

BEST

BELLONA ENVIRONMENTAL CCS TEAM

INSURING ENERGY INDEPENDENCE

A CCS ROADMAP FOR POLAND



BELLONA ENVIRONMENTAL CCS TEAM

Acknowledgements and legal disclaimer

The Bellona Foundation, Krakow, Poland, 2011

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Authors (in alphabetical order): Virginia Corless, Erlend Fjøsna, Jan Havlik, Jonas Helseth, Eivind Hoff, Tone Knudsen, Derek Taylor, Gøril Tjetland, Marek Zaborowski.

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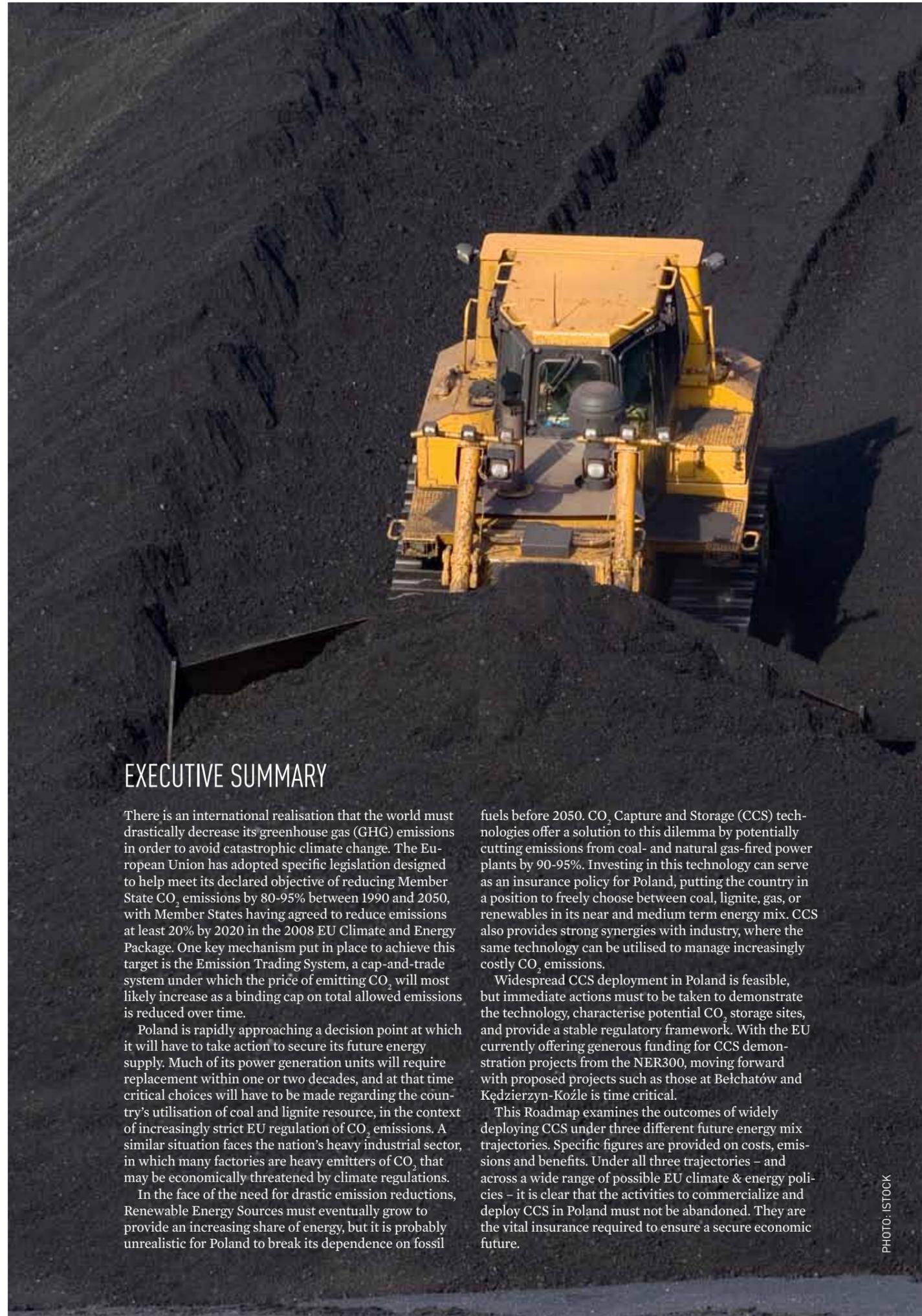
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EXECUTIVE SUMMARY

There is an international realisation that the world must drastically decrease its greenhouse gas (GHG) emissions in order to avoid catastrophic climate change. The European Union has adopted specific legislation designed to help meet its declared objective of reducing Member State CO₂ emissions by 80-95% between 1990 and 2050, with Member States having agreed to reduce emissions at least 20% by 2020 in the 2008 EU Climate and Energy Package. One key mechanism put in place to achieve this target is the Emission Trading System, a cap-and-trade system under which the price of emitting CO₂ will most likely increase as a binding cap on total allowed emissions is reduced over time.

Poland is rapidly approaching a decision point at which it will have to take action to secure its future energy supply. Much of its power generation units will require replacement within one or two decades, and at that time critical choices will have to be made regarding the country's utilisation of coal and lignite resource, in the context of increasingly strict EU regulation of CO₂ emissions. A similar situation faces the nation's heavy industrial sector, in which many factories are heavy emitters of CO₂ that may be economically threatened by climate regulations.

In the face of the need for drastic emission reductions, Renewable Energy Sources must eventually grow to provide an increasing share of energy, but it is probably unrealistic for Poland to break its dependence on fossil

fuels before 2050. CO₂ Capture and Storage (CCS) technologies offer a solution to this dilemma by potentially cutting emissions from coal- and natural gas-fired power plants by 90-95%. Investing in this technology can serve as an insurance policy for Poland, putting the country in a position to freely choose between coal, lignite, gas, or renewables in its near and medium term energy mix. CCS also provides strong synergies with industry, where the same technology can be utilised to manage increasingly costly CO₂ emissions.

Widespread CCS deployment in Poland is feasible, but immediate actions must be taken to demonstrate the technology, characterise potential CO₂ storage sites, and provide a stable regulatory framework. With the EU currently offering generous funding for CCS demonstration projects from the NER300, moving forward with proposed projects such as those at Bełchatów and Kędzierzyn-Koźle is time critical.

This Roadmap examines the outcomes of widely deploying CCS under three different future energy mix trajectories. Specific figures are provided on costs, emissions and benefits. Under all three trajectories – and across a wide range of possible EU climate & energy policies – it is clear that the activities to commercialize and deploy CCS in Poland must not be abandoned. They are the vital insurance required to ensure a secure economic future.

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PREFACE

The potential applications of CO₂ Capture and Storage technologies are not often discussed in Poland, and when they are, most analyses limit themselves to a strict evaluation of the implications of an initial demonstration project, such as that proposed at the power plant of Bełchatów. At the same time, Poland faces serious unanswered questions about its future energy security and economic health in the face of future climate and energy policy. This Roadmap sets out to bridge that gap by offering a realistic appraisal of CCS deployment as a means to insure against such rising CO₂ costs and ensure secure sustainable economic development in Poland.

To this end, the current energy demand, energy supply, and industry situations in Poland are described in the context of CO₂ emissions. This situation is projected

into the future, utilizing models of three potential future Polish energy mix trajectories, and the impacts of different levels of CCS deployment are calculated. Specific conclusions regarding the economic and environmental outcomes of each future scenario are provided, with the hope they may serve as guideposts in evaluating the policy and investment choices now facing Poland's government and energy sector actors.

A combination of publicly available official data from Polish and international sources, together with Bellona's own research in Poland is used to construct this roadmap. Although presented now as a complete exercise, the reader is invited to share with Bellona relevant new information or data as the roadmap will be updated accordingly.

A WORD FROM JERZY BUZEK, PRESIDENT OF THE EUROPEAN PARLIAMENT



“Access to energy is critical for the development of all countries. Poland is no exception to this and our country's continued economic development will heavily rely on its extensive coal reserves for decades to come. These coal reserves give us a high level of security of supply for nearly all of our electricity and also for much of the

heat required by both our population and our industry.

In the future, we must increase the efficiency with which we produce and use our energy. We may discover unconventional gas resources, develop technologies such as underground coal gasification and increase our investment in renewable energies. But we will still depend on coal to meet the larger share of our energy needs because, in addition to energy supply security, it also provides us with energy at a reasonable cost which cannot be assured by other forms of supply.

However, the use of coal is not without its challenges. Some of these we have already met through the intro-

duction of technologies such as flue gas desulphurisation (FGD). But one major challenge still confronts us. This is to very significantly decrease the amount of carbon dioxide (CO₂) that burning coal - in all its forms - emits into the very air we breathe and is, by far, the biggest contributor to changing the global climate.

The only technology that has been developed to meet this challenge - while allowing us to continue to use one of Poland's most valuable natural resources - is carbon dioxide capture and storage (CCS).

I am very proud that we in Poland are at the forefront of the development and demonstration of this technology. This is where we should be and need to be. It puts us in a position to benefit from the technology in the short, medium and longer term, and can enable Poland to become a net exporter of clean energy in the future.

I therefore very warmly welcome this CCS Roadmap by the Bellona Foundation. It very clearly shows that CCS can play an important, if not vital, role in the months and years ahead as Poland continues to develop its policies to help us achieve a secure, competitive and sustainable energy future.”

1.0 BACKGROUND

There is an international realisation that anthropogenic CO₂ emissions – the most important greenhouse gas - need to be drastically reduced in order to avoid triggering catastrophic climate change. The best models currently predict that this can be achieved by limiting global temperature increases to 2 degrees Centigrade, which in turn requires keeping the concentration of CO₂ equivalents (CO₂e)¹ in the atmosphere below about 450 parts per million (ppm)². Currently in 2011, the concentration is approximately 391 ppm, increasing by about 2 ppm per year. Staying below 450 ppm will require cutting global emissions before 2050 on the order of 80%, with the developed countries effectively eliminating their net emissions.³

CO₂ Capture and Storage (CCS) offers the potential to radically reduce CO₂ emissions from large point emissions such as coal- and gas-fired power plants and emission-intensive industrial facilities. In this capacity, it plays an important role as a transition technology. It will help CO₂-intensive economies to comply with climate regulations while maintaining competitiveness. More importantly, CCS can offer secure access to affordable energy during the time it takes to transition to a fully renewable energy economy (IPCC, 2005).⁴

No one technology holds the answer to achieving necessary greenhouse gas (GHG) emission reductions or securing affordable energy in the face of climate policy; indeed, only full use of all available measures – such as switching to renewable energy sources, enhancing energy efficiency, curbing emissions from agriculture and forestry, as well as deploying CCS – will solve the energy and climate challenge.

This roadmap in large describes only one of these climate change mitigation technologies, namely CCS, and possible strategies for large scale implementation of this technology in Poland.

1.1 FACTORS IMPACTING THE COST OF CO₂ EMISSIONS

EU policies for combating climate change

The European Union has adopted specific legislation towards meeting its objective of reducing EU Member State CO₂ emissions by 80-95% between 1990 and 2050. In 2008, the EU adopted a package of climate and energy legislation that will reduce GHG emissions by at least 20% by 2020 compared to 1990 levels, notably by revising the EU Emissions Trading System (ETS)⁵ to deliver two-thirds of that reduction. The ETS is a “cap-and-trade” system that caps the total number of Emission Unit Allowances (EUAs),

¹ CO₂ equivalents (CO₂e) is a unit used to express the warming potential of all greenhouse gases (e.g. methane) in terms of that of CO₂. For example each gram of methane has the warming effect of 23 grams of CO₂, 1g methane = 23g CO₂eq.

² The special report of the Intergovernmental Panel on Climate Change (IPCC, 2002) calculates the CO₂ concentration at 380 ppm in early 2004, see http://ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf. Taken into account the 2 ppm increase per year, the current concentration is about 391 ppm.

³ For more details about Bellona’s recommendations on combating climate change, see http://bellona.org/reports/How_to_Combat_Global_Warming

⁴ For the special report of the Intergovernmental Panel on Climate Change (IPCC), see http://ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf

⁵ For overview of the EU ETS, see http://ec.europa.eu/clima/policies/ets/index_en.htm





PHOTO: ISTOCK

each of which permit the emission of 1 tonne of CO₂ equivalent, available each year, with a cap that decreases over time. Covered entities, such as power plants and industrial plants, must surrender EUAs for all CO₂ emitted. High emitters may choose whether to reduce emissions or to purchase additional EUAs or other credits recognized by the ETS, such as Certified Emission Reductions (CERs) sold by developing countries. The price of EUAs is determined by a supply and demand market principle. It is an open question whether the emission reduction target for 2020 should be increased from 20% to 30%, which would result in a lower emissions cap, and thus a higher CO₂ price, within the ETS.

The EU has repeatedly set out ambitions for CCS deployment in Europe, the most relevant being that: CCS shall be commercially available by 2020; all new fossil power plants shall be equipped with CCS from then on; and, until then, all new facilities shall be designed to be CCS-ready⁶. Furthermore, the EU has singled out CCS as one of six strategic climate & energy technologies until 2050, and wants to fund up to 12 demonstration plants by 2015 in order to accelerate the development and commercialisation of this technology.

It is highly probable that, as climate change begins to adversely impact human civilisation, increasingly stringent measures to reduce anthropogenic emissions of greenhouse gases (GHG) will be implemented.

One likely mechanism used to implement those policies will be the existing ETS, with an accelerated decrease of its cap. The more stringent climate policy becomes – and thus the lower the cap gets – the higher the EUA price. It will add an ever-higher cost to the price of each tonne of coal or cubic meter of natural gas⁷ burned. The higher this price is, the more difficult the market position of fossil-based facilities – particularly CO₂-intensive coal-based power producers and energy-intensive industries. And the more attractive alternative investments – such as those in CCS – become.

Predicting the future price of EUA is subject to many uncertainties (see Figure 4B). Significant price volatility has been observed since the beginning of EU ETS operation in 2005, with prices growing rapidly in 2007 and 2008 due to large price increases in commodity markets, falling in mid-2008 due to the economic crisis and stabilizing in late 2009 at around 15 EUR. The uncertainty surrounding future EUA prices is incorporated into the investment decisions of power sector actors, and makes investors reluctant to undertake capital-intensive investments in CCS technologies. In the current improved system, however, such high price volatility is less likely, due to stricter monitoring.

This uncertainty is a key reason why a complementary system to the ETS, such as a CO₂ tax or a CO₂ emission performance standard (referred to as EPS, meaning setting a limit on the amount to be

emitted per kilowatt-hour electricity produced)⁸, is under discussion across Europe and in the US. By imposing absolute limits – rather than a volatile price – on emissions, such a system would create certainty for low-carbon investors, a high priority in the EU policy. If an EPS system is adopted it is likely to incorporate emission limits that become stepwise stricter over a given time period. This would mean that during the first few years only the worst emitters (in g CO₂/kWh) will be affected, whereas later, when the levels become more strict, only the cleanest of technologies will meet the performance standard. Because it is only when the power sector gains confidence in investing in CO₂ mitigation technologies – whether through risk sharing efforts from the government or through such policies that provide more certainty regarding the future cost of CO₂ emissions – that energy investors will consider deploying CCS.

Encouraging such investment decisions is a necessity for the long term economic health of CO₂-intensive power and industry sectors, even were EUA prices to remain below 20 EUR through 2020. Coal-fired power plants have operating lifetimes that exceed 40 years, and on that time horizon, moving towards 2050, there is no doubt that unabated coal-fired power plants in the richer parts of the world will become uneconomic or simply forbidden.

1.2 CCS, A SOLUTION FOR REDUCING EMISSIONS

CO₂ capture is a technology in which CO₂ is separated from a mixture of several different gas components, usually sourced from a concentrated stream such as combustion flue gases or gases from industrial processes. Currently, many coal power plants in the world are fitted with systems for separating NO_x and SO_x from the flue gases prior to releasing it into the atmosphere in order to avoid e.g. acidification of rain.

Today, there are thousands of power generation plants and industrial plants worldwide emitting large volumes of CO₂ into the atmosphere. Using CO₂ capture technology on these emission sources will prevent the majority of these emissions from entering the atmosphere and instead make the CO₂ available for storage or utilisation. Once the CO₂ is captured, it is normally compressed so that it becomes a fluid which can be pumped through a pipeline, transported in tankers, or further processed via utilisation in chemical processes. There are a range of principles and technologies for CO₂ capture, and the optimum solution is specific to the type of process, mixture of gases, quality requirements, etc. that characterise the plant generating the emissions.⁹

⁶ See 1) European Commission, Supporting Early Demonstration of Sustainable Power Generation from Fossil Fuels, Brussels, COM(2008) 13 final and 2) European Commission, An Energy Policy for Europe, COM(2007) 1 final, 2007
⁷ The definition of natural gas in this roadmap means natural gas from hydrocarbon formations and does not, therefore, include biogas.

⁸ For more details about Bellona's position on EPS, see http://bellona.no/porta/bellona.org/files/fil_Bellona_Position_Paper_on_CCS_-_1Dec08.pdf
⁹ For more information about the CCS technology, see the Bellona CCS web at <http://www.bellona.org/ccs>

2.0

WHY CCS IN POLAND

2.1 CURRENT ENERGY SITUATION

The nature of the Polish power sector is defined by two key characteristics: it is heavily coal and lignite dependent, and its generating fleet is very old and will require almost total replacement in a few years. In 2009, almost 90% of Poland's electricity was produced from coal and lignite, with only 3% from natural gas, and 6% from renewable energy sources. This energy mix is the result of Poland's very rich domestic lignite resources, that have long provided cheap domestic energy, and promise to remain abundant long into the future. Mining and subsequent use of coal has a long historical tradition in Poland, such that it is widely viewed by Polish citizens as an important part of the nation's wealth, heritage, and independence.

Despite the low cost of lignite, electricity prices in Poland are among the highest in Europe when compared to average household income. Figure 2B compares the price per kWh of electricity as a fraction of median equalised household income in Poland to that in other European nations. Poland ranks in the top five, with relative electricity costs two times higher than those in the UK, and more than four times higher than those in Denmark, Finland, France, and Sweden.¹⁰ The already proportionally

¹⁰ Eurostat 2009. <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>



HARD COAL

55%

LIGNITE

33%

BIOMASS AND BIOGAS

3%

NATURAL GAS

3%

OTHER FUELS

3%

WIND

2%

HYDRO

1%

GROSS ELECTRICITY PRODUCTION IN POLAND IN 2009

PHOTO: ISTOCK

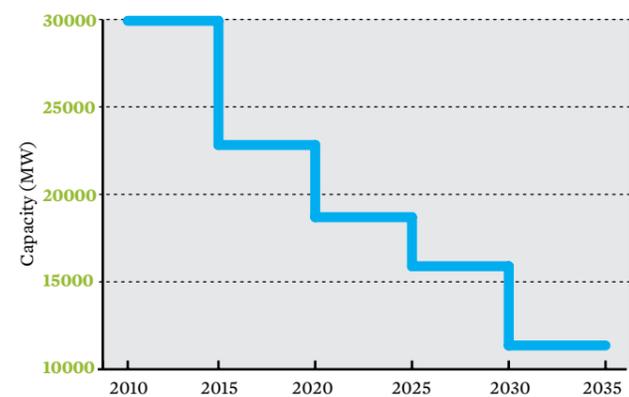
high price of electricity makes Polish citizens and politicians alike particularly sensitive to potential changes in that price, as any price increase will have a significantly greater impact on household disposable income in Poland than in most of its European neighbours.

More than 75% of power production facilities in Poland are owned in part by the state, and there is a longstanding open debate within the government and industry as to whether the sector should privatise further. Power generation in Poland is concentrated largely in the central and southern parts of the country, close to coal resources and the major population centres. Bełchatów power plant, located about 50km south of Lodz, is the largest power plant in Poland, generating more than 20% of the nation's electricity. It is also the largest lignite-fired plant in Europe, and could soon become one of the largest fossil-fuelled power generation facilities in the world, with a capacity of more than 5.3 GW. In general, Poland's coal-fired generation fleet is very old, with more than 70% of power plants over 30 years old, 40% over 40 years old, and 15% over 50 years old,¹¹ with more than half slated for retirement within 5 – 20 years.¹² According to energy experts, multibillion Euro investments will be required to renew the exhausted power sector and guarantee uninterrupted supplies of electric energy. Any delays in investment decisions may lead to blackouts in the near future.

The advanced age and coal-dependence of the Polish generating fleet make it one of the most carbon-intensive in Europe, with the Polish power sector emitting 1.12 tonnes CO₂eq per MWh of electricity produced, compared to 0.45 tonnes CO₂eq/Mwh in EU27 and 0.39 tonnes CO₂eq/Mwh in EU15.¹³ This high GHG emission profile results from the low energy efficiency of the sector's aged power plants, as well as the dominance of highly CO₂-intensive coal and lignite in the energy mix. Bełchatów power plant is the largest single CO₂ emission source in Europe, emitting 30 million tonnes of CO₂ per year.

FIGURE 2C EXPECTED RETIREMENT SCHEDULE OF EXISTING FOSSIL FUEL POWER PLANTS IN POLAND

(Source: Polish Energy Policy until 2030, 2009. Polish Ministry of Economy, Warsaw)



11 Zielona Księga Narodowego Programu Redukcji Emisji, 2010
 12 Ministry of Economy 2009, Polish Energy Policy until 2030, MoE, Warsaw
 13 Eurostat 2009. <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

2.2 FUTURE DEVELOPMENT OF THE ENERGY SECTOR

On November 10th, 2009 the Council of Ministers adopted the Polish National Energy Policy until 2030 (PEP).¹⁴ In that document the government made a strong commitment to maintain domestic coal and lignite as the primary fuel for electricity generation in Poland, as it is cheap and guarantees national energy independence and security. However, there are many legal, political, and economic factors that may change the outlook for coal in Poland, all made more influential in the face of the impending replacement of almost the entire Polish power generating stock in the coming decades.

EU climate and environment policy will likely make unabated electricity generation from coal plants uneconomic. Already such policies exercise pressure on power plants to meet strict environmental standards. The perceived risk of more stringent future emission regulations will shape investment decisions in the power sector. It may, for example, lead to additional fuel switching from coal to less carbon-intensive – or carbon neutral – fuels. Indeed, significantly more investment in new natural gas-fired facilities has already been witnessed than was predicted in the PEP, while RWE recently decided to abandon planned coal-fired power plant projects in Poland.

National policy, such as the current red and yellow certificate programmes that promote electricity production from natural gas or new initiatives such as a 'grey' certificate programme to support CCS, may elevate particular technologies and fuels.

Discovery of national shale gas resources could make natural gas an affordable and secure domestic fuel, provided environmentally safe exploration and extraction.

Fuel and technology price evolution will shape the relative appeal of various technologies, from coal-fired power plants to renewable generation.

Energy price evolution will shape energy demand, with increasing energy prices likely to spur enhanced energy efficiency measures applied by the public and government.

The Role of the Government

The Polish government plays a crucial role in shaping these factors and with them future energy demand and energy mix. In addition to its role in influencing EU climate and energy policy in Brussels, the government has various national legal, economic and regulatory incentives at its disposal with which to support particular electricity generation technologies (e.g. through a system similar to the existing tradable certificates for renewable generation and combined heat and power units). Moreover, the government retains ownership of several major electricity generation companies and therefore may drive developments as a power sector investor.

