbons produced are available. Applying an appropriate formation volume factor (B) to extracted hydrocarbons to attain the subsurface volume now available for CO_2 storage (Equation 3.2). As 70 – 80 % of Romanian oil and gas resources have already been exploited, the potential for CO_2 storage is very high as shown in Table 3.2.
Equation 3.2 Storage Capacity In Depleted Hydrocarbon Reservoirs
$G_{CO2} = UR_P.B.\rho$
Where: UR_P is the Ultimate Recoverable Oil (or Gas) based on sum of produced volumes and expected reserves.
ρ (Mt/Sq.km) – Density of CO_2 evaluated at pressure and temperature that represents anticipated storage conditions;

TABLE 3.2 ESTIMATED CO_2 STORAGE POTENTIAL IN DEPLETED HYDROCARBON RESERVOIRS

Field name	Lithology	Top Depth (m)	Proven ultimate recoverable gas (109 m³)	Proven ultimate recoverable oil (106 m³)	B_{gas}	B_{oil}	CO_2 density (t/ m³)	Total estimated CO_2 storage capacity (Mt)
Arad (Turnu)	sandstones	850	4	8.3	0.005	1.5	0.5	10
Timisoara (Satchinez)	sandstones	1096	-	8	-	1.5	0.5	5
Copsa Mica	sandstones	800	80	-	0.005	-	0.5	100
Ludus-Iernut-Tarnaveni	sandstones	800	12	-	0.005	-	0.5	15
Targu Mures	sandstones	1000	20	-	0.005	-	0.5	25
Sangeorgiu de Padure (Fantanele)	sandstones	800	25	-	0.005	-	0.5	25
Rogojel (Spinoasa)	sand	800	30	-	0.005	-	0.5	25
Targu Jiu (Iasi–Gorj)	sandstones	800	-	25	-	1.5	0.5	15
Turceni (Bobaia)	sands	3700	-	83	-	1.5	0.5	50
Ghercesti	sands	1770	-	0.57	-	1.32	0.5	9.59
Malu Mare	sands	1770	464	116.25	0.0062	1.5	0.5	6
Slatina	Sands and sandstones	800	-	25	-	1.5	0.5	15
Pitesti and Colibasi (Hintesti)	sands	800	-	16.6	-	1.5	0.5	10
Ramnicu Valcea and Govora (Babeni)	sands	800	-	83.4	-	1.5	0.5	50
Targoviste and Doicesti (Teis)	sands	1000	-	33.3	-	1.5	0.5	20
Campina	Kliwa sandstone	-	-	8.4	-	1.5	0.5	5
Baicoi and Floresti	sands	800	-	8.6	-	1.5	0.5	5
Ploiesti and Brazi (Aricesti)	sands	900	-	18	-	1.5	0.5	10
Tataru	sands	950	-	51.25	-	1.05	0.5	15
Bucuresti East (Glina)	Sands and sandstones	860	-	9	-	1.5	0.5	5
Bucuresti West (Gradinari)	Marly sandstones, sands	930	-	10.2	-	1.5	0.5	5
Buzau (Berca)	sands	2400	-	9		1.5	0.5	5
Ramnicu Sarat (Ghergheasa)	sands	2000	40	-	0.005	-	0.5	50
Tecuci (Tepu)	sands	1494	-	9	-	1.5	0.5	5
Barlad (Glavanesti)	sands	1000	-	8	-	1.5	0.5	5
Total estimated CO_2 storage capacity in hydrocarbon fields (Mt)								**490.59**

re-development of 6-8 fields and the wider application of EOR technologies (Langanger & Huijskes, 2010). Romgaz is also investigating the possibility of rehabilitating a number of its brown field sites (Radu, 2011).

The high level of CO_2 EOR expertise in the region may help accelerate on-going development. Hungary with a much smaller hydrocarbon sector has achieved nearly 20 million extra barrels of oil production due to CO_2 EOR (Nemeth, et al., 1988). The presence of a state-owned oil and gas firm, Romgaz, is also advantageous for the deployment of CO_2 EOR in the country. National firms such as these, as is the case of MOL in Hungary, are incentivised to maximise indigenous resource production for the national benefit. In contrast, multinational organisations will often favour investment with a more rapid payback, prioritising projects with possible larger returns and therefore larger risks (Godec, 2011).

To effectively leverage these advantages Romania will need to catalogue existing pipeline and injection infrastructure, its expected decommissioning dates and its applicability for CO_2 transport and storage. In order to prevent existing infrastructure falling out of use into disrepair or the corridors being sold off, dialogue between pipeline owners and anticipated end-use operators of CO_2 storage sites should be encouraged immediately. This is especially true if offshore storage is to be considered in the future, as recreating offshore pipeline and rig infrastructure would otherwise be very expensive. With sufficient planning and cooperation, the retirement of the yet to be exploited Doina & Ana gas fields in the Black Sea may be repurposed as CO_2 storage facilities (Beacom, 2011).

3.2.4 CO_2 IMPORT & THE POST-HYDROCARBON ECONOMY

The large volumes of high quality CO_2 storage available in Romania and the long history of subsurface activities place the country as potentially the preeminent CO_2 storage provider in the region. Utilising oil and gas expertise built up over the preceding century, Romania could position its self as a key provider of CO_2 storage to other nations. Existing wells and redundant gas pipelines may be repurposed to transport and inject CO_2 thereby reducing investment outlay and further increasing the country's competitive advantage. As with Scotland, Romania may position itself as a post-hydrocarbon economy, substituting the declining extraction of hydrocarbons for the injection of CO_2 and building a carbon storage service economy. Cross-border transport and export of CO_2 is anticipated to become necessary for many European countries to meet climate obligations, with the industry growing to a significant scale as early as 2030 (Neele, et al., 2011). Importation and storage of CO_2 from neighbouring countries such as Hungary, Bulgaria and perhaps even Germany could generate valuable revenues while providing high quality employment in design, operation and monitoring of transport and storage facilities.

3.2.5 CONFLICT FOR THE SUBSURFACE

As with many natural gas import dependent countries in the region, the Romanian government has set out a policy goal to increase gas storage in an attempt to insulate the nation from any possible future supply constraints (Alexandru, et al., 2009). Romania currently has significant underground natural gas storage capacity, a total of eight facilities provide a capacity of approximately 3.1 Bm^3 and is expected to increase by 53.1% by 2015 (Cociancig, 2009) (Ogeinja, 2011) . An expansion of this storage capacity may lead to competition with CCS for suitable storage sites, however the large storage potential present in Romania should minimise direct competition.

The explosion in global interest in shale gas has attracted prospectors to Romania. Large international hydrocarbon firms such as Chevron have already secured blocks (business-review.ro, 2011). Local operators such as Petrom have also begun to perform shale gas feasibility studies in the Romanian Foreland Basin (Langanger & Huijskes, 2010). According to a report issued this spring by the U.S. Energy Information Administration (EIA), Romania, Hungary and Bulgaria have a joint recoverable shale gas reserve of 538 billion cubic meters or one tenth of Poland's estimated reserves (EIA, 2011). However shale gas reserve estimates in Poland have been drastically revised downward as more extensive surveys are completed. Hungary's MOL has also secured drilling rights but is currently prioritising conventional resources as costs of shale gas exploration are high. Romania currently has no specific legislation for shale gas exploration or production (Gloystein & Neely, 2011). If shale gas is to be produced in Romania then stringent environmental standards will need to be in place, the siting of hydraulic fracturing activities will also need to be distinct from CO_2 storage operations.

3.3 FUNDING CCS DEPLOYMENT

Funding from the EU may be made available to co-finance future CCS projects and related infrastructure. The EU has allocated €19 billion for Romania in the form of regional development and cohesion funds the in the 2007-2013 period. The future allocation of structural funds to incentivise the commercialisation of CCS would be reasonable. CCS development would be relevant under operational programmes of the structural funds such as "Infrastructure and Environment" and "Innovative Economy" (Spencer, et al., 2010). Funds for cross-border co-operation such as the INTERREG programme may be used to finance investments in CCS infrastructure such as international CO_2 pipelines or the joint management of a cross-border storage unit. Encouraging the development of cross border CO_2 transport networks will be necessary for Romania to reap the full benefit as a CO_2 storage hub. Funding through the Norwegian financial mechanism could help support CCS in Romania, receiving €115m. In addition European Economic Area (EEA) grants including Norwegian grants total €306m from 2009 to 2014. Some of these funds may be used to finance detailed CO_2 storage qualification and front-end engineering and design (FEED) studies for CCS projects. In early 2012, the Norwegian government committed €20 million to research and development co-operation with Romania. These funds are pre-defined for the Getica CCS Demo Project, and will be used for FEED studies on capture and transportation infrastructure along with storage site appraisal (Ulstein, 2012).

With respect to Enhanced Oil Recovery (EOR) Romania should consider incentives to encourage the deployment of the technology in the near term. Specific EOR incentives could help to kick start early CCS deployment, accelerating development of the technology and the end result of a low carbon society. These incentives could take the form of tax reductions, credits or modification to the tax basis. Incentives will need to be efficiently designed and only apply for the period necessary to establish

CO_2 EOR. The Romanian government may consider directing the additional revenues from increased oil production to future investments in CCS, including infrastructure, research, and storage characterisation. These revenues may also be made available to fund loan guarantees to prospective CCS projects (Birkeland, et al., 2011). *

Subsequent to the demonstration phase of CCS, support will still be necessary to incentivise the deployment of commercial CCS plants in the 2020s. The Romanian government and regulatory authorities will need to investigate what CCS support mechanisms are suitable for the Romanian energy sector. These may include a feed in tariff for CCS, a carbon price floor and or a capacity mechanism. The goal of such incentives is to reduce uncertainty and provide a solid business case for commercial investment. The EIB could play a vital role in providing loans and guarantees to CCS projects in Romania.

3.4 LEGAL ASPECTS

↘ Establishing a robust legal framework for CO_2 storage is of utmost importance in creating the necessary certainty and confidence that will allow investors and companies to realise an early CCS project and subsequently set long-term plans. The EU has addressed this by adopting Directive 2009/31/EC on the geological storage of carbon dioxide, which must be transposed by all Member States. The Directive provides a legal framework for the management of environmental and health risks related to CCS. Member States may opt for different regimes and solutions, which either stay close to the text of the directive or go beyond and provide for stricter regulation. The Directive requires EU Member States to determine whether and where CCS will take place on their territory.

Romania has been proactive in the transposition of the CCS Directive into national law, beginning in early 2010. The Ministry of Environment and Forests collated input from governmental stakeholders, with ISPE, GeoEcoMar and the University of Bucharest advising on technical matters. The "Government Emergency Ordinance on the geological storage of carbon dioxide" was made public for consultation on the 22 February 2011. The technical transposition of the Directive was completed through GEO no 64/2011 on the 29 June 2011, providing a legal basis and framework for the geologic storage of CO_2 in Romania. However GEO no 64/2011 should not be considered a full transposition as such but a direct transplant of the provisions within the EU Directive. At present the legal framework cannot be interpreted as fully workable and specific clarification on future rules and procedures need to be enacted. The law contains no procedures on authorisation, monitoring, financing or the establishment of a central implementing body (Jozon, 2011). At present, responsibility for CCS falls under a large number of different ministries and national agencies. Cooperation between these bodies is essential if CCS projects are to be implemented in a timely and efficient manner. The National Agency for Mineral Resources (NAMR) has emerged as the main implementing body for CCS, tasked as the competent authority for CO_2 storage; it is to develop specific procedures for the granting of storage permits (Getica CCS, 2011). Secondary legislation has been elaborated on, providing rules for the operation, reporting and inspection of the CCS value chain. National codes for the transportation of CO_2 via pipelines and guaranteeing non-discriminatory access to CO_2 transport networks are also now in place.

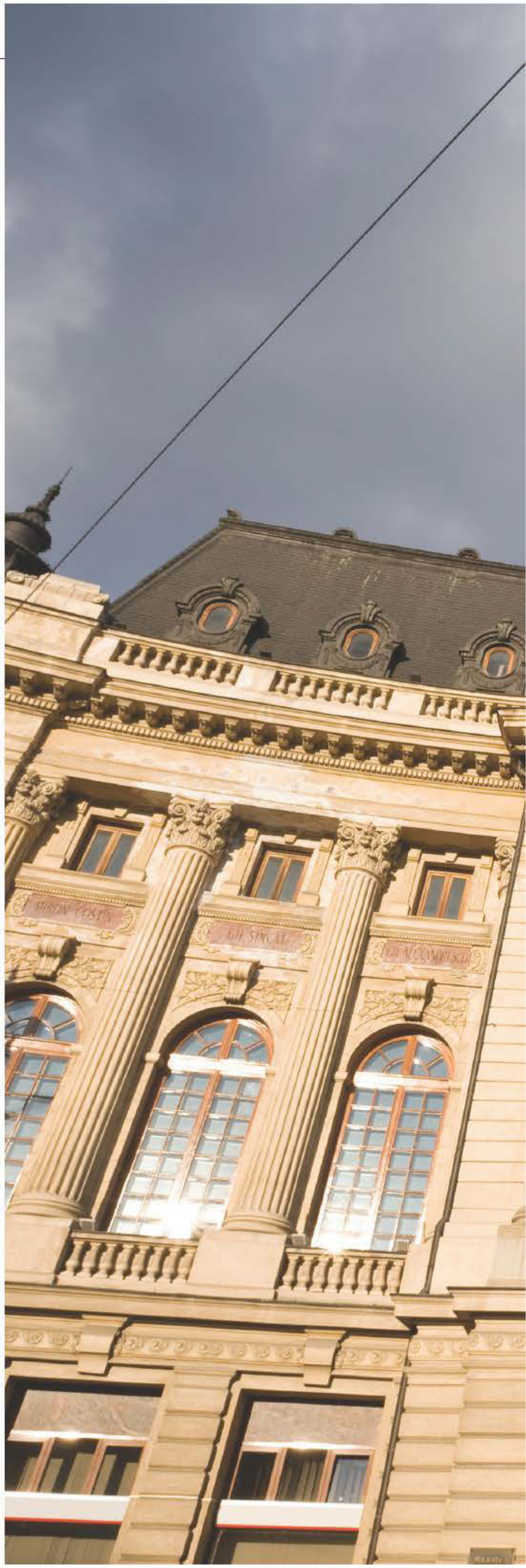
The Romanian government has sought to test and analyse the current national CCS regulatory landscape. The implementation of the Global CCS Institute's regulatory "toolkit" allows for a critical review of the permitting process, highlighting any possible stumbling blocks a CCS development is likely to face. The toolkit has been used to simulate a dry run of the permitting process for the Getica CCS project (GCCSI, 2011). Application of the toolkit has helped identify gaps and barriers present in the current permitting process. These issues need to be remediated to allow streamlining of the implementation of a CCS value chain in Romania (METBE, 2011).

3.5 PUBLIC PARTICIPATION

↘ The majority of CO_2 storage in Romania is likely to take place onshore. Experience from other countries indicates that people living near proposed storage sites may object to CO_2 being stored in the vicinity of their homes and workplaces. The proper engagement of the local communities in the area of such a project is crucial. However to date the Romanian government and Getica project participants have a mixed record with active public outreach and inclusion. According to a Eurobarometer poll, Romania has the second lowest public awareness of CCS in Europe, with only 4% of respondents claiming to know what it was (Eurobarometer, 2011). The very low visibility of CCS among the public by no means guarantees that public acceptance will evolve in a positive manner. Yet there is no indication at present that the Romanian public will be unsupportive of CCS projects. Available published information on the Getica project highlights the advanced industrial nature of the demonstration along with the benefits this will bring to Romanian service and technology firms. The government has recognised the need to involve the public in the permitting and planning of CCS projects, however during the process of transposition of the EU CCS Directive the relevant government authorities did not initiate much public outreach. The government has commissioned a social study in the region of the proposed Getica project, it is hoped that the information produced will help project developers more effectively communicate the benefits of the project with local stakeholders and the public in general (METBE, 2011).

CCS projects will provide sustained skilled employment long after the initial construction phase of capture plant and CO_2 transport infrastructure is complete. CO_2 capture facilities are large with many complex processes, these facilities will require skilled operators and technicians. CO_2 storage operations will also be dependent on skilled professionals to plan, operate and monitor storage sites. As discussed, the use of CO_2 as a valuable commodity in other industries will provide employment opportunities. Increased activity due to EOR projects will benefit employment throughout the entire energy value chain. The use of CO_2 in agricultural settings such as advanced greenhouse techniques and

* Read Further - Birkeland et al. (2011). Improving the Regulatory Framework, optimizing organization of the CCS value chain and financial incentives for CO_2-EOR in Europe



the production of algae for biofuels will provide both skilled and unskilled opportunities. Biomass supply necessary for co-firing as discussed in Section 5.1 will promote valuable employment in currently disadvantaged rural areas.

In many countries NGOs are trusted and perceived as non-partisan providers of information. As such the role of NGOs can have a major effect on shaping public opinion of large infrastructural projects. Romanian NGOs with an interest in environmental protection have attended various information and workshop events regarding the Getica project. However CCS is not a current priority for local environmental organisations such as Terra Millennium III or the National Centre for Sustainable Development; both have yet to set out a clear position on CCS. In 2007, the ClubCO_2 was founded as a vehicle to promote and disseminate CCS information. The design and administration of a public outreach program are country and site specific, dependent on local values, concerns, economy and prior experience with the project proponents. There is no certain way to guarantee positive public reception of any project. However, in very general terms, providing accurate information and engaging in open and sincere dialogue to with local communities reduces the risk of a negative perception of CCS. Crucially, public trust in the parties providing information must be high.

3.6 RECOMMENDATIONS

- Further investigate and improve estimates of total CO_2 storage capacity, particularly in light of the large spread in estimates performed so far.

- Produce detailed assessments of depleted hydrocarbon fields available for CO_2 storage. Characterise trapping mechanisms, cap rock integrity, injectivity, formation heterogeneity, barriers to CO_2 flow, and the condition of legacy wells.

- Execute a knowledge transfer program to ensure that experience from gas handling and gas storage industries is leveraged for CCS deployment, from an economic, technological, and risk management perspective.

- Build expertise in CO_2 EOR and investigate best practice while also implementing incentives to kick start CO_2 EOR projects. Make CO_2 EOR a more attractive investment for private industry with an effective tax regime.

- Evaluate the availability and suitability of the existing natural gas pipeline network for future CO_2 transport needs. A National Programme addressing the timing and potential re-use of pipelines or corridors, as well as injection wells is crucial for timely CCS implementation.

- Begin investigation of suitable electricity market reform such as a capacity mechanism to reward low carbon baseload generation. Mechanisms such as these will be necessary to support post-demonstration CCS project, providing greater certainty for long term investments.

PHOTO: ISTOCK

4.0 PATHS TO A LOW-CARBON ROMANIAN POWER SECTOR

Romanian energy policies will need to evolve to take into account EU climate change policies and legislation. This will bring about new costs and liabilities. This chapter describes the possible opportunities available to the Romanian Electricity Production Industry (EPI) to mitigate these costs, with a primary focus on assessing the applicability of CCS to the generation system. The costs of delay and inaction in not confronting unrestrained emissions are also highlighted. The scale of future obligations from emissions trading will not only affect the energy sector, but consequently the competitiveness of the wider economy.

This chapter investigates when and how CCS will need to be implemented if Romania is to avoid damaging costs. Large scale deployment of CCS will require a national plan to support and promote investment in CO_2 capture, transport and storage. Timely capacity building, using the technical, legal and financial experience gained during demonstration projects, will be critical for the efficient adoption of CCS. Investment decisions must be informed by an understanding of the emissions reduction potential, the timelines for, and potential cost impacts of widespread CCS application in Romania.

This report examines CCS implementation in two possible energy trajectories using different fuels and technologies. The scenarios are designed as a tool to provide information on the efficient implementation of CCS and to as accurately as possible describe the cost and benefits of CCS within the Romanian generation sector. The roadmap should serve as a valuable resource to inform a national CCS deployment plan. The modelling and development of the power sector along with the impacts of CCS deployment was carried out using the Long Range Energy Alternatives Planning software (LEAP).