14 Ministry of Economy 2009, Polish Energy Policy until 2030, MoE, Warsaw

FIGURE 2B SCALED ELECTRICITY PRICES AS A FRACTION OF MEDIAN EQUIVALISED INCOME IN EUROPE

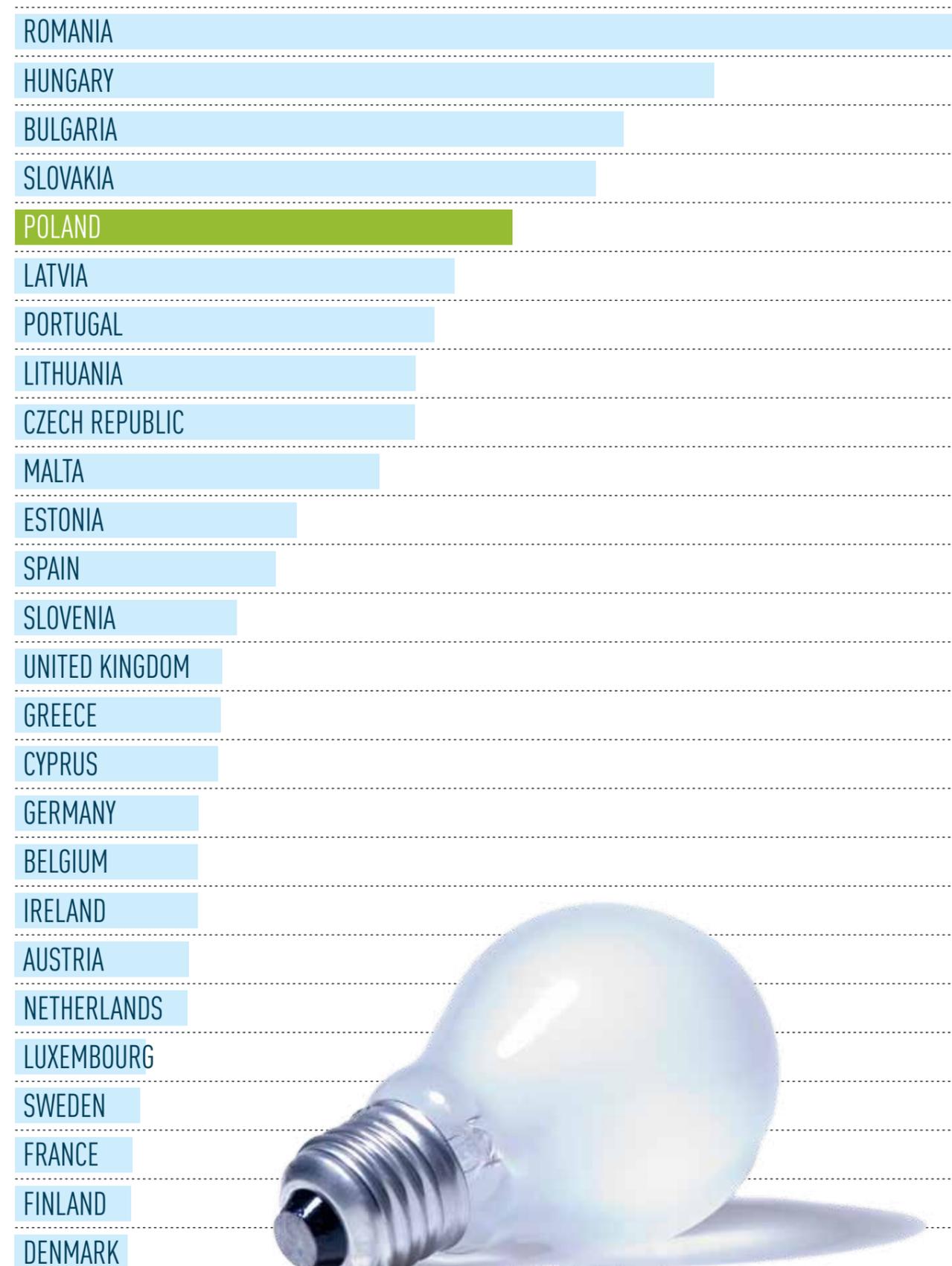
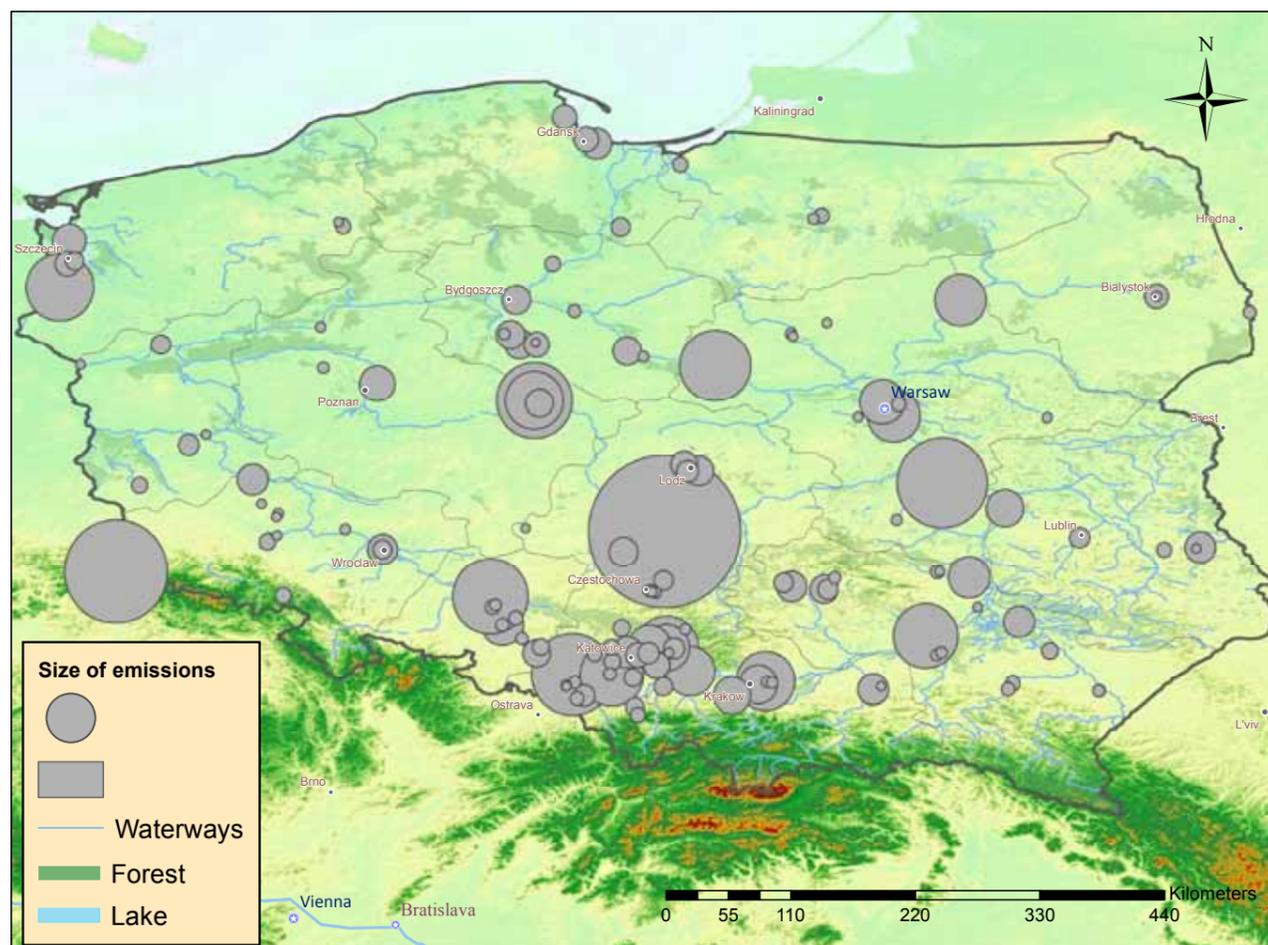


FIGURE 2D PRESENT DAY CO₂ EMISSION POINT SOURCES



Most data regarding CO₂ sources in this study is collected from the PL EPRTTR 2010 and 2007 databases. Additional data sources can be found in Appendix 3 and Table 3A and GIS data may also be downloaded from www.bellona.org/ccs

Currently, the government has not made use of its holdings to assume first-mover risk and drive the adoption of new technologies. However, its ownership roles in many major generation facilities give it plentiful opportunities to do so in the future.

Depending on how government policy, EU mandates, and market conditions evolve, energy demand and mix in Poland may indeed develop as predicted in the PEP, with rapid demand growth and a continued dependence on coal. However, it is also likely that gas may come to play a much larger role in the energy mix, whether because of enhanced native resources or policy drivers, or that demand may grow more slowly than predicted in the PEP, if energy efficiency measures are implemented by the government or if high energy prices drive down consumption. Alternatively, new international grid interconnections may be established that allow Poland to import electricity. More imports would open the Polish power sector to wider competition, which might keep prices down but would also be highly controversial. All told, the future development of the power sector remains highly uncertain, with much to be decided in the coming years as the technically exhausted generation fleet is replaced.

2.3 MAINTAINING ENERGY SECURITY AND A COMPETITIVE INDUSTRY

Future EU climate and energy policy combined with the near-total coal-dependence of the Polish power sector makes for a potentially dangerous cocktail. No matter how the energy mix and power sector evolve in the coming years, increasingly strict emission limits may pose serious risks for Polish prosperity and security. Continued use of coal will become ever more expensive, straining Polish citizens already paying some of the proportionally highest electricity bills in Europe, and rapidly decreasing the competitiveness of Polish heavy industry. Shifting towards natural gas is likely to entail increased dependence on foreign fuel supplies and corresponding reductions in energy independence and security, as well as increasing volatility in energy prices. As emission restrictions tighten, government options for policy action will become ever more constrained, as angry citizens facing high electricity bills and slowed economic growth demand action and native fuel stocks lose their viability for power generation.

But it does not have to be so. By enabling low-carbon manufacturing and power generation from coal and natural gas, CCS provides a technological tool that could guarantee compliance with whatever EU climate regulations may come in the next decades, while maintaining its energy independence, utilising its domestic fuel resources, controlling its electricity costs, and maintaining flexibility in its national energy and economic policies.

However, the great potential of CCS cannot be realized without advanced preparation. Indeed, CCS may be thought of as Poland's insurance policy against future restriction on CO₂ emissions, and as with any insurance, reaping its benefits requires investing in coverage in advance. That investment comes in the form of R&D and demonstration projects that develop expertise and know-how, bring down costs, and so lay the foundations for economy-wide CCS deployment if and when it becomes necessary.

MAIN ACTORS

Though until recently largely ignored in Poland, CCS has become a subject of increasing interest with the preparatory work on the demonstration projects and implementation of the CCS Directive. The main CCS actors in the civil sector, industry, research and the government are:

GOVERNMENT

- Ministry of Environment – responsible for coordinating the legislative work on the CCS directive
- Ministry of Economy – runs the Polish Clean Coal Technology Program to support ‘clean coal’ technologies, mainly CCS
- National Geological Institute – will likely be the competent authority that oversees CO₂ storage regulation and enforcement

INDUSTRY

- PGE – Polska Grupa Energetyczna – operator of Bełchatów (Łódź Region)
- TAURON Polska Energia – involved in EOR research
- PKE – Południowy Koncern Energetyczny – Katowice (Silesia)
- Grupa LOTOS S.A. – involved in EOR research
- ZAK – Zakłady Azotowe Kędzierzyn (Opolskie Region) – operator of the Kędzierzyn plant
- ZAP – Zakłady Azotowe Puławy (Lubelskie Region)
- PKE – Południowy Koncern Energetyczny – Katowice (Silesia)

CIVIL SECTOR

- Actors that regularly or occasionally express themselves on CCS:
- demosEuropa
 - WWF
 - Greenpeace
 - Bellona Polska

RESEARCH

- Institute for Chemical Processing of Coal – CO₂ capture research
- Mineral and Energy Economy Research Institute – CCS technology research
- The Oil and Gas Institute – transport and storage research
- Polish Geological Institute – storage research¹⁵

¹⁵ For a complete list of research institutes dealing with CCS, see http://bellonapolska.pl/files/lista_badawcze.htm

3.0

AN INSURANCE POLICY

➤ In 2007, after the EU heads of state and government endorsed the goal of constructing a set of industrial-scale CCS demonstration projects, the European Commission began to create an economic and legal framework to support 12 flagship demonstration CCS power-plant projects. These demonstration projects are expected to start operation by 2015, and all aim to show the potential of CO₂ capture and storage while testing the technology and gaining valuable know-how. The demonstration projects will also help catalyze further investments by bringing down capital costs through technological learning and reducing risk through experience. In 2009, the EU awarded 1 billion EUR to six such demonstration projects (one of which was Bełchatów, see below) under the European Energy Programme for Recovery (EEPR). It also decided to competitively allocate 300 million EUAs from the ETS New Entrants Reserve (hence its acronym NER300) to CCS and innovative renewable energy demonstration projects. At January 2011 prices, the NER300 will be worth approximately 4.5 billion EUR. The Commission aims to finance at least eight CCS projects with these funds, and it is expected that the six recipients of EEPR funds will be well placed to receive additional funding. The two EU schemes, NER300 and EEPR, may cover up to 50% of the net costs of CCS demonstration projects. This demonstration project programme provides Poland with the ideal opportunity to begin construction of its CCS insurance policy. Working with the EU to develop at least one first-generation commercial-scale CCS facility by 2015 will enhance Poland's position as a technological and economic leader in Central Europe, and help the nation develop the experience and investor confidence necessary to facilitate wide-scale CCS deployment in the future.

Demonstration projects

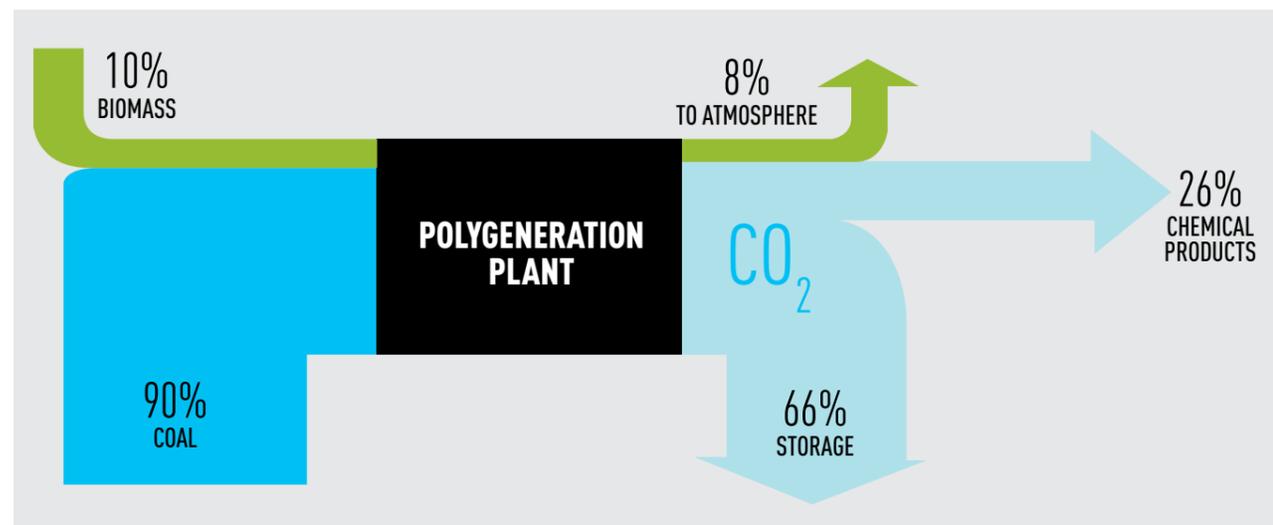
Indeed, the Polish government has already recognized the potential importance of the demonstration programme for Poland, and informed about its interest to apply for EU funding for two demonstration projects on Polish soil. The Bełchatów project (Łódź Region) has already received European Commission's EEPR grant and will be carried out in Poland as flagship European demonstration projects, while the Kędzierzyn-Koźle project is in the planning-phase. Even though the Bełchatów project has received 180 million EUR from the European Economic Recovery Package (EERP), the Polish government has not yet made a decision on how to assure financing for the remaining capital costs. Its options include using external funding resources from the EU (by reallocating some resources within the EU structural funds priority axis 3 "Resource management and prevention of environmental threats" or priority axis 2 "Waste Management," and by covering some costs from the national budget. The EU Commission and investors have made it clear that financial help from the national government will be indispensable, in addition to those resources available through EU grant mechanisms and the European Investment Bank (EIB). From 2013, Member States will be able to partially cover the operating costs of the demonstration projects with ETS income. Poland could also apply for free allowances for the power sector under the condition that equivalent amount (to the value of allocated allowances) will be invested in energy infrastructure, including CCS, under specific EU requirements. These free allowances will, however, only be available until 2020. Assuring financing of the demonstration projects is crucial, and the government and industry must cooperate closely to do so.¹⁶

¹⁶ Steps towards establishing a close cooperating between the government and industry are already taken with the ongoing research performed within the National Programme. The Programme analyses the potential for underground CO₂ storage in saline aquifers.



PHOTO: MAREK ZABOROWSKI

FIGURE 3A ENERGY & CHEMICAL PRODUCTION AT THE KĘDZIERZYN CHEMICAL PLANT



3.1.1 BEŁCHATÓW

Bełchatów power plant is the largest lignite power plant in Europe, and in 2011, when the new 858 MW block begins operation, with a 5.3 GW capacity, over 30 million tons of CO₂ emissions will be emitted each year. Bełchatów power plant and its associated lignite mine belong to the Polish Energy Group (PGE), the largest energy producer in Poland. The Bełchatów demonstration project aims to apply post-combustion CO₂ capture technology to parts of the new unit. The capture unit will use an amine process known as “advanced amine” to capture approximately 25% of the CO₂ emissions – about 2.1 million tonnes of CO₂ annually – from the new generation unit with a 90% capture efficiency. Three potential CO₂ storage sites in underground saline formations have been identified after an initial site review, with a final decision regarding the storage location expected in 2011.

The project will have a capital cost of approximately 610 million EUR,¹⁷ based on a PGE analysis placing the CCS cost at 67 EUR/tonne. In March 2010, the European Commission allocated 180 million EUR for the Bełchatów CCS demonstration plant. Further EU funding may include the EU structural and cohesion funds and other national funding may come from the Polish National Fund for Environmental Protection and Water Management The Norwegian Financial Scheme and potentially some other smaller funding sources could be used for related research activities.¹⁸

17 PGE states that the project costs is 610 EUR million, out of which the capture installation represents 370 million EUR, transmission pipelines cost is 114 million EUR and the installation for injection into the reservoir is 126 million EUR. See <http://ekobudowanie.pl/aktualnosci/1283-czy-beda-pieniadze-na-ccs-w-belchatowie>

18 For an interim progress report on CCS installation in Bełchatów, see http://microsites.ccsnetwork.eu/microsite_files/uploads/docs/6-1.pdf

3.1.2 KĘDZIERZYN-KOŹLE

A first-in-the-world ‘Zero-Emission Power and Chemical Complex’ that integrates IGCC (Integrated Gasification Combined Cycle) generation technology with CCS is planned for construction at the Kędzierzyn Chemical Plant in Silesia. The 308 MW project will use IGCC generation technology to produce electricity from synthesis gas made from hard coal and biomass through the process of coal gasification, and pre-combustion capture technology to capture 2.5 million tonnes of CO₂ per year. Polygeneration technology will be used to produce not only heat and power, but also additional synthesis gas for sale or export.

Plans call for 28% of the captured CO₂ to be utilized in chemical products such as methane, urea, hydrogen, methanol, and, in the future, synthetic fuel. Indeed, the methanol produced in Kędzierzyn will be sufficient to cover all Polish demand for the product. The remaining 72% will be stored. The project is estimated to cost 1,4 billion EUR¹⁹ in capital expenditure. As in the Bełchatów case, the net costs will need to be met utilizing resources from the EU and the national government.

19 Out of which 0,6 billion EUR from the EU Demonstration Programme contribution (EEPR), 0,3 billion EUR from the EU Structural funds, and 0,5 billion EUR from private funds of ZAK and PKE. Detailed analysis of the remaining part of funding has not been published yet.



PHOTO: ISTOCK

3.1.3 PILOTS FOR UNDERGROUND COAL GASIFICATION

Several R&D projects have looked at underground coal gasification (UCG), coal bed methane extraction (CBM) and the possibility of injecting and storing CO₂ in support of these processes.

The Polish Clean Coal Technology Platform has claimed that several trillion tonnes of coal are still available in the Polish subsurface, and the platform is now conducting a research programme on UCG in order to extract parts of these reserves. Currently, this work is at a pilot scale and further research, in particular focused on environmental concerns, is needed. A publication from the Central Mining Institute (Kapusta and Stanczyk, 2010²⁰) attempts to describe the causes and parameters influencing the degree of pollutants in the groundwater during underground gasification of hard coal and lignite. The Kapusta and Stanczyk study

20 Krzysztof Kapusta and Krzysztof Stanczyk, “Pollution of water during underground coal gasification of hard coal and lignite”, Fuel, In Press, Corrected Proof, Available online 27 November 2010

covers a variety of hazardous water-borne contaminants which have been identified during different UCG operations, and in some locations long-term groundwater contamination was observed. Given these findings, more research is required on extraction methods prior to extensive roll-out of subsidies to this industry.

One R&D project²¹, the RECOPOL project, investigated the technical and economic feasibility of storing CO₂ permanently in subsurface coal seams. The project looked at CO₂ injection in coal seams whilst simultaneously producing gas through the CBM process. The project was followed by MoVeCBM (EU 6FP) in 2006-2008 where comprehensive monitoring programme was applied at the site. The pilot site had previously been used to produce gas from thin underground coal seams.

21 The RECOPOL project was funded by EU 5th Framework Programme (5FP 2001-2005). See <http://recopol.nitg.tno.nl/recopol2.shtml>

3.1.4 FURTHER OPTIONS

The Police storage location (in the Szczecin area) is located approximately 200 kilometres north of Jänschwalde in Germany, where there is a CCS demonstration project that has received 180 million EUR under the EU's EEP. Failure to secure public participation in the early stages of the project has led to a situation in which Jänschwalde is facing severe local resistance to its plans for underground storage. This could potentially hold back a project that is otherwise very well placed to be amongst the first EU demonstration projects for CCS. This is an example of a cross-boundary opportunity in which Poland might benefit from sharing investment costs and operating expenditures with other countries by offering storage infrastructure and capacity.

3.1.5 R&D TO COMPLEMENT DEMONSTRATION PROJECTS

Early deployment of CCS technology will give Poland a significant regional first-mover advantage, as it is one of only a few of its neighbours applying for EU funding to construct a CCS-equipped power plant. This will bring with it technical and political know-how that will prove valuable tools if and when the need for large scale deployment of CCS arises. Moreover, the research and development associated with early CCS deployment can serve as a stimulus to companies connected with the energy industry as it will both be the main actor commissioning the research as well as benefitting from it.

Given the character of the Polish energy sector, the nation's rich fossil resources, and its access to domestic geological storage formations, there are several research areas that might yield significant technological and economic benefits, including:

- Low cost post-combustion solutions optimised for Polish power plant technologies
- New coal pre-combustion technologies, such as underground coal gasification combined with CCS
- Reduction of energy consumption in CO₂ absorption processes to reduce the overall CCS energy penalty and associated additional fuel and capacity costs;
- Detailed knowledge about deep underground saline formations suitable for CO₂ storage

This R&D should be facilitated by participation in international exchanges and research programmes,²² both to foster fruitful collaborations and to educate more Polish engineers and scientists in CCS technologies.²³

Finding the necessary funds for R&D in Poland is a challenge. The scale of research needs and associated costs most probably exceeds the available state funding. Therefore much of the burden of financing CCS R&D must fall on the private sector. This,

however, entails a risk that the great potential for CCS technology in Poland may be squandered, as Polish companies' investments in R&D are traditionally very low. This paucity of investment in innovation stems largely from a dearth of state-sponsored incentives and support-mechanisms.²⁴

To drive innovation in cost-intensive energy industries and Poland's as a leader in CCS technologies, the state needs to actively support R&D programmes aimed at CCS technologies in industry and academia. Such programmes might include a National Support System for CCS technologies, a CCS R&D Fund with on the order of 100 million EUR over five years, or appointing a Vice Minister for CCS Technologies to aid the demonstration projects, assure funding, communicate with the public, and negotiate with industry.

3.2 REDUCING INDUSTRY EMISSIONS

While the majority of Polish CO₂ emissions originate from coal burning, the emissions from some CO₂-intensive industry facilities are also significant. The IEA estimates that almost half of the global emission reductions from CCS should occur in industry in order to achieve a 50% reduction in CO₂ emissions by 2050²⁵ at the lowest possible cost (IEA, 2009 and GCCSI, 2009).²⁶ UNIDO's 2010 synthesis report on CCS in industrial applications²⁷ puts forth global sectoral approaches – policies applied to particular industrial sectors globally – as a promising policy tool for reducing CO₂ emissions from industry in the short term.