4.1 MODELLING THE FUTURE OF THE ROMANIAN POWER SECTOR

To model the power generation of a specific country, predictions and forecasts must be combined with reasonable assumptions made on likely outcomes. Approaching the electricity generation system in Romania presents many unique challenges in this regard. The EPI in Romania is currently undergoing rapid change, with much of the present infrastructure to be replaced in the next decade. Existing fossil, nuclear, hydro and renewable capacities are modelled based on the projections from both the unpublished Draft Strategical Directions and Objectives for Romanian Energy Sector for the period 2011–2035 and the Romanian National Renewable Action Plan (2010).

An exception to those government predictions is the commissioning dates of the two future nuclear reactors at Cernavodă (3 & 4). The current timeframe for the commissioning of these nuclear plants appears to be overly optimistic. The recent collapse of the international consortium involved in the projects will result in delays and almost certainly the missing of the proposed commissioning date of 2017. As such, the expected completion of these plants has been delayed and staggered in the model, with Cernavodă 3 coming online in 2022 and Cernavodă 4 generating four years later, in 2026. This extra time will be necessary for the government to find new financiers and vendors to construct the plants. The two subsequent New Nuclear Plants proposed by the government to be completed in 2023 & 2028 appears to be an unrealistic time frame as the plants

PHOTO: ISTOCK

are currently in the earliest phase of planning with no site, financing or technology committed. The commissioning of these plants in the reference model is expected in 2030 and 2035 respectively.

The current energy complexes of Rovinari, Isalnita and Turceni are vertically integrated mine-fed generating plants. The upgrading and remediation of portions of these plants will extend their operational life. Brown field replacement of this lignite capacity with three new high efficiency 500 MW units in the late 2020s would allow for continued exploitation of local lignite until mid-century. However the expansion of lignite generation beyond this modest level is not seen as viable due to the limited availability of economically extractible lignite.

The Draft Strategical Directions and Objectives for Romanian Energy Sector for the period 2011–2035 calls for the additional installation of approximately 6 gigawatts (GW) of new fossil generation capacity by 2035. As no decision has yet been made on the composition of this capacity, it is necessary to assign appropriate fuel and technology. The proposed capacity is distributed as shown in Table 4.1. The 800 MW imported coal Large Combustion Plant (LCP) 'Planned Coal' is currently progressing through the planning process and will be operated by the Italian utility Enel. Uncertainty surrounding the subsequent plants is very high and as such a probable installation outcome utilising best available technology has been chosen. As discussed earlier, the constrained availability of economic indigenous lignite will restrict the expansion of lignite generation; due to this new coal capacity outside of the three "energy complexes" will use imported coal.

TABLE 4.1 PRELIMINARY FUTURE GENERATION CAPACITY

Fuel and technology installation post 2015 is the BEST interpretation of the preliminary national plan for future generation capacity.

	2015	2016-2020	2021-2030	2026-2030	2031-2035
Name in the model	Planned Coal	Future Gas A	Future Gas B	Future Coal A	Future Gas C
Planned capacity additions	800 MW	1050MW	350MW	1050MW	2650MW
Fuel	Imported coal	Local & imported gas	Local & imported gas	Imported coal	Local & imported gas
Technology	Supercritical pulverised coal combustion plant	Combined Cycle Gas Turbine (CCGT)	Combined Cycle Gas Turbine (CCGT)	Integrated Gasification Combined Cycle (IGCC)	Combined Cycle Gas Turbine (CCGT)

Based on the initial assumptions described above, two energy trajectories have been constructed - the Romanian Energy Policy (ROEP Trajectory) and the High Coal Substitution (HCS Trajectory). Both of these are modelled to meet projected energy demand, maintaining a sufficient capacity margin. With the estimate of electricity demand growth used, extra generation capacity may be needed in the final years of the modelling period to guarantee supply.

4.1.1 ROMANIAN ENERGY POLICY (ROEP) TRAJECTORY

The Romanian Energy Policy (ROEP) trajectory is a "best fit" to current government priorities; describing the landscape of the Romanian EPI to mid-century. This trajectory includes the two proposed new nuclear power plants of 1.1 GW each, commissioning in 2030 and 2035, respectively. Even accounting for the delay in nuclear commissioning, it is clear that this energy future will be dominated by the presence of large amounts of nuclear, hydro and renewable (primarily wind) generation systems (Figure 4.1). The dominant presence of these low marginal cost generators reduces the role of fossil fuels. However the remaining lignite and coal capacities will still emit significant quantities of CO_2 and as such be liable for high costs under the ETS.

4.1.2 HIGH COAL SUBSTITUTION (HCS) TRAJECTORY

The high level of institutional, economic and regulatory uncertainty within Romania leads to ambiguity when projecting the future. In order to address this uncertainty it is necessary to produce an alternative trajectory in which Romania fails to construct the proposed two new nuclear power plants in 2030 and 2035. In this trajectory, these plants are substituted by two 1.1 GW highly efficient imported coal IGCC plants. Due to the overall increase of fossil fuels when compared to the ROEP trajectory, the role of Carbon Capture and Storage (CCS) in this trajectory is crucial to reduce ETS costs and ensure a competitive generating sector. Substituting natural gas fired plants in place of new IGCC plants would result in lower ETS costs, though greater natural gas import dependency could reduce the energy supply security of Romania.

4.1.3 MODELLING FUTURE EU CLIMATE POLICY

The rising cost of CO_2 emissions permits is expected to be the driving factor in decarbonising the electricity sector, providing the major incentive for the application of CCS. In order to capture the possible impacts on the Romanian power sector, some quantitative model of those future policies is required. A very simple representative model is adopted, based on the ETS, with slow linear growth of €2 per year in the EUA price, reaching €50/tonne in 2030 and to €90/tonne in 2050. Such a model represents a conservative future EU climate policy, which imposes a slow and steady reduction in the ETS cap through 2050. This choice falls toward the medium range of European Commission EUA price forecasts, becoming increasingly conservative as we move towards mid-century, as shown in Figure 4 2. The future will almost certainly bring changes in the CO_2 price and the introduction of other climate policy mechanisms unforeseen in this simple model. However, it can serve as an indicator of the possible magnitude of future EU policy impacts on energy production in Romania.*

* Detailed information regarding model dynamics and assumptions may be found in the Appendix I; including CCS technology choice, commissioning dates, costs for capture transport & storage etc.

FIGURE 4.1 ELECTRICITY CONSUMPTION BY FUEL

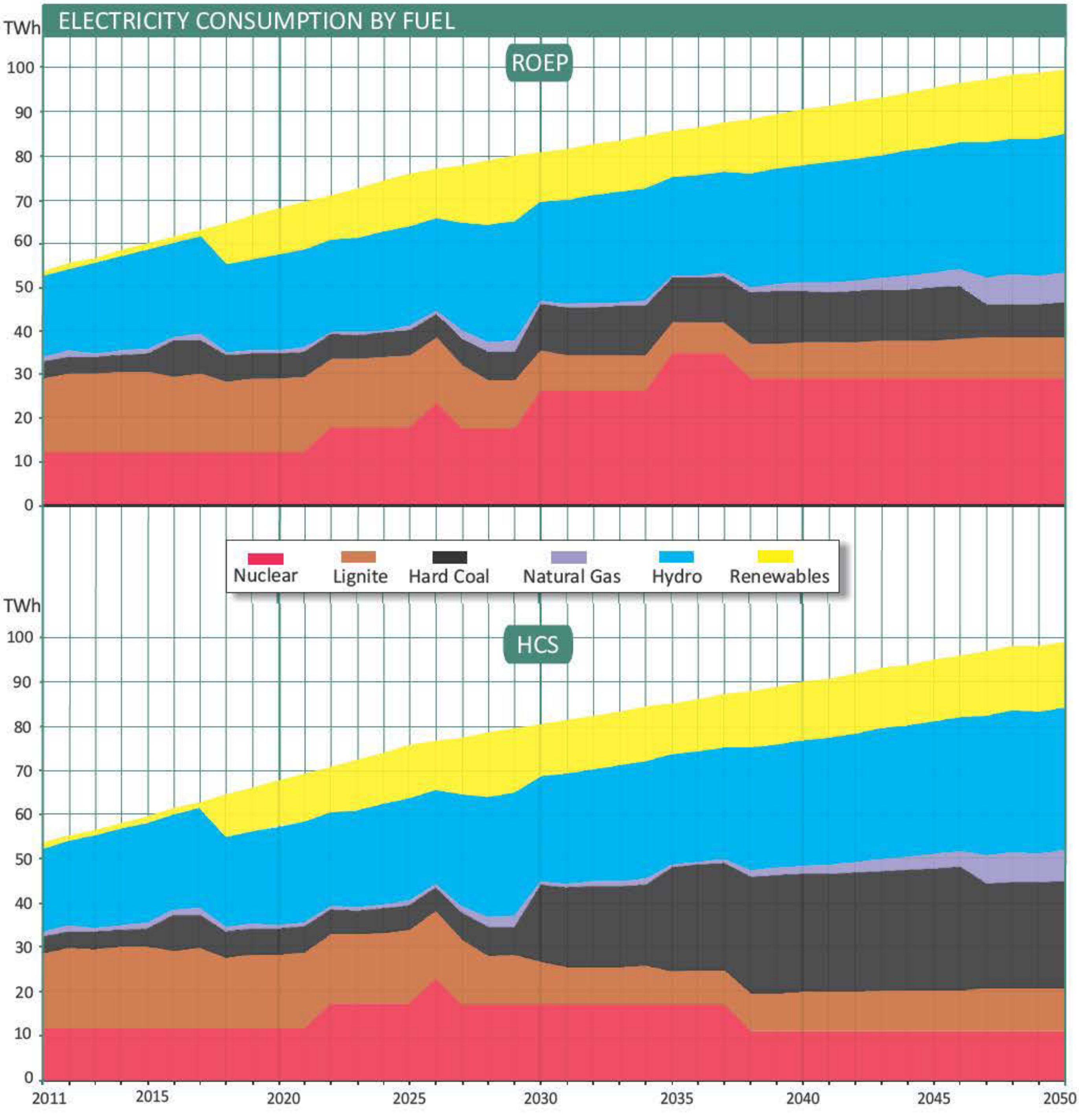
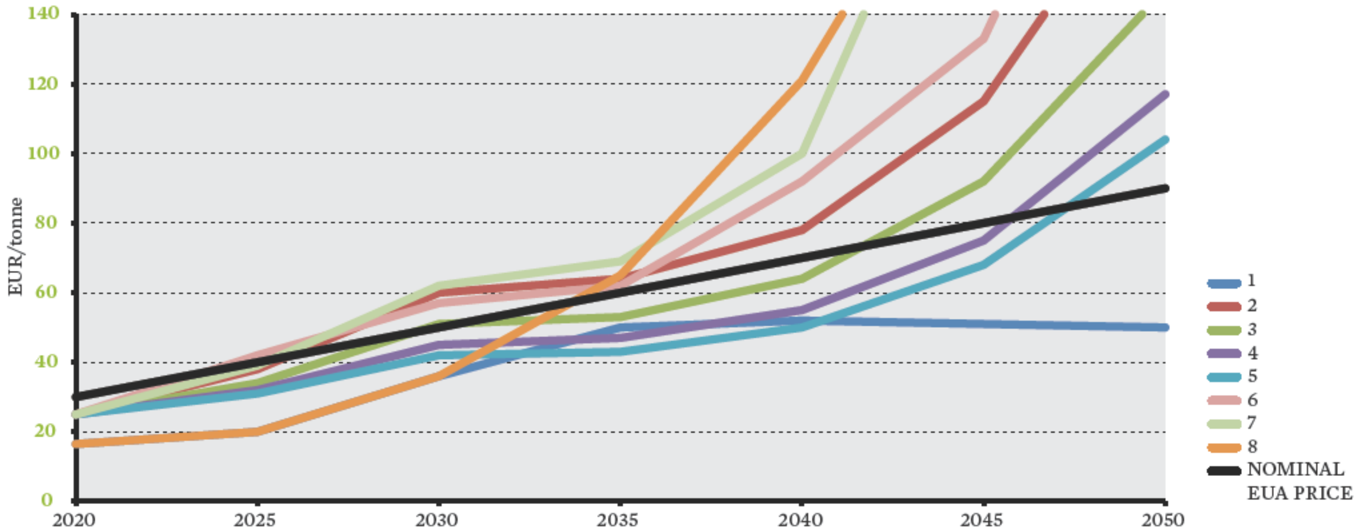


FIGURE 4.2 SELECTION OF RECENT EUA PRICE ESTIMATES

The EUA price projections are the same used by the 2011 European Commission's report: "Impact Assessment: Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. A Roadmap for moving to a competitive low carbon economy in 2050." 1 = Reference (fragmented action, reference fossil fuel prices). 2 = Effective Technologies (global action, low fossil f. prices). 3 = Effect Tech (frag. action, ref. fossil f. prices). 4 = Effect Tech (frag. action, oil shock). 5 = Effect Tech (frag. action, high fossil f. prices). 6 = Delay Electrification (glob. action, low fossil f. prices). 7 = Delay CCS (glob. action, low fossil f. prices). 8 = Delay Climate Action (frag. action, ref. fossil f. prices). (European Commisson, 2011 (b))



4.2 THE ROAD AHEAD, LONG-TERM OUTCOMES OF CCS DEPLOYMENT IN THE POWER SECTOR

↘ In both trajectories commercial CCS is applied to all new-build lignite and coal thermal plant post 2023. The supercritical coal plant currently planned to be commissioned in 2015 is the only retrofit, with CCS integration in 2025. Post combustion capture is used at new lignite capacity commissioned in the 2020s. Imported coal capacity added post-2029 uses pre-combustion capture technology. The diverse nature of the Romanian electricity sector, including technologies such as hydro, wind, nuclear, coal, lignite and natural gas produces a complex system of interactions. The low marginal cost of hydro and wind, while the high availability of nuclear, especially in the nuclear dominated ROEP trajectory lead to an intense competition for baseload generation. In this system, coal and lignite plants generally meet intermediate load, but may operate at baseload, such as during periods of low hydro or renewable availability. The viability of CCS in such a system where large combustion plants are not guaranteed baseload generation is of critical importance for the future of the technology in Romania, and many other nations around the world.

Significant gas generation capacity is present in both trajectories, primarily to maintain a sufficient capacity margin, providing backup for wind and hydro generation. Low utilisation of natural gas capacity over the period precludes the application of CCS.

↘ 4.2.1 ROEP+CCS

The unabated ROEP energy trajectory sees a downward trend in net CO_2 emissions, reducing by approximately 25% until 2030. The bulk of this abatement is due to the retirement of old, inefficient thermal plants. The installation of large amounts of nuclear capacity over the period also reduces the need for CO_2 intensive capacity such as coal or gas. However as all legacy plants are replaced by 2030, emissions reductions stagnate. Fuelled by new coal, lignite and gas capacity, emissions climb again slowly until mid-century reaching 17 Mt of CO_2 in 2050. Although CO_2 emissions in 2050 are a reduction from current levels they still pose a very large liability to the electricity production sector. The annual cost of non-abatement through the ETS in 2050 at €90/tonne of CO_2 is estimated at €1.5 billion.

It is clear that a nuclear intensive strategy with nuclear power generating 29% of electricity would not be sufficient to insulate the Romanian economy from the costs and obligations of climate change. When applying CCS to the ROEP trajectory, significant investment begins in the 2020s as all new coal and lignite facilities are outfitted with the technology. These investments bring about a dramatic decrease in CO_2 emissions, as all unabated coal and lignite are retired and replaced by nuclear and CCS-equipped fossil plants. The CO_2 intensity of the generation system plummets, by 2030 gross emissions have diminished to approximately 2.9 Mt of CO_2, an 84% reduction over the same scenario without abatement.

The small amount of emissions that remain by 2050 arise from low utilised unabated gas power plants and small-scale generation such as CHP units that are not good candidates for CCS. Emissions are reduced by 82% from business as usual by 2050. Residual emissions from CCS-equipped facilities also contribute, as capture technology efficiency is modelled at 95%.

Under the conservative model for the future ETS EUA price described in Figure 4.2, the generation system of Romania will be more competitive with CCS than without, particularly post-2030. In 2030 alone, net savings due to avoided purchases of EUAs at €50 a tonne equal approximately €770 million, growing to over €1200 million in 2050 at €90 a tonne. By reducing the number of EUAs that need to be purchased, CCS helps to curtail electricity price rises. The savings generated far outstrip the costs of CCS. The electricity cost impact shown in the Figure 4.3 only reflects the cost of generation from thermal plants and does not include the cost effects of nuclear, hydro or other renewables. The lifetime costs incurred through the implementation of CCS, including annual operation and annualised investment costs, are less than the projected costs of unabated emissions (see Figure 4.5). Simply stated post-2025 the projected additional costs of CO_2 capture, transport and storage fall below the cost of emitting CO_2.

In alternative cases in which the costs of CO_2 capture, transport, and storage are higher, or in which the EUA price grows more slowly, CCS deployment may be less cost competitive than taking no action until the early 2030s. However the technology will become the most economically beneficial choice over the long term. These cases are explored in the Sensitivity Analysis in Section 4.2.3. CCS thus is shown to be a potentially crucial tool for preserving the future competitiveness of the Romanian economy under any future ambitious climate policy.

4.2.2 HCS+CCS

The HCS trajectory investigates the likely costs and benefits incurred if the proposed two new green field nuclear facilities planned for the 2030s are replaced by two highly efficient imported coal generation units. Emissions from the HCS trajectory begin by following the same path as those of the ROEP model. Emissions decline as inefficient legacy generation is retired. Post-2030 the two trajectories greatly diverge, emissions begin to climb rapidly as large new CO_2 point sources come on stream. By 2050 emissions reach approximately 28 Mt of CO_2, almost twice that of the unabated ROEP trajectory. These emissions would incur huge costs from the ETS, estimated at €2.5 billion per annum by mid-century, severely increasing electricity prices. It is clear that in such an energy future CCS would play a pivotal role in limiting energy cost rises. It is also possible that new gas-fired CCGT plant could be utilised to meet electricity demand in place of coal. This would lead to a reduction in overall CO_2 emissions relative to new coal generation. However emissions would still be high and therefore costly, so these plants too would ideally be equipped with CCS.

The implementation of CCS on this HCS trajectory is modelled to evolve under the same installation path as that in the ROEP+CCS scenario. CCS is fitted to three new-build lignite units, a new-build coal plant and one major retrofit to a coal plant. However, as this energy trajectory includes two additional large point sources, these plants too will be fitted with CCS from the outset in 2030 and 2035. The application of CCS has a dramatic effect on the CO_2 intensity of the Romanian electricity system, preventing 20 Mt of CO_2 emissions a year by 2030. CCS keeps emissions low as more thermal units are introduced and by 2050 more than 25 Mt of CO_2 a year is avoided, a reduction of 87%. In 2030 savings due to forgone EUAs at €50/tonne equal €1000 million, growing to €2200 million in 2050 at €90/tonne. CCS-equipped fossil generation provides more affordable electricity than unabated generation. EUA purchases decline markedly in the late 2020s due to stock retirement and large new-build CCS capacity additions. This abatement avoids the purchase of 20 million EUAs, including the cost of CCS implementation results in an anticipated saving of €1.7 billion in 2050 alone (Figure 4.5). The electricity cost impact shown in the Figure 4.4 only reflects the cost of generation of thermal plants and does not include the cost effects from nuclear, hydro or other renewables. As unabated emissions are higher in this energy trajectory the "value" of CCS implementation is greater due to the much larger avoided costs. Inversely a failure to implement CCS will produce extremely large liabilities for the energy production industry (see Figure 4.5).