In Poland, the energy-intensive manufacturing and construction industries in 2007 were responsible for 11.4% of the CO₂ emissions related to energy consumption. In addition industrial processes aside from energy consumption were responsible for 7.4% of overall Polish emissions. Adding petroleum refining to this picture, the yearly emissions from these industries amount to 65.1 million tonnes/year, or ca. 20% of total Polish CO₂ emissions (EC, 2010).²⁸

With increasing R&D investments worldwide on CCS technologies for these industries, the potential in the medium term is promising. In the immediate future, ammonia plants offer the cheapest option for CCS in Poland.

This potential for industrial CCS needs to be acknowledged in Polish CCS demonstration and deployment plans. Ammonia plants in particular should be incentivised for early CCS demonstration, and the transport and storage network developed for the power sector should also include the major industrial CO₂ emission points. The industry will benefit from these efforts to secure land rights and construct pipe lanes as well as from economies of scale.

22 e.g. the EU Framework Programmes

23 Examples of ongoing R&D projects within research programmes and international exchange are e.g. the "Sub-seabed CO₂ Storage: Impact on Marine Ecosystem E CO₂ – The Ocean tomorrow" coordinated by IFM GEOMAR and with partners from research institutions in Norway, Germany and Poland and CO₂ geological storage projects under the KIC-InnoEnergy Project (<http://brain-c-jcoal.info/ccd2010/Keynote%20address%20Szmuc.pdf>)

24 Poland, compared with major OECD countries, offers one of the lowest tax benefit per USD invested in research and development. Deloitte estimated that for the three-year period from 2006 to 2008 tax credits for research and development in Poland only benefited 128 companies as opposed to 430 in the UK. Polish entrepreneurs received tax breaks totalling 27 000 EUR, whilst companies in UK received 1 776 million EUR (New York: Deloitte, 2010).

25 Baseline year 2000

26 Technology Roadmap, International Energy Agency, 2009, http://iea.org/papers/2009/CCS_Roadmap.pdf and Global CCS Institute, WorleyParsons, Schlumberger, Electric Power Research Institute, Baker & McKenzie, Strategic Analysis of the Global Status of Carbon Capture & Storage, 2009, <http://globalccsinstitute.com/resources/publications/strategic-analysis-global-status-carbon-capture-storage>

27 For report, see http://unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Energy_Efficiency/CCS/review_%20workshop_%20report.pdf

28 European Commission: EU ENERGY IN FIGURES 2010 – CO₂ Emissions by Sector. http://ec.europa.eu/energy/publications/doc/statistics/ext_co2_emissions_by_sector.pdf

TABLE 3A MAJOR INDUSTRIAL EMISSION POINT SOURCES IN POLAND

| Plant name | Region | Industry sector | Main product | City | Latitude | Longitude | CO ₂ emission (tonnes/yr) |
|---|--------------------|---|--------------------|------------------|-----------|-----------|--------------------------------------|
| Polski Koncern Naftowy ORLEN S.A. zakład w Płocku | mazowieckie | Manufacture of refined petroleum products | Petroleum products | Płock | 52.58333 | 19.66667 | 6 160 000 |
| ArcelorMittal Poland S.A., Oddział w Dąbrowie Górniczej | śląskie | Manufacture of basic iron and steel and of ferro-alloys | Iron and steel | Dąbrowa Górnicza | 50.343379 | 19.281864 | 4 920 000 |
| ArcelorMittal Poland S.A. Oddział w Krakowie | małopolskie | Manufacture of basic iron and steel and of ferro-alloys | Iron and steel | Kraków | 50.07974 | 20.066786 | 4 210 000 |
| Górażdże Cement S.A., Cementownia Górażdże | opolskie | Manufacture of cement | Cement | Chorula | 50.533722 | 17.9775 | 2 230 000 |
| Grupa Ożarów S.A. | świętokrzyskie | Manufacture of cement | Cement | Karsy | 50.902626 | 21.680992 | 2 100 000 |
| Zakłady Azotowe "Puławy" S.A. w Puławach | lubelskie | Manufacture of fertilisers and nitrogen compounds | Fertiliser | Puławy | 51.45 | 21.96667 | 1 720 000 |
| Zakłady Chemiczne "POLICE" S.A. | zachodniopomorskie | Manufacture of fertilisers and nitrogen compounds | Fertiliser | Police | 53.575283 | 14.541092 | 1 360 000 |
| Cementownia "CHELM" S.A. | lubelskie | Manufacture of cement | Cement | Chełm | 51.140519 | 23.515742 | 1 180 000 |
| KGHM POLSKA MIĘDŹ S.A., Huta Miedzi GŁOGÓW | dolnośląskie | Copper production | Copper | Głogów | 51.678184 | 15.996804 | 1 170 000 |
| Zakłady Azotowe w Tarnowie-Mościcach S.A. | małopolskie | Manufacture of chemicals, and chemical products | Chemical products | Tarnów | 50.014675 | 20.920587 | 1 160 000 |

3.2.1 AMMONIA: THE LOWEST HANGING CCS FRUIT

Ammonia (NH₃) is produced by separating hydrogen from carbon atoms in hydrocarbons such as natural gas, a process that produces pure CO₂ as a by-product. Modern fertiliser plants – which account for more than 80% of ammonia production – generate between 1.6-3.8 tonnes of CO₂ per tonne of ammonia produced²⁹, of which around 70% comes directly from the production of hydrogen for ammonia.

Because pure CO₂ is a natural by-product of the process, CCS for ammonia production merely requires energy to compress CO₂, and the infrastructure to transport and store it. Depending on the cost of transport and storage, this could mean a cost as low as 13 EUR per tonne of CO₂ and a production cost increase of only 3-4 percent respectively (IEA, 2009).³⁰ As global fertiliser demand is expected to increase significantly in the next decades³¹, ammonia production is not only a low-hanging fruit, but also a rapidly growing one: it must be reaped.

An early application of CCS in this industry in Poland would give the country a strong position as a sustainable leader in this market.³² In Poland, there are 3 major fertiliser factories, all of which emit more than 1 Mt/year of CO₂ (see Table 3A). They are situated in the regions of Zachodnio-Pomorskie, Kujawsko-Pomorskie and Lubelskie. The facility in Zachodnio-Pomorskie (Western Pomerania) – the chemical plant in Police, just north of Szczecin – is an excellent candidate for early CCS deployment. It is located very close to potential storage sites; it is profiling its focus on sustainability³³, and it is moreover situated on a distance of approx. 40 km from the PGE coal fired plant Dolna Odra, which will require a CO₂ transport and storage infrastructure. Likewise, the Anwil SA facility in the Kujawsko-Pomorskie region not far from Torun is located at a distance of approx. 45 km from the coal-based electricity plant Cergia Torunska Energetyka and thus similarly offers opportunities for combined CO₂ transport and storage infrastructure (see Figure 3E).

3.2.2 MEDIUM AND LONG TERM INDUSTRIAL CCS

Several other energy-intensive industries have very high CO₂ concentrations in their flue gas streams, which means the cost of capture should be relatively low. Steel and cement both offer CO₂ concentrations of 20-25% (about double the concentration for coal-fired power plants) at different stages of the production process. Petrochemical and pulp and paper can have even higher concentrations, although the total CO₂ volumes are smaller. For all of these sectors, CCS is the only available option for significant emission reductions (CE Delft, 2010).³⁴

3.2.3 IRON AND STEEL

R&D on CCS in the steel industry is progressing, with the French-based project ULCOS-BF³⁵ with saline formation storage the most advanced pilot project in Europe. There is, as yet, no commercial-scale CCS project operational for any steel mill. Equipping steel mills with CCS is estimated to cost 51-57 EUR per tonne of steel produced (GCCSI estimate) and increase overall production costs by 15-22% (GCCSI, 2009).³⁶ In Poland, there are two main steel mills with a complete production cycle, IPS.S.A in Dabrowa Gornicza and IPS.S.A in Krakow, both in the south. Both are owned by ArcelorMittal, the second biggest steel producer in the world. After privatisation in 2004, the steel mills in Poland were modernised with new technologies that reduce CO₂ emissions by up to 60%. Due to these relatively recent upgrades, major new investments in these facilities cannot be expected for another 15-30 years.

Even though no immediate CCS projects in the steel industry are expected in Poland, future CCS application in the industry have to be taken into account in infrastructure planning. In the long term, these facilities present excellent opportunities for CCS: the two ArcelorMittal steel mills are by far the largest industrial CO₂ emission points in Poland, and are located close to power plants that will require CO₂ transport and storage infrastructure. As the EUA price rises, CCS will be the only technology available to keep the sector alive, in Poland and elsewhere.

3.2.4 CEMENT

CO₂ concentrations in cement production are similar to those in steel production, which means the cost per tonne of CO₂ captured and stored should be comparable. This price is estimated to 22-23 EUR per tonne of produced cement. However, the lower value per ton of cement will trigger a higher relative cost increase for CCS in cement production, in the range 36-48 percent (GCCSI, 2009).³⁷ On the other hand, the potential for utilizing excess process heat will lower the capture costs in this industry.³⁸

As in the steel industry, many plants in the commercial cement sector were modernised after 2000, moving the Polish cement industry to the top of the European market. Current production capacity exceeds current domestic demand by a factor of two³⁹, indicating that even if demand grows rapidly in the coming years, further investments are unlikely to occur in the next 10-15 years. Looking further into the future, CCS deployment on the cement industry will be facilitated by the fact that most Polish cement plants are located in the south, where there will be ample coal-based CO₂ storage and transport infrastructure to support CCS in the industry.

29 International Fertilizer Industry Association (IFA): Energy Efficiency and CO₂ Emissions in Ammonia Production [2009]. <http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Publication-database.html/Energy-Efficiency-and-CO2-Emissions-in-Ammonia-Production.html>

30 International Energy Agency, Technology Roadmap, 2009, http://iea.org/papers/2009/CCS_Roadmap.pdf

31 IFA: Fertilizer Outlook 2010 - 2014.

32 There is currently only one proposed CCS project for ammonia production globally, namely the Coffeyville Resources facility in Kansas according to a sectoral report from UNIDO: CCS Roadmap for Industry: High-purity CO₂ sources. http://unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Energy_Efficiency/CCS/High%20Purity_FINAL%20DRAFT.pdf

33 Zakłady Chemiczne "POLICE" SA. <http://zchpolice.com/en/firma/ochrona-srodowiska/srodowisko>

34 CE Delft: Technological developments in Europe – A long-term view of CO₂ efficient manufacturing in the European region [2010]. http://cedelft.eu/?go=home.downloadPub&id=1098&file=7207_finalreportMaKEV.pdf

35 A project under the EU-funded ULCOS programme: <http://ulcos.org/en/press.php>

36 Global CCS Institute, WorleyParsons, Schlumberger, Electric Power Research Institute, Baker & McKenzie, Strategic Analysis of the Global Status of Carbon Capture & Storage, 2009, <http://globalccsinstitute.com/resources/publications/strategic-analysis-global-status-carbon-capture-storage>

37 Global CCS Institute (GCCSI): Strategic Analysis of the Global Status of Carbon Capture and Storage [2009]. http://iea.org/papers/2009/CCS_Roadmap.pdf

38 The ECRA (European cement research association) is participating in a CO₂ capture pilot test facility at Norcem's facility in Brevik, Norway, which are looking into the potential of utilizing excess heat in CO₂ capture from a cement plant.

39 Polish cement industry webpage, http://polskicement.pl/3/3/artykuly/10_66.pdf

FIGURE 3B MAJOR INDUSTRIAL EMISSION POINT SOURCES IN POLAND

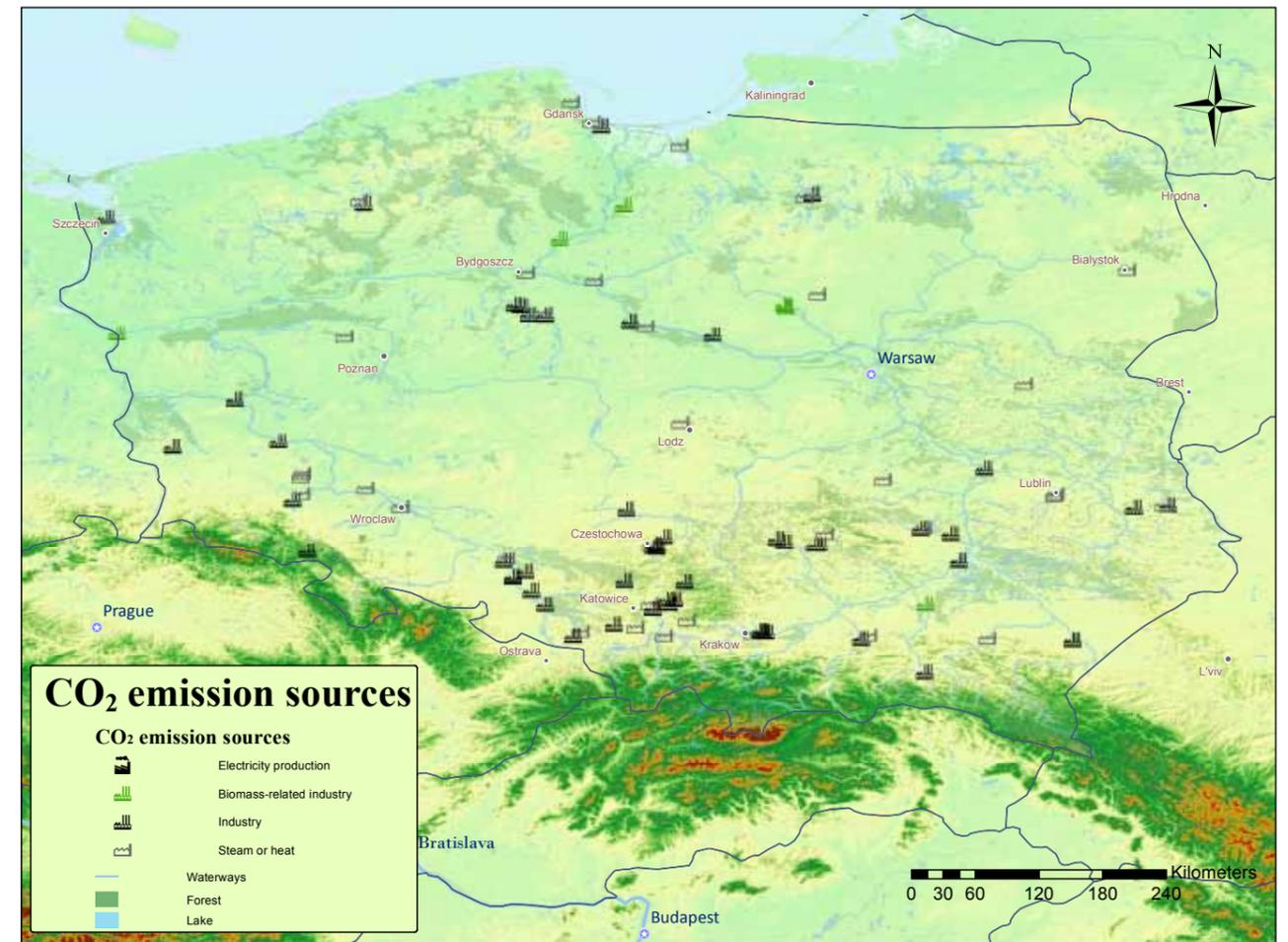


FIGURE 3Ca GEOLOGICAL STORAGE CAPACITY IN POLAND

This map was produced using data from the Polish National Programme “Assessment of formations and structures suitable for CO₂ geological storage including monitoring plans”, the 2008 Storage Atlas and Tarkowski (2008)⁴³. For a more detailed map showing potential storage structures and e.g. shale gas licencing areas contact Adam Wójcicki in PGI-NRI.

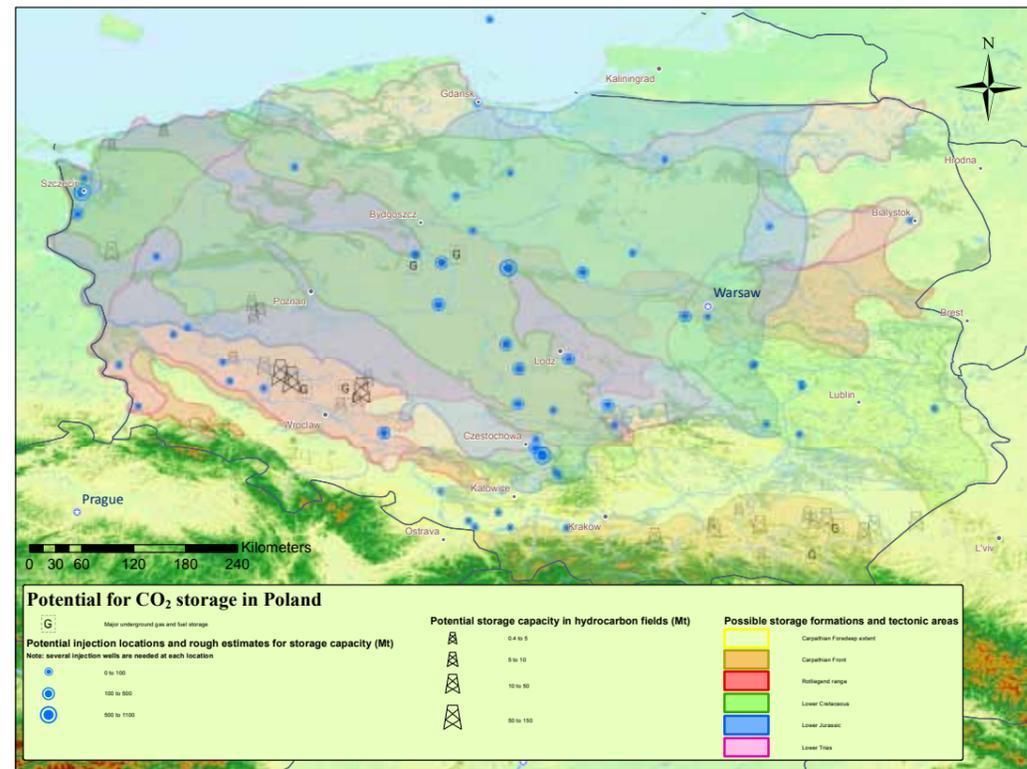
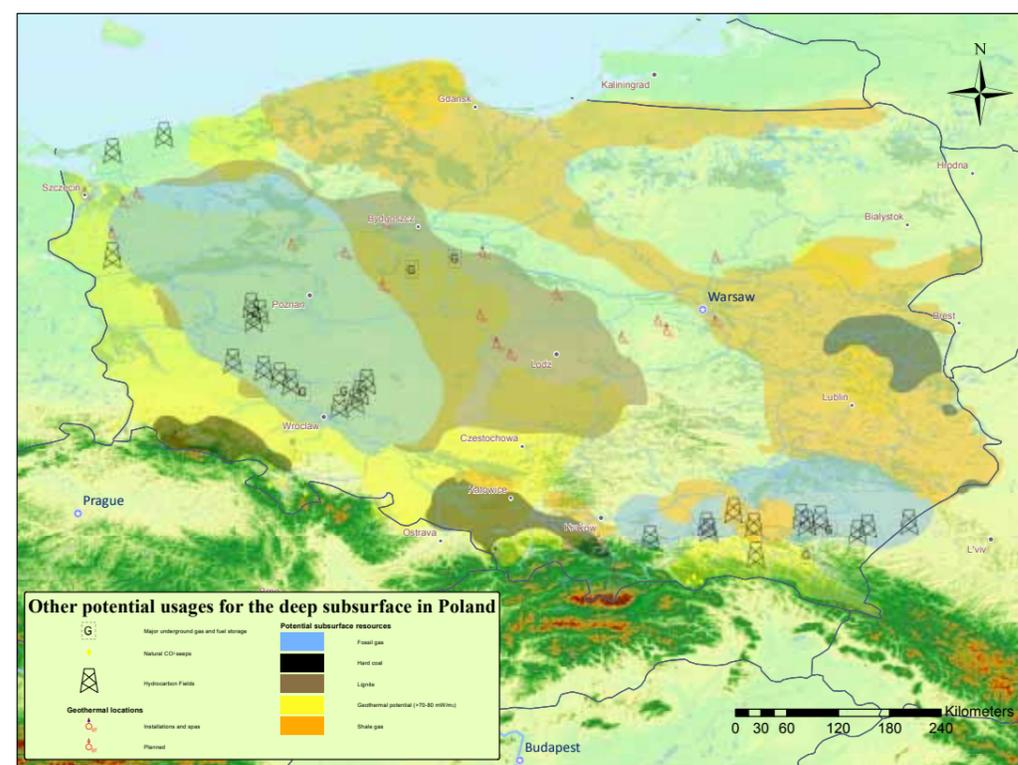


FIGURE 3Cb POTENTIAL SUBSURFACE RESOURCES IN POLAND.

Data are modified from figures published by the Polish Geological Institute - National Research Institute.



3.2.5 PETROLEUM REFINERIES

There is a high level of variability in unit types and process complexity in this sector, as many refineries have multiple, relatively small CO₂ sources with different specifications. Nonetheless, the high purity of some of those sources could offer opportunities for low cost demonstration of CCS, if located close to a storage site. The biggest Polish petroleum refinery – Orlen in Plock – offers a good CCS opportunity due to its central location in Poland near many power sector emitters and potential geological storage sites. The LOTOS petroleum refinery on the Baltic coast near Gdansk in the Pomorskie Region, with CO₂ emissions of more than 1 Mt/year, could become a good candidate for CCS if CO₂ transport and storage infrastructure is developed in this area, most likely offshore.

3.2.6 PULP AND PAPER PRODUCTION – A POSSIBLE OPPORTUNITY FOR SUSTAINABLE BIOFUELS PRODUCTION AND BIO-CCS

Producing one tonne of pulp results in about seven tonnes of so-called ‘black liquor’. This is usually burnt in a black liquor recovery boiler to generate much of the energy needed by the production facility. However, black liquor could instead be used to produce higher-value biofuels through gasification⁴⁰. A gasifier for methanol production requires an investment twice that of the recovery boiler, appr. 345 million EUR instead of 171 million⁴¹, but the resulting biofuels will be of higher value than the steam produced from a boiler. Converting the black liquor into bio-methanol releases large amounts of CO₂, which can be captured for only 10-20 EUR/tonne (CE Delft, 2010).⁴² Especially in cases in which the black liquor recovery boiler requires upgrading, replacing it with a CCS-equipped gasifier system becomes an excellent option.

At the present time, even with the recent increase in the co-firing of biomass with coal for power generation, the dominant source of biomass-related CO₂ emissions in Poland remains pulp and paper producers. The main pulp and paper emissions point source is the International Paper facility at Kwidzyn in the Pomorskie region, south of Gdansk, with emissions in the range of 430,000 tonnes CO₂/year. Around 50 km to the south-west, the Mondi Swiecie facility likewise has a black liquor boiler, a coordinated effort is thus conceivable. On the medium to long term, these facilities’ proximity to potential offshore storage sites under the Baltic Sea bed could make them highly interesting sites for bio-CCS deployment.

3.3 STORAGE

Poland has enormous – but still largely uncharacterized – onshore storage capacity in deep saline formations, and some additional offshore storage capacity. The potential for future geothermal energy utilisation has become part of the Polish energy debate, which presents potential competition of industrial use of the subsurface more than 800 m underground. Given the demand for storage space, its potential conflict with geothermal, and the

preliminary state of knowledge regarding its extent and distribution, there is a great need for expanded research to characterize the storage potential in Poland. This need is partly covered by the ongoing National Programme for Identification of Formations and Structures for Safe CO₂ Geological Storage⁴³ and by the development of monitoring programmes for some select potential storage sites, but more research is urgently needed. Polish experience in CCS originates from CO₂ and H₂S storage in a gas field related to a small scale industrial project in Borzeccin since 1995. In addition, the country has stored CO₂, H₂S and CH₄ in other oil and gas fields for more than 10 years (e.g. Kamień Pomorski) (Jedrysek 2007).