4.2.3 SENSITIVITY ANALYSIS

By investigating the impacts of higher and lower costs on the model it is possible to examine the sensitivity of the results and forecast produced to technology variations and other factors. The HCS scenario with widespread CCS deployment has been recalculated using a lower capture efficiency value, increased capture energy penalties, high and low limiting values for capital, interest rates, transport, storage and fuel costs (see Table A1.1 Key Model Parameters). Figure 4.6 describes the annual total costs for all individual sensitivity cases, as well as limiting "very worst" and "very best" cases combining all high/low costs and factors. Figure 4.7 shows the total CO_2 emissions from the HCS trajectory with no CCS deployment scenario, one with CCS deployment and one with CCS together with reduced capture efficiency. In Figure 4.8 the resulting CO_2 avoidance costs for each sensitivity case are compared to three potential CO_2 emission costs: those of the nominal model detailed in Appendix I Section A1.2, and two further sensitivity

FIGURE 4.3 CCS DEPLOYMENT SCENARIO APPLIED TO THE ROEP TRAJECTORY

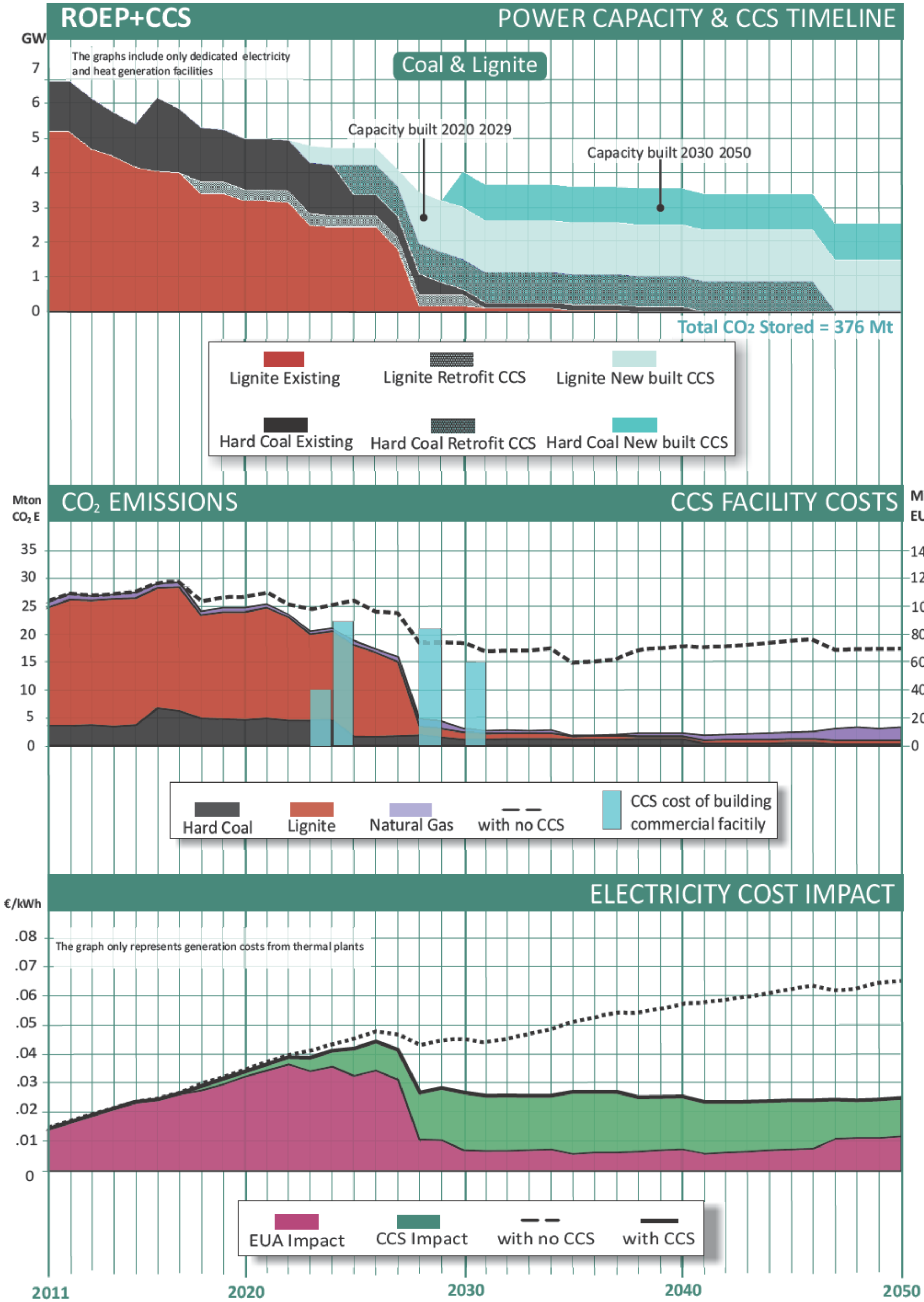


FIGURE 4.4 CCS DEPLOYMENT SCENARIO APPLIED TO THE HCS TRAJECTORY

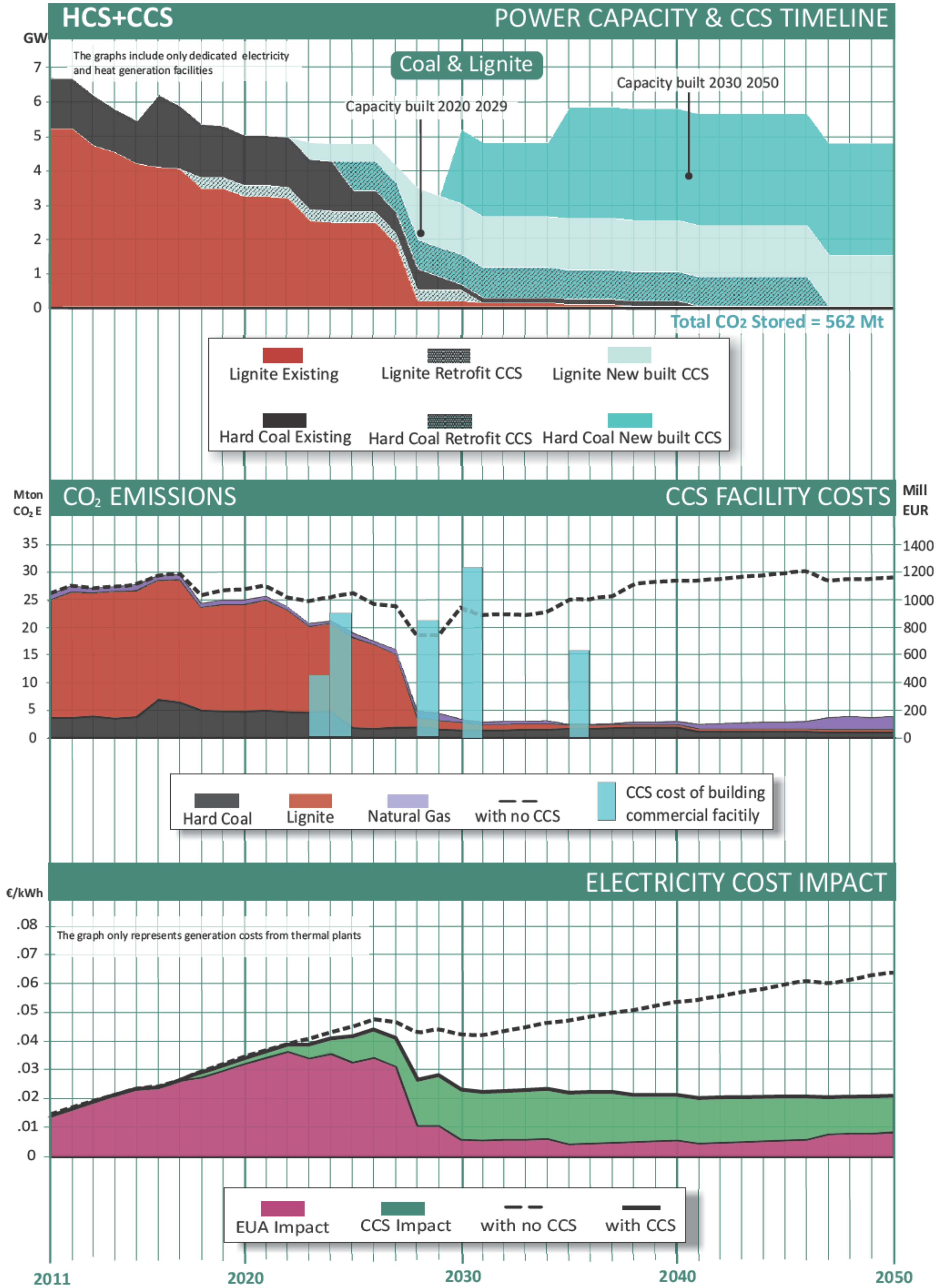


FIGURE 4.5 TOTAL COSTS AVOIDED BY APPLYING CCS TO ROEP AND HCS TRAJECTORIES

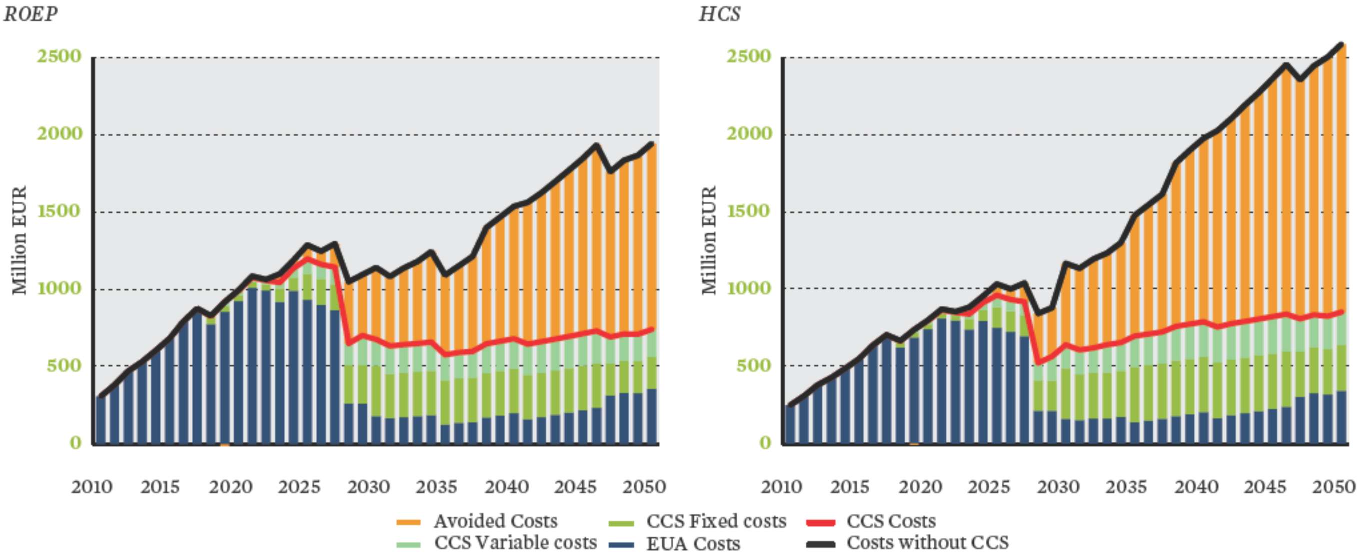


FIGURE 4.6 EUA AND ADDITIONAL CCS COSTS OF DEPLOYMENT APPLIED TO THE HCS TRAJECTORY IN ALL SENSITIVITY CASES

All the sensitivity results are shown in blue

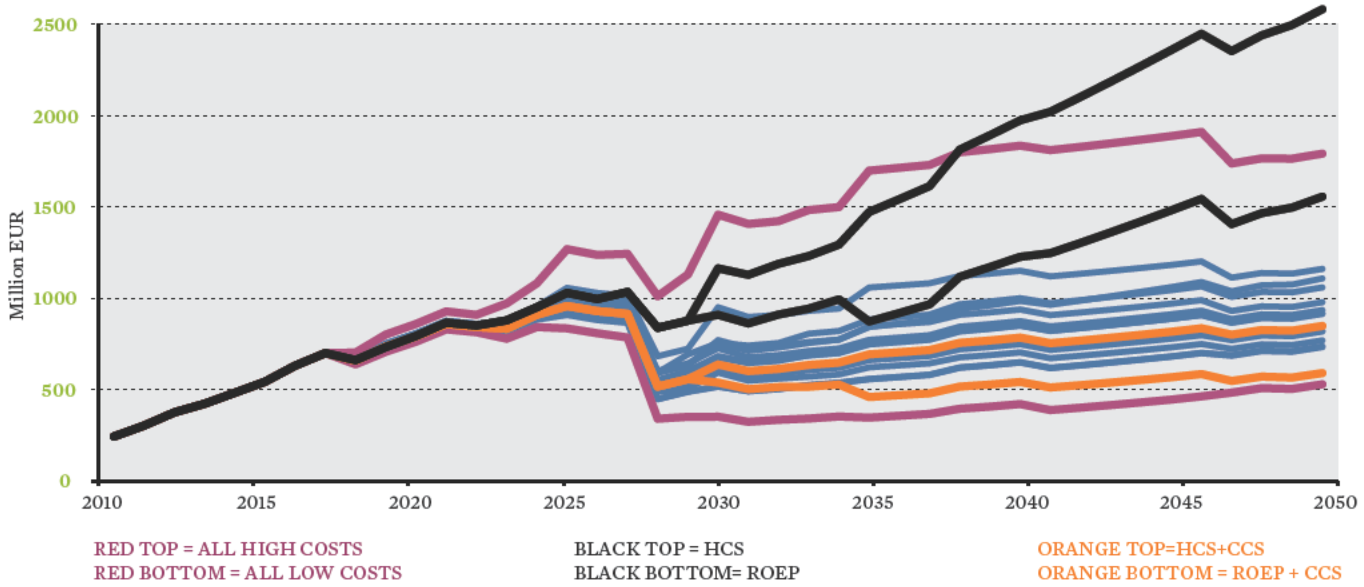


FIGURE 4.7 CO_2 EMISSIONS FROM THE HCS TRAJECTORY

No deployment (HCS), CCS deployment (HCS+CCS) and low capture efficiency (HCS+CCS+Low Capture Efficiency) CCS deployment scenarios

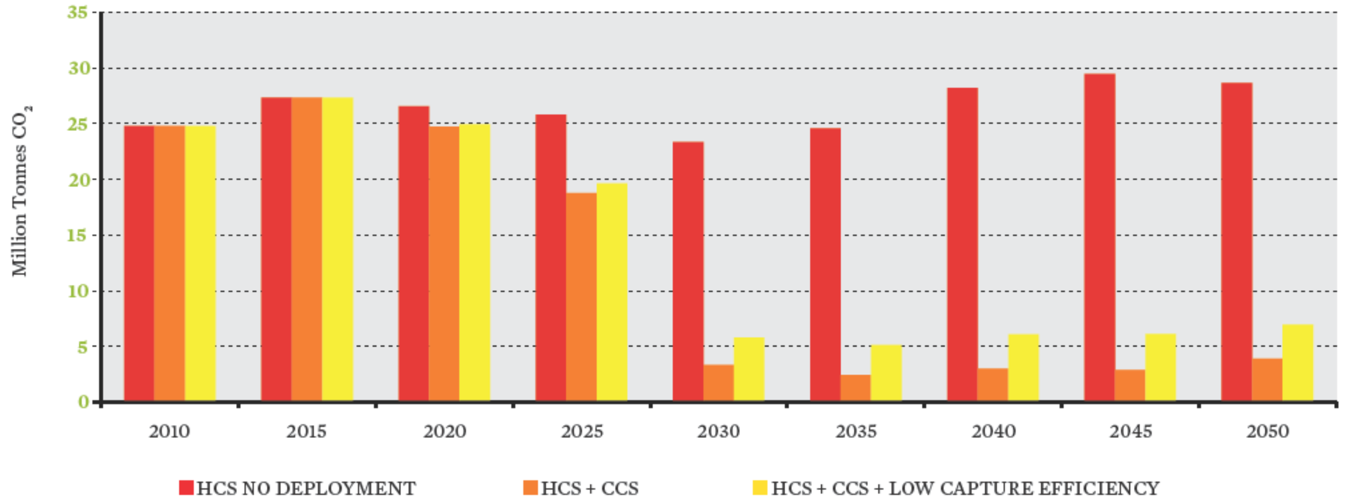
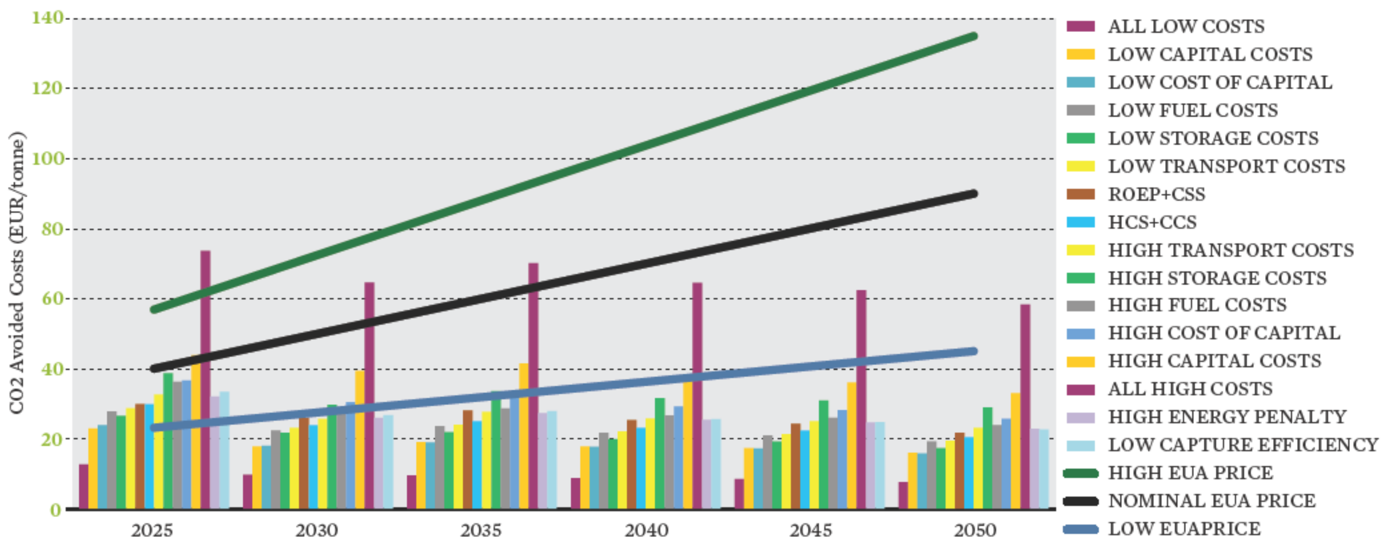


FIGURE 4.8 CO_2 AVOIDANCE COSTS FOR THE DEPLOYMENT OF CCS APPLIED TO THE HCS TRAJECTORY IN ALL SENSITIVITY CASES



cases in which the EUA price is 50% higher or 50% lower than nominal after 2020.

These figures show that the key findings of Section 4.2, i.e. that CCS will prevent damaging electricity price rises, hold true under even the most extreme limiting value of any one CCS cost or capability parameter. Only in the case when ***all*** possible CCS parameters are set to the most pessimistic and disadvantageous values does this finding change. Even here, assuming a nominal EUA price, CCS becomes cost-saving within the time span of both scenarios. Similarly, in the case of a very low EUA price, CO_2 avoidance with CCS becomes cost effective under nominal CCS cost & capability from 2030. Only in the most pessimistic case, where the EUA price grows very slowly and multiple components of CCS are very expensive does non-abatement become the less costly option. In all other sensitivity cases, deploying CCS should be the preferred economic choice.

4.3 CCS MANAGING RISK AND PROVIDING ENERGY CHOICE

↘ Output from the model indicates the very large liabilities present in both energy trajectories due to the ETS, especially if planned nuclear capacity fails to materialise. In both energy trajectories CCS will be necessary to curtail energy price rises and will help maintain a competitive economy into the future.

This HCS+CCS scenario presents the large downside risks inherent in Romanian energy planning. If any uncertainty surrounds the future of the proposed nuclear plants, then it is imperative that Romania develop CCS technology. As the on-going experience with the construction of the Cernavodă complex attests, the planning and building of nuclear plant in Romania can be a long, difficult process. The prospects and economics of nuclear power in general have become increasingly uncertain. Countries have begun to alter their energy policies to reflect this, notably Germany, where all operational nuclear plants are to close by 2022. The 2011 IEA World Energy Outlook highlights these current uncertainties, with the production of a Low Nuclear Case. The report notes that the relative economics of nuclear power compared with other generation technologies may continue to deteriorate for a host of reasons. Ever more stringent safety standards may further increase the costs of nuclear. Public opposition and renewed anti-nuclear activism may cause delays or the abandonment of projects, resulting in higher financing costs as institutions insulate themselves from higher risk. The report also highlights the coming critical shortage of skilled nuclear professionals, noting that the increased uncertainty surrounding the future of the nuclear industry will deter students from pursuing a career in the industry.

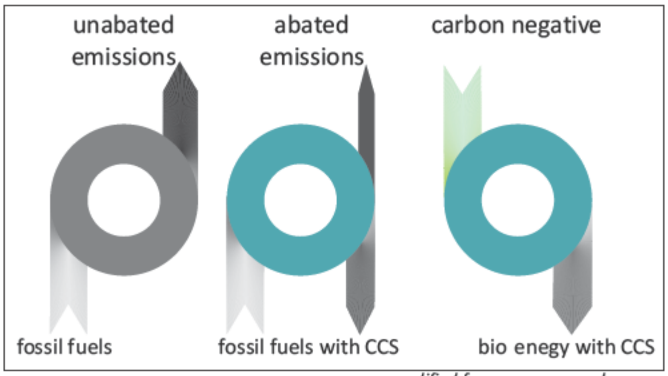
A failure or delay to construct the new nuclear plants is likely to produce a scramble to install fossil capacity in the early 2030s. As obligations under the ETS would dramatically increase with the installation of new thermal electricity facilities, it is critical that Romania has the relative expertise and capacity to install and operate CCS facilities. Failure to prepare for this alternative energy future may result in the energy system falling in-between two stools, incurring massive costs as a result.

Little confidence can be placed in the present plans concerning future energy supply and demand in Romania. Previous experience has shown these plans may change rapidly due to political, systemic and management factors. It is crucial that a range of technologies are available to cope with these evolving plans, avoiding large possible costs that would otherwise eventually fall on the Romanian people. CCS offers Romania increased energy and technology options, including the use of some indigenous resources, that could help reduce uncertainty and mitigate possible future risks. Having more tools available to the energy planner and provider is especially important in Romania, where uncertainty is high and institutional capacity low. It would be ill-advised for the Romanian government or the energy sector to place too much faith in a single technology.

5.0 BIO-CCS & CARBON NEGATIVE

In order to stabilise atmospheric CO_2 at 400ppm in this century, global net emissions will have to fall to near zero and even become negative (Azar, et al., 2010). Negative emissions may be achieved in a number ways, principally reforestation and biochar production. However using biomass in plants fitted with CCS (often referred to as Bio-CCS) is currently the only viable technology to allow societies to achieve substantial CO_2 negative. Emissions resulting from combustion of sustainably produced and processed biomass are recognised as being neutral. If CO_2 emitted in such processes is captured and stored, carbon-negative value chains are attained which withdraw more CO_2 from the atmosphere than they emit. The introduction of sustainable biomass to CCS equipped fossil power plants or the use of CCS at biofuel production facilities will produce a net uptake of CO_2 out of the atmosphere as shown in Figure 5.1.

FIGURE 5.1 CARBON BALANCE OF ENERGY FROM DIFFERENT SYSTEMS



modified from news.mongabay.com

The EU Energy Roadmap 2050 highlights the need for carbon negative solutions, stating that negative carbon emission technologies may be needed to meet overarching targets (European Commission, 2011). Studies and analyses using global economy models have shown that Bio-CCS will be indispensable to achieve climate goals over the course of this century (Gough & Upham, 2011) (Carbo, et al., 2011) (Eisenberger, et al., 2009). The Intergovernmental Panel on Climate Change (IPCCC) has also confirmed that carbon negative solutions will be a key part of the upcoming 5th assessment report to be published in 2013.

With sustainable and well-managed policies, Romania has the potential to become the EU leader in carbon negative electricity and biofuel production. Abundant CO_2 storage capacity along with large quantities of sustainable biomass place Romanian at the forefront of this important emerging industry.

5.1 CO-FIRING IN COAL POWER PLANT

The use of sustainable biomass in energy has many benefits, including reduced fuel costs, improved security of supply and reduced environmental impact. Managed correctly these resources provide ample scope for combining biomass use with CCS (Bio-CCS) possibly resulting in "negative" carbon emissions (see Box)

Co-firing at coal power plants involves the use of two or more fuels at a plant such as coal and woody biomass. The use of biomass as an energy source reduces the CO_2 intensity of the electricity generation and has been used in countries such as the UK as a cost-effective way to reduce emissions. Co-firing at power plants contributed 11% of the UK's total renewable capacity in 2009 (Thornley, 2011). Co-firing with biomass in a plant fitted with CCS can produce a double benefit. In such a case, not only are the emissions from the combustion of coal prevented from entering the atmosphere, but the biogenic CO_2 contained in the biomass is also captured and stored leading to a reduction of CO_2 in the atmosphere, producing a carbon negative effect.

PHOTO: ISTOCK

The main challenges of co-firing are related to the properties of different fuel types combusted, particularly the calorific value, moisture content, ash production and combustion characteristics. As such, various technologies perform differently depending on the biomass type and the quantities co-fired (Table 5.1).

PULVERISED COAL COMBUSTION (PCC)

Biomass may be blended with coal and combusted in existing coal burners. This incurs very low capital costs but limits the amount of biomass utilisation to a few percentage of thermal input. Separate handling of biomass from coal and the installation of dedicated biomass burners may allow for 20% thermal input from biomass, though this process involves higher capital costs. It is also important to note that to date biomass co-firing has not been demonstrated at ultra-supercritical temperatures (Gough & Upham, 2010).

FLUIDISED BED COMBUSTION (FBC)

FBC is a common and economical design of coal power plant, offering a high degree of fuel flexibility, achieving high boiler efficiencies with difficult low grade fuels. These reactors are very flexible with fuel quality and may rapidly switch from coal to biomass co-firing with minimal investment. This flexibility allows for the combustion of large amounts of biomass, with utilisation increasing on a seasonal basis if necessary (Marin, 2008).

PRECOMBUSTION GASIFICATION (IGCC)

The utilisation of biomass in the gasification process is relatively straightforward offering no major technological or operational hurdles over coal gasification. As with FBC this allows for the flexible utilisation of high percentages of biomass if sufficient fuel is available (Rhodes & Keith, 2005).
Table 5.1 Comparison of Biomass Co-Firing Fraction with Various Combustion Technologies (Klein, et al., 2011)

TABLE 5.1 COMPARISON OF BIOMASS CO-FIRING FRACTION WITH VARIOUS COMBUSTION TECHNOLOGIES
(Klein, et al., 2011)

Boiler type	Biomass fraction
PCC	3% - 20%
FBC	20% - 90%
IGCC	10% - 100%

As such the technology choice of future LCP should be carefully analysed to maximise the possibility of poly-fuel use. This is of particular importance for the three "future lignite facilities", where fluidised bed technology may be preferred to allow for the efficient co-firing of ligneous materials (Gough & Upham, 2010). IGCC plant in the form of future coal facilities will be ideal candidates for co-firing of biomass. As such co-firing may be implemented at new generation plants with CCS with little technological or commercial risk. Co-firing technology is rapidly advancing, and possesses low risks to the operation, performance or integrity of new build plants (Livingston, 2011).

Romania has extensive and diverse sustainable certified biomass resources including wood from forest exploitation, wood waste from industrial process, agricultural waste from cereals, animal manure and biodegradable urban waste. At present Romania produces and consumes huge volumes of solid biomass, the vast majority of which is burned in small inefficient residential stoves. The centre for promotion of clean and efficient energy in Romania (ENERO) has published extensive research on the biomass availability in Romania (ENERO, 2009).

Estimates for the certified sustainable use of forestry and industrial waste for energy total 80PJ/yr. in 2020 with a total potential of 140PJ/yr. Even with the use of this biomass, forested areas of Romania are anticipated to expand. The National Renewable Energy Action Plan (NREAP) 2010 states that wood biomass available for energy will increase. The Ministry of Environment and Forests has put measures in place sustainably increasing forest biomass intended for energy production. Afforestation, reforestation and the management of existing forests will increase supplies. Harvesting will operate under strict conditions taking into account biodiversity and nature conservation.

Agricultural waste offers another large source of solid biomass for energy, ENERO estimates an available resource of 200PJ/yr. with 110 PJ/yr. available for energy by 2020. The National Renewable Energy Action Plan anticipates biomass waste from agriculture to increase as agricultural production per unit area increases.

Policies to encourage the use of biomass for energy must be designed with care; biomass use must be sustainable and perverse incentives producing conflicts over use must be avoided. Stakeholders and end-use industries must be consulted to achieve the efficient allocation of available biomass. Current recommendations from the ENERO report "Biomass Master Plan for Romania 2010", propose the incentivisation of high efficiency residential stoves, reducing consumption and liberating biomass for utilisation at Combined Heat and Power Plant (CHPP) and District Heating (DH) facilities (ENRO, 2010). At present the report forecasts only a fraction of the available 152 PJ of biomass for energy in 2020 will be co-fired at large power plants, with an anticipated 33.5 PJ made available for CHPP and district heating (Table 5.2).

TABLE 5.2 ANTICIPATED SOLID BIOMASS ALLOCATION ADAPTED FROM ENRO (2010)

	2009		2020	
Technology	**PJ**	**%**	**PJ**	**%**
Residential stoves/boilers	119	97,9	117	77,1
Local boilers & DH	2.3	1,9	20	13,2
CHP	0.2	0,2	13.5	8,9
Co-firing power no CCS	0.04	0,0	1.26	0,8
Co-firing LCP+CCS	0	0,0	0	0,0
Total Solid Biomass	122	100,0	152	100,0

The application of a larger proportion of this available biomass for co-firing with CCS will offer greater benefits in the medium term. The higher thermal efficiencies of large combustion plant combined with the capture of produced CO_2 results in a double benefit. Firstly the efficient return on a bioenergy resource (depending on the transport distances involved) and secondly the captured CO_2 will result in negative CO_2 emissions (see Section 5.0). *CO_2 stored in biomass during photosynthesis will not simply be rereleased to the atmosphere but stored for geological timescales in subsurface reservoirs. This will actively begin to reduce CO_2 concentrations in the atmosphere, making a significant impact on climate change while providing cost-effective energy to fuel economic growth.*

At present current climate mitigation schemes fail to incentivise the application of biogenic carbon capture. As the combustion of biomass is CO_2 neutral it does not incur costs or liabilities under the European Emissions Trading Scheme, and as such the capture and storage of this carbon would twice remove this liability. *It is clear that new incentives will be necessary to promote carbon negative solutions needed to fight climate change.*

5.1.1 BIOMASS WITH CCS AND THE ROMANIAN ELECTRICITY SECTOR

Below is an integrated model of effect of biomass co-firing on the Romanian energy sector. Building on the results from the CCS modelling exercise, the costs and benefits of using biomass at CCS equipped facilities can be estimated.

In this section biomass co-firing only applies to new build power plants with CCS. Two scenarios for the integration of co-firing are proposed the "LowBio" beginning at 5% in 2020 rising to 10% in 2030 & the "HighBio" starting with 10% in 2020 rising to 20% in 2030. These rates of utilisation are technologically modest, practical, sustainable and achievable.

In the model, local biomass for energy is assumed to cost the same per GJ as imported coal, such price convergence is likely as traditional fossil fuels become more expensive. Co-firing of biomass could stimulate development of supply chains and generate cost-effective markets. This, in turn, could increase the efficiency of production of indigenous biomass (Berndes, et al., 2010). Incentives for biomass co-firing could also be offered to enhance security of energy supply.

The implementation of biomass at LCP does incur additional capital and operational costs. These costs are primarily due to extra facilities needed for fuel storage, handling and transport. At higher fractions of biomass co-firing, plants such as pulverised coal may require further modifications, increasing costs. These costs per megawatt are given in Table A1.1, however the modest level of biomass co-fired in this model likely means that these costs are overestimates (Loo & Koppejan, 2008).

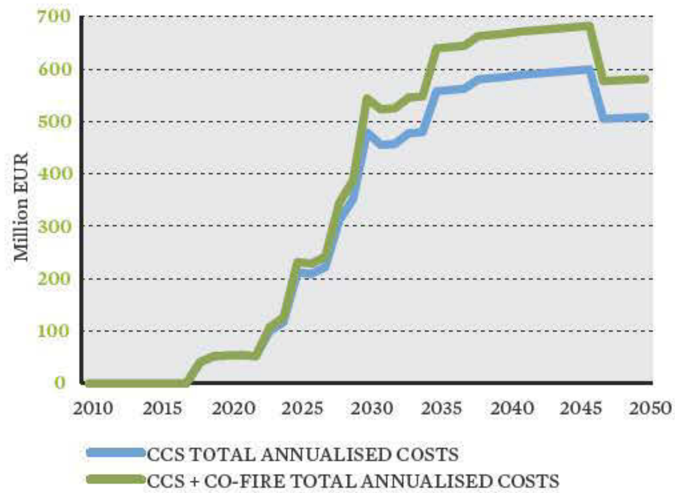
Biomass co-firing is dependent on many factors and as such the application of co-firing will need to be undertaken on a plant by plant basis. For instance facilities with greater access and transport links to local ligneous material should be prioritised, consuming more biomass than distal power plants. The availability of biomass will become an important consideration in siting of new greenfield power plants such as the future coal A to C. Wood biomass is concentrated in the North-East, Central and North-West development regions. The richest regions for biomass from agricultural waste are South-East, South and North-East. A maximum co-firing limit of 20% at any plant has been chosen for practical and logistical reasons. The lower energy density of biomass results in increased amounts of fuel needed to be transported to and handled by a plant.

Under this modelling scenario Romania is rewarded double EUA credits for every tonne of CO_2 negative it achieves. Under a system such as this the cost and benefits of Bio-CCS become increasingly attractive. With biomass integration CCS begins to offer more than a cost effective way to avoid climate liabilities. Bio-CCS is a technology that will actively generate rents for the removal and storage of atmospheric CO_2.

5.1.2 HIGH COAL SUBSTITUTION + CCS + BIOMASS CO-FIRING

The potential of co-firing can be seen when modelled on the HCS+CCS scenario. This energy scenario includes the greatest number of CCS enabled plants and so gives the largest opportunity for negative CO_2 emissions. The capital expenditure for both the LowBio and HighBio scenarios, optimising facilities for biomass co-firing will be the same (Figure 5.2).

FIGURE 5.2 ADDED CAPEX AND OPERATIONAL COST FOR CO-FIRING ABOVE NOMINAL HCS+CCS COSTS



The application of the LowBio scenario begins with 5% co-firing in 2020, climbing to 10% in 2030, with solid biomass integration at all seven CCS enabled thermal plants. As the percentage of co-firing increases and a greater number of CCS enabled plants are commissioned, the electricity generation system of Romania approaches carbon neutral in 2030. The addition of the final IGCC plant in 2035 tips the system into carbon negative. For the next decade more biogenic CO_2 is sequestered than is emitted from anthropogenic sources such as gas fired power plants, permanently trapping and removing 1 Mt of CO_2 from the atmosphere. The final years of the period modelled see minor positive emissions due to increasing energy demand and supply from unabated fossil sources.

The consumption of biomass for the system is 7 PJ in 2029 rising to 30.7 PJ in2040 or 20% of annual available biomass resource for energy (Table 5.3). As such the consumption of solid biomass in this LowBio scenario is comparable to the proposed consumption in CHPP and DH plants by 2020. It is evident that this scenario is highly achievable, with a minimum reallocation of available resources. The savings achieved by producing carbon negative electricity reduce the costs of CCS implementation and operation, adding further to the consumer price reduction from the no CCS unabated trajectory.

TABLE 5.3 BIO-CCS BIOMASS REQUIREMENTS & CARBON NEGATIVE ACHIEVED

		Biomass use PJ (2040)	% use of total energy biomass (2040)	Biomass use Thousand Tonnes (2040)	Carbon Negative over period 2020-2050	Total Biogenic CO_2 stored
HCS+CCS	LowBio	30,7	20	2790	8 Mt	64 Mt
	HighBio	61.4	40	5580	69 Mt	130 Mt
ROEP+CCS	LowBio	18,5	12	1681	1 Mt	41 Mt
	HighBio	36.9	24	3354	35 Mt	82 Mt

More intensive use of biomass in the "HighBio scenario" with 20% co-firing post 2030 provides further carbon negative gains removing 69 Mt of atmospheric CO_2 by 2050. However this places a greater demand on biomass resources, consuming some 40% of biomass available for energy. When carbon negative is rewarded for every tonne of CO_2 negative achieved, substantial cost reductions in electricity generation are anticipated (Figure 5.3) (Figure 5.4) (Figure 5.5). A review of CO_2 intensities under the HCS Trajectory with unabated, CCS Deployment, LowBio and HighBio Scenarios is given in Figure 5.6.

The effects of Bio-CCS co-firing on the ROEP+CCS energy trajectory are similar; however the consumption of biomass is reduced along with the potential for gross carbon negative due to the lesser role of thermal generation (Table 5.3).

The volumes of biomass necessary to achieve carbon negative electricity generation are relatively modest, more so when compared to the available sustainable biomass for energy in Romania. With sufficient oversight and prudent management Romania can lead Europe into a Carbon Negative future (see Appendix III Section A3.2).

FIGURE 5.3 ELECTRICITY COST IMPACT ON HCS TRAJECTORY OF LOWBIO AND HIGHBIO SCENARIOS

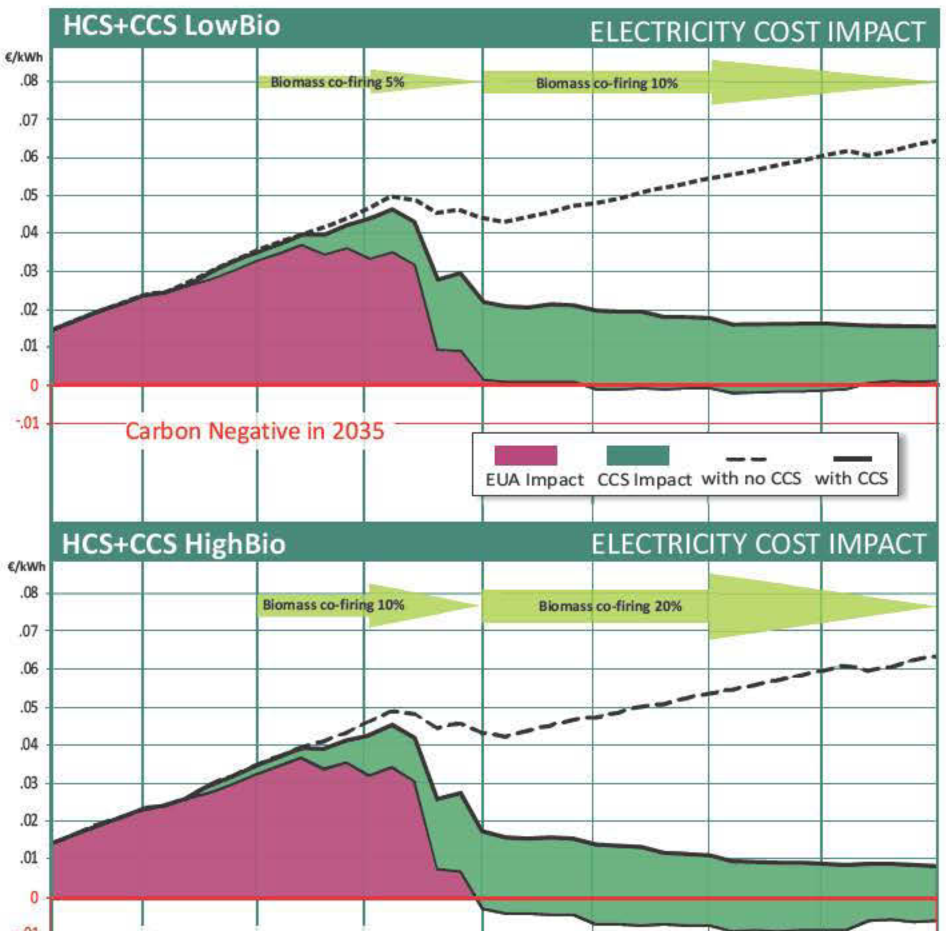


FIGURE 5.4 TOTAL ELECTRICITY COST IMPACT OF CCS UNDER HCS UNABATED, HCS+CCS DEPLOYMENT, HCS+LOWBIO & HCS+HIGHBIO CO-FIRING