3.3.1 POTENTIAL DOMESTIC CO₂ STORAGE SITES

CO₂ can be stored in micropores in deeply buried sandstones and carbonates in approximately the same way that oil and gas has been stored in the deep subsurface for millions of years. According to a report carried out under the Geocapacity study⁴⁴ there are a number of storage formations and prospective sites for CO₂ underground storage within Poland. The study gives a wide range of estimates for the potential onshore storage capacity in saline formations. The midrange estimate included in the European database gives a storage capacity of 3522 million tonnes (Mt) in Mesozoic formations in mapped structures, while the conservative estimate place the value at 1761 Mt. The mid-range estimate for regional storage capacity for in formations in and outside structures are set to about 80 Gt (gigatonne). This is not, by any means, a set number. Injectivity and pressure-buildup will affect the storage capacity, and in order to achieve the desired storage capacity pressure distribution through water production, alternating injection points, stimulation and extensive well grids might be needed.

Another study is the “Atlas of the possibilities of CO₂ geological sequestration in Poland”⁴⁵ elaborated by Polish partners of EU Geo-Capacity project in 2008. It provided the following storage capacity estimations (mid-range) for particular structures: Saline formations 8299 Mt, Hydrocarbon fields 1021 Mt and CBM 295 Mt. This study addresses approximately the same number of subsurface structures as a 2008 study by Tarkowski.⁴⁶ The Tarkowski study looked at 37 saline formation storage locations⁴⁷ in the industry-intensive central and NW regions of the Polish Lowlands⁴⁸. It presents storage capacity estimates based on borehole data, and reports a total volumetric storage capacity of 17.5 Gt just for structures at the studied locations.

The true value of the storage capacity will determine how long Poland has available domestic CO₂ storage space. Using values for annual CO₂ storage needs calculated in Chapter 4, these estimates place the final year for fully domestic CO₂ storage anywhere from

43 The programme covers the whole of Poland and the Polish economic zone in the Baltic Sea. The study is centred around eight regions selected on the basis of the national economics and existing work with regards to potential storage sites. Five potential storage sites will be studied in detail, - three in saline aquifers (two of them associated with planned CO₂ emission reductions under the EU Flagship Programme under PGE Belchatow and PKE/ZAK Kedzierzyn) and one in a producing oil field and the last one in relation with enhanced coal methane extraction. Monitoring programmes will be developed as part of the programme.

44 EU 6th framework programme. Project no. SES4-518318. The website with results from the project (in English) is found under: <http://geocapacity.eu>

45 The Atlas was ordered by the Ministry of Environment and results from the project can be found on the website (in Polish): <http://skladowanie.pgi.gov.pl/co2atlas>

46 R. Tarkowski, “CO₂ storage capacity of geological structures located within Polish Lowlands’ Mesozoic formations; Gospodarka Surowcami Mineralnymi”, 24/1, p.101-111 (2008)

47 Compared to the GeoCapacity study Tarkowski (2008) included more (but roughly the same) structures.

48 Several of the emission sources are within a radius of <50 km to 100 km from potential injection sites.

2046 (for 1761 Mt available storage) to after 2110 (more than 17 500 Mt available storage).⁴⁹ The large range in capacity estimates underlines the great need for further studies.

The candidate geologic formations where CO₂ could be stored are mostly situated in the Polish Lowlands, in northern and central Poland (see Figure 3D). In particular, Mesozoic rocks⁵⁰ have the properties required for storing large volumes of CO₂: large thicknesses, thick regional seals, good porosity, good reservoir properties and fewer fractures and fissures. CO₂ can also be stored in depleted hydrocarbon fields. In Poland, these are located onshore in the south-eastern and western parts of the country, with 14 medium-to-small scale fields in the south-east and 15 in the west potentially available for CO₂ storage.⁵¹ Several of these are in close proximity to large CO₂ emission sources in central and northern Poland. In the southern and western parts of Poland, early captured CO₂ emissions could be stored in depleted oil and gas fields, and later emissions transported to larger CO₂ storage locations further north.

Offshore storage in the Baltic could be considered for CO₂ emissions from the northern parts of the country. Poland has one medium-sized oil field in the Polish economic zone of the Baltic sea, and Grupa Lotos has indicated it will pursue future hydrocarbon exploration in this region. Captured CO₂ emissions from the north could also be shipped or piped abroad, e.g. to suitable offshore areas in the Baltic or North Seas⁵². The Geocapacity study also assessed storage capacities in coal fields in the Silesian Coal Basin. Other basins were not studied either because they were unsuitable for storage or insufficient data was available to characterise them. The preliminary calculations of storage capacity was +/- 400 Mt with a relatively high associated uncertainty. The related topic of potential CO₂ storage in coal seams is covered in section 3.1.3 of this report.

Due to the vast storage possibilities in Poland, conflicts with other subsurface usages like shale gas production, drinking water reserves, oil and gas production, UCG, CBM, geothermal energy generation etc. are not expected to present significant barriers.

The first NER300 call for proposals (see section 3.0), launched 9 November 2010, requires selected projects to have a good plan for storing captured CO₂ within four years of grants being awarded. Such awards are expected in 2012. In order to meet this requirement and those in the EU CO₂ Storage Directive (2009/31/EC)⁵³ set out for the properties of the storage site, studies⁵⁴ must be carried out prior to beginning injection. This means studies must be started immediately if Polish projects are to qualify for NER300 support.

From an economic perspective, it might become interesting for Poland to use its large storage capacity to store additional CO₂ from other countries. A stronger focus on national storage R&D would strengthen the competitive advantage of Polish geological R&D institutions with regards to utilisation of the deep sub-surface.

3.3.2 CO₂ INFRASTRUCTURE

Land available for pipelines to link emission points to storage sites with CO₂ pipelines will be a scarce resource, so careful and very early planning will be necessary to ensure their effective development. Doing so will require careful site capacity characterisation, so that concentrated emissions sources can be linked to adequately sized storage sites in the safest and most economic manner. Figure 3E presents a map showing what such a CO₂ infrastructure network might look like, showing transport corridors, possible CO₂ injection sites and outlines of possible storage formation.

The majority of the CO₂ could be transported by 32" pipelines with a capacity of >20 Mt/y over distances shorter than 180 km.⁵⁵ The Silesia region is an excellent candidate for the first local pipeline network, because it has the highest concentration of CO₂ emission in the country and is close to potential storage sites.

In order to meet the NER300 requirement that storage begin by 2016 to receive full support under the first call for proposals, the construction of adequate transport infrastructure must be an immediate priority.

3.3.3 AN EARLY OPPORTUNITY FOR CO₂ STORAGE

Although insufficiently explored in Poland so far, using anthropogenic CO₂ as a resource to enhance petroleum production provides an opportunity to deploy CCS in a faster and more economical way. In addition, the use of captured CO₂ for Enhanced Oil Recovery (EOR)⁵⁶ has the potential to accelerate the full deployment of CCS.

Europe is the world region with the most comprehensive pricing of CO₂ emissions. Yet it has very little CO₂-EOR. CO₂ utilisation for EOR makes CCS projects profitable, or, for low oil prices, at least less costly. The injected CO₂ can be permanently stored if suitable CO₂ pricing conditions or stricter CO₂ emissions regulations make it worthwhile to do so. Studies estimate that an incremental oil recovery of 3-18.9% is achievable using CO₂ for EOR, depending on lithologies and heterogeneity of the producing reservoir (Ferguson, 2009; Aam, 2010; Richards, 2011).

The 2009 Geocapacity study states that CO₂ for EOR at Barnowko-Mostno-Buszewo (BMB)⁵⁷, the largest crude oil deposit in Poland, is of likely large potential (Geocapacity, 2009⁵⁸). The Polish oil-company LOTOS presented possibilities for CO₂-EOR and CCS in their Baltic offshore licences in the Ministry of Economy (Warsaw) at a Polish-Norwegian CCS workshop in 2010⁵⁹. The company presented plans to transport CO₂ streams from hydrogen production at the LOTOS refinery in Gdansk (450 000 tons

55 See also chapter 4.2.2 for more details.

56 Enhanced Oil Recovery is a generic term describing techniques for increasing the amount of crude oil or gas that can be extracted from a mature field. Injection of CO₂ in mature fields can increase the output of oil and gas.

57 Primary oil and gas reserves in place where in 1999 calculated to be 498.2 million barrels of oil and condensate and 1038.3 billion cubic feet of gas, with recoverable resources of 76.6 million barrels of oil and 349.6 billion cubic feet of gas (Górski et al. 1999). The recovery factors at this time was 15.7% for oil and 33.5% for gas. See also Maciej Górski, Zofia Wojtkowiak and Stanisław Radecki, "Barnówko-Mostno-Buszewo (BMB): the largest crude oil deposit in Poland", 1999, Petroleum Geoscience, Vol. 5 pp.5-15

58 The Geocapacity study estimates that one can store more than 50 Mt CO₂ in the Przemysł gas field in the SE of the country. Other >50 Mt storage capacity fields are Żuchlow, Zaleczerwierz and Bogdaj-Uciechow in the western part of the country.

59 The presentation can be found under http://mg.gov.pl/files/upload/8140/Sekwestracja_warszawa_wersja%20ang.pdf

49 R. Tarkowski, "CO₂ storage capacity of geological structures located within Polish Lowlands' Mesozoic formations; Gospodarka Surowcami Mineralnymi", 24/1, p.101-111 (2008)

50 Solidified sediments deposited 250 to 65 million years ago

51 The Geocapacity study estimates that one can store more than 50 Mt CO₂ in the Przemysł gas field in the SE of the country. Other >50 Mt storage capacity fields are Żuchlow, Zaleczerwierz and Bogdaj-Uciechow in the western part of the country.

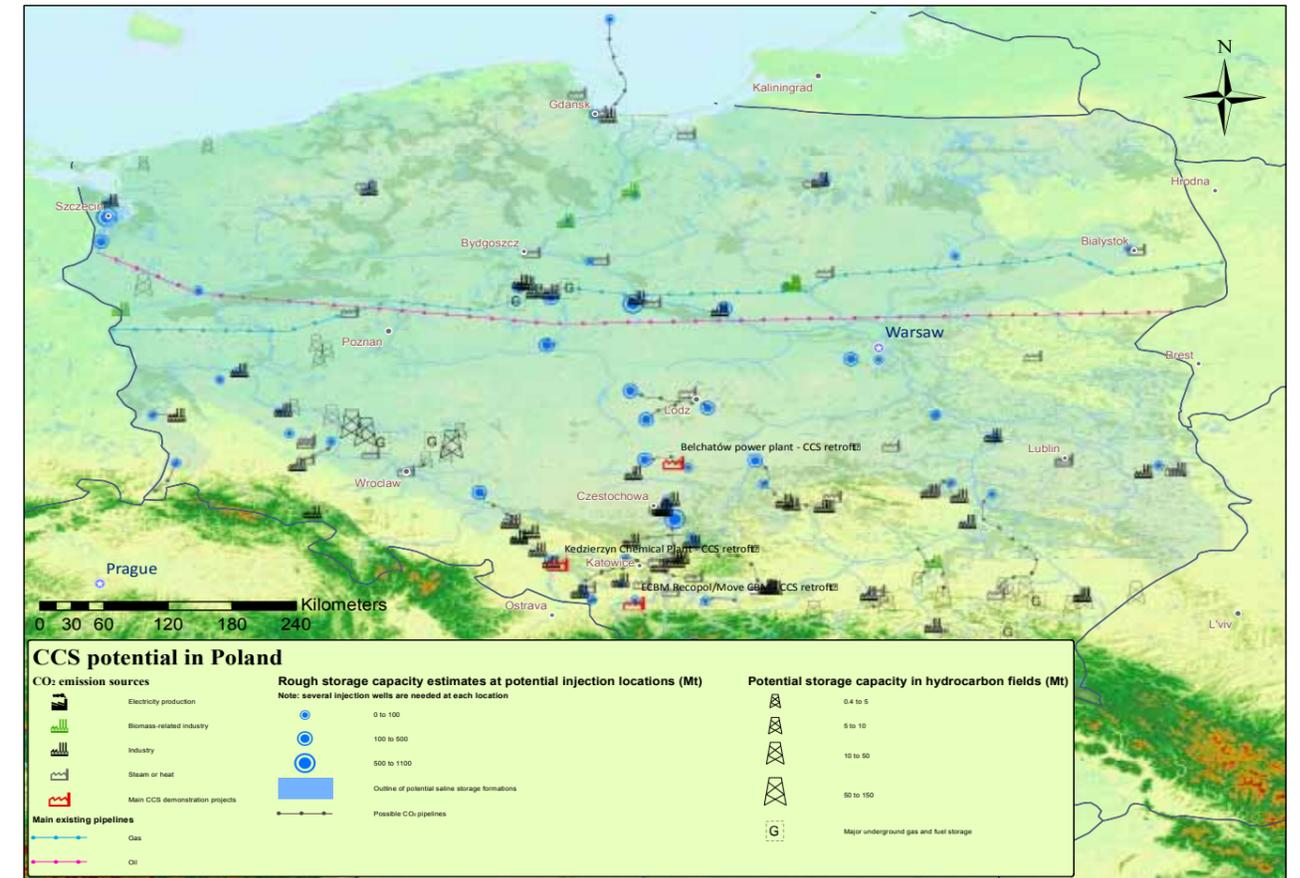
52 Both being regions where the Polish petroleum concern Grupa Lotos operates.

53 Commission of the European Communities, "Proposal for a directive of the European parliament and of the Council on the geological storage of carbon dioxide" and amending Council Directives 85/337/EEC, 96/61/EC, Directives 2000/60/EC, 2001/80/EC, 2006/12/EC, Regulation (EC) No1013/2006 and drafts for guidance documents to the CO₂ geological storage directive, June 2010, http://ec.europa.eu/environment/climat/ccs/eccp1_en.htm

54 e.g. seismic surveying, test drilling and studies of injectivity, storage capacity, overlying sealing rocks etc.

FIGURE 3D POSSIBLE FUTURE INFRASTRUCTURE FOR CO₂ STORAGE AND TRANSPORT IN POLAND

The suggested pipeline gates and storage locations are artificial and only included to illustrate one of several complete CCS value-chain solutions.



of CO₂ per year) for a little over 100 km out to the B3⁶⁰ and B8 oil fields.⁶¹

In addition, there are a few small scale CO₂ - EOR projects at e.g. Kamień Pomorski, B3 and "Integration of CO₂ sequestration with EOR- CO₂ technology in the Polish offshore fields".

The proximity of hydrocarbon fields in the western and south-eastern part of Poland to large CO₂ emitters like power plants and industrial facilities might be ideal for enhanced oil and gas production with CO₂ injection. Incremental oil can be recovered whilst storing >30% of the injected CO₂. It should be noted that if the right incentives to store CO₂ are in place 100% of the injected

CO₂ could be stored in EOR operations. In order to pursue this opportunity⁶² the use of CO₂ incentives aimed at CCS is crucial. ETS is leading the way, but provides insufficient investment security. A range of tax incentives for CO₂ - EOR could be considered⁶³, but more favourable - Poland could consider to require CO₂ for EOR and to stimulate Third Party Access through injunction and prohibition when assessing the oil or gas field operator's Plan of Development and Operation (PDO).

In order to determine the true potential of CO₂ for EOR in Poland, more assessment is required.

60 "Analysis of geological and technological study for B3 oil field" by AGH and LOTOS.

61 As part of the KIC - InnoEnergy Project European Institute of Innovation and Technology - EIT. A 1st stage pilot project with partners from AGH, SUT, IchPW, GIG, Tauron, ZAK Kedzierzyn, PGNiG, LOTOS. Some information can be found in this presentation by AGH at the JCC Day September 2010: <http://brain-c-jcoal.info/ccd2010/Keynote%20address%20Szmuc.pdf>

62 The Polish crude oil production has increased steadily from 2 000 barrels per day in 1990 to 12 400 barrels per day in 2009, with a peak of 16 700 barrels per day in 2004. The total oil production (NGL, condensate, crude oil etc.) reached 34 000 barrels per day and natural gas production 207 billion cubic feet in 2009. In order to keep the production, rates efforts to maintain production in terms of EOR should be taken.

63 Tax exemption, measures on depreciation time, tax credit etc.

STORAGE - CONCLUSIONS AND RECOMMENDATIONS: R&D

The Polish R&D sector should focus on the development of technologies for implementing and monitoring underground storage in deep saline formations, as developing the tools to utilize this plentiful and valuable national resource can provide Polish geological R&D institutions with a competitive advantage.

Transport

Due to the geographical distribution of potential storage locations and large emission points, it may be feasible to establish local pipeline networks without interconnections. A good candidate region for the first such local pipeline network is Silesia.

Site characterisation

In order to optimise the transport network, further site investigation should be commenced as early as possible. The National Programme could be the first step.

Timeline

Construction of the transport network should begin as soon as the public communication process for the project is complete, and since navigating the complicated permission process in Poland may take more than five years.

3.4 LEGAL ASPECTS

Establishing a robust legal framework for CO₂ 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 that need by adopting Directive 2009/31/EC on the geological storage of carbon dioxide, which must be transposed by all Member States by June 2011. 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 may stay close to the text of the directive or go beyond and provide for stricter regulation. The Directive leaves to Member States to determine whether and where CCS will take place on their territory.

The Polish Ministry of Environment (MoE) is responsible for the coordination of the legislation for CCS. The legislative process with public consultation was initiated in November 2009 and resulted in a bill proposal submitted by the MoE to the Council of Ministers on 25 November 2010. Final adoption is expected to happen in June 2011, however, there are doubts about such a tight schedule at the moment.⁶⁴ It is expected that the National Geological Institute will be the competent authority to oversee CO₂ storage regulation and enforcement.

The MoE proposed that Polish legislation regarding CCS and geological storage be limited solely to supporting and regulating demonstration projects. Though some stakeholders in the

consultation process were in favour of dedicated CCS legislation due to the complexity of the subject, the MoE opted to amend existing legislation. The bill primarily amends the Act on Geological and Mining Law, which is to be the key regulation covering CCS activities. However, the bill also introduces a number of relevant amendments to other regulations, namely: the Act on Freedom of Economic Activity; the Environmental Law; the Act on Access to Information on the Environment and its Protection, Society's Participation in the Protection of the Environment and Environmental Impact Assessment; Construction Law; the Land Use Act; and the Energy Law, which will be amended to allow a CO₂ transmission network and to design an entity⁶⁵ to act as the CO₂ transport network operator. As the demonstration phase draws to a close in 2018, the technical, legal, and safety lessons of that phase should be assessed and the existing regulatory framework revised. At that time, a legal act dedicated solely to CCS will likely be appropriate. It is advisable that such an act should be ready for the early commercial stage of CCS deployment around 2020.

3.5 PUBLIC PARTICIPATION

Most CO₂ in Poland will be stored underground onshore in saline or hydrocarbon formations. Past experience around the world suggests that people living near CO₂ storage sites may object to CO₂ storage close to their homes and livelihoods. Local people have to be involved at the very earliest stages of planning while they can still influence siting.

CCS technology is often perceived as suspicious simply because it is unknown and appears complex at first sight. To avoid this suspicion, the information campaign must cover all aspects of the technology.

There are several examples such as that of Barendrecht in the Netherlands, Schleswig-Holstein and Schwarze Pumpe in Germany that have shown how local opposition to CO₂ storage may significantly delay projects. Conversely, successful CCS projects such as Lacq in France, Otway in Australia or Ivanić in Croatia have shown that true dialogue is possible and key to projects' success.

In general, public awareness and support for CCS will improve if the following steps are taken:

- the investor begins a sincere dialogue with the local communities long before an investment decision is made, with the intention of taking their opinion into account when deciding on which site to put forward in permit applications
- the government, environmental NGOs and independent experts are involved in the dialogue
- information material in Polish is provided to citizens living in proximity of the capture, transport and storage area
- CCS is put into the context of the climate and energy challenge
- local communities should profit from storage, e.g. as the CCS amendments to the Geological and Mining Law suggest to provide the municipality with a special tax of app. 0.50 EUR per tonne of CO₂ stored.⁶⁶

⁶⁴ January 2011.

⁶⁵ There is up to now no indication as to how will the Polish government treat this issue. From current experience on similar issues, it is advisable the government sets up a private company to operate this network.

⁶⁶ With app. the same amount being taxed to the national budget.

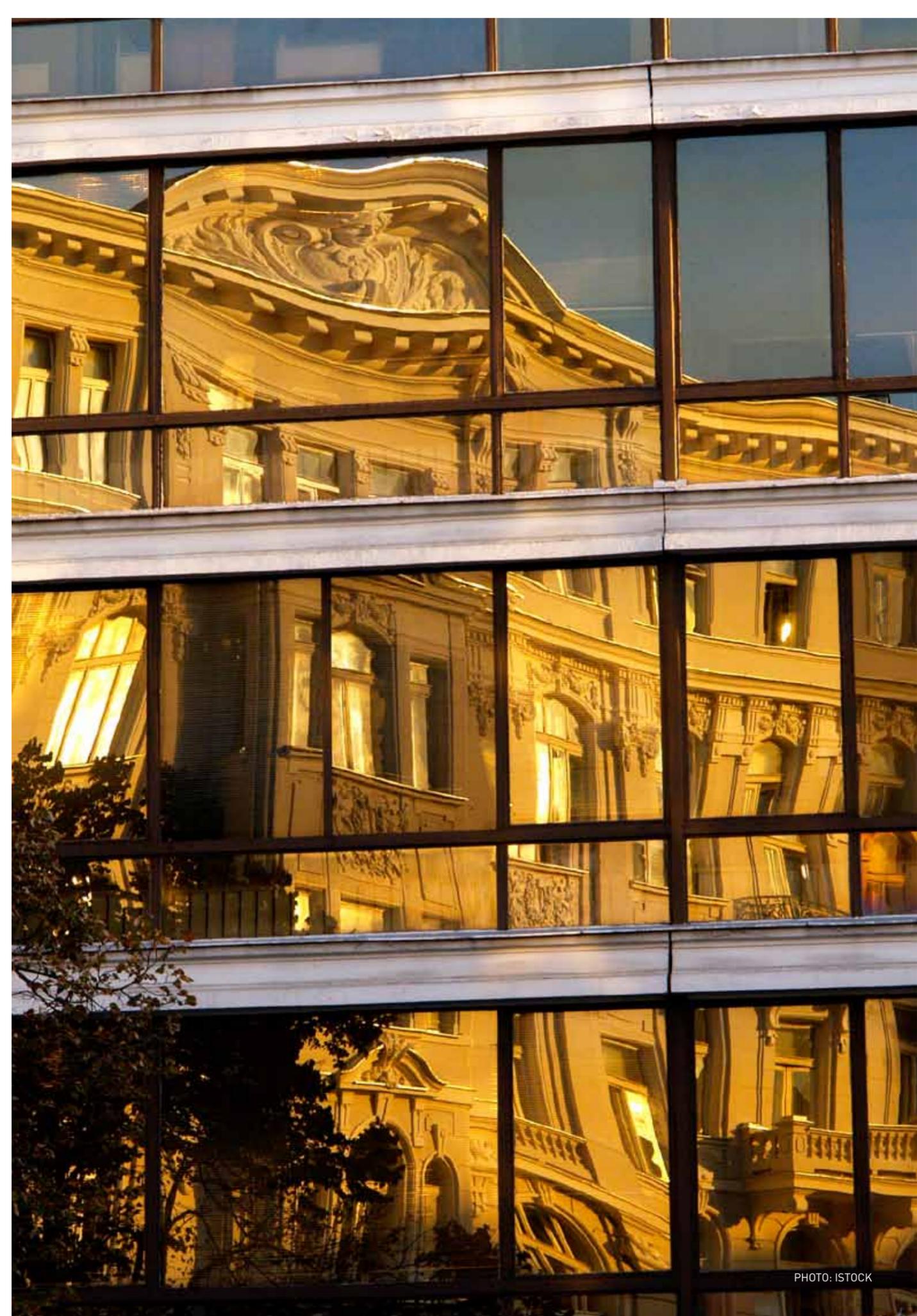


PHOTO: ISTOCK

4.0

PATHS TO A LOW-CARBON POLISH POWER SECTOR

↳ Once Poland has ensured that it can deploy CCS should environmental policies make it necessary to do so, the next question will be: when and how to deploy CCS? Large scale deployment will require a national plan to support widespread investment in CO₂ capture, transport, and storage, built upon the technical, legal, and financial learning obtained through demonstration projects. That plan must be shaped by an understanding of the emission-reduction potential of, necessary timelines for, and potential cost impacts of widespread CCS application in Poland.