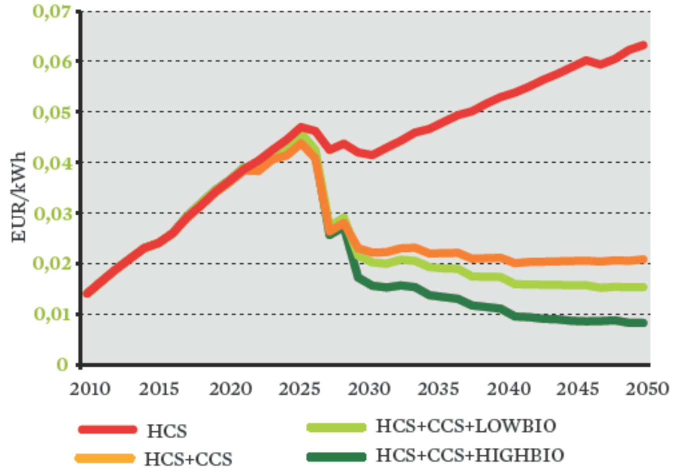
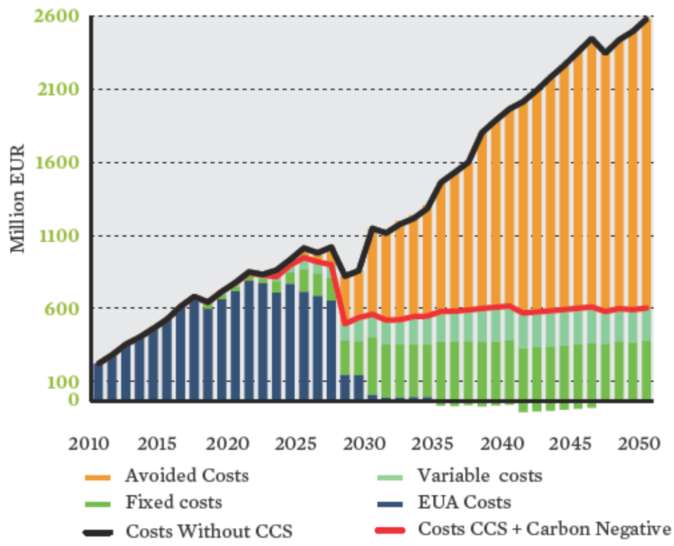
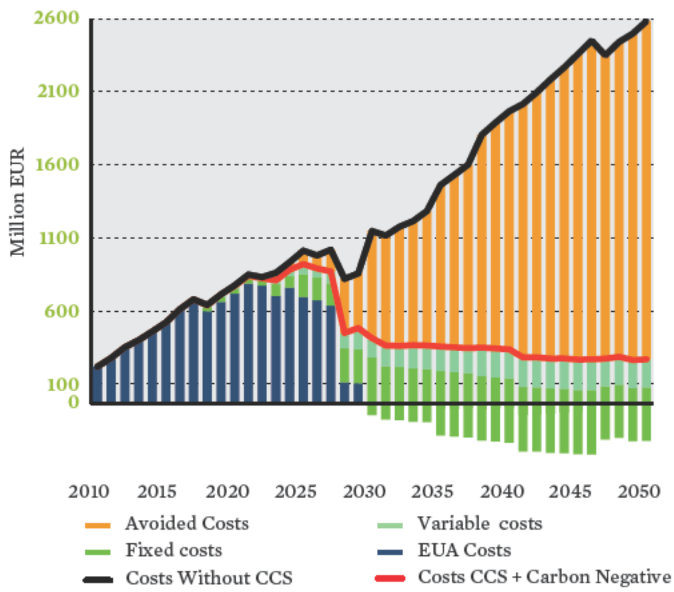


FIGURE 5.5 TOTAL COSTS AVOIDED BY APPLYING LOWBIO & HIGHBIO TO HCS+CCS DEPLOYMENT SCENARIO

HCS+CCS+LowBio



HCS+CCS+HighBio



5.2 BIOFUEL PRODUCTION & CCS

↘ Romania has significant advantages in the area of advanced biofuels production, and is well placed to become a European leader in this growing industry. According to the Romanian Renewable Energy Action Plan (NREAP) a minimum of two million hectares of arable land is presently not being used. This land offers great potential for the production of energy crops on the short to medium term, such as sugar cane for ethanol and oil seeds for bio-diesel, with minimal effect on other agricultural activities. In this way, a production capacity, experience and a biofuels market can be created. In the medium term, waste and residues from both agriculture and forestry can be utilised for large-scale biofuels production as 2nd generation, advanced biofuels penetrate the market, and so expand the country's production potential further. At present, around 50% of arable land is used for food production, while less than 8% is all that is needed to meet the requirements of the EU renewable energy directive (RED) of 10 % renewable energy in transport by 2020. Increasing agricultural productivity per unit area could also add to the available biomass. Recent research shows that Romania has a total realisable potential to sustainably produce 117 PJ/yr (Teckenburg, et al., 2011), far surpassing EU RED 2020 requirements for its domestic market and with sufficient governmental oversight, providing excess production for export (ENERO, 2009) (ENRO, 2009 (b)).

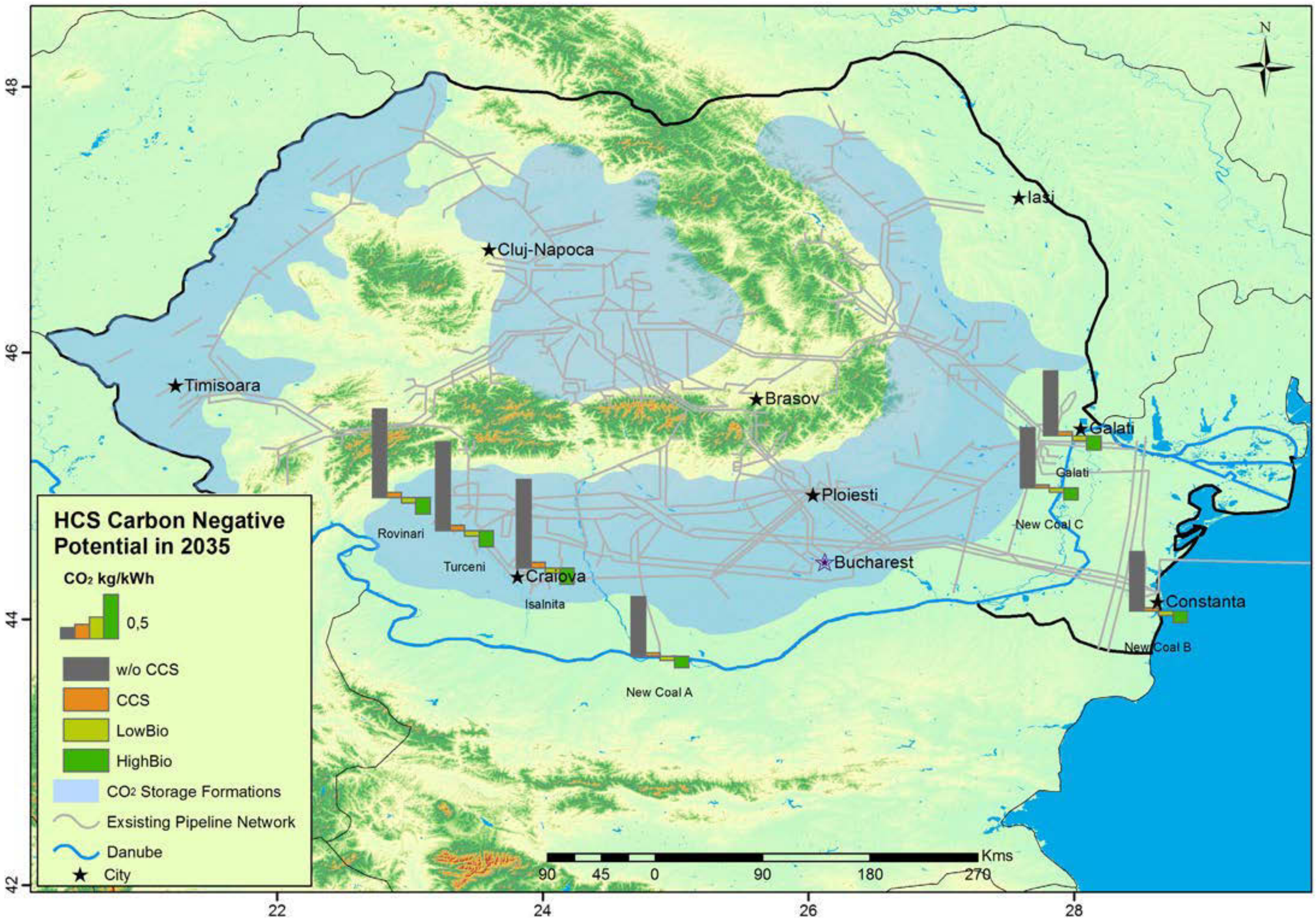
The biofuels sector has been growing steadily in Romania and continues to receive support, as of January 2011 the government increased the minimum blend-values of biodiesel and fuel ethanol from 4 % to 5 % vol. (Balkans.com, 2011). Financing in the form of EU structural funds and from the European Bank for Reconstruction and Development (EBRD) have been made available to promote and incentivise the growth of a biofuel industry. The EBRD plans to support the Remetea ethanol plant due for completion in 2013 (BlackSeaGrain, 2011). Romania has moreover already successfully attracted private investment to expand domestic biofuel production. As an example the American company Farmers Ethanol, is preparing to develop a $200 million integrated vegetable and animal farming complex in Prahova County that would also include a bioethanol plant with a capacity of 73,000 tonnes per year.

The promising future of biofuel production in Romania will benefit additionally from the application of CCS. The integration of CCS to such plants would result in the production of biofuels with negative lifecycle emissions (Carbo, 2011). Biofuel production combined with CCS is a relatively new area of research and is quickly gaining interest, both in Europe and globally. The incremental cost of CO_2 capture from biofuel production is generally very low, as the CO_2 by-product streams are often of high purity. The pure stream of CO_2 negates the need for additional separation equipment, with only driers and compression units necessary to prepare the CO_2 for transport to a storage site. With the expected need for negative emission solutions to deal with climate change, the combination of biofuels and CCS technology can provide a comparatively low-cost way to achieve such solutions, with short-term commercialisation possible once the correct incentives are in place.*

The declining reserves of Romanian oil along with the revenues it provides may be offset by the increasing production of sustainable ethanol and 2nd generation bio-diesel and other Fischer-Tropsch (FT)-based fuels. Fischer-Tropsch production involves the gasification of biomass and the conversion of this gas to clean liquid fuels, providing high conversion efficiencies. These fuels, if produced in sufficient quantity for export, would generate valuable income for the country. Biofuel production will help create green jobs for a carbon restricted future, not least in impoverished rural areas. For Romanian industrial firms currently involved in fuel refining and upgrading, the opportunities to use and evolve their expertise in a forward-looking technology development

* Biofuel production technologies and the cost of CCS integration are discussed further in appendix III.

FIGURE 5.6 CO_2 INTENSITIES OF HCS TRAJECTORY WITH CCS DEPLOYMENT, LOWBIO AND HIGHBIO SCENARIOS



should be most welcome. Incentives for carbon negative biofuels would further increase the competitiveness of the Romanian bioenergy sector. Abundant CO_2 storage, strong technical resources and available biomass ideally position Romania to take advantage of future frameworks established to encourage carbon negative biofuel production.

↘ 5.2.1 CASE STUDY FOR AVIATION FUEL

The aviation industry, while currently only contributing about 2 % of global greenhouse gas emissions, is expanding rapidly both globally and in the EU. As a result GHG emissions from aircraft are growing rapidly, in spite of minor improvements in efficiency. Tackling these growing emissions is the motivation for the inclusion of aviation into the ETS from January 2012.

Low carbon energy sources are regarded as necessary to begin to decarbonise the aviation industry. However, existing jet engine developments along with the high energy requirements of passenger flight make it technologically difficult to replace liquid fuels. For this reason, bio-aviation fuels offer the most feasible method to decarbonise the aviation industry. The inclusion of aviation into the ETS provides an increasing impetus for airplane manufacturers and operators to develop and access sufficient sustainably produced bio-aviation fuel.

Investments already under way highlight the capacity of Romanian industry and agriculture to take advantage of this growing need for aviation biofuels. Chief among these is the large international and Romanian consortium spearheading the production of bio-aviation fuel (see box).

The Romanian bio-aviation fuel project, including Tarom (the Romanian flag carrier), Airbus, Honeywell and Camelina Company España, aims to produce 100,000 tonnes of bio-aviation fuel by 2015, equivalent to approximately 50% of Romanian domestic annual aviation fuel demand in 2007. The biofuel will be produced on approximately 400,000 hectares from Camelina, an oil seed plant well-suited to marginal land. Pilot crops covering 32 hectares were begun in 2010, with the first demonstration flights set to begin in 2012 (Dimitriu & Eychenne, 2011). UOP is applying its aviation biofuel refining technology; CCE is contributing its knowledge on Camelina agronomy, including technologies on Camelina growth and plant science. Airbus is providing technical and project management expertise and is sponsoring the sustainability assessment and life cycle analysis studies. Tarom is coordinating the project and is a good example of a Romanian company building expertise and seizing opportunities in growth market. The project is the first of its kind in Europe, with farmers, refineries and a commercial airline working together towards sustainable production of bio-aviation fuels and shows how Romani is well-placed to supply bio-fuels for the European aviation industry.

The Tarom aviation fuels project, while instrumental in developing a market for and knowledge about aviation biofuels in Romania and Europe, does not provide the extra benefit of low-cost carbon-negative fuel production, due to the production method. The potential of CCS-applicable high-purity Fischer-Tropsch (FT) derived liquid fuels for aviation, using versatile biomass feedstock, is very promising. This is both due to the much lower content of sulphur and lower particulate matter emissions during combustion and due to the high-purity CO_2 available for storage, potentially containing more than 50 % of the carbon in the biomass feedstock. Romania, with its large available CO_2 storage capacity, should therefore encourage aviation biofuels production based on the FT process.

5.3 ACTIONS TO ENCOURAGE CO_2 NEGATIVE

Romania more so than any other EU member state has the ability to integrate high volumes of indigenous, sustainable biomass into the energy mix. The use of these resources is incentivised primarily under the EU ETS, under which biomass combustion, as opposed to the combustion of fossil fuels, does not require allowance surrenders. However, the ETS does not currently have provisions to reward negative emissions. This means that in the EU, there is currently no economic incentive for storing CO_2 captured from biomass combustion or conversion. To put it simply, as far as the EU ETS is concerned, these CO_2 emissions do not exist as they are neutral over time.

Synergies between huge biomass resources, vast CO_2 storage capacity and technological competence combine to propel Romania to the forefront of carbon negative, not only in Europe but the world. As follows it is important that Romania does not overlook the opportunities for a Romanian industry for bio-CCS. The biomass and biofuels sector in particular need to become aware of the benefits of Bio-CCS at an early stage, to be able to position themselves for rising CO_2 prices.

Romanian stakeholders and national government will need to be proactive in pursuing the case for rewarding carbon negative; the country likely has more to gain than any other in the EU if carbon negative were to be recognised under the EU ETS. In the short term, as a minimum, the EU should make funding available for pilot and flagship Bio-CCS projects, and Romania would be very well placed to reap the benefits of such a flagship scheme. Working with EU partners to secure positive outcomes for the inclusion of carbon negative in incentive schemes would hence be a boon for Romania.

Aside from the financial and climate benefits potentially generated from Bio-CCS deployment, the technology may provide social and political rewards too. Romania would garner regional and international prestige by contributing to the development and deployment of innovative systems for atmospheric greenhouse gas abatement, helping to transform current emission intensive sectors such as aviation into potential CO_2 sinks.

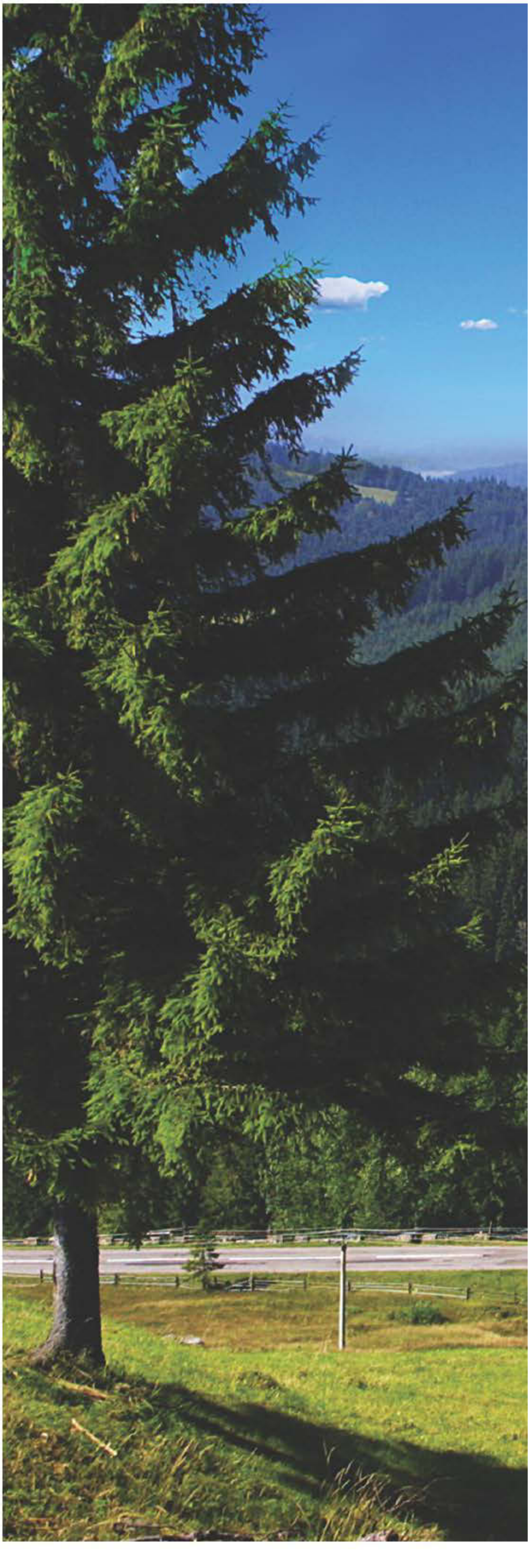



PHOTO: ISTOCK

6.0 INDUSTRY & CCS

At present the majority of Romania's large point source CO_2 emissions originate from coal and lignite combustion for electricity production, however emissions from some CO_2 intensive industry facilities will also need to be reduced in the future. The IEA estimates that to efficiently achieve a 50% reduction in global CO_2 emissions by 2050, CCS will be necessary to reduce industry emissions. It is estimated that almost half of the global emission reductions from CCS will occur in industry (IEA, 2010). CCS is the only technology able to reduce emissions from many manufacturing processes, such as the production of steel and cement where CO_2 is an unavoidable by-product.

In 2008, Romanian energy-intensive manufacturing and construction industries were responsible for 20% of national CO_2 emissions from direct energy consumption. In addition, industrial process emissions such as CO_2 released as a direct by-product of manufacture were responsible for 16% of overall Romanian emissions (EC, 2010). The major industrial emitters where CCS is applicable are cement (5Mt/a), Iron and steel (4 Mt/a), Refineries (3.5 Mt/a) and Ammonia (2.7 Mt/a) (E-PRTR, 2009) (Figure 6.1). These industries have become a focus for CCS R&D. In the immediate future, ammonia fertiliser plants offer the most economical large-scale application of CCS to industry. A detailed survey of large industrial sources of CO_2 will need to be undertaken. These sources will need to be included in the design and development of a CO_2 transport and storage network.

Several other energy-intensive industries have high CO_2 concentrations in their flue gas streams, reducing the costs of capture. Steel and cement both generate rich CO_2 streams with concentrations of 20-25% (about double the concentration for coal-fired power plants) at different stages of the production process. Petrochemical industry can have even higher concentrations, although the total CO_2 volumes are smaller. For all of these sectors, CCS is the only available option for significant emission reductions (UNIDO, 2010).