To that end, this chapter presents a CCS deployment scenario for the Polish power sector, responsible for more than 44% of national GHG emissions. The scenario is designed as a tool to help answer the questions of how and when to deploy CCS, and as a guidepost for a national CCS deployment plan. It is applied to three possible development trajectories for the power sector, designed between them to capture the range of possible future energy mix and demand paths, introduced in Chapter 2, that Poland may take in the coming years.

The scope of this roadmap is limited to plotting a realistic path for CCS deployment in Poland to affordably comply with EU law. It does not address in detail other climate change mitigation options, such as renewable energy deployment, energy efficiency measures, etc. Calculations involving costs therefore include only those directly related to GHG emissions and CCS: the cost of GHG EUAs under the ETS, and the additional capital, fuel, transport, and storage costs attributable to CCS.

All modelling of the development of the power sector and the impacts of CCS deployment was carried out using the Long-Range Energy Alternatives Planning software (LEAP).

4.1 MODELLING THE FUTURE OF THE POLISH POWER SECTOR

↳ The Polish government forecasts that electricity demand will grow at a rate of about 1.8% annually over the next 20 years, indicating a sharp increase in demand over time. This rapidly growing demand combined with the nation's aged power generation fleet indicates that a great deal of new capacity (about 1GW of new generating capacity per year) will need to be built over the next decades. Though many proposals have been published over the last two decades for the construction of this new capacity, almost no definite plans have been publically announced, making the development of the sector in coming years difficult to predict. The government's national energy policy foresees this new capacity coming primarily in the form of new lignite and hard coal facilities, complemented with some natural gas plants, possibly some share of nuclear and an increasing share of wind power towards 2030. However, as discussed in Section 2.2, recent developments in Poland suggest that power sector investors may favour a larger share of natural gas in the generation mix, particularly if gas prices remain low and short-term EU climate and energy policy incentivises less carbon-intensive facilities.

Moreover, Poland may have significant incentives to increase energy efficiency over the next years, leading to much slower growth of electricity demand. Already Poland's energy costs are

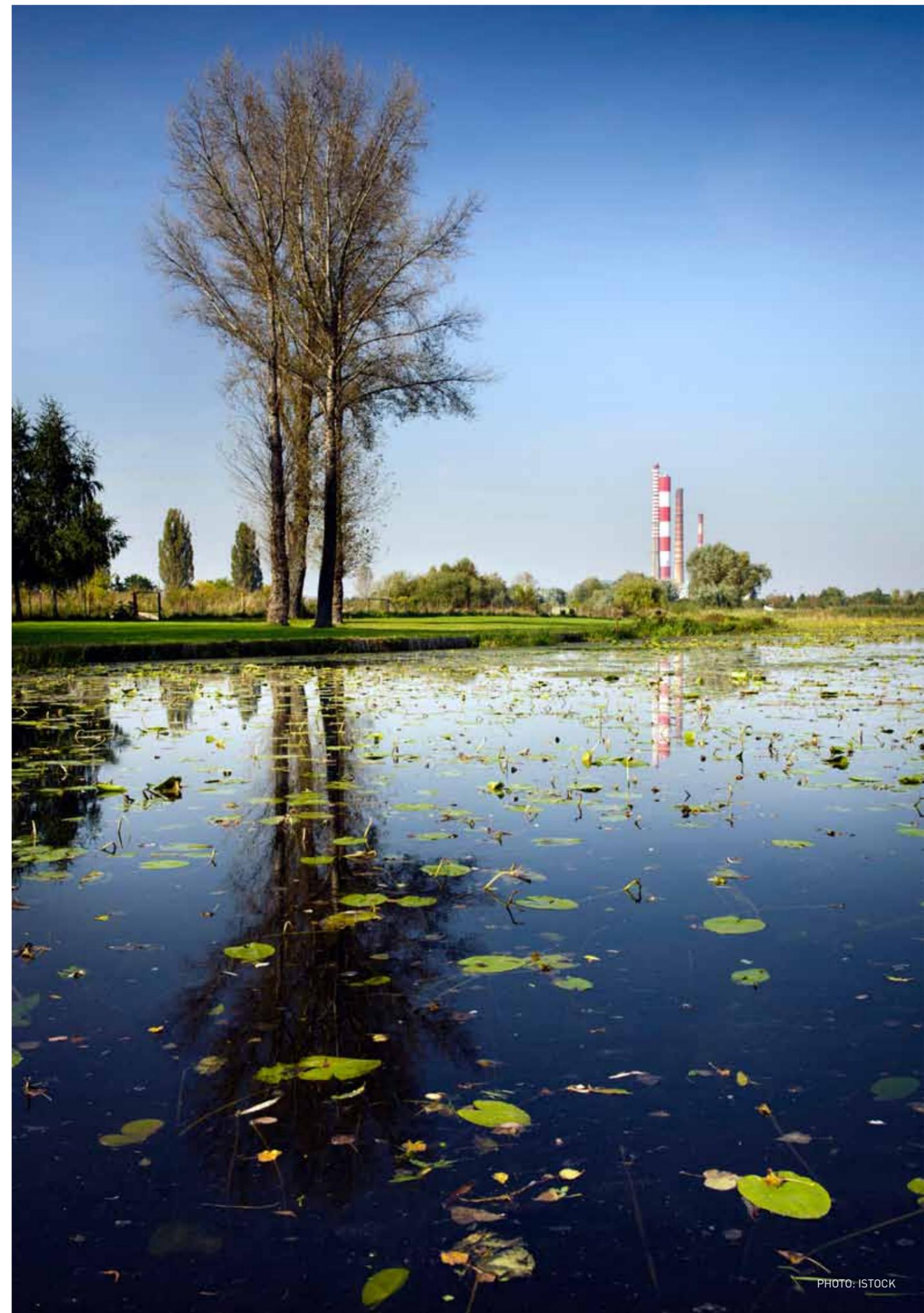




PHOTO: ISTOCK

among the highest in Europe, as compared to household income levels, and this price pressure, if combined with a government policy promoting efficiency measures, might significantly decrease future demand. To account for these uncertainties, three energy demand/mix trajectories are modelled:

- **National Energy Policy (PEP):** Follows the government predictions contained in the 2009 Polish Energy Policy until 2030,⁶⁷ with annual electricity demand growth of close to 2% and an energy mix that continues to depend primarily on coal- and lignite-fired generation. Following the PEP, even by 2030 natural gas generation accounts for less than 10% of the nation's electricity supply, barely up from its approximate 3% share in 2010. The first nuclear power plant becomes operational in 2020, when it produces about 7% of the nation's electricity, ramping up to 18% by 2030. Renewables grow to account for more than 13% of electricity generation by 2020, in line with binding national legislation which requires that 12.9% of electricity come from renewable sources by 2017. Their share remains steady at about 15% after 2020, reflecting the PEP's prediction of very little growth in renewables capacity after that year, and in line with the assumptions of the reference scenario in Greenpeace Polska's 2008 Energy Revolutions report.⁶⁸
- **Gas Expansion (GAS):** Assumes the same growth in electricity demand as in the PEP trajectory, but assumes a greater representation of gas-fired generation in the energy mix, as suggested by recently increased investments in gas CHP and

as would be supported by the discovery of significant domestic shale gas resources. Though coal and lignite continue to play a dominant role, natural gas is assumed to play a larger part, providing more than 15% of Poland's electricity in 2020 and over 20% after 2030. Nuclear and renewables capacity remains the same as in the PEP trajectory, with all additional gas capacity replacing coal capacity.

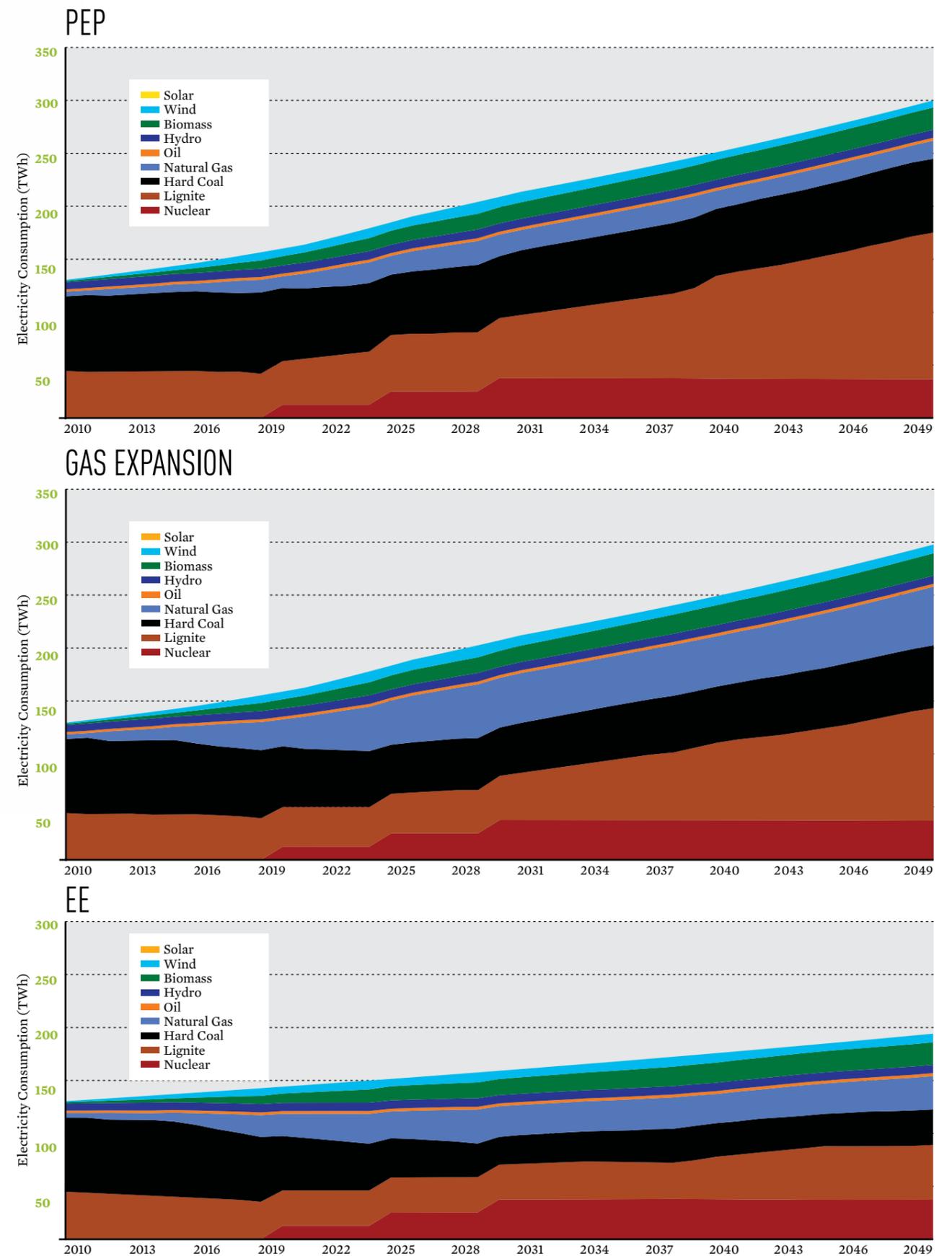
- **Energy Efficiency (EE):** Assumes a significantly slower 1% annual growth rate for electricity demand, due to the adoption of significant energy efficiency measures in Poland. It represents a minimum emission trajectory within the context of the current framework of the power sector, reducing CO₂ emissions via both fuel switching and the adoption of efficiency measures. Renewables and nuclear capacity remain the same as in the other trajectories. Total fossil capacity decreases to reflect the decreased demand, and the fossil energy mix is the same as in the Gas Expansion trajectory.

In all trajectories, electricity demand, capacity, and utilization development is projected from 2030 to 2050 according to the trends of 2010-2030 period. Though capacities of lignite, hard coal, natural gas, and other energy sources grow at proportional rates after 2030, the increasing nuclear baseload capacity after 2020 relegates some hard coal facilities from baseload to intermediate load generation, such that the share of electricity produced from hard coal becomes less in later years. Figure 4A shows the energy mix and demand profile through 2050 for each trajectory.

⁶⁷ Ministry of Economy 2009, Polish Energy Policy until 2030, MoE, Warsaw
⁶⁸ Greenpeace Polska. [R]ewolucja energetyczna dla Polski; Scenariusz zaopatrzenia Polski w czyste nośniki energii w perspektywie długookresowej, October 2008. <http://greenpeace.org/poland/press-centre/dokumenty-i-raporty/rewolucja-energetyczna-polska>

FIGURE 4A ELECTRICITY CONSUMPTION BY FUEL IN THE PEP, GAS EXPANSION, AND EE TRAJECTORIES

Three possible futures for the Polish energy sector: electricity consumption by fuel in the PEP, Gas Expansion, and EE trajectories



4.1.1 BUILDING POWER SECTOR TRAJECTORIES

For each energy mix trajectory – PEP, Gas Expansion, and Energy Efficiency – we construct detailed models of the power generation fleet, beginning with the existing generating stock in Poland – with characteristics as reported by the Polish Energy Market Agency⁶⁹ – and built up using generic 200 MW blocks in order to meet projected future energy demand and in accordance with the assumed energy mix in each trajectory. Existing stock is retired, through 2030, according to the schedule predicted by the Polish government in the PEP, and then at an extrapolated rate such that all currently existing fossil-fuelled plants are decommissioned

by 2040. Renewable, nuclear, small-scale industrial, and other distributed power generation capacity is modelled according to the capacity projections for those technologies in the 2009 Polish National Energy Policy – which we linearly project to 2050 – and is kept constant among scenarios and trajectories.

Peak capacity needs are projected using the 2009 annual load duration curve for Poland, as measured by the Polish power operator.⁷⁰ Combined heat-and-power, lignite, hydro, and, later, nuclear units supply baseload power; gas, hard coal, and later, wind and solar units provide midlevel demand coverage; additional gas and pumped hydro units provide peaking power. Units

69 Energy Market Agency, Power Sector Statistics 2010, EMA, Warsaw

70 PSE Operator S.A. http://pse-operator.pl/index.php?dzid=78&did=&lang_id=2

TABLE 4A KEY MODEL PARAMETERS

| Parameter | 2010 | 2030 | 2050 |
|--|-------------------------|---------------------|---------------------|
| EUA Price (€) | 10 (10/10) | 50 (25/75) | 90 (45/135) |
| Lignite Emission Factor (tonnes CO₂/TJ) | 107.8 | - | - |
| Coal Emission Factor (tonnes CO₂/TJ) | 94.9 | - | - |
| Natural Gas Emission Factor (tonnes CO₂/TJ) | 55.8 | - | - |
| Biomass Emission Factor (tonnes CO₂/TJ) | 109.6 | - | - |
| Lignite Price (€/GJ) | 1.42 (1.00/4.00) | - | - |
| Coal Price (€/GJ) | 3.24 | - | - |
| Natural Gas Price (€/GJ) | 6.78 (2.50/8.00) | - | - |
| Biomass Price (€/GJ) | 3.76 | - | - |
| New Lignite/Coal Plant Efficiency (%) | 30 | 35 | 40 |
| New Natural Gas Plant Efficiency (%) | 40 | 45 | 55 |
| Energy Penalty (%) | | | |
| • 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 |
| Calculated nominal CO₂ avoidance cost – Capture only (€/tonne) | | | |
| • Pulverised Coal | 21 | 13 | 12 |
| • Oxycombustion | 31 | 15 | 13 |
| • IGCC | 25 | 10 | 9 |
| • NGCC | 48 | 36 | 34 |
| Co-firing Capital Costs (Thousand €/MW) | 161 | 129 | 104 |
| Transport Cost (€/tonne) | 1.2 (0.5/12) | 1.2 (0.5/12) | 1.2 (0.5/12) |
| Storage Cost (€/tonne) | 5 (2/12) | 5 (2/12) | 5 (2/12) |
| Currency Conversion | | | |
| • USD/EUR | 1.4 | 1.4 | 1.4 |
| • PLN/EUR | 4 | 4 | 4 |

are run with capacity factors based on those currently measured in the power sector by the Polish Energy Market Agency⁷¹, or – in the case of technologies such as nuclear that do not currently exist in Poland – at capacity factors based on those predicted by the Polish Institute for Sustainable Development in its Alternative Energy Policy until 2030 report.⁷²

Emission factors for the typical lignite, coal, and natural gas mixes used in Poland are employed, and are given in Table 4A. Nominal efficiencies are assumed for all fossil plants, with new plant efficiencies improving over time; these values are given in Table 4A, and are consistent with the 2010 average fleet efficien-

71 Energy Market Agency, Power Sector Statistics 2010, EMA, Warsaw

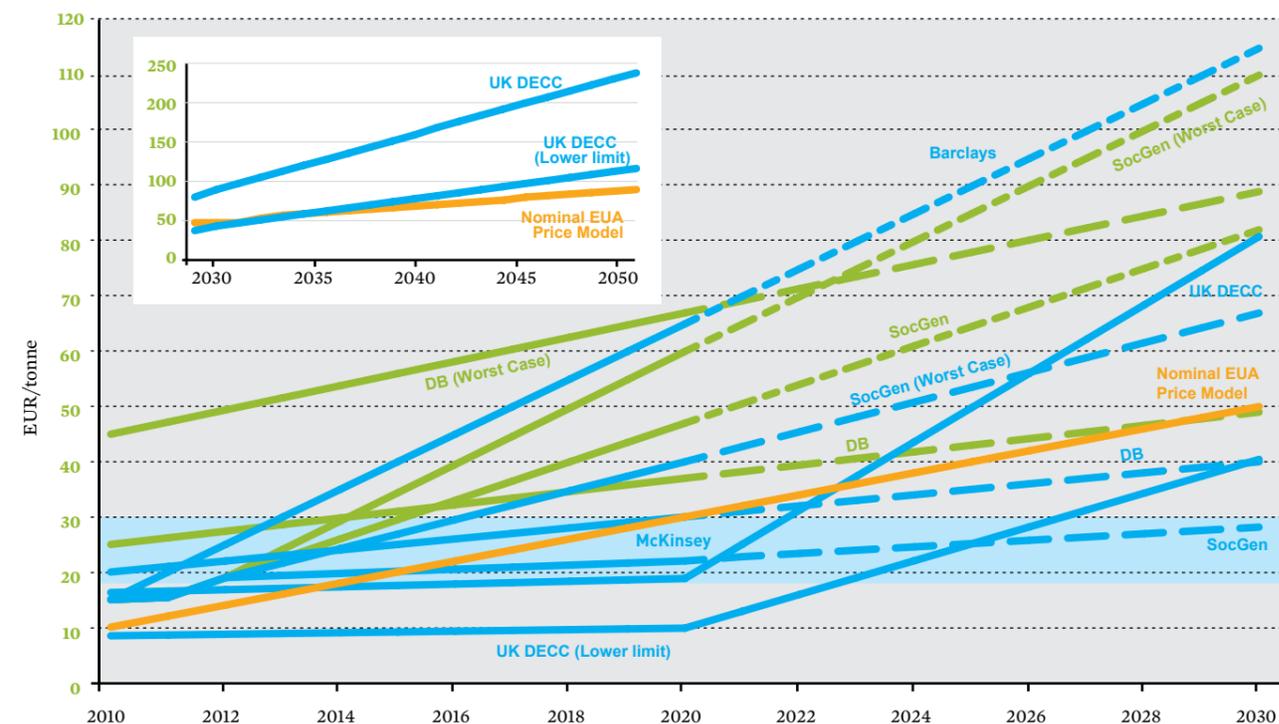
72 Institute for Sustainable Development 2009, Alternatywna Polityka Energetyczna do roku 2030, Warsaw

cies reported by the Energy Market Agency.⁷³ New fossil plants are assumed to have a nominal lifetime of 30 years. 30 years is a good assumption for the economic lifetime of a plant, but Poland's current fleet of very old facilities illustrates that it may be an underestimate for the actual operational lifetime of new coal plants. If the new coal plants built in the model in fact have lifetimes longer than 30 years assumed, that will serve only to reduce the overall cost of CCS in the scenario, as fewer new CCS-equipped facilities will be required in later years.

73 Energy Market Agency, Power Sector Statistics 2010, EMA, Warsaw

FIGURE 4B EUA PRICE FORECASTS FROM EU GOVERNMENT AND THE FINANCIAL SECTOR

A Selection of Recent EUA Price Forecasts Estimates from: UK Department of Energy & Climate Change (middle and low projections),⁷⁴ Barclays Bank,⁷⁵ Deutsche Bank,⁷⁶ Société Générale,⁷⁷ and McKinsey & Company⁷⁸. Blue (green) lines show estimates assuming a 20%(30%) EU 2020 emission reduction target; solid lines show forecasts from the listed source, while dotted lines indicate a linear projection of a forecast.



74 UK Department of Energy & Climate Change, Updated short term traded carbon values for UK public policy appraisal, June 2010, http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/1_20100610131858_e_@_carbonvalues.pdf

75 Alrroya.com, Barclays boosts phase III EU carbon forecast on auction supply, 5 August 2010, <http://english.alrroya.com/node/52657>

76 Deutsche Bank, Carbon Emissions: May You Live in Interesting Times... August 2010, http://www.rumoursandfacts.com/wp-content/uploads/2010/09/DB_Interesting_Times_30.8.10.pdf

77 Carbon Positive, EU Carbon prices rely heavily on targets, CER rules, October 2010, <http://www.carbonpositive.net/viewarticle.aspx?articleID=2156>

78 McKinsey & Company, Carbon Capture & Storage: Assessing the Economics, 2008, http://www.mckinsey.com/client-service/sustainability/pdf/CCS_Assessing_the_Economics.pdf



↳ 4.1.2 MODELLING FUTURE EU CLIMATE POLICY

Though the exact scale and scope of future EU climate and energy policy is uncertain, it is very likely that some increasingly significant restrictions on GHG emissions will be imposed in the coming years. In order to capture the possible impacts of such restrictions on the Polish power sector, some quantitative model of those future policies is required. Because no consensus prediction of future policy regarding GHG emissions impacts is available, we adopt a very simple representative model based on the ETS that posits slow linear growth in the EUA price under the existing ETS scheme, from 10 EUR/tonne CO₂eq in 2010, to 50 EUR/tonne in 2030, to 90 EUR/tonne in 2050.

Such a model represents a very conservative future EU climate policy, which imposes a slow and steady reduction in the ETS cap through 2050. This choice falls toward the low end of government and investor forecasts for the EUA, as shown in Figure 4B, with some envisioning EUA prices well over 100 EUR after 2030. Though the future will almost certainly bring changes in the CO₂ price and the introduction of other climate policy mechanisms unforeseen in this simple model, it can serve as a realistic and transparent representation of future pressures on GHG emissions with which to assess the likely magnitude of future EU policy impacts on energy production in Poland.

↳ 4.2 APPLYING CCS

Two scenarios – one with widespread CCS application and one without any – are constructed and their outcomes modelled for each of the three power sector energy mix/demand trajectories described above in Section 4.1.

- Full deployment: A countrywide rollout of CCS in line with EU policy, which sets out to make CCS commercial by 2020, and widely deployed thereafter. Assumes application of CCS to coal and lignite plants in the central and southern regions of Poland beginning in 2020, and to gas plants in 2025. Deployment continues at a rapid pace until near-total deployment in all regions is achieved soon after 2035.
- No deployment: Assumes no deployment of CCS until 2050. Serves as the reference case.

In the Full deployment scenario, CCS is applied first to coal plants in the central and southern regions of Poland, areas that already host many industrial facilities and are conveniently located close to storage locations in central Poland. Because it is assumed that initial CO₂ transport and storage infrastructure development will concentrate in the emissions-intensive central region of the country, deployment of coal CCS to the NW is delayed by 5 years to allow time for the development of similar infrastructure in that

region. Deployment to the NE region follows yet 5 years later, as it is assumed special precautions will be required, particularly with respect to CO₂ transport, to ensure that the large nature preserves in that region are not damaged by CCS infrastructure. Because the cost-per-tonne of CO₂ capture at gas-fired facilities is higher than that at carbon-intensive coal-fired facilities – because the current demonstration projects in Poland all focus on CCS as applied to coal – gas plants are assumed to be outfitted with CCS five years after their coal counterparts in each region. Retrofits are assumed to begin five years after new build plants begin incorporating CCS, due the greater costs and technical challenges they face. As required by EU policy, all plants built without CCS after 2010 are assumed to be CCS-ready, such that the space, transport, and storage needs of a future retrofitted CO₂ capture facility are taken into account in the planning and permitting process. The Full deployment scenario also assumes the successful completion of at least one demonstration project by 2020, such as that planned at Bełchatów.

In early years of CCS deployment, all coal-based CO₂ capture is assumed to use post-combustion capture technology. In later years, as a range of technologies mature and more new-build plants include CO₂ capture capabilities, IGCC, oxycombustion, and post-combustion technologies are all assumed to be in use.

When CCS is applied to a plant, it is assumed that 95% of its CO₂ emissions are captured, 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 4A, are linearly extrapolated from recent IEA estimates for 2015 and 2030, and assumed to remain constant after 2030. For CCS retrofits, the energy penalty leads to a decrease in the nameplate capacity of the facility. In the Full Deployment scenario applied to the PEP trajectory, this results in a 3% decrease in total generating capacity by 2040, small enough that no additional capacity is needed to meet demand. Retrofits are applied only to plants with at least 15 years of projected life at the time of retrofit.

Modelling the additional costs of carbon capture, transport, and storage through 2050 is challenging, given the large uncertainty surrounding the future price of technology and geological storage. The additional capital costs for CO₂ capture technology are based on the most recent estimates in the International Energy Agency's report, 'The Projected Costs of Generating Electricity,' which gives a range of possible additional capital costs for several CCS technologies in 2015 and 2030. From these ranges the mean additional costs for each CCS technology are taken as nominal values, while the maximum and minimum values are taken as limiting cases for sensitivity analysis (values in Table 4A; See Sec. 2.3.2 for Sensitivity Analysis). We compared the IEA capital cost estimates with those from a 2007 study carried out by Rubin, Chen and Rao at Carnegie

TABLE 4B CCS DEPLOYMENT TIMELINE

Lists the first year of operation of CCS-equipped facilities by region and fuel type.

| Full CCS Deployment | | | | | | |
|---------------------|-----------------------|-----------|-----------------|-----------|-----------------|-----------|
| Region | Central & South (65%) | | Northwest (25%) | | Northeast (10%) | |
| | New Builds | Retrofits | New Builds | Retrofits | New Builds | Retrofits |
| Lignite & Hard Coal | 2020 | 2025 | 2025 | 2030 | 2030 | 2035 |
| Natural Gas | 2025 | 2030 | 2025 | 2030 | 2030 | 2035 |

Mellon University, ‘The cost and performance of fossil fuel power plants with CO₂ capture and storage,’ and with those in the 2007 MIT study The Future of Coal and found the values in both additional studies comfortably within the range of the IEA estimates. The additional capital costs of CCS in retrofits are assumed to be 20% higher than those for new builds.

The additional capital costs are linearly extrapolated between the 2015 and 2030 IEA estimates, which assume a 20-25% decrease in capture capital costs for coal plants in that interval. Beyond 2030, we assume that capture capital costs decrease by 10% between 2030 and 2040, and by 10% again between 2040 and 2050. This modest drop in costs after 2030 is quite conservative, and assumes that the majority of technological learning takes place by 2030, with only minor cost improvements in later years.

All CO₂ capture capital costs are annualised over the remaining life of the power plant beginning at the time of CCS implementation, and a 10% annual interest rate is assumed. This value is consistent with that assumed by the IEA, and somewhat lower than that assumed in the MIT and Rubin et al. studies.

Because of the energy penalty of capturing and compressing CO₂, additional fuel costs per kWh of electricity produced are incurred. These costs are calculated for each CCS-equipped facility in the model, based on the efficiency loss due to CCS and the fuel prices – assumed constant over time – listed in Table 4A.

↳ 4.2.1 STORAGE COSTS

For the CO₂ stored onshore using legacy wells in depleted oil and gas fields, storage costs will be relatively low. Storage in saline formations will be more costly as pre-feasibility studies will be required to know for sure that a given candidate storage site is suitable for storing large amounts of CO₂. Monitoring costs and operational costs for onshore CO₂ storage are lower than for equivalent sites offshore, but proximity to populated areas could require additional monitoring.

To estimate an average storage cost in Poland, onshore storage in saline formations with no use of legacy wells has been assumed, giving an approximate cost of 5 EUR/tonne, with sensitivity limits of 2-12 EUR/tonne. CO₂ storage at several locations and with a high number of wells (>250 wells) is preferred in order to avoid significant underground pressure build-up, and to allow for down-time of some injectors.

CO₂ stored in depleted oil and gas fields with legacy wells will decrease costs, whilst amounts stored offshore will increase them.

↳ 4.2.2 TRANSPORT COSTS

Because most of the CO₂ transport network in Poland will utilise onshore pipelines, the transport costs are relatively low. Transporting CO₂ will cost about 1.20 EUR/tonne, with sensitivity limits of 0.50 - 12 EUR/tonne, as calculated under the following assumptions:

- The majority of the CO₂ could be transported by approximately 32” pipelines with a capacity of >20 Mt/y over distances shorter than 180 km⁷⁹. For the cost simulations it is estimated that 9 such pipelines are needed.

⁷⁹ Note that none of these numbers are firm. They are chosen in order to give a rough estimate of transport costs for a given CCS deployment scenario in Poland. The pipe sizes are chosen in order to suggest associated costs for a pipeline which is dimensioned to give a good compromise between capacity and pipeline rigidity. A larger diameter (than 32”) could increase challenges of thermal expansion and other mechanical effects.

- Up to 35-40 unique emissions point connected to the network through <10 km long 12” pipelines carrying >2,5 Mt/y
- 2 pipelines with capacity of <2,5 Mt/y 12” <180km for a couple of small scale projects
- pipelines with capacity of <10 Mt/y 32” <180km for larger projects or hubs/clusters
- 2 pipelines with capacity for <20 Mt/y 32” <750 km for more remote larger projects or hubs/clusters (no “close” storage location)
- 2 pipelines with capacity for <20 Mt/y 32” <1500 km for more remote larger projects or hubs/clusters (no “close” storage location)

The values assumed for storage and transport costs are given in Table 4A, together with sensitivity boundaries on transport and storage prices given, which are consistent with those in the 2009 Worley Parson et al report ‘Strategic Analysis of the Global Status of CCS’. Because no significant technological learning is expected, we assume transport and storage costs do not evolve in time. However, some change in costs may be seen in the future as transport and storage infrastructure improves and risk premiums stabilise.

↳ 4.3 THE ROAD AHEAD – LONG-TERM OUTCOMES OF CCS DEPLOYMENT IN THE POWER SECTOR

Taken together, these energy mix trajectories and CCS deployment scenarios – constructed on a robust foundation built of the best current estimates for the future evolution of electricity demand, fuel price, power generating facilities, and carbon capture technologies – paint a compelling picture of the potential CCS holds for Poland. In the face of unknown but likely future climate mandates, whether in the form of rising EUA prices or new emissions performance standards, CCS gives Poland the power to ensure it can utilise its native energy resources, meet its internal energy demands, protect its energy independence, and guard against potentially unlimited future economic costs.

Figures 4Ca&b show the CCS deployment timelines, investment requirements, and CO₂ emissions for the Full deployment scenario applied to the coal-intensive PEP and alternative Gas Expansion energy mix and demand trajectories. Significant investment in CCS begins in the 2020s and increases rapidly thereafter. These investments bring with them dramatic decreases in CO₂ emissions compared to both current and future predicted levels: in the Full deployment scenario applied to the PEP and Gas Expansion trajectories, power sector emissions are 108 Mt and 106 Mt by 2030 respectively, and fall to below 26 Mt in both cases by 2050. By contrast, under the No deployment scenario applied to the PEP/Gas Expansion trajectories emissions are projected to reach 147 Mt/129 Mt in 2030 and 211 Mt/186 Mt by 2050. These reductions represent a more than 80% reduction in total electricity-related emissions by 2050 as compared to 2010 levels. The 20% of emissions that remain by 2050 arise mostly from small-scale generation units that are too small to be good candidates for CCS, such as industrial combined heat-and-power facilities and small natural gas generators. Residual emissions from CCS-equipped facilities also contribute, rendered inevitable by the impossibility of a perfectly efficient capture technology. Figures 4Da&b show the regional distribution of emissions as a function of time under the Full Deployment scenario applied to the PEP trajectory.

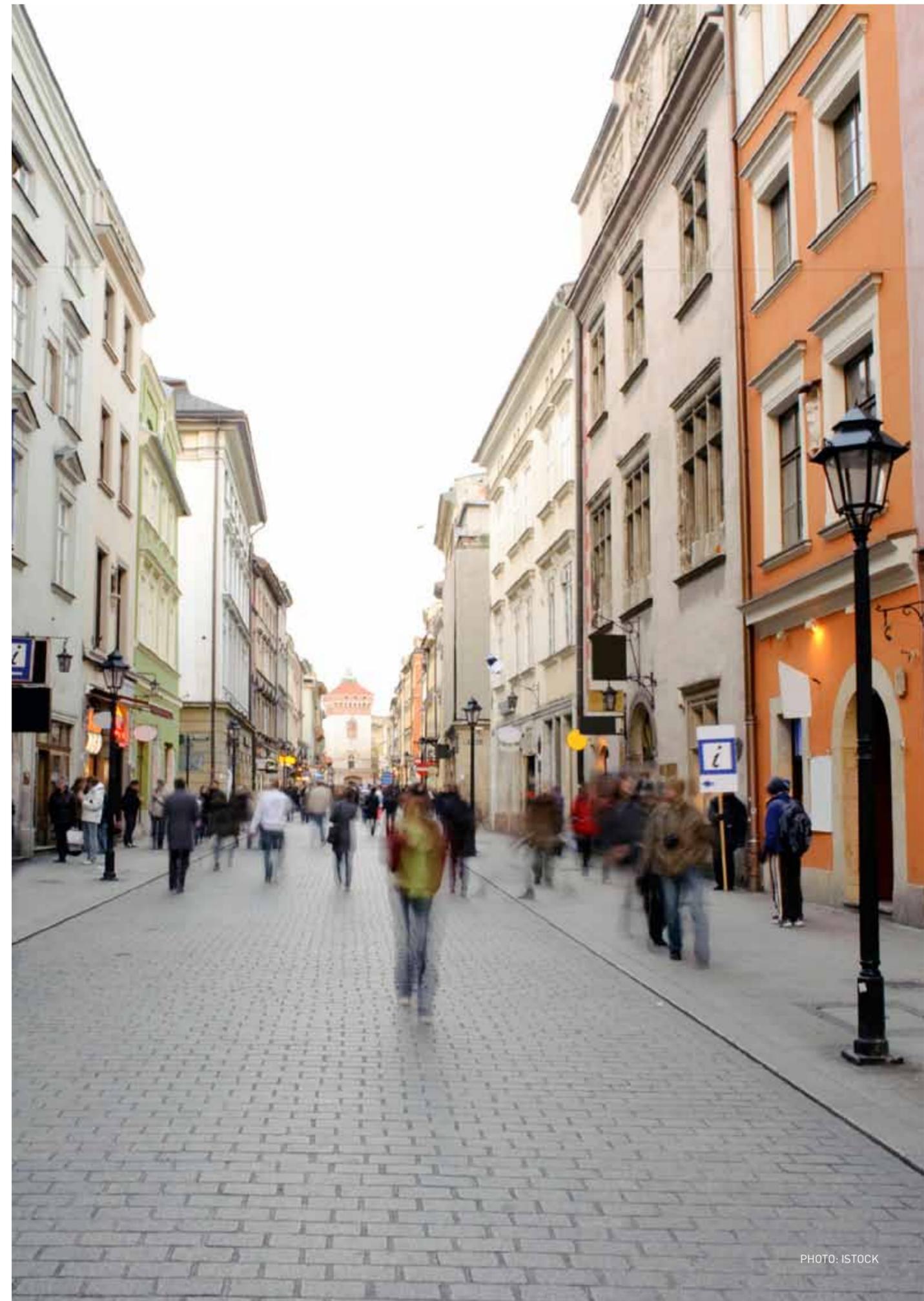


PHOTO: ISTOCK

FIGURE 4C A&B FULL CCS DEPLOYMENT SCENARIOS APPLIED TO THE PEP AND GAS TRAJECTORIES
 The Full CCS Deployment scenario applied to the PEP and Gas Expansion energy mix and demand trajectories. CCS capacity as a function of fuel, CO₂ emissions, CO₂ capture investment costs, and the electricity cost impact of EUA & additional CCS costs until 2050.

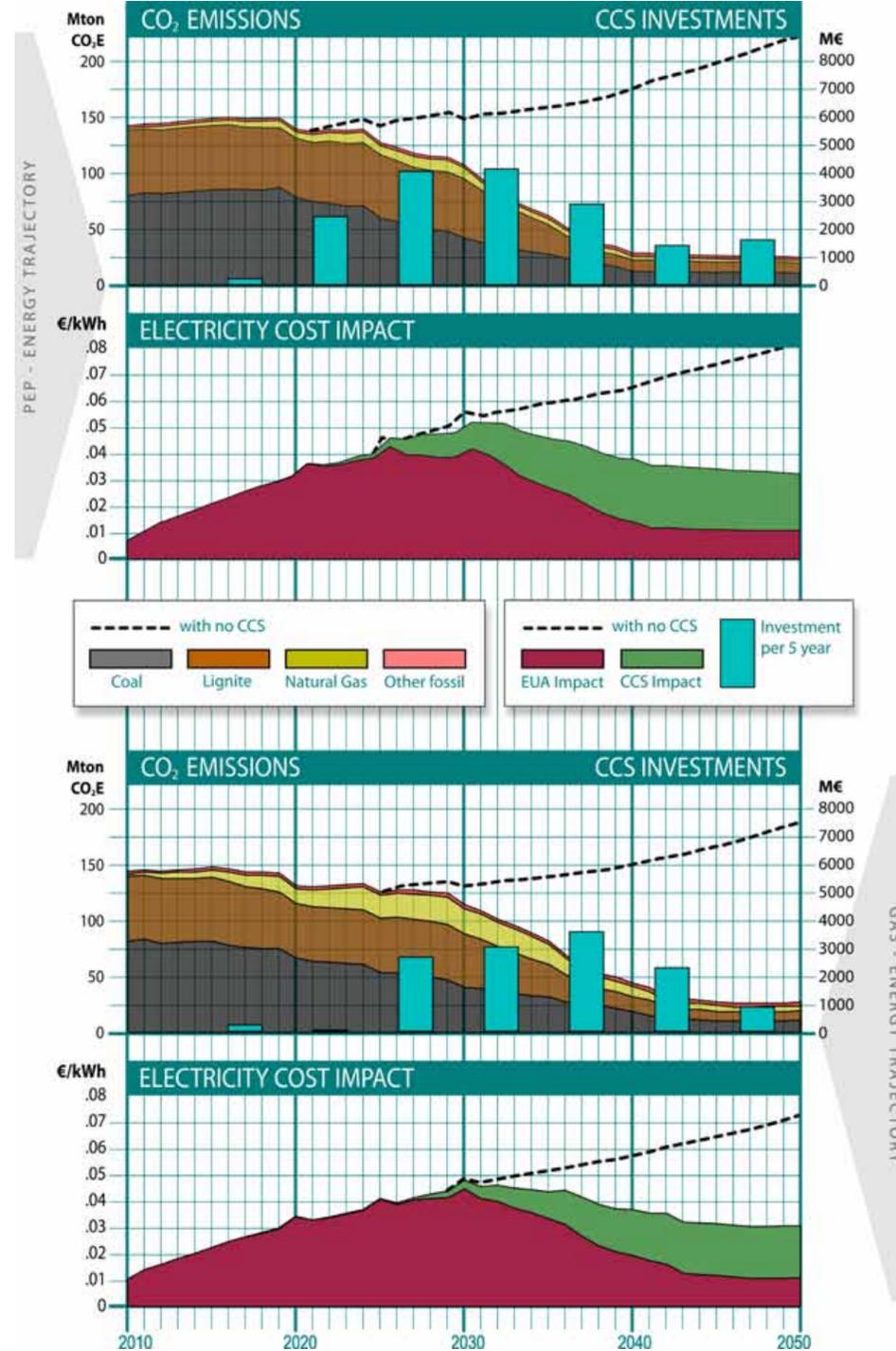
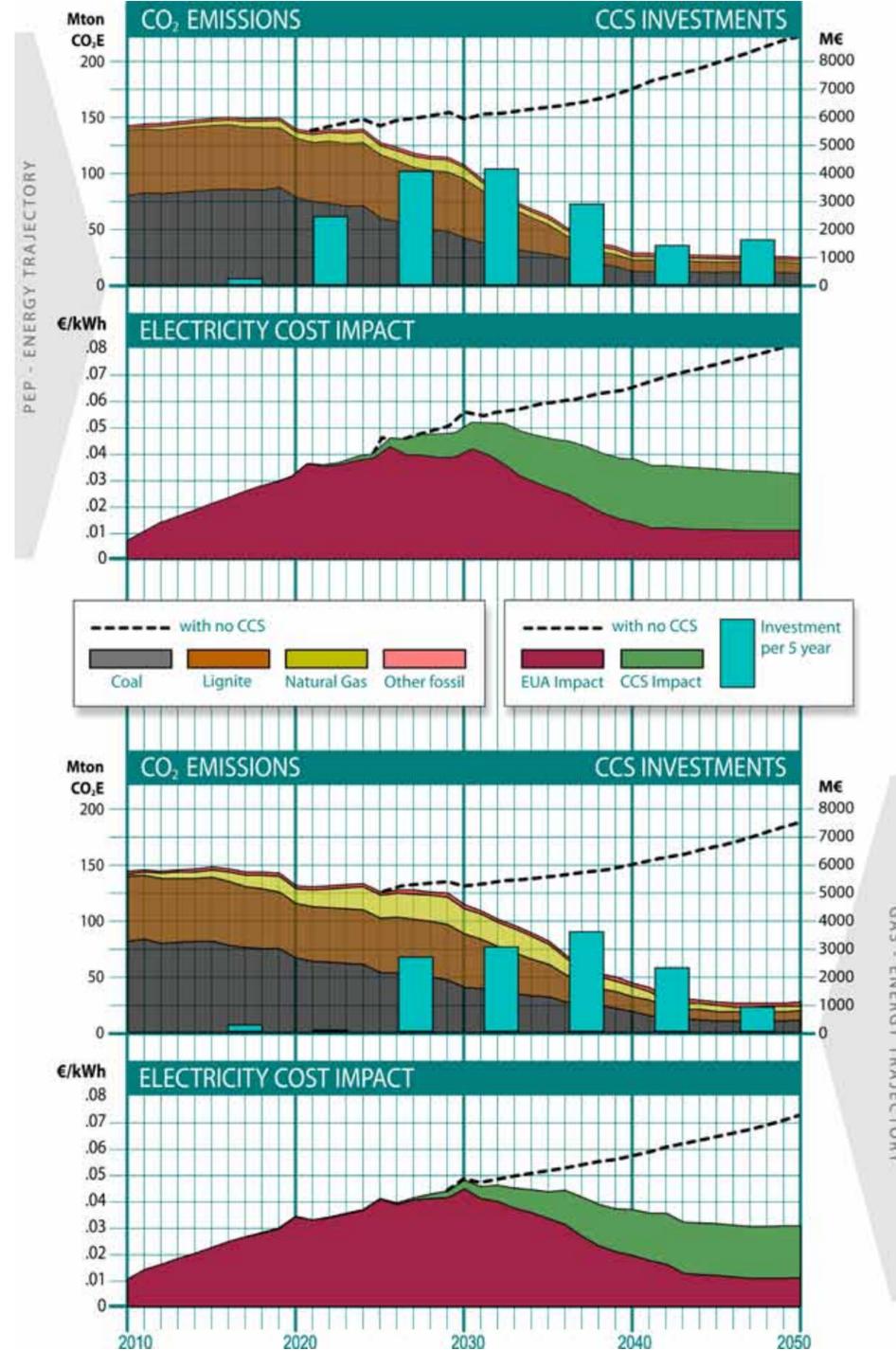
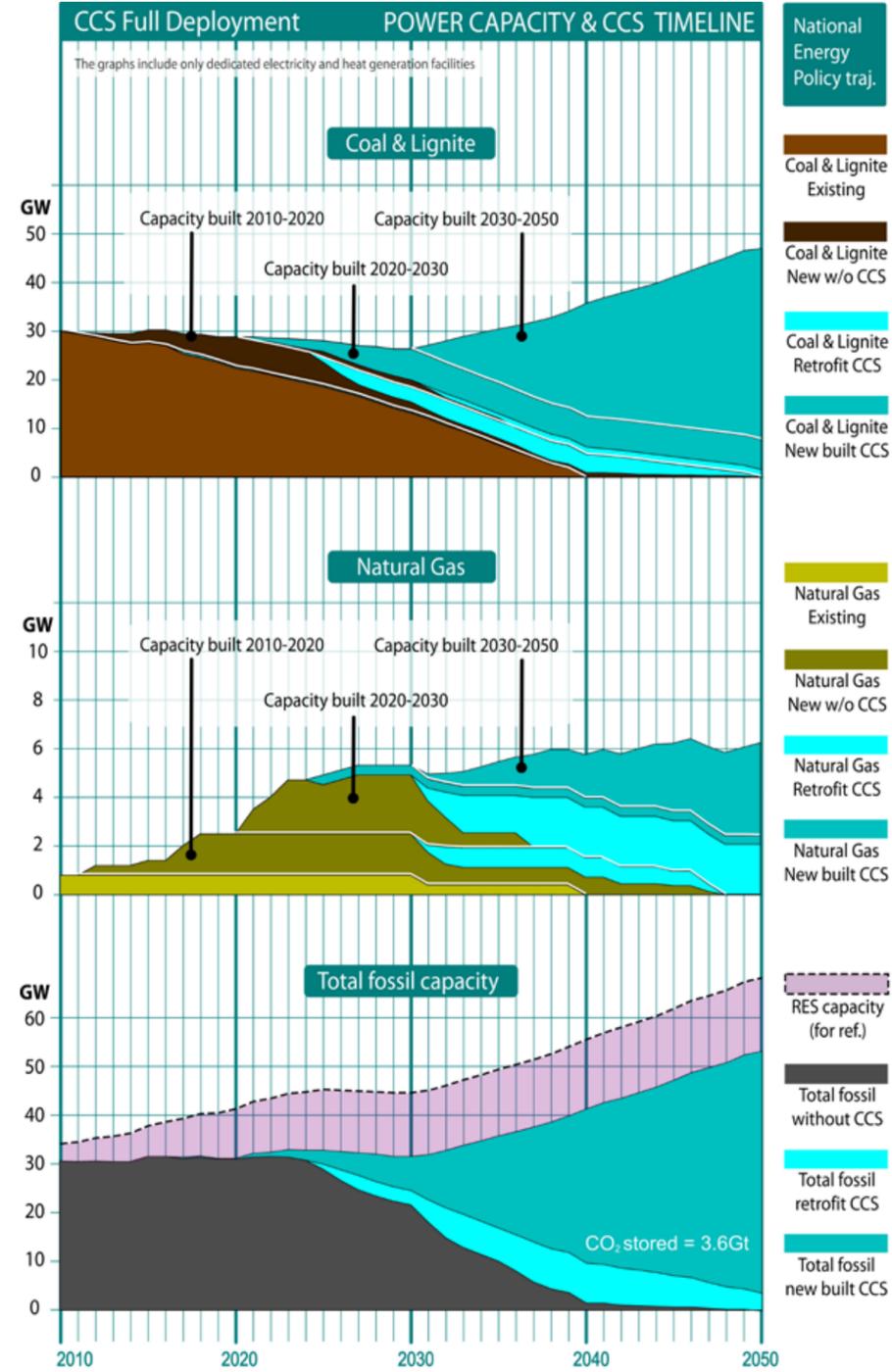
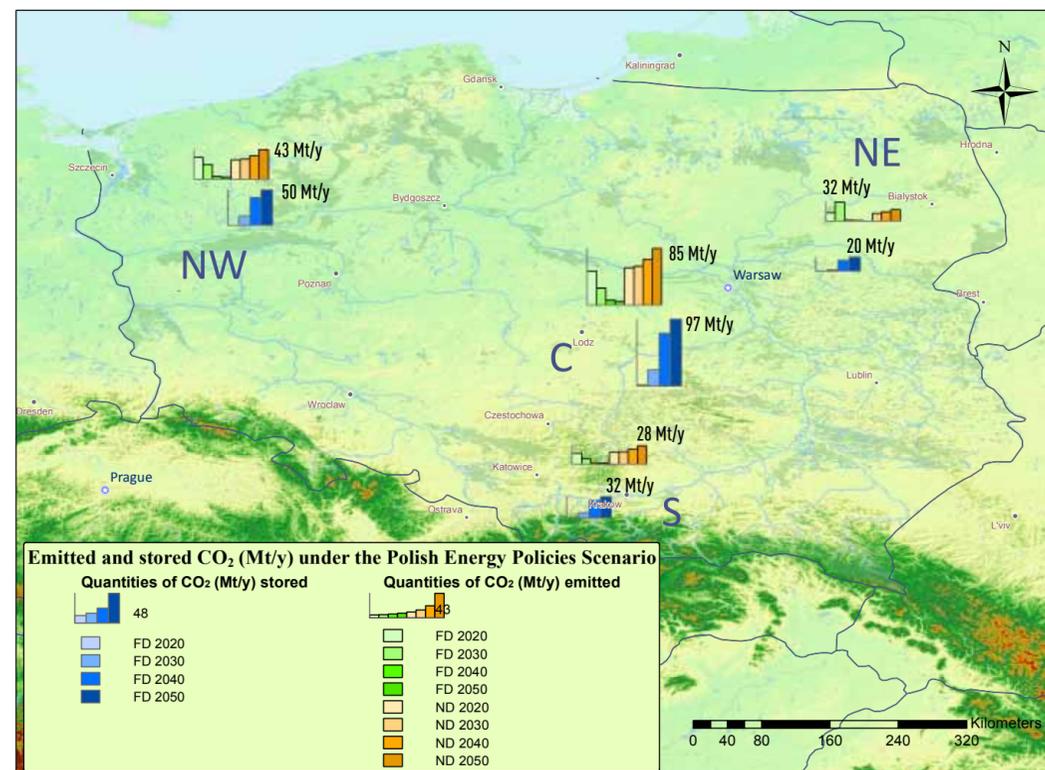


FIGURE 40a CO₂ EMISSIONS FROM THE POWER SECTOR IN POLAND UNDER THE "POLISH ENERGY POLICIES"

Maps of power sector emissions in Poland as a function of time under the Full Deployment scenario applied to the PEP (left) and Gas Expansion (right) trajectories. The emission sources in Poland have been divided into four approximate regions: The North-West (primarily Szczecin region), the Centre (around the bigger cities of central Poland), the South (the heart of the Polish energy generation between Czestochowa and the southern border) and the North-East (which is a region with comparably less CO₂ emissions, but where there is a need for a specific CO₂-transport regime because of the important nature reserves in this region). Each of these four regions is portrayed in two graphs; the blue-turquoise graph shows the amount of CO₂ stored in a given region by 2020, 2030, 2040 and 2050 respectively, whereas the graph in green (Full deployment) and orange (No deployment) shows the amount of projected CO₂ emissions of this region calculated for 2020, 2030, 2040 and 2050.