6.1.1 AMMONIA: THE LOWEST HANGING CCS FRUIT

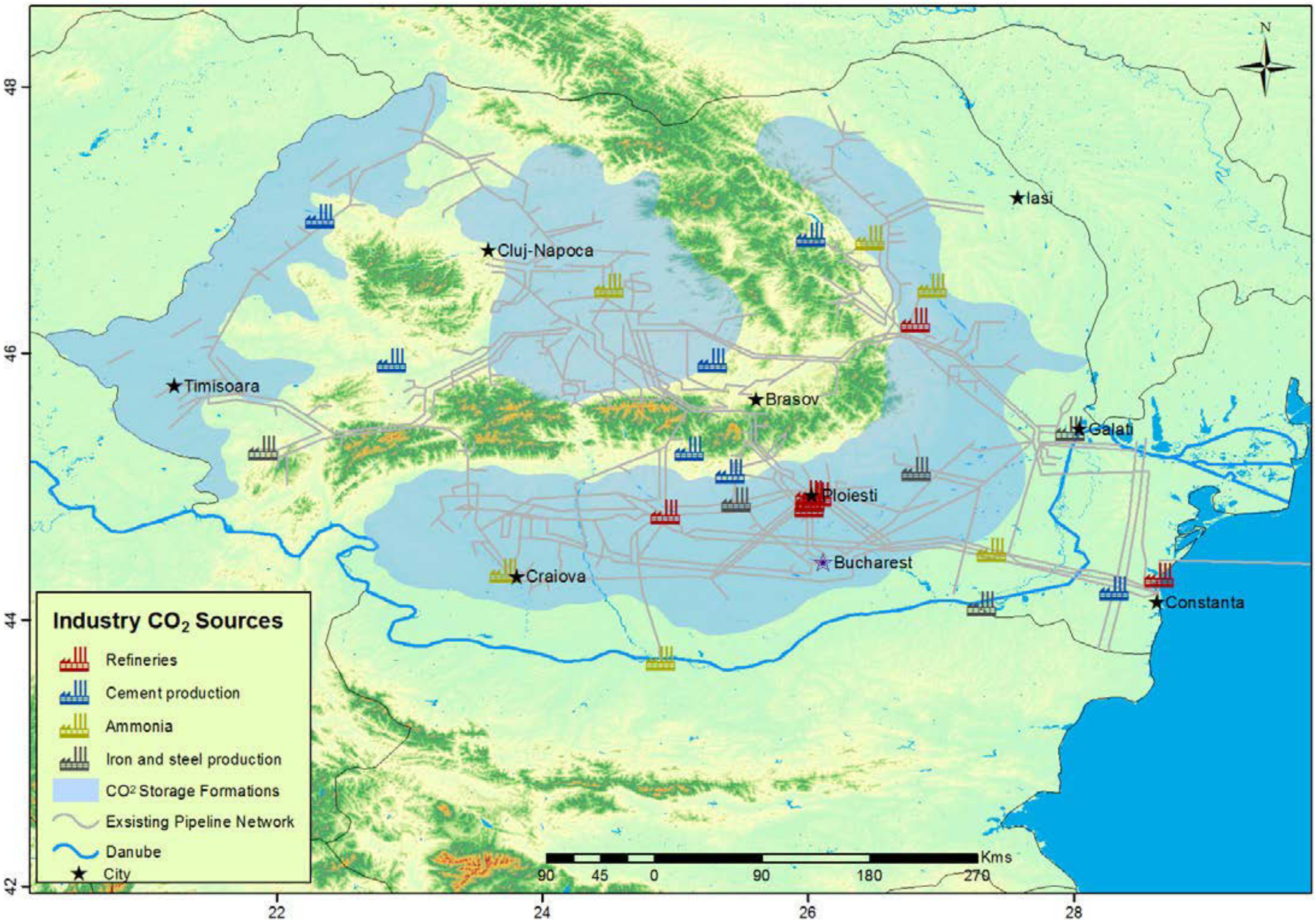
Ammonia (NH3) production is a process with a pure stream of CO_2 as a by-product. Modern fertiliser plants, which account for more than 80% of ammonia production, generate between 1.6-3.8 tonnes of CO_2 for every tonne of ammonia produced (IFA, 2009). As with ethanol and bio-diesel production the presence of a pure stream of CO_2 negates the need for energy intensive CO_2 separation and capture technologies. CCS at ammonia production facilities only requires energy to compress CO_2, and the infrastructure to transport and store it. This results in costs as low as €13 per tonne of CO_2 stored, increasing the cost of ammonia with only 3-4 percent (IEA, 2011).*

Global fertiliser demand is expected to increase significantly in the next decades, so CO_2 emissions from ammonia production will need to be tackled. Application of CCS to ammonia production is both a low-hanging fruit and a rapidly growing one.

Six facilities in Romania produced 1.3 million tonnes of ammonia in 2009 with gross CO_2 emissions from the fertiliser industry of 2.7 Mt CO_2/yr. (USGS, 2009). The Petrom ammonia plant near Craiova and the Donau fertilizer plant, although relatively small (both emitting 317,000 tonnes/yr) are ideally situated to integrate into the proposed CCS cluster in the south-west and based around

* In the Canadian province of Alberta, a project breaking ground in 2012 will capture CO_2 from the Agrium Fertilizer plant to be transported via pipeline for EOR. The Alberta government is supporting the demonstration project (Roche, 2011).

FIGURE 6.1 LOCATIONS OF MAJOR CCS APPLICABLE INDUSTRIES



the Getica CCS project. The larger Amonil operated facility at Slobozia in the south of the country may be well placed to access east west CO_2 pipelines in the future.

↘ 6.1.2 IRON AND STEEL

Elsewhere in Europe, work is currently underway to develop cost effective CO_2 capture technologies for iron and steel plants. Much of this work is coordinated by Ultra Low CO_2 Steel (ULCOS), an international consortium including 48 organisations founded in 2004. ArcelorMittal, the leading member of the consortium and operator of the largest steel mill in Romania, is currently proceeding with a novel CCS demonstration at a steel plant in France. The Florange site has been chosen to demonstrate the implementation of large-scale CCS technology at a blast furnace. Equipping steel mills with CCS is estimated to cost approximately €51-57 per tonne of steel produced and increase overall production costs by 15-22% (GCCSI, 2009).

By far the largest steel mill operating in Romania is the ArcelorMittal planned plant, emitting 3.8 Mt CO_2/yr. These emissions are even greater than from the 800MW coal plant planned for construction in the Galati region. Tackling emissions from such a large point source will be economically unavoidable, both for ArcelorMittal and the Romanian government. The proximity of the planned supercritical coal power plant and steel mill provide an ideal opportunity for the development of a CCS cluster. Both facilities would need to cooperate to develop a shared CO_2 pipeline network, which would reduce the overall investment burden and lead to economies of scale, reducing the cost of CCS for both facilities.

↘ 6.1.3 CEMENT

CO_2 concentration in the waste gas from cement production is similar to that from a steel production process, meaning that the cost per tonne of CO_2 captured from these processes are comparable. This additional cost of capture and storage is estimated to be €22-23 per tonne of produced cement. However, due to the low relative value of cement, the additional cost of CCS in cement production would be quite high, increasing production costs by more than 40% of total cost (IEA, 2010) (IEA, 2011). Partial capture of 30% to 50% of CO_2 produced can be economically accomplished using an oxyfuel process. The fuel would then be combusted in an oxygen/CO_2 atmosphere with the flue gas recycled through the pre-calciner, resulting in lower capital and operational CO_2 capture costs. Efficiency gains and capital cost reductions are necessary and anticipated; the potential for utilizing excess process heat to drive the capture process could lower the capture costs in this industry.

Seven large cement plants emit a combined 4.8 Mt CO_2/yr, although no single facility has emissions exceeding 1 Mt CO_2/yr. The largest source currently operated is Holcim SA at Campulung with emissions of 918,000 tonnes CO_2/yr. The same company also operates a marginally smaller plant emitting 756,000 tonnes CO_2/yr. in the North West at Alesd. Both facilities are located close to depleted hydrocarbon reservoirs and saline formations for CO_2 storage. Lafarge cement near Medgidia in the south east of the country may be a candidate for inclusion in a CCS cluster. Depending on the storage site selection, CO_2 captured from New IGCC Coal and planned coal with the subsequent transport pipelines could pass close to the cement plant.

6.1.4 PETROLEUM REFINERIES

There is a total of eight refineries currently operating in Romania, the major facilities being Petrobrazi, Petromidia and Petrotel-Lukoil. With annual CO_2 emissions of 1.1, 0.6 and 0.7 Mt CO_2/yr respectively, it is clear that these major emitters will need to be tackled into the future.

There is a high level of variability in unit types and process complexity in this sector, as many refineries have multiple, relatively small CO_2 sources with different specifications. However, the high purity of some of those sources could offer opportunities for low-cost demonstration of CCS, if they are located close to a storage site.

6.1.5 MODELLING THE CONTRIBUTION OF INDUSTRY CCS

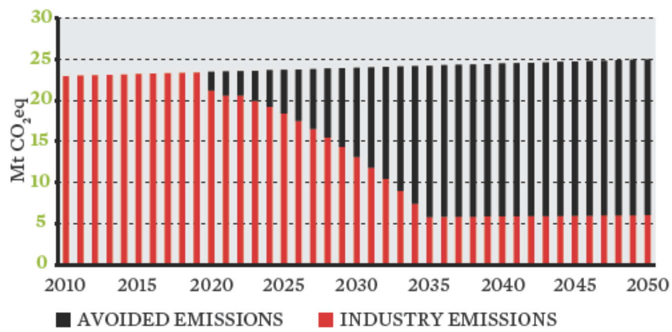
A simple representative model of CO_2 abatement in industry due to CCS is shown in Figure 6.2. In order to reflect both process-related and energy-related emissions, a hybrid model was constructed using emissions data from the major CCS-applicable industries described in Section 6.0. Growth predictions for industry process and direct emissions through to 2050 were built using Eurostat and International Energy Agency (IEA) figures. In the 2009 Energy Technology Transitions for Industry, the IEA provides high and low baseline predictions for direct and process emissions of the cement, steel, and petrochemical industries through to 2050. Predictions are broken down regionally, with the "Economies in Transition" region including most of Central and Eastern European nations such as Romania. Fertilizer manufacture is assumed to follow a similar development pattern in emissions profile. These modelled industry emission growth rates have been used to project large point source emissions in Romania.

Due to the large variety of carbon capture technology options to decarbonise the wide variety of industry processes, a simple representative model was chosen. Here CCS is applied to industries gradually and linearly, beginning at a low level in 2020 and progressing with all applicable industrial sites outfitted by 2035. Conservative estimates for the proportion of process and direct emissions available for capture are also used, with these values improving linearly to 2035.

As the steel industry modernises practices and refits to updated blast furnaces, CCS technology may achieve 50% reductions in total steel plant emissions in 2020 rising to 100% by 2050 (Lamberterie, 2011) (Birat, 2009). Refineries undergo a similar advance with 50% capture possible in 2020 and growing to 60% in 2035 as more CO_2 streams become economical to capture (Rootzén , et al., 2009). Cement and fertiliser plants begin with more modest overall CO_2 capture rates as early CCS implementation will likely target process emissions. However, as equipment is replaced and upgraded, a greater capture rate from both process and direct emissions will be achieved (ECRA, 2009) (Hoenig, et al., 2007) (Brown, 2010). This is simply modelled as a linear progression to 2035 when 100% of emissions will be eligible for CO_2 capture.

FIGURE 6.2 A SIMPLE AND NOMINAL DEPLOYMENT MODEL OF CCS TO APPLICABLE INDUSTRIES IN ROMANIA.

CCS deployment to steel, refining, cement and fertiliser sectors beginning in 2020, with complete application by 2035.



7.0 MEETING THE CHALLENGES OF THE FUTURE

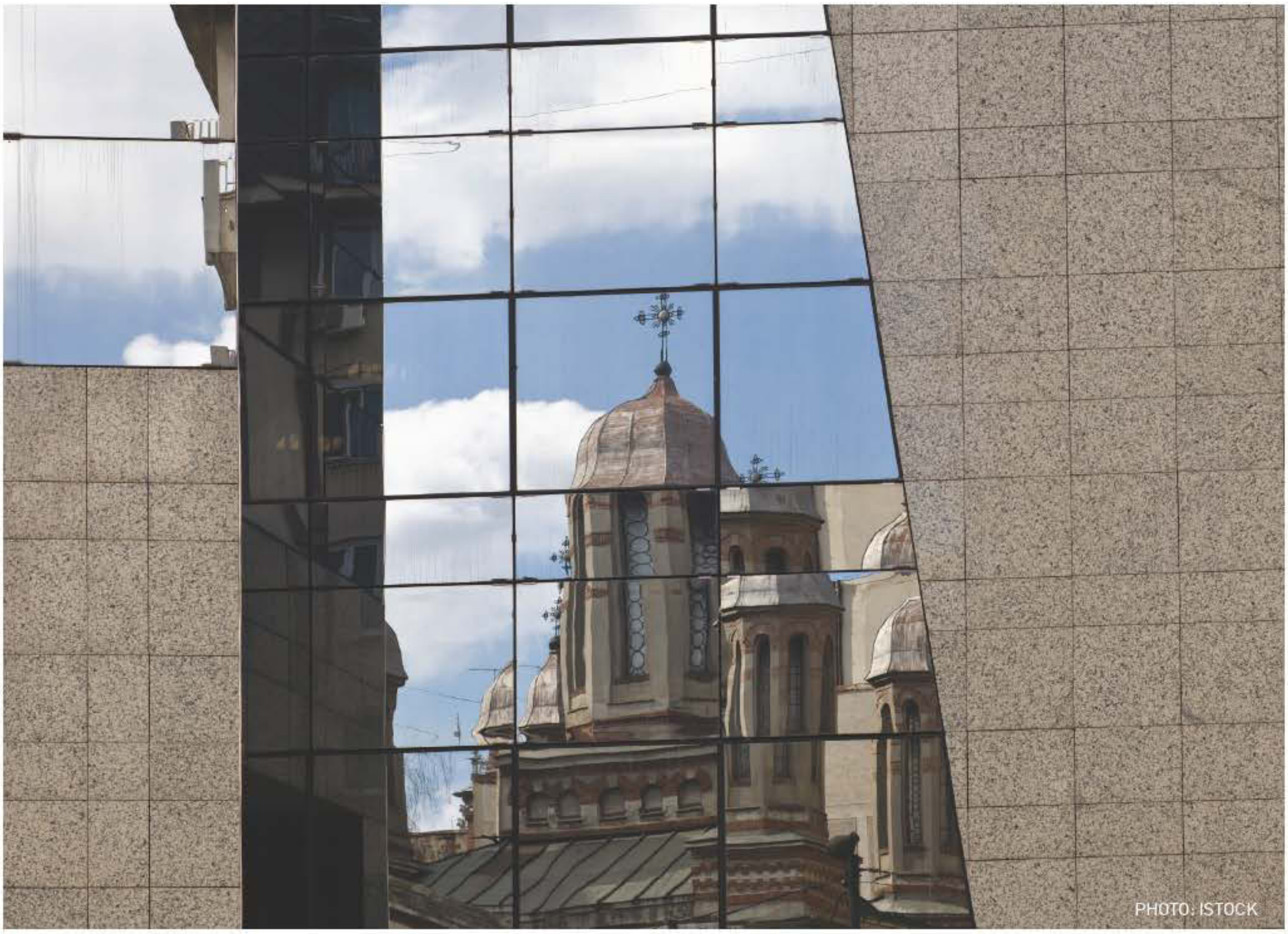
Romania has undergone a difficult economic and political reorganisation in the past two decades, creating much hardship for the population. The reforms on-going - the continued liberalisation of the economy, the strengthening of institutions and the campaign against corruption are all necessary to enhance the prosperity and well-being of Romanians. With prudent policies Romania could become a regional leader, particularly with respect to energy and low carbon industries. These reforms become increasingly urgent as the world becomes ever more competitive and, as with Europe as a whole, Romania will need the tools and institutions to meet the challenges of the 21st century. CCS will have a key part to play in Romania meeting its economic goals while also satisfying the country's obligations to reduce GHG emissions. Romania clearly has many competitive advantages with respect to the transport and storage of CO_2.

Romania has already met many of the challenges necessary to realise CCS, far surpassing the efforts of neighbouring countries to prepare for increasingly strict EU climate controls. The country has proactively sought investment for demonstration projects, begun the transposition of relevant legislation and participated in the EU technology platforms. A consistent effort will be necessary over the coming years to build on these achievements, developing and retaining knowledge to prepare for commercial CCS application.

The knowledge-building and experience gained from a successful Getica CCS demonstration project will be an invaluable asset for a country which is facing a range of opportunities and challenges related to CCS. The demonstration project could serve to open the way for a number of commercial opportunities, several of which Romania could take a leading role on. Building capacity now, both human and technical, is a minimum requirement to allow for the timely and efficient deployment of CCS. A detailed investigation of individual potential CO_2 storage reservoirs is necessary with assessment of their injectivity, trapping structures, and the condition of any legacy wells. Adequately assessing CO_2 storage sites is a lengthy process that must be started now in order to avoid delays.

7.1 ENERGY CHOICE

Current Romanian energy policy relies heavily on future nuclear generation facilities. As nuclear offers a low life cycle carbon footprint it would help to meet emission reduction targets. However future nuclear generation will have hurdles to overcome, including economic, political and technical, with the risk of delays and even cancellations. In addition, the planned expansion of nuclear generation will not be sufficient to decarbonise the Romanian generation sector, with large CO_2 sources remaining. CCS on coal or gas will be critical to provide technology choice, as these are the only other dependable low CO_2 generation technologies available. A failure for Romania to develop CCS technology would therefore risk exposing the economy to excessive energy cost or energy supply shortages.



7.2 REDUCING THE COSTS OF CLIMATE COMPLIANCE

Romania has a long operational history in the oil and gas sector, with production spanning more than a century. Depleted oil and gas reservoirs offer ideal storage sites for CO_2 as they are usually well-charaterised and with proven trapping mechanisms. This storage potential combined with decades of relevant expertise could lead to competitive storage costs. Establishing transnational CO_2 storage markets could generate a boon for the Romanian economy. The country has the ability to become a regional storage hub. Importing CO_2 would provide income and skilled employment contributing positively to the balance of payments.

Romania as a hydrocarbon province has significant unrecovered resources. The use of CO_2 for Enhanced Oil Recovery (EOR) would allow Romania to maintain production from ageing fields while permanently storing CO_2. Revenue from recovered oil would further improve the economic argument for CCS, especially for the early adoption of the technology. Again, Romania is in a unique position to maximise returns from EOR as the majority of hydrocarbon reservoirs are located onshore, greatly reducing capital and operating costs. Romania should consider incentives to encourage the development of EOR activities such as tax rebates or credits. At least part of the additional revenues from increased oil production from EOR could be earmarked for future investments in CCS.

7.3 CARBON NEGATIVE VALUE CHAIN

The use of Bio-Energy is a major pillar of Romanian national plans to reduce CO_2. Romania has a very large sustainable biomass potential, including agricultural, forestry and industrial waste along with underutilised arable land that could be available for dedicated energy crops. When a proportion of this biomass is consumed or reprocessed in facilities equipped with CCS, negative carbon emissions may be achieved, with CO_2 permanently removed from the atmosphere.

Romania has competitive advantages at all stages of the carbon negative value chain, with the availability of sustainable cost effective biomass, the possibility of an onshore CO_2 pipeline network and very large, well-characterised storage potential. With the correct oversight, Romania can take the lead in this vital industry. In order to avoid irreversible climate change, future regional and global agreements are expected to incentivise carbon negative, providing capital streams that Romania could use. The production of carbon negative electricity and biofuels could become a key Romanian industry.

In parallel, the growth of carbon negative value chains in Romania would attract technology investment and build expertise. Romanian firms would be well-placed to become international leaders in the technology, exporting technology, services and knowhow.

8.0 ACTIONS

↘ Enforce minimum standards on all new thermal generation, additional to the requirement for complete CCS readiness. Biomass co-firing ability will be mandatory at all new coal and lignite plant. Construction permissions will be based on assessments of available storage sites, possible transport corridors along with the availability of sustainably produced biomass for energy production.

↘ Further refine and reassess CO_2 storage legislation. Reduce administrative complexity by streamlining procedures, reducing duplication and establishing a central implementing body. Critical clarification will be needed for procedures regarding authorisation, monitoring and financing.

↘ Accelerate near-term commercial CCS through the promotion of an intra-industry CCS forum. Highlight the commercial opportunities between low-cost CO_2 providers such as the fertiliser and gas processing industries with CO_2 consumers such as for Enhanced Oil Recovery (EOR) in hydrocarbon production industry.

↘ Enable commercial CCS deployment by comprehensively characterising available CO_2 storage capacity, ensuring sufficient storage capacity is available by 2020.