■ Full deployment
 ■ Full deployment
 ■ No deployment

FIGURE 40b IMPACT OF CCS ON POWER SECTOR CO₂ EMISSIONS IN POLAND UNDER THE GAS EXPANSION TRAJECTORIES

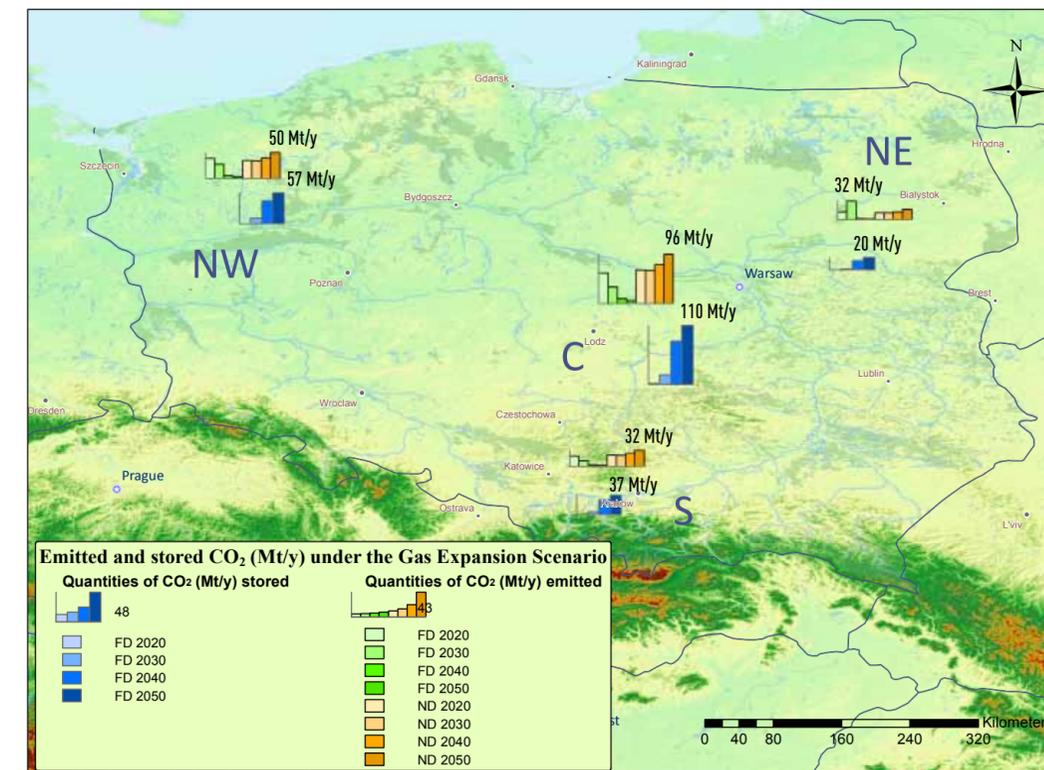
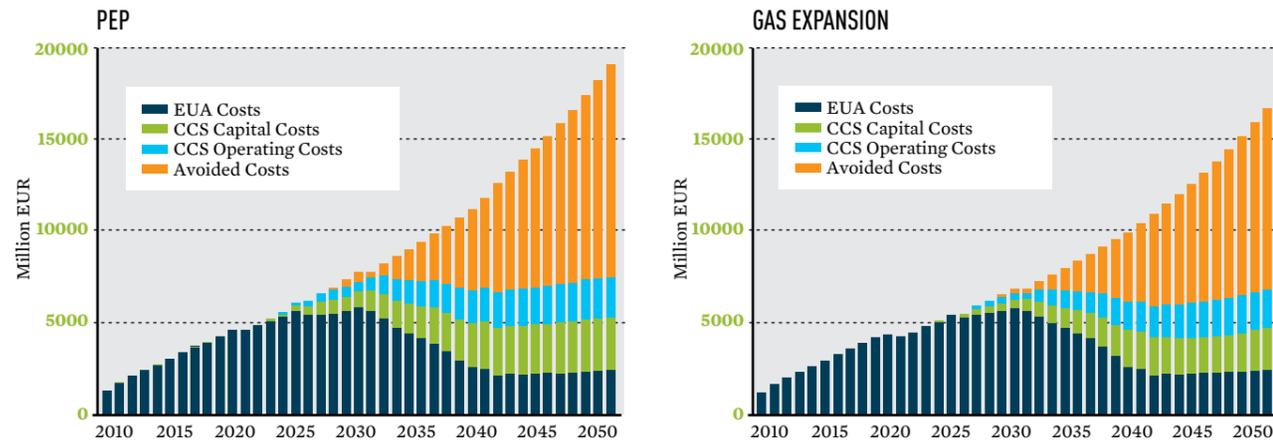


FIGURE 4E A&B
TOTAL COSTS AVOIDED BY APPLYING THE FULL DEPLOYMENT SCENARIO TO THE PEP AND GAS EXPANSION TRAJECTORIES



Emissions reductions such as these will meet any likely future emissions cap set by the EU. The timing of such a cap would dictate the necessary rate of CCS deployment; the Full Deployment scenario demonstrates that a 30% reduction in power sector emissions compared to current levels is fully possible by 2030. If faced with a rising CO₂ price rather than a falling emissions cap, these emission reductions will protect Poland from large unbounded electricity cost increases and benefit its balance of payments. Assuming the conservative model for the future ETS EUA price described in Section 4.2 (1 EUA costs 50 EUR in 2030; 90 EUR in 2050), Figures 4Ea&b show that a power sector with CCS will become cheaper in annual costs (including annualised investment costs) than one without, saving the economy billions of EUR each year almost immediately upon widespread CCS application in the late 2020s. This occurs because – under the assumed model for the future EUA price, and utilizing the projected additional costs of CO₂ capture, transport, storage assumed in this model – the abatement cost of capturing and storing CO₂ falls below the cost of emitting CO₂ by 2030, such that applying CCS saves money almost from the time it is first deployed. In alternative cases in which the costs of CO₂ capture, transport, and storage are higher, or in which the EUA price grows more slowly, CCS deployment might remain more expensive than taking no action through the 2020s and early 2030s, but will still become the more economically beneficial choice in the long run. These cases are explored in the Sensitivity Analysis in Section 4.3.1 below.

CCS thus is shown to be a potentially vital tool for preserving the future health of the Polish power sector under any future ambitious climate policy. However, as discussed earlier in this roadmap, that power sector is in a period of transition and may develop along quite different paths over the coming decades. How does CCS fare in a future that looks more like the Energy Efficiency energy mix and demand trajectory?

Much the same. The trends observed for the PEP and Gas Expansion case – in terms of significant emissions reductions, and potential economic benefits – hold true for the Energy Efficiency energy mix and demand trajectory. Figure 4F shows the emis-

sions under the Full Deployment scenario for all three energy mix trajectories, compared to their No Deployment counterparts (complete deployment timelines and emissions projections for the EE trajectory are shown in Appendix A). Without CCS, even the very-much-less carbon-intensive EE trajectory, which includes a larger share of less carbon-intensive gas in its energy mix and a significantly reduced electricity demand growth rate, achieves only a 30% reduction in emissions by 2050 as compared to 2010 levels. The consensus among the world’s scientists, captured in the International Energy Agency’s Energy Technology Perspectives 2010,⁸⁰ is that much greater reductions – on the order of 70-80% in Europe – will be necessary by that time if irreversible climate change is to be averted. EU and global climate policy is therefore likely to demand similarly larger emissions reductions, such that CCS is likely to become necessary no matter which energy mix and demand trajectory the Polish power sector follows in the coming years.

In terms of economic outlook, all three energy mix and demand trajectories show similar trends. Figure 4G shows the electricity cost impact of GHG emissions and CCS under the Full deployment scenario for all three energy mix and demand trajectories, using the same EUA price model as above. In all trajectories – following the trend discussed in detail for the PEP trajectory – a world with CCS becomes less expensive than one without CCS in the 2030s, and becomes ever more so through to 2050.

There is, of course, significant uncertainty regarding the future CO₂ price; it arises from an immature market that may change in time with policy and economic developments. However, as demonstrated in Section 2.1, that uncertainty does not tend towards more modest future carbon prices – indeed, many estimates predict the EUA price will grow at a significantly more rapid rate than that assumed here.

80 International Energy Agency, Energy Technology Perspectives 2010, <http://iea.org/techno/etp/index.asp>



PHOTO: ISTOCK

FIGURE 4F CO₂ EMISSIONS UNDER THE NO AND FULL DEPLOYMENT SCENARIOS APPLIED TO THE PEP, GAS EXPANSION, AND EE ENERGY MIX & DEMAND TRAJECTORIES

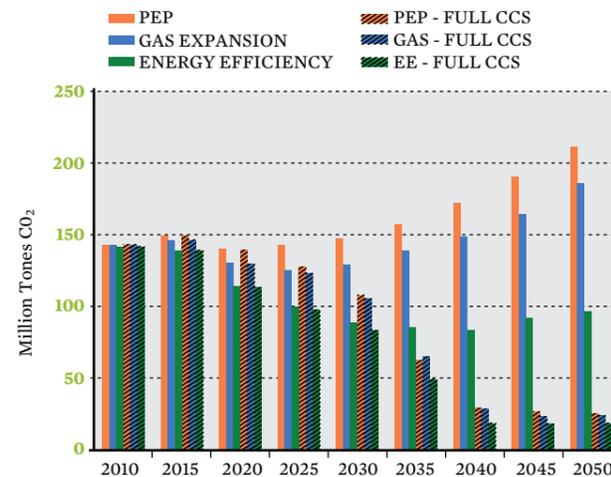


FIGURE 4G TOTAL ELECTRICITY COST IMPACT OF CCS & EUA COSTS UNDER THE NO AND FULL DEPLOYMENT SCENARIOS APPLIED TO THE PEP, GAS EXPANSION, AND EE ENERGY MIX & DEMAND TRAJECTORIES

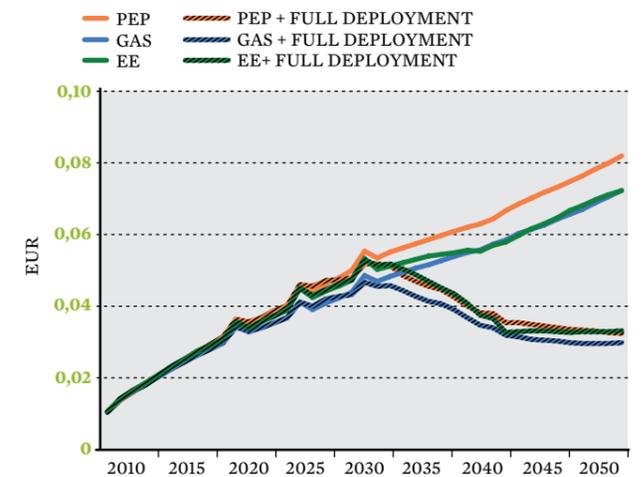
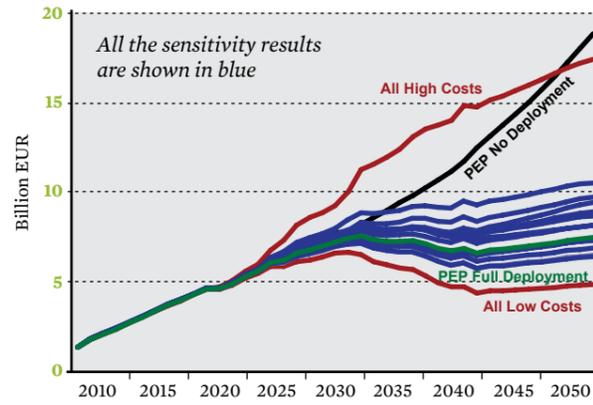


FIGURE 4H EUA AND ADDITIONAL CCS COSTS OF THE FULL DEPLOYMENT SCENARIO APPLIED TO THE PEP TRAJECTORY IN ALL SENSITIVITY CASES



It is thus precisely this uncertainty that makes CCS-readiness so important: though the cost of future CCS technologies is somewhat uncertain, the cost of future allowances or the rigor of future emissions limits is much more so – and may well end up much higher and stricter than those assumed here. Preparing the way for CCS is thus a way to reduce uncertainty and mitigate possible future risk, making available a path with predictable future costs (those of CCS investments) as an alternative to one with unknown, highly variable, and potentially devastating ones (those of emissions permits or emissions cap compliance).

4.3.1 SENSITIVITY ANALYSIS

Because uncertainty exists surrounding the specific future capabilities and costs of CCS technologies, a sensitivity analysis is carried out for the Full Deployment scenario applied to the PEP trajectory to test the impacts of cost and technology variations on our economic and emissions conclusions. The Full Deployment scenario is recalculated using a lower capture efficiency value (which raises operating emissions), higher capture energy penalties (which raise costs), and high and low limiting values for capital, interest rates, transport, storage, and fuel costs, as given in Table 4A.

Figure 4H shows the annual total costs for all individual sensitivity cases, as well as limiting cases combining high (low) capital, interest, fuel, transport, and storage costs. In Figure 4I, the resulting CO₂ avoidance costs for each sensitivity case are com-

FIGURE 4J CO₂ EMISSIONS FROM THE PEP TRAJECTORY, UNDER THE NO DEPLOYMENT, FULL DEPLOYMENT, AND FULL DEPLOYMENT + LOW CAPTURE EFFICIENCY SCENARIOS

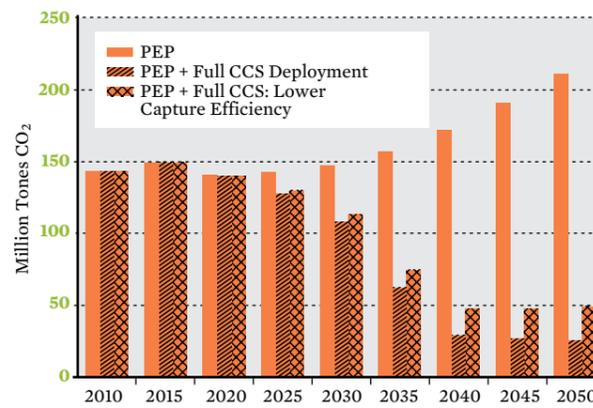


FIGURE 4I CO₂ AVOIDANCE COSTS FOR THE FULL DEPLOYMENT SCENARIO APPLIED TO THE PEP TRAJECTORY IN ALL SENSITIVITY CASES

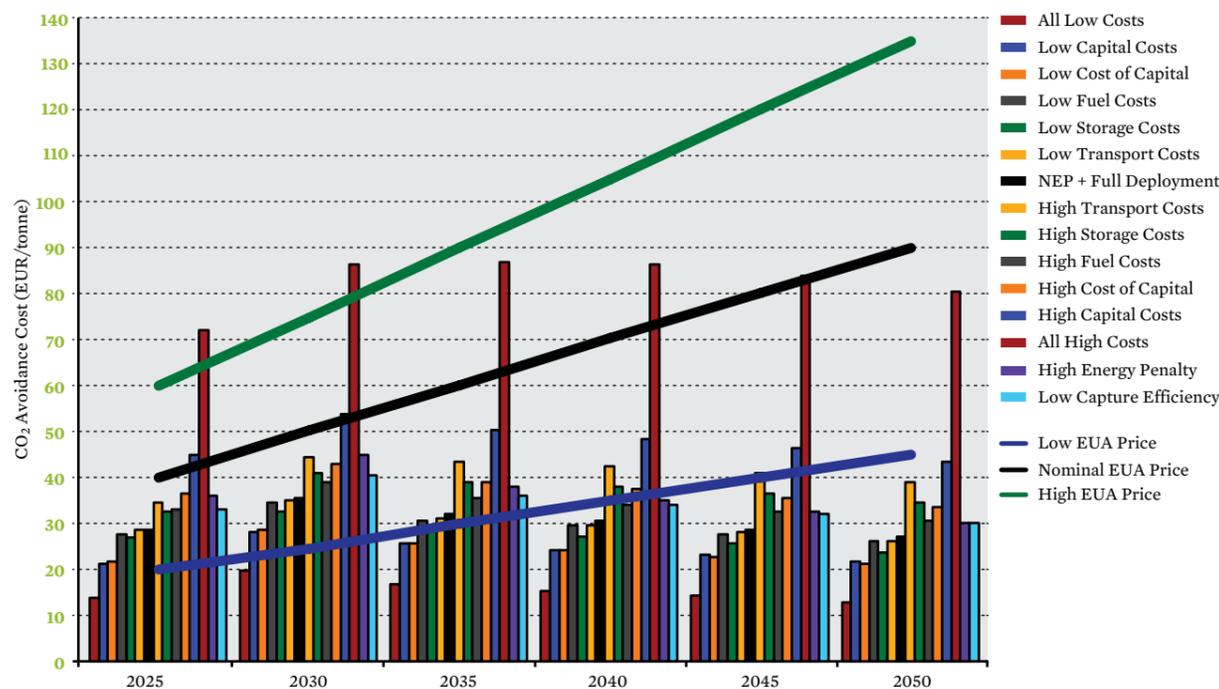


FIGURE 4K CO₂ EMISSIONS AND THE ELECTRICITY COST IMPACT OF A “DELAYED ACTION” FULL DEPLOYMENT SCENARIO APPLIED TO THE PEP TRAJECTORY

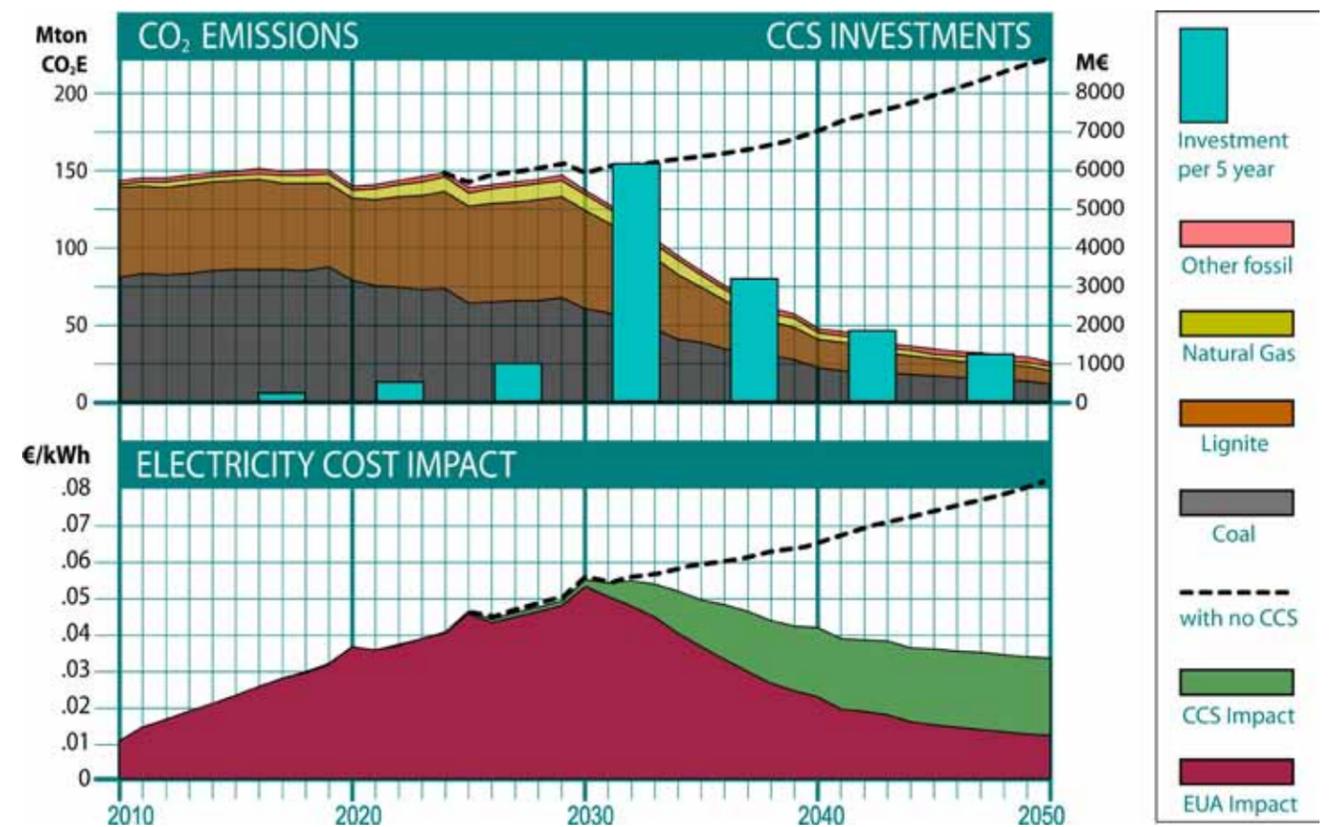
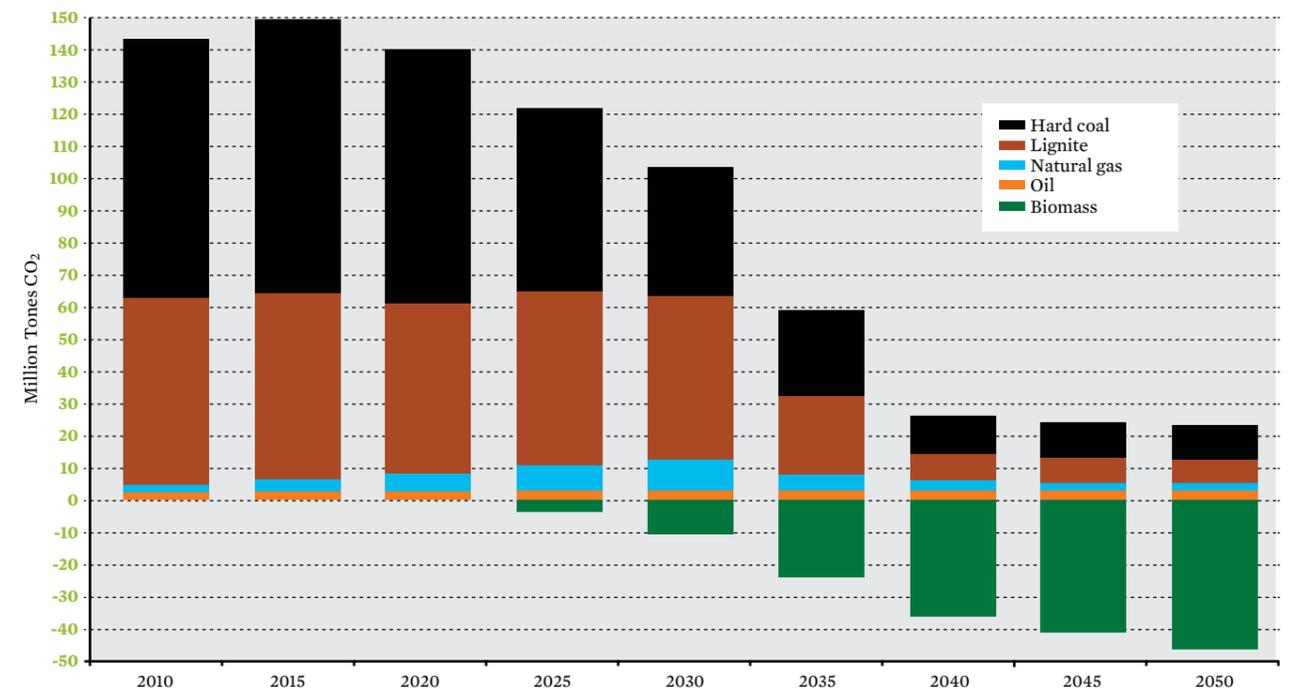


FIGURE 4L CO₂ EMISSIONS BY FUEL IN THE FULL DEPLOYMENT + BIO SCENARIO APPLIED TO THE PEP TRAJECTORY



pared to three potential CO₂ emission costs: those of the nominal model described in Section 4.2, and two further sensitivity cases in which the EUA price is 50% higher or lower than nominal after 2020. Figure 4J shows the total CO₂ emissions from the PEP trajectory under the No Deployment scenario, the nominal Full Deployment scenario, and the Full Deployment sensitivity scenario with decreased capture efficiency.

Taken together, these figures show that the key findings of Section 4.4 – that by 2035, CCS not only dramatically lowers emissions, but also lowers energy costs – hold true under even the extreme limiting value of any one CCS cost or capability parameter. Only in the case when every CCS cost parameter is set to its highest value does this finding change – but even then, assuming a nominal EUA price, CCS becomes money-saving within the time span of the scenario. Similarly, even in the case of a very low EUA price, CO₂ avoidance with CCS becomes cheaper than buying emission allowances under the nominal CCS cost & capability model by 2040. Only if all factors are aligned against CCS – if the EUA price grows very slowly and multiple components of CCS are very expensive – does it become less costly for Poland to avoid CCS than deploy it. In all other sensitivity cases, deploying CCS remains a wise economic choice. Moreover, CCS remains a good option even if unforeseen legal, financial, or technical delays postpone widespread implementation of CCS in the 2020s. Figure 4K shows the emissions reductions and electricity cost impacts of a “delayed action” case of the Full Deployment scenario applied to the PEP trajectory, in which each stage of CCS deployment before 2030 is delayed by 5 years. Even under this delayed scenario, significant cost savings and emission reductions are still achieved well before 2040. This is not an endorsement of delayed action, as delaying CCS implementation will significantly increase Poland’s vulnerability to adverse economic pressure from increasingly stringent climate policies. However, it does clearly show that early delays are no justification for abandoning widespread CCS deployment, as significant benefits can still be reaped even from late deployment, albeit less than those reaped from early and decisive action.

4.4 CARBON NEGATIVE POTENTIAL THROUGH BIOMASS UTILISATION

↳ Utilisation of biomass in the Polish power sector may, in the long-term, lead to carbon-negative electricity generation, effectively removing CO₂ from the atmosphere. This is possible because biomass absorbs just about as much CO₂ when it grows as it emits when it is burnt. Assuming that the biomass is sustainably grown and replanted, this implies that biomass burnt for energy can be close to carbon neutral (i.e. does not produce net greenhouse gas emissions). When biomass is burnt or gasified for energy generation at a plant fitted with CCS – whether in a standalone biomass plant or co-fired with fossil fuels – the biogenic CO₂ captured and stored is effectively removed from the atmosphere and becomes a negative contribution to total emissions.⁸¹

⁸¹ For further reading, see For Bellona’s description of ‘carbon negative’ energy production, see for example the “How to Combat Global Warming” report from 2008, page 84 and further: http://bellona.org/filearchive/fil_Bellona_CC8_Report_-_Final_version_-_30_mai.pdf

Using biomass in this way will add to an already increasing demand for sustainably produced biomass. In the EU alone, the Member States’ recent national renewable energy action plans call for biomass to account for more than 10% of total energy consumption, and more than 50% of renewable energy consumption, by 2020.⁸² The challenge will be finding enough sustainable, genuinely carbon-neutral biomass. The EU has introduced mandatory sustainability criteria for bio-fuels and liquids (see Appendix 2), and the European Commission is still reflecting on developing such criteria for solid and gaseous biomass. As the biomass market develops, sustainability criteria governing biomass production regardless of final usage will be needed that protect biodiversity and fragile environments, ensure significant emission savings are achieved with biomass use, protect food production, account for the impacts of indirect land use change, and provide the predictability necessary for industry while maintaining flexibility to reflect new scientific findings.

Though recent biomass promotion policies in Poland have at times distorted the local biomass market, leaving local users unable to acquire adequate fuel as biomass is diverted to large facilities for co-firing, the sustainable biomass market of 2025 is expected to look far different. Global suppliers growing biomass specifically for fuel on marginal or reclaimed lands may make sustainable biomass an environmentally sound and widely available fuel. Only in that case may widespread utilisation of biomass in Poland become a viable and cost-effective emission reduction option.

To roughly estimate the impacts of such a biomass utilisation strategy, we introduce a Full Deployment + Bio scenario, which extends the Full Deployment scenario by adding 20% biomass co-firing to all hard-coal and lignite plants after 2025. Capital costs for retro-fitting existing coal stock to co-fire biomass are taken from U.S. National Renewable Energy Laboratory estimates, while additional costs due to fuel-switching are modelled using the current average cost of biomass in Poland. These are given in Table 4A. The actual price of biomass in the future is uncertain, and will depend on supply and demand in the worldwide biomass market.

↳ 4.4.1 A CARBON NEGATIVE FUTURE FOR THE POLISH POWER SECTOR?

Given the very carbon-intensive nature of Poland’s existing power sector, the idea of that same sector one day becoming not only low carbon, or carbon neutral, but carbon negative, may sound highly unlikely. However, combining large scale utilisation of biomass with the widespread deployment of CCS makes such a scenario a possibility.

As an example of this potential, Figure 5 shows the power sector CO₂ emissions for the Full Deployment + Bio scenario applied to the PEP trajectory, grouped by fuel; the effects of capturing and storing CO₂ from biomass are seen in the large negative swathe at the bottom of the plot. Indeed, these negative emissions, combined with low total power sector emissions achieved through wide-scale application of CCS to conventional fossil fuel-fired plants, leads to a carbon negative power sector by 2050

⁸² Biomass for Energy: overview of National Renewable Energy Action Plans Conference on sustainable biomass for European Energy, http://www.biomassconference.eu/lectures/MS_02_conference%20sustainable%20biomass%20for%20european%20energy%2029%20nov%202010%204.pdf



in all three energy mix/demand trajectories, with total emissions of -23MT, -15MT, and -1 MT in the PEP, Gas Expansion, and EE trajectories respectively. Because of its large share of coal – and thus increased opportunity for co-firing – the PEP trajectory under the Full CCS Deployment + Bio scenario goes carbon negative as early as 2040.

A carbon-negative power sector would provide economic benefits, whether through the selling of emissions allowances on the carbon market, or through the avoidance of more expensive emissions reductions in other sectors, such as transportation.

However, the successful and environmentally sound realisation of such a carbon negative pathway for Poland’s power sector

depends on the future development of the global biomass market. For example, including 20% biomass co-firing in all coal plants in the PEP trajectory would require some 430 terajoules (TJ) per year of sustainable biomass fuel in 2040, and 530 TJ per year by 2050. As a very rough estimate, meeting such demands would require some 125000 hectares and 160000 hectares, respectively, of dedicated commercial biomass cultivation (large areas, but still less than 1% of Poland’s total land area). The viability of widespread biomass utilisation will depend on the world finding ways to grow and transport enough sustainable biomass. The fact that the highly carbon-intensive Polish power sector might in this way become carbon-negative is strong motivation to do so.



SAFEGUARDING THE FUTURE ECONOMY

Poland stands in a strong position and at a critical decision point regarding the future of its fossil-based energy supply. With the initiatives taken to promote two ambitious demonstration plants - at Bełchatów and Kędzierzyn - and to conduct geological storage surveys in several regions of the country, a solid will has been demonstrated which could make Poland a regional leader on CCS technologies.

With its rich resources of coal and lignite, Poland is well positioned to preserve its energy independence for decades to come, until it can fully provide for itself using renewable energy. It can continue being self sufficient in energy while maintaining a competitive industry, both in the short and long term. The ever stricter EU regulations on greenhouse gas emissions will only pose a small threat to the economy, as long as the right actions continue to be taken.

Such actions include continuing the initiatives already taken to develop and commercialise CCS technologies – which should be the main priority in the short term. In the longer term, the focus should be on actions to build the best possible future energy sector for the country, including both a widespread deployment of CCS, significant improvement of energy efficiency and a ramp up of renewable energy generation.

The roadmap presents an analysis of the current situation and outlines possible paths to take, but it does not aspire to make absolute recommendations regarding the choices that Poland needs to make to secure its future. It is, however, clear that there is one insurance policy in which Poland needs to invest in order to maintain its strong position and freedom of choice regarding its future energy supply. It must go forward with its CCS demonstration plants, and the other activities required to allow commercialisation of CCS – such as continued and extended geological storage surveys, implementation of necessary policies and legal framework, public information campaigns, etc.

The roadmap has examined the outcomes of applying CCS to three different energy mix trajectories reflecting possible development in Poland's energy mix and demand for electricity. This was done in order to put specific figures on the costs, emissions, and benefits of the different choices at hand.

Under all three trajectories – and across a wide range of possible EU climate & energy policies – it is clear that the activities to commercialize and deploy CCS in Poland must not be abandoned as they are indeed required to ensure a secure economic future.





ACTIONS

✎ Decide to make the implementation of CCS demonstration programs a political priority for Poland and appoint a Vice Minister for CCS, with the stated objective of making at least 1-2 plants operational before 2020.

✎ Remove one of the main obstacles for CCS by immediately transposing the EU CO₂ Storage Directive.

✎ Make available affordable capital to the private sector by reducing the risk through measures such as government warranties, grants, and loan guarantees.

✎ Reduce commercial uncertainties for investing in CCS facilities by either establishing an emission performance standard, providing an EUA price floor, enforcing a CO₂ tax, introducing a certificate programme for CCS or similar measures.

✎ Reduce the total cost of energy production and reduce national GHG emissions by strengthening subsidies and support programs for improving the energy efficiency in all parts of the economy

✎ Enforce the existing EU requisite that all new large fossil-fuelled plants are built – as a minimum – as CCS-ready facilities by putting into place the regulatory instruments needed.

✎ Make it feasible that new plants in all regions can be built as CCS-ready by the government taking immediate responsibility for the necessary identification of near-term storage sites and CO₂ transport corridors.

✎ Enable large scale storage of CO₂ by implementing necessary legislation and by fully characterising all available storage capacity in Poland, including that in the Baltic Sea, and by exploring the potential of EOR opportunities.

✎ Accelerate the development of carbon negative solutions and CO₂ storage opportunities by launching a government-funded CCS R&D programme on the scale of 100M EUR over five years, and by adopting tax incentives for private sector research.

✎ Launch a nationwide information campaign to introduce climate change, CCS technologies, and key actors to the general public. Begin focused public consultations with communities near likely storage sites.

FIGURE A1
The Full CCS Deployment scenario applied to the Energy Efficiency energy mix and demand trajectories, with results from the PEP trajectory for comparison. CCS capacity as a function of fuel, CO₂ emissions, CO₂ capture investment costs, and the electricity cost impact of EUA & additional CCS costs until 2050.

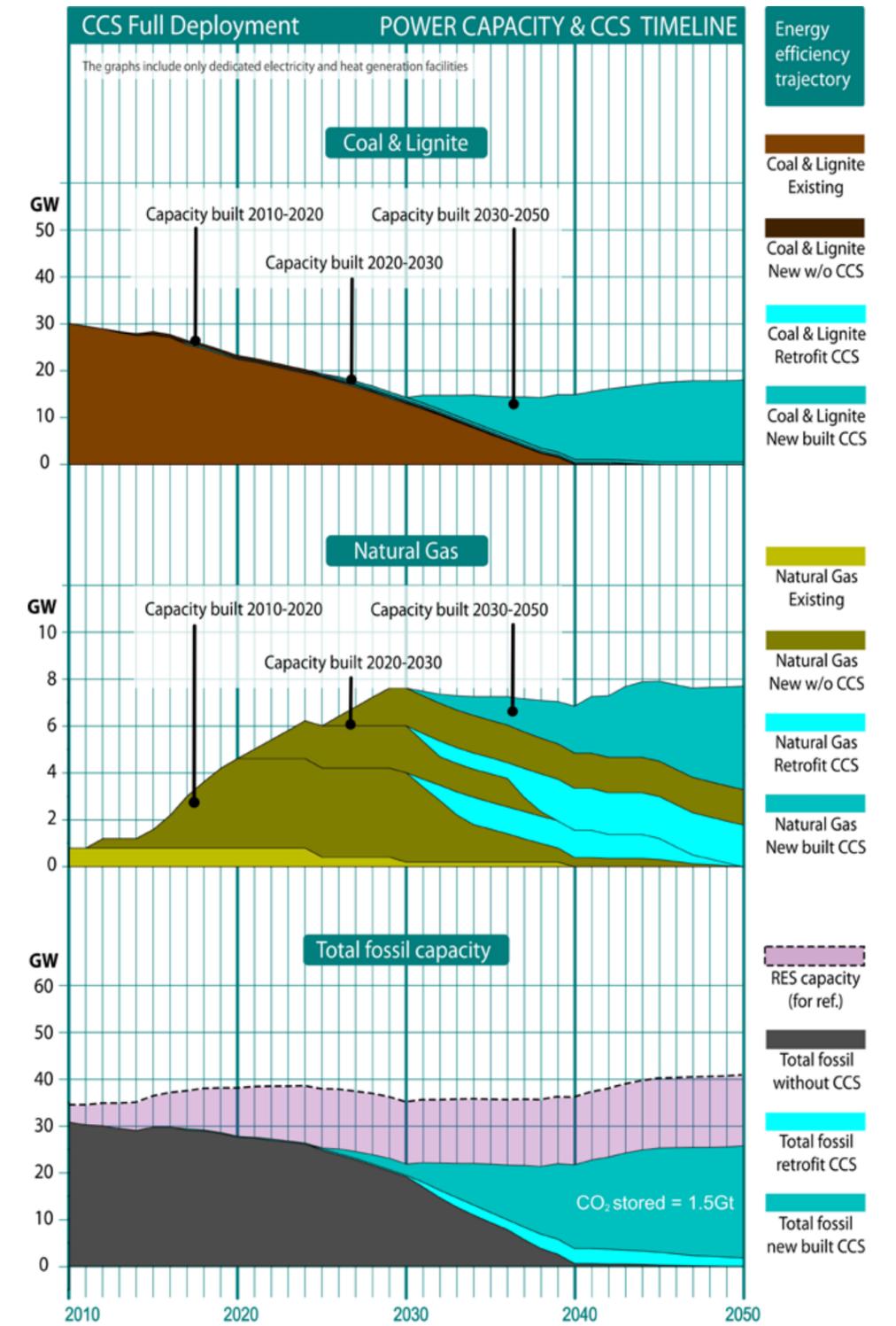
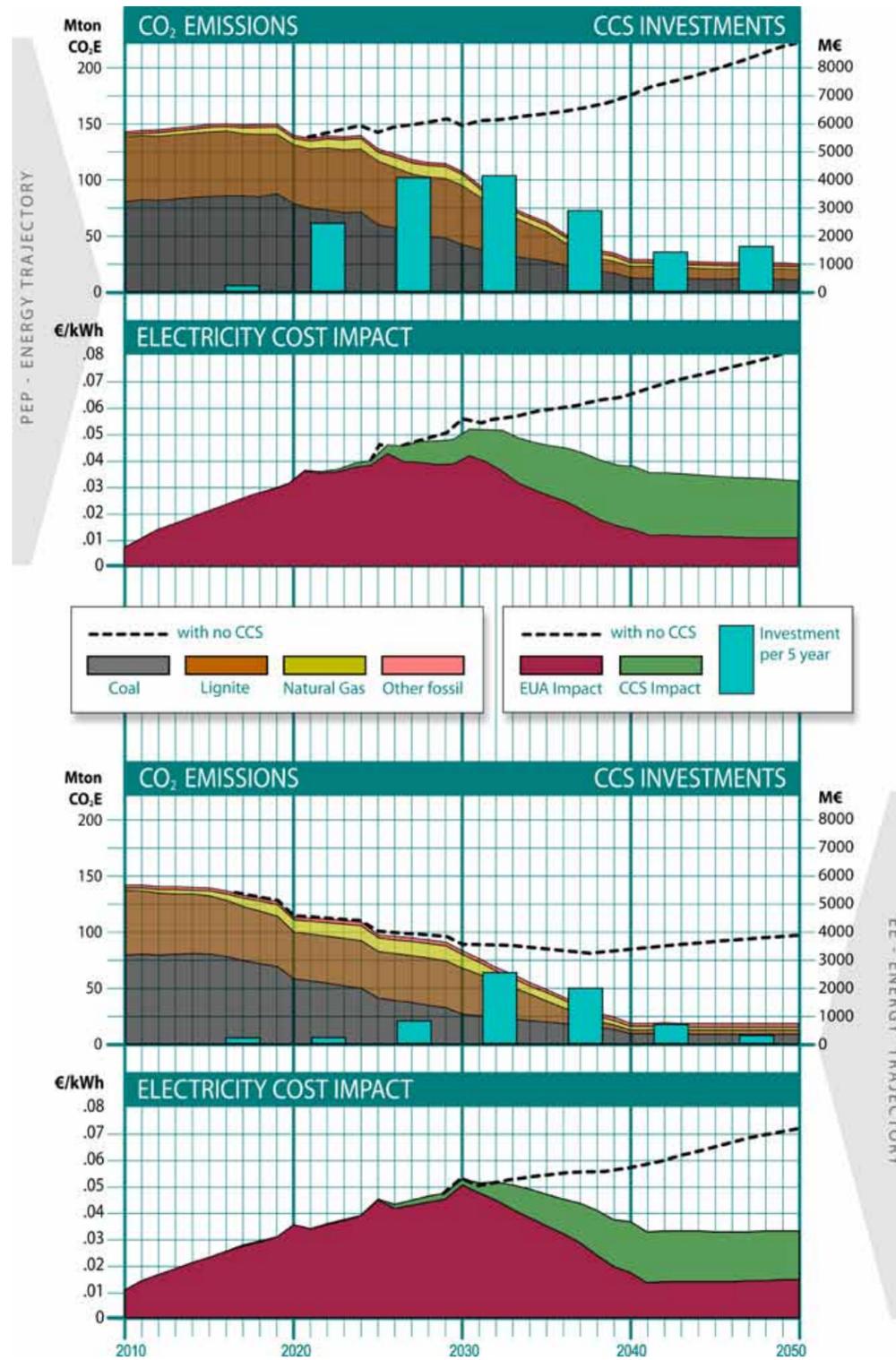
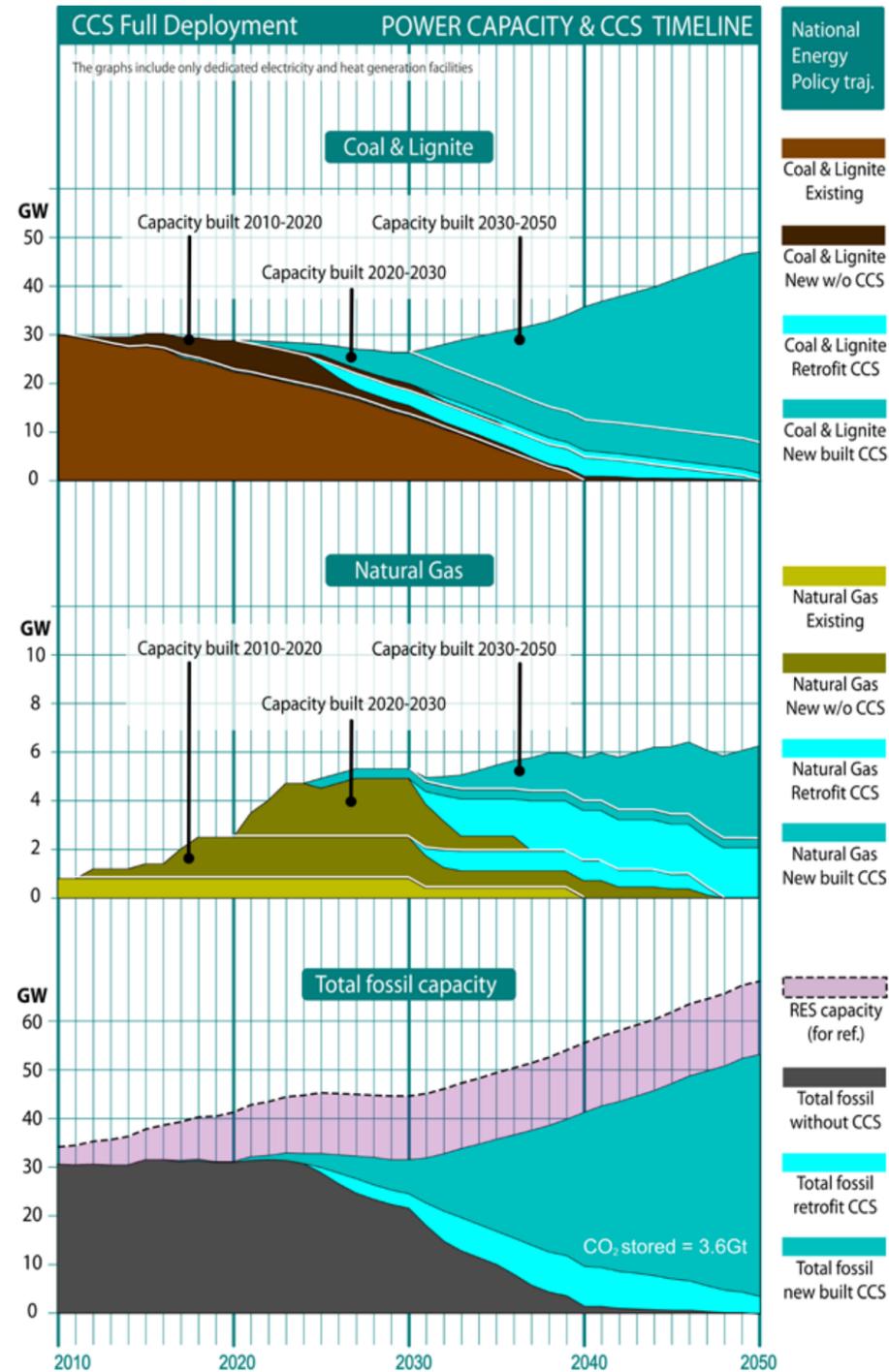