↘ Enable low cost CO_2 storage through characterisation and co-operation with permit holders of depleted and end-of-life hydrocarbon reservoirs. Immediately begin to assess, catalogue and make available data relevant to CO_2 storage. Simultaneously streamline permitting, making storage space available to prospective CO_2 storage operators.

↘ Establish market reforms, to reward dependable low carbon generation, reducing commercial uncertainty for investors and operators of future CCS plants. Assess suitable policy suite including,feed in tariffs, capacity mechanisms, EUA price floor and emissions performance standards.

↘ Define CCS development clusters, identifying all applicable emitters, transport networks and storage sites. Characterise industry emission profiles, forecasting future landscape enabling efficient CCS investment. Conduct industry outreach and education with particular attention on cement and steel industries.

↘ Develop and retain necessary skills through university, institutional and industry partnerships.

↘ Thoroughly and continually reassess long-term energy and electricity supply strategies. Effective strategies require planners to critically assess resource supply availability, looking beyond short term supply windfalls.

PHOTO: ISTOCK

APPENDIX

APPENDIX I

MODELLING CCS IMPLEMENTATION

A1.1 MODELLING THE POWER SECTOR AND CCS

The modelling and development of the power sector along with the impacts of CCS deployment was carried out using the Long Range Energy Alternatives Planning software (LEAP). LEAP is a scenario-based energy-environment modelling tool, accounting both energy and non-energy sector GHG emissions.

A1.2 BUILDING THE POWER SECTOR TRAJECTORIES

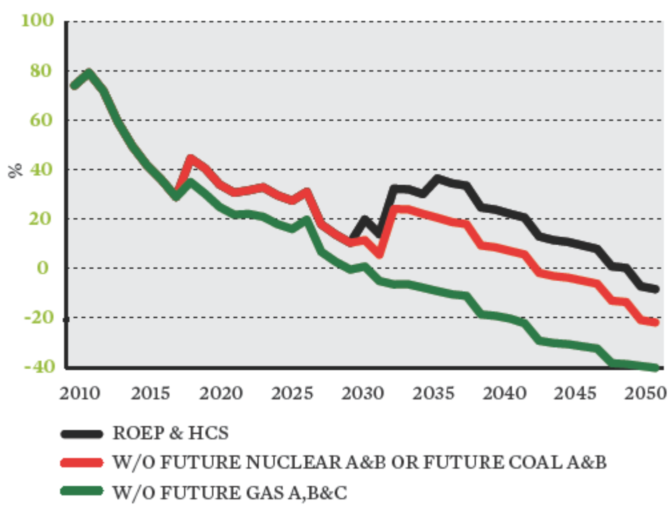
The baseline year for the start the simulation was set at 2009 due to the availability of initial data regarding values such as capacities, maximum operating hours per year and efficiencies (among others). The values for the Romanian generation fleet were a compilation of three main public sources: The European Pollutant Release and Transfer Register (E-PRTR, 2011 version); the World Emission Trading Scheme (ETS); and the International Energy Agency (IEA) database together with internal Romanian data provided by ISPE. According to the schedule predicted by the Romanian government, most of the existing fossil-fuelled stock would be retired through 2030. Existing small lignite and small natural gas combined heat and power (CHP) plants stay in operation to be progressively decommissioned until 2045. The remaining legacy CHP plants are retained to cover the peak heat demand of households (Romanian National Energy Strategy during the period 2011-2035, in prep). Hydropower and other renewables were modelled in line with the draft document of the Romanian National Energy Strategies and the Renewable Action Plan (2010).

The peak capacity needs were projected using the 2009 annual load duration curve from the Romanian transmission network operator Transelectrica (Transelectrica) and provided by ISPE. Low margin cost generation units such as hydro and renewables (mostly wind) were assigned the highest possible merit order; when capacity was available these plants were given priority dispatch to the grid. Both coal and lignite combustion plants, along with nuclear generation units were assigned to baseload, the latter due to its high availability and relatively low flexibility. Combined cycle gas turbine plants operate at peaking load and for balancing of the network during periods of low renewable availability.

Capacity factors and availability were based on those currently measured in the power sector by ISPE. The availability of the nuclear power plants (NPP) and the CHP plant were assigned availability of approximately 90% and 50% respectively. The CHP plants generate on a seasonal basis, operating regardless of the electricity demands present on the grid in order to provide district heating. Due to the uncertain wind availability and periods of drought, the projected maximum availability of the rapidly growing wind generation capacity and hydropower was set to 35% and 50% respectively (ISPE).

The reserve margin of a generation system is the percentage of excess capacity available above peak demand. This is an important factor when measuring system robustness and indicates its ability to function with loss of capacity due to planned maintenance or unscheduled outages such as drought in the case of hydro. For systems with a large supply capacity of intermittent renewables such as wind generation it is necessary to describe effective or de-rated capacity margin. The available energy capacity is taken into account, resulting in a more robust assessment of a system's supply security. In the model the reserve margin deceases as old legacy capacity is retired. The installation of new capacity maintains the reserve margin at an acceptable 20% by 2040, similar to the EU average (Figure A1.1). However if electricity demand progresses as proposed in the modelling scenarios, further generation capacity could need to be installed in the final years of the modelling period. Due to the distant time horizons BEST has not added the capacity or proposed a technology to meet this demand.

FIGURE A1.1 DE-RATED RESERVE MARGIN FORECASTS



Electricity export to neighbouring economies over the modelled period was assumed to remain constant from current levels at approximately 10% of generation.

Emission factors for the typical lignite, coal, and natural gas consumed in Romania are employed, and are given in Table A1.1. All new build generation plants were assumed to be designed to best available technology, with nominal efficiencies assumed for all new fossil plants; these values are given in Table A1.1.These efficiencies are representative of current proposed new generation facilities in Romania.

New fossil and nuclear plants were assumed to have a nominal lifetime of 30 years. This value is relatively conservative for the operational life of a modern plant and has been chosen for consistency within the model. If new fossil and nuclear plants continue to operate beyond this timeframe it would serve only to reduce overall cost, as less new capacity would be necessary. Longer average operating life would also reduce the annualised capital expenditure on new CCS equipped facilities, as costs could be distributed over a longer time horizon.

TABLE A1.1 KEY MODEL PARAMETERS

High and low limits used in the sensitivity analysis are shown in parentheses.

Parameter	2010	2030	2050
EUA Price (€)	10 (10/10)	50 (25/75)	90 (45/135)
Lignite Emission Factor (tonnes CO_2/TJ)	112,2	-	-
Coal Emissions Factor (tonnes CO_2/TJ)	94,9	-	-
Natural Gas Emission Factor (tonnes CO_2/TJ)	56,1	-	-
Biomass Emission Factor (tonnes CO_2/TJ)	109,6	-	-
Lignite Price (€/GJ)	1.52 (1.00/4.00)	-	-
Coal Price (€/GJ)	2.19 (1.00/4.00)	-	-
Natural Gas Price (€/GJ)	5.50 (2.50/8.00)	-	-
Biomass Price (€/GJ)	2,19	-	-
New Coal Plant efficiency (%)	45	50	50
New Lignite Plant Efficiency (%)	40	45	45
New Natural Gas Plant Efficiency (%)	60	60	60
Energy Penalty (pp)			
• Pulverised Coal	11 (16)	8 (12)	8 (12)
• Oxycombustion	12 (18)	8 (12)	8 (12)
• IGCC	13 (20)	4 (6)	4 (6)
• NGCC	8 (13)	7 (11)	7 (11)
Capture Efficiency (%)	95 (85)	95 (85)	95 (85)
Additional Capital Cost (Thousand €/MW)			
• Pulverised Coal	952 (533/1202)	571 (400/1250)	391 (324/1013)
• Oxycombustion	1500 (557/2071)	714 (371/1429)	579 (301/1157)
• IGCC	905 (457/1214)	571 (343/1214)	463 (278/984)
• NGCC	440 (229/583)	250 (171/441)	203 (139/434)
Cost of Capital (% per year)	10 (5/15)	10 (5/15)	10 (5/15)
Nominal Plant Lifetime (years)	30	30	30
Co-firing Capital Costs (Thousand €/MW)	161	129	104
Transport Cost (€/tonne)	1.5 (0.5/4)	1.5 (0.5/4)	1.5 (0.5/4)
Storage Cost (€/tonne)	4 (1/12)	4 (1/12)	4 (1/12)
Currency Conversion (USD/EUR)	1,4	1,4	1,4

A1.3 APPLYING CCS

When CCS was applied to a plant in the model, CO_2 emissions were reduced by 95% and its efficiency is reduced to reflect the energy penalty incurred by the capture and compression processes. Energy penalties for coal and gas capture technologies, given in Table A1.1 were linearly extrapolated from recent IEA estimates, between 2015 and 2030, and assumed to remain constant post-2030.

For the single envisioned CCS retrofit, the energy penalty leads to a decrease in the nameplate capacity of the facility. As only one plant received a retrofit, the effect of the loss of capacity to the reserve margin was insignificant and as such the system did not require any additional capacity due to the implementation of CCS.

Modelling the additional costs of CO_2 capture, transport, and storage through 2050 was challenging, given the uncertainty surrounding the future price of technology and geological storage. The capital costs in the model are based on the most recent available estimates, including the International Energy Agency's report, 'The Projected Costs of Generating Electricity,' which provides a range of possible capital costs for several CCS technologies in 2015 and 2030. From these ranges the average of additional costs for each CCS technology was taken as the nominal value in this model, and the maximum and minimum values as limiting cases for a sensitivity analysis. These capital cost estimates were also crosschecked and compared with those from a 2007 study carried out by Rubin, Chen and Rao at Carnegie Mellon University, 'The cost and performance of fossil fuel power plants with CO2 capture and storage,'. The most recent major report regarding future costs of CCS, published in 2011 by the Zero Emissions Platform (ZEP) provides a comprehensive study of anticipated capital and operational costs of the CCS value chain (Zero Emissions Platform, 2011). Projected values from both ZEP and Rubin et al were found to fit conformably with estimates from the IEA.

The additional capital costs for CCS in retrofits were assumed to be 20% higher than those for new builds. The capital costs were linearly extrapolated between the 2015 and 2030 IEA estimates, which assume a 20-25% decrease in capital costs for coal plants in that interval. Beyond 2030, the assumption was that capital costs decreased by 10% between 2030 and 2040, and again by 10% between 2040 and 2050.

This modest drop in costs after 2030 is quite conservative and assumes that the majority of technological learning takes place prior to 2030, with only minor cost improvements in later years. All capital costs were annualised over the remaining life of the power plant, beginning at the time of CCS implementation with a 10% annual interest rate assumed. This value is consistent with that assumed by the IEA, and somewhat lower than that in the Rubin et al. study. The impact of a higher or lower cost of capital was evaluated in the sensitivity analysis.

Because of the energy penalty of capturing and compressing CO_2, additional fuel costs per kWh of electricity produced were incurred at CCS-equipped facilities. These costs were calculated for each CCS-equipped facility in the model, based on the efficiency loss due to CCS and the fuel prices.

A1.3.1 TRANSPORT COSTS

CO_2 transport costs were estimated to fall within a range of €0.50-€4 per tonne, with a nominal value of €1.5 per tonne. Transporting CO_2 for storage in Romania is anticipated to be economical, as only onshore pipeline transportation is envisioned in this report. The presence of a well-developed natural gas pipeline network reduced the possibility of permitting and planning delays, as new dedicated CO_2 pipelines followed existing corridors and rights of way established by existing networks.

These price estimates for transport and storage used in this report are consistent with those in the 2009 Worley Parsons report for the Global CCS Institute, 'Strategic Analysis of the Global Status of CCS' and the ZEP report 'The Costs of CO_2 Capture, Transport and Storage'. Because no significant technological learning is expected, this report assumed that transport and storage costs would not evolve over time. However, some cost decreases may be realised due the increasing operational experience and reducing novelty. Also as transport and storage infrastructure improves, risk premiums should decrease.

The cost estimates for transport and storage do not take into account the development of possible CCS "hubs and clusters". Areas such as the south-west region with many large point sources may develop shared infrastructure, reducing operating costs and providing economies of scale. This in turn would lead to reduced risk and cost for operators.

A1.3.2 STORAGE COSTS

The costs of transporting and storing CO_2 were calculated per tonne of CO_2 captured. The availability of well-characterised depleted oil and gas fields will likely reduce the cost of storing CO_2. However there remains a large uncertainty as to how many legacy wells may be used or if new facilities would be necessary.

Storage costs were estimated to fall within a range of €1-12 per tonne, with a nominal value at Romania of €4 per tonne. This value is less than costs anticipated in the Getica demonstration project of €8 a tonne of CO_2 stored (Filip, 2011). This is due to the use of novel and more costly deep saline formations for CO_2 storage at the Getica project.

APPENDIX II

GEOLOGY OF ROMANIA: POTENTIAL CO_2 STORAGE SITES CHARACTERISATION.

A2.1 DESCRIPTION OF THE MAIN STRUCTURAL UNITS.

The alpine Carpathian Fold Belt divides Romania in two main structural areas: central-northwestern (the Carpathian Orogen and the Pannonian and Transylvanian Depressions) and south and northeastern (the Carpathian Foreland) areas. The Carpathian foreland includes the eastern flysch units, the Carpathian foredeep and the three platforms: Moldavian,Scythian and Moesian platforms. The North Dobrogean Mountains constitutes the eastern outer limit of the Scythian platform (Figure A2.1).

The most important areas from the point of view of storage in saline aquifers are in the rocks of the intra-Carpatian depressions (the Pannonian and Transylavannian Depressions) and in the rocks of the Carpathian Foreland (in particular the the Moldavian Platform and the Moesian Platform) (see Table 3.1). There is also

FIGURE A2.1 GEOLOGY OF ROMANIA & DIVISION OF THE MAJOR STRUCTURAL UNITS

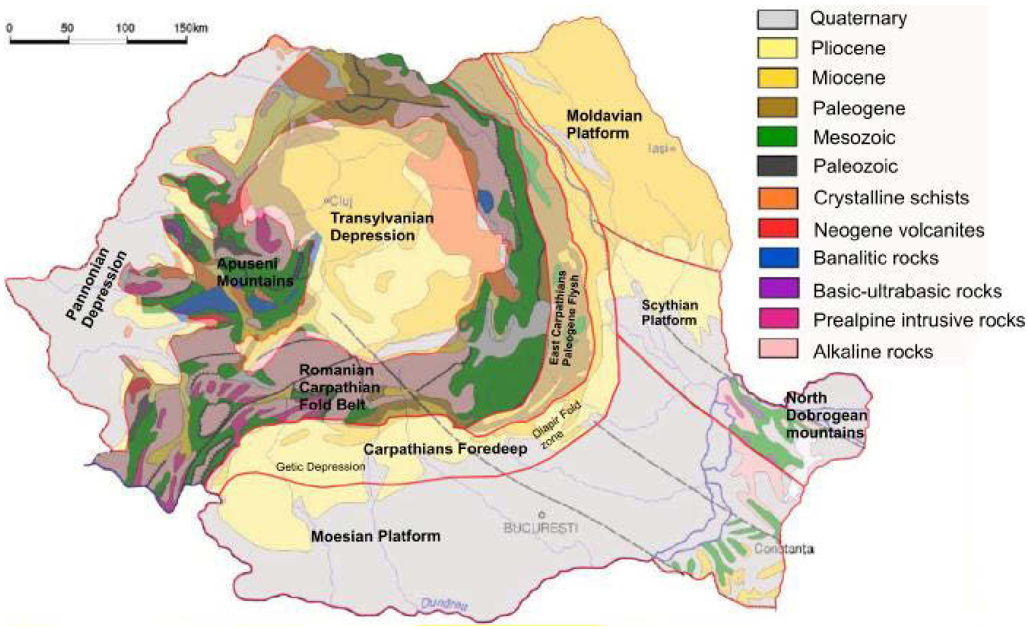
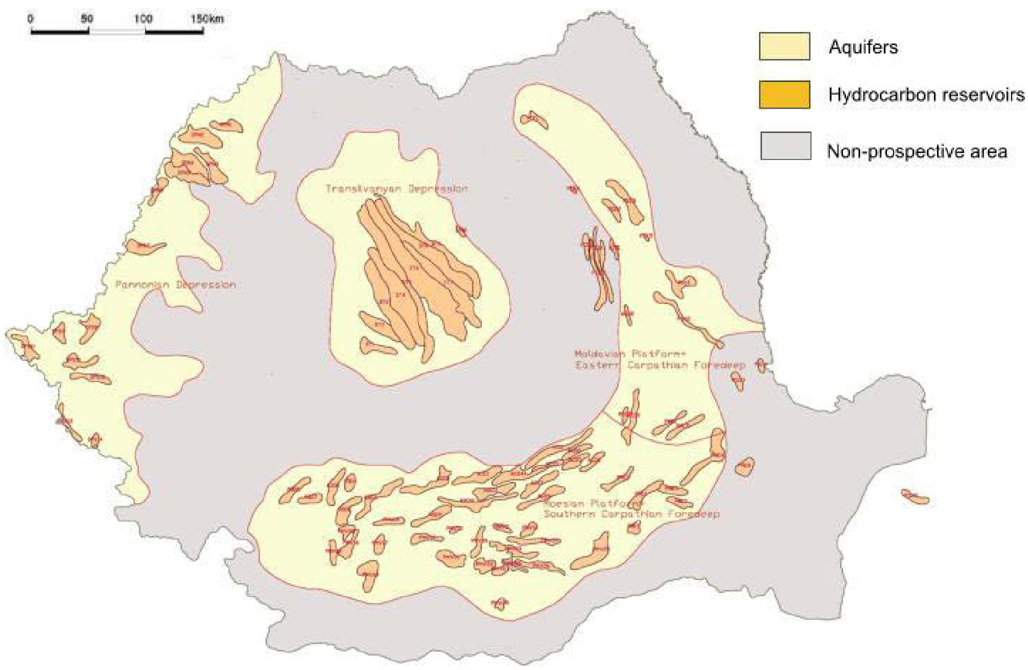


FIGURE A2.2 DEEP AQUIFERS AND ASSOCIATED HYDROCARBON RESERVOIRS IN ROMANIA

A characterisation of the main hydrocarbon reservoirs in Romania is given in Table 3.2.



significant storage potential in many areas on the Carpathian Foreland, both in the two platforms mentioned above together with in the rocks of the Carpathian Foredeep, the Eastern Carpathian Palaeogene Flysch and the Scythian Platform (see Table 3.1).

A2.1.1 CENTRAL AND SOUTHWEST ROMANIA: THE ROMANIAN CARPATHIAN FOLD BELT AND INTRA-CARPATHIAN DEPRESSIONS

The Carpathian orogenic belt is a segment of the Tethyan chain generated during different compressional stages during Cretaceous (inner zones) and Neogene (outer zones). The fold belt includes remnants of the Tethys oceanic crust and its continental margin, overlain by post-tectogenetic Upper Cretaceous and Palaeogene sediments. Two Neogene intra-molassic depressions (Pannonian and Transylvanian) overlie the inner zones of the fold belt (Sandulescu, 2009).

The Romanian sector of the Carpathians covers the eastern and southern Carpathians and the Apuseni mountains (Figure A2.1). Both Eastern and Southern Carpathians are divided in two main structural units: a) the Dacides (metamorphic rocks and Palaeozoic-Mesozoic sediments), and b) the Moldavides, (flysch and molasse of Early Cretaceous-Middle Miocene). These flysch units contain hydrocarbon reservoirs, but their capacity for CO_2 storage is very low.

The Pannonian Depression (Figure A2.1) is a Middle Miocene-Pliocene intra-Carpathian molassic depression formed by Badenian littoral and calcareous formation and Sarmatian and Pannonian sandy formations, the latter interbedded with calcareous marls. The Pannonian depression overlies the Palaeozoic and Mesozoic facies of the alpine Carpathian orogen.

The Pannonian formation contains saline aquifers (Figure A2.2) at 60-300 m and 900-2000 m deep, separated by a 600 m thick impermeable marly clay. The level of aquifer with potential forCO_2 storage is at 1200 m deep and presents bulk porosity of 20%. Over half of the hydrocarbon accumulations are located within Miocene reservoirs (Badenian and Sarmatian metamorphies, organogen-calcareous limestones and calcareous sandstones, and poorly cemented Pannonian argillaceous sandstones) (Figure A2.2 and Table 3.2). The gas accumulations are mainly within Pannonian reservoirs. The fluctuating sedimentary environment conditions and the intense tectonic activity during the Neogene made favourable the formation of high quality traps and seals for hydrocarbons. The source rock is predominantly pellitic, present in the Badenian, Sarmatian and Pannonian formations.

The Transylvanian Depression (Figure A2.1) is also an intra-Carpathian Miocene-Pliocene molassic depression, the largest in Romania. Overlying the Tethysian suture, the Dacides and the post-tectonic marine and non-marine infill of the Carpathian fold belt. The post tectonic infill consists of Upper Cretaceous (Senonian) sandy flysh in the western part of the depression, overlain by Eocene marine facies (marls, limestones and sandstones) interbebbed with lacustrine facies (clay sands and sandy limestones). The overlying Oligocene combines sandy marls, limestones, coals, bituminous clayey-schists and sandstones facies and clayey-sandy flysh facies in north-northwestern and south-southeastern parts of the depression, respectively. The Lower Miocene shows interbedded facies of clays, marls, sandstones and conglomerates and the Middle Miocene-Pliocene sucessions are similar to those of the Pannonian Depression (Badenian, Sarmatian and Pannonian formations, from bottom to top), except for an evaporitic level in the Lower Badenian. Depression subsidence started at the end of Lower Miocene and extended in Badenian.

The Transylvanian Depression contains saline aquifers within the Badenian and Sarmatian formations, between 900 and 2000 m deep (Figure A2.2). The sandy Sarmatian formation at 1000 m deep constitutes a potential CO_2 storage aquifer of 200 m thick and a bulk porosity of 20%. Gas accumulations have been mapped within Paleogene (sandstones and limestones), Lower Miocene (sandstones) and Badenian to Pannonian (sands, marly sands and sanstones) reservoirs (Figure A2.2 and Table 3.2). Most of reservoirs are internally compartmentalised vaulted stratiforms sealed by pinch-out or by impermeable lithologies..

A2.1.2 SOUTHERN AND EASTERN ROMANIA: THE CARPATHIAN FORELAND.

The Carpathian Foreland comprises the eastern Carpathian Paleogene Flysch, the Carpathian Foredeep and three Precambrian to Palaeozoic platforms with folded and metamorphosed basements (Sandulescu, 2009). The Carpathian Foreland presents the most important structural units for hydrocarbon generation in Romania (Figure A2.2 and Table 3.2).

The Eastern Carpathians Paleogene Flysch formation (Figure A2.1) contains five producing Oligocene sandstone reservoirs at depths between 700 and 1700 m. The reservoirs show thicknesses in the range of 1-85 m and present porosities of 14-25% and permeability of 18-25 mD (Paraschiv, 1989) (Table 3.2).

The Carpathian Foredeep (Figure A2.1) is formed by strongly tectonized Upper Miocene to Lower Pleistocene molasses that covers most of the outer Carpahians and the neighbouring platforms. Its greater subsiding areas are divided in two structural units, namely the Diapir Folds Zone and the Getic depression (Figure A2.1).

The most important hydrocarbon accumulations (oil) in the Diapir Fold Zone are contained within four structural alignments. In general, the structural aligments of the Diapir Fold Zone present productive layers in Oligocene, Meotian, Pontian, Dacian, Sarmatian and Romanian rocks located at depths between 300 and 3300 m (Table 3.2). The bulk porosity and permeability of these productive layers are 24-30% and 100-300 mD respectively. The hydrocarbon accumulations (oil and gas) in the Getic Depression are present in a total of six structural alignments located at Oligocene, Burdigalian, Helvetian, Sarmatian and Meotian productive layers between 650 and 2500 m deep. The bulk porosity and permeability of these productive layers are 17-33% and 10-510 mD respectively.

The Moldavian Platform (Figure A2.1) is formed by Proterozoic (Vendian) detrital deposits overlain by lower Palaeozoic clays and sandstones, Silurian, Devonian and Mesozoic calcareous rocks and molassic Neogene sediments. Silurian limestones and limy-sandstones and Miocene deposits contain the main deep saline aquifers in the Moldavian Platform. The main hydrocarbon reservoirs (gas) are within BurdigalianMiocene calcareous units, presenting average bulk porosity of 14% (Table 3.2).

The Scythian Platform (Figure A2.1) is limited to the east by the North Dobrougean Mountains and the Black Sea. The sedimentary cover of the Platform includes, from bottom to top, Permian molasse and Triassic-Jurasic-Neogene deposits that preferentially deposits at intra-depression areas (such as the Barlad Depression). The deep saline aquifers at the Scythian Platform are contained within Meotian, Sarmatian and Pleistocene sands, and at the North Dobrougean promontory those are contained within Cambro-Ordovician, Middle Triassic, Lower Cretaceous and Badenian and Sarmatian deposits. The hydrocarbon reservoirs of the Scythian Platform (mainly gas) are located at the Barlad Depression, represented by Middle Jurassic sandstones, Badenian sands and sandstones and Sarmatian limestones (Table 3.2). The source rocks are marls and blackish clays from Lower-Middle Jurassic, Upper Badenian and Lower Sarmatian. The hydrocarbon deposits are located within Neogene sediments, consisting on basal Badenian and Sarmatina limestones, detrital sands interbeddings of Badenian, Sarmatian and Plicoene formations (Table 3.2).

The Moesian Platform (Figure A2.1) is situated in the southern part of the Carpathian foreland. The basement consist on Precambrian metamorphic rocks that outcrop in the Middle Dobrougean Mountains. The sedimentary cover of the Moesian Platform consist, from bottom to top, of Ordovician-Middle Cambrian deposits and four major levels of carbonate deposition interbedded with detrital sequences of Middle Devonian-Lower Carboniferous, Middle Triassic and Middle Jurassic-Cretaceous age. The Neogene deposits are strongly influenced by the subsidence of the foredeep, leading to a decrease of sediment thickness gradually to the south.

The deep saline aquifers at the Moesian Platform are either linked to hydrocarbon deposits or contained within Cretaceous formations of high geothermal gradient. The main hydrocarbon reservoirs are represented by Middle Devonian-Lower Carboniferous, Middle Triassic, Malm-Neocomian and Turonian-Senonian carbonate rocks (dolomites and limestones) (Paraschiv, 1979), Barrenian and Albian calcarenites, Permo-Triassic, Lower and upper Triassic and Dogger gritty rocks, Albian glauconitic sandstones, Lower Sarmatian gritty limestones, poorly-cemented Sarmatian and Pliocene sands and sandstones (Table 3.2). These hydrocarbon reservoirs are mainly oil fields (58%) and gas fields (42%). Most of the oil fields occur within Mesozoic formations and mainly Dogger, Permo-Triassic and Palaeozoic formations contain the gas fields.

APPENDIX II

BIOMASS & BIOFUELS

A3.1 BIOMASS & SUSTAINABILITY

Issues addressed in the European sustainability criteria relate to sustainability in production (land management, cultivation and harvesting), land use, land use change and forestry accounting (direct land use change), life cycle analysis and greenhouse gas performance and energy conversion efficiency. In the Renewable Energy Directive (RED), the sustainability criteria are: minimum GHG savings values of 35%, rising to 50% in January 2017 and to 60% from January 2018 for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017. Raw material should not come from "high biodiversity value areas", from the conversion of "high carbon-stock areas", or from undrained peat land, respectively. Agricultural raw materials cultivated in the Community are obtained in accordance with specific agricultural regulations of the EU. Economic operators must show compliance with the criteria using the "mass balance method" for verifying the chain of custody. (Compliance with the criteria can be proven in one of three ways: (1) EU-level recognition of voluntary schemes which address one or more of the sustainability criteria (2) through bilateral or multilateral agreements with third countries and (3) by Member States' national verification methods.) Wastes and residues only need to fulfil the minimum GHG requirements, not the other criteria. Biofuels and bioliquids which do not meet the criteria cannot be counted towards the EU's renewable energy targets or the targets of the Fuel Quality Directive (Directive 2009/30/EC) and national renewable energy obligations or benefit from financial support.

A3.2 ROMANIAN BIOMASS, AVAILABILITY AND ALLOCATION

The Romanian government has sought to quantify in detail the national potential of biomass for energy. In 2009 and 2010 the Centre for Promotion of Clean and Efficient Energy in Romania (ENERO) along with the Romanian and Dutch governments produced comprehensive reports assessing the availability, market position and relevant actors in the biomass sector of Romania. Additionally under the European Union's 7th Framework Programme the SUSPLAN project provided detailed insight to the integration of Renewable Energy Sources (RES) including biomass to the Romanian energy sector.

Building on the estimates and end use of available biomass for energy in "Biomass Master Plan for Romania 2010" it is clear that sufficient quantities of sustainable biomass are available to allow Romania to produce carbon negative electricity (Figure A3.1). This report assumes no growth in biomass resource for energy post 2020.

The Biomass Master Plan for Romania anticipates large volumes of biomass to be consumed by Combined Heat and Power (CHP) and District Heating (DH) systems post 2020. The majority will continue to be consumed in residential stoves with only a fraction of the available resource earmarked for co-firing at large combustion plant. The reallocation of a proportion of biomass resources to CCS equipped thermal plant will permanently store biogenic CO_2. CCS equipped plant in 2035 and Romanian biomass resource distribution are displayed in Figure A3.2.

A3.3 BIOFUEL PRODUCTION TECHNOLOGY

The fermentation of sugary or starchy plant matter produces ethanol transport fuel and CO_2 in equal quantities. These compounds are easily separated as both exist in different phases. In an idealised case approximately 67% of the carbon is retained within the ethanol fuel while the remaining 33% is available for capture and storage (Table A3.1).

Bio-diesel is produced from oil seed such as rapeseed or sunflower. While current biodiesel production has little potential for low-cost CCS deployment, 2nd generation biodiesel made through biomass gasification offers truly promising prospects. Research for the US Department of Energy suggests that such biomass-to-liquids (BTL), when combined with CCS, can offer up to a 358 % reduction in lifecycle greenhouse gas emissions compared to the conventional fossil fuels they replace (Tarka, et al., 2009). The biomass, the sourcing of which can be versatile, is gasified at high temperatures, subsequently the CO_2 is separated and the

FIGURE A3.1 BIOMASS ALLOCATION FOR ENERGY & REQUIRED BIOMASS FOR BIO-CCS.

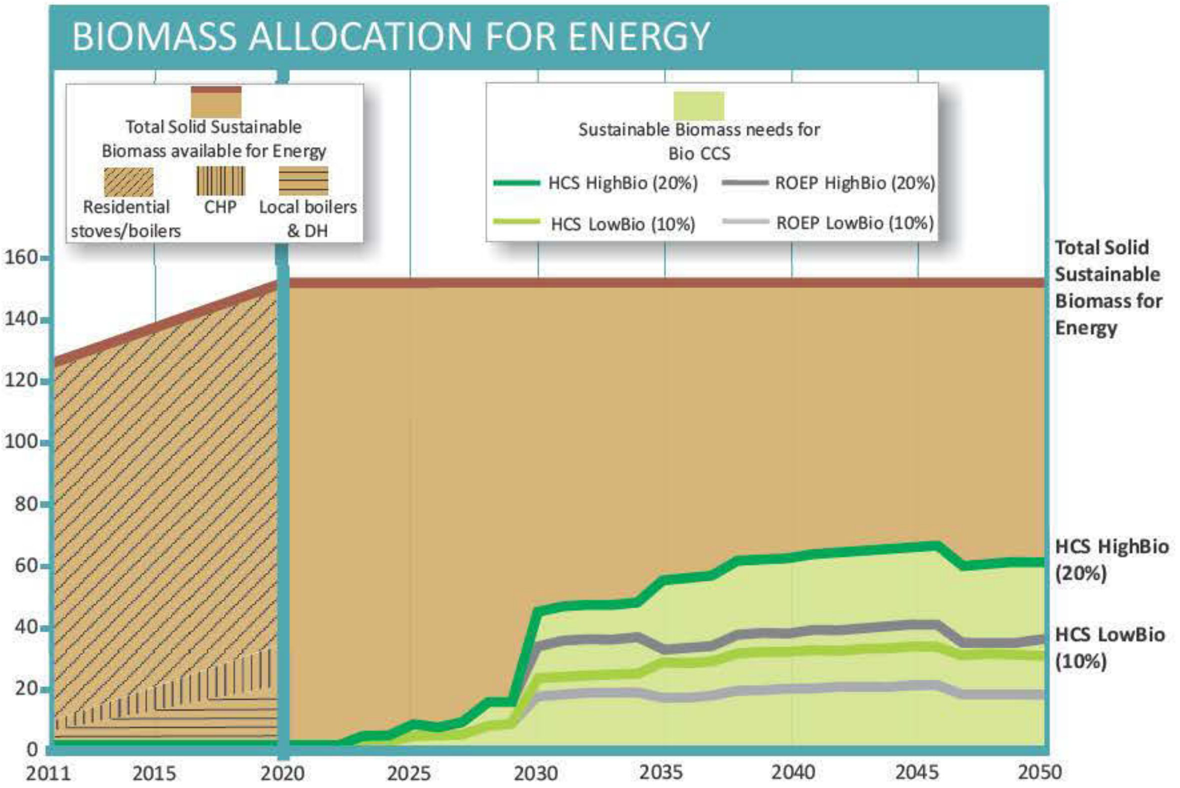
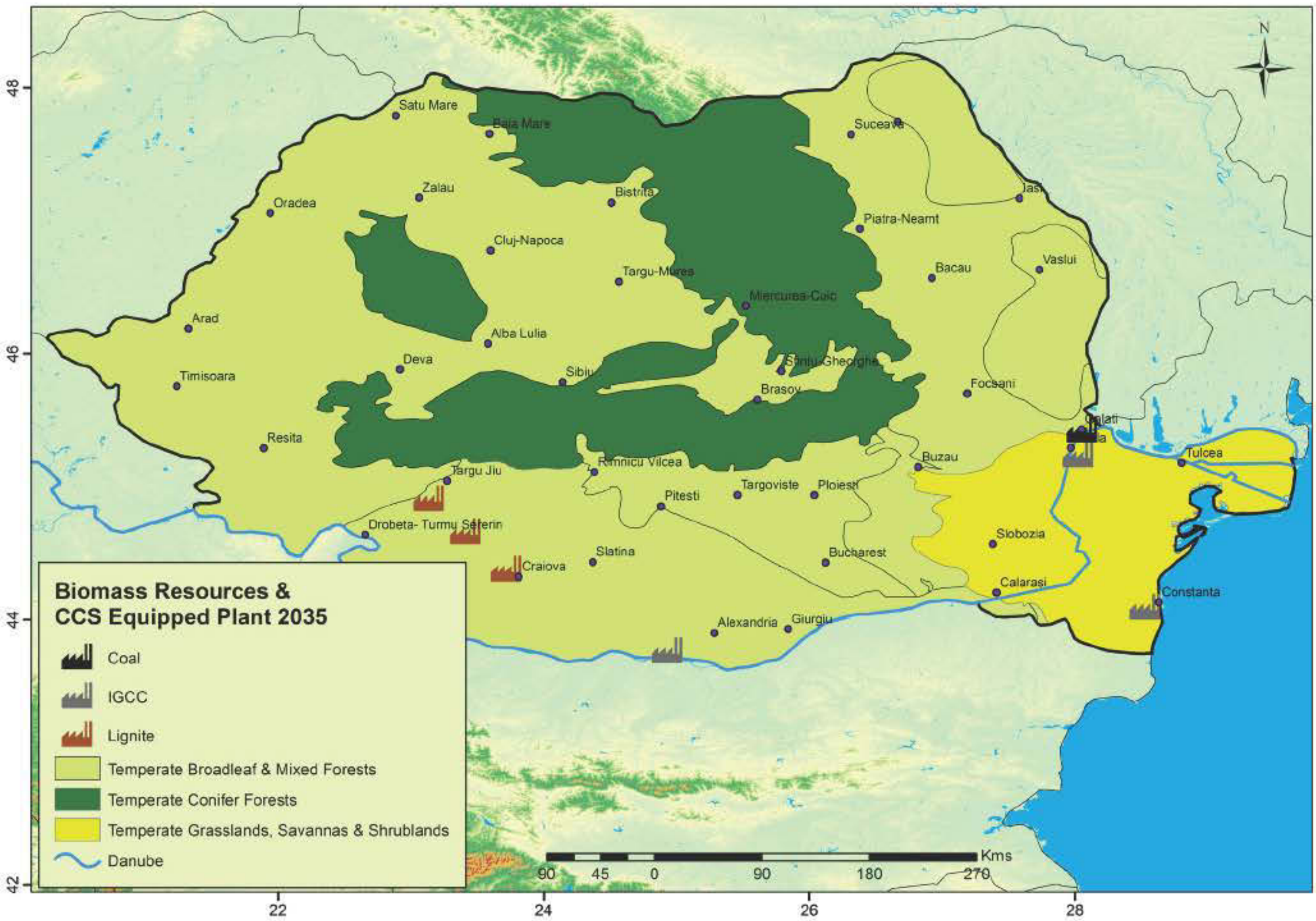


FIGURE A3.2 BIOMASS RESOURCE DISTRIBUTION AND CCS EQUIPPED PLANTS IN 2035



remaining syngas fed through a Fischer-Tropsch (FT) process where it undergoes liquefaction. Approximately 37% of the initial carbon is retained within the produced diesel fuels while a high purity CO_2 stream containing 52% of the biogenic carbon can be easily captured (Carbo, et al., 2010). Another important benefit of FT diesel (as well as other FT fuels, e.g. aviation fuels) is the reduction of SO_X, NO_X and particulate matter (PM) due to the higher purity when compared to petroleum-derived diesel. This will have a positive effect on public health and the built environment in traffic-dense areas. With rising CO_2-prices, Bio-CCS could in fact, when negative CO_2-emissions become sufficiently incentivised, provide a further economic driver for superseding current inefficient biodiesel production with more advanced 2nd generation FT biodiesel production. Not only does the FT process allow for low additional cost CO_2-negative but due to the higher efficiency of biomass conversion land use is optimised, resulting in higher biofuel yield per hectare of energy crop. The process also provides the opportunity of utilising solid wooden biomass and a diverse range of agricultural wastes as feedstocks for liquid fuel production.

Hydrogen fuel may moreover be produced from biomass, providing the maximum potential CO_2-negative biogenic fuel. Hydrogen is then generated through the gasification of solid biomass, with the carbon monoxide and carbon dioxide separated. Hydrogen is a versatile fuel, which can be utilised in fuel cells in transport vehicles, heating installations and electricity generation. The production of hydrogen may take place at standalone gasification units or at co-fire equipped IGCC plants, such as future coal facilities built in Romania.

TABLE A3.1 POTENTIAL FOR CO_2 NEGATIVE FROM VARIOUS BIOFUELS

Process	CO_2 Purity for Capture	CO_2 Negative (of initial biomass carbon content)
Ethanol	99%	15-35%
Bio-Diesel	>95%	50%
Hydrogen	>95%	>95%

A3.3.1 BIOFUEL & CCS INTEGRATION

As described, the high purity CO_2 available at many biofuels production facilities – which means an absence of the need for capture technology equipment – results in low costs of CCS integration, likely among the least costly of any CCS application. This makes biofuel CCS a low-hanging fruit for early CCS adoption. The addition of capture and compression equipment to a large 235 million litre/yr. 1st generation bioethanol plant is expected to have little impact on the OPEX of the plant, while CAPEX will only be marginally affected with an increase of 0.9% (Rhodes & Keith, 2003).

Prior to appropriate incentives for negative CO_2, the low cost of CO_2 capture from many biofuel facilities provides attractive economies for early Carbon Capture and Use (CCU). The reuse of captured CO_2 from biofuel plants for Enhanced Oil Recovery (EOR) would be an early commercial opportunity to advance CO_2 knowledge and infrastructure. Commercial Bio-CCS and EOR projects are already operational, notably in the US. In 2009, the petroleum firm Chaparral Energy started purchasing one million tonnes of CO_2 a year from a bioethanol production facility in Liberal, Kansas. The captured CO_2 is transported 90km to Texas, where it is injected into an ageing oilfield for EOR. This project is entirely commercially motivated, operating under a framework with no CO_2 price and zero incentives for carbon negative (Chaparral Energy, Inc., 2011).

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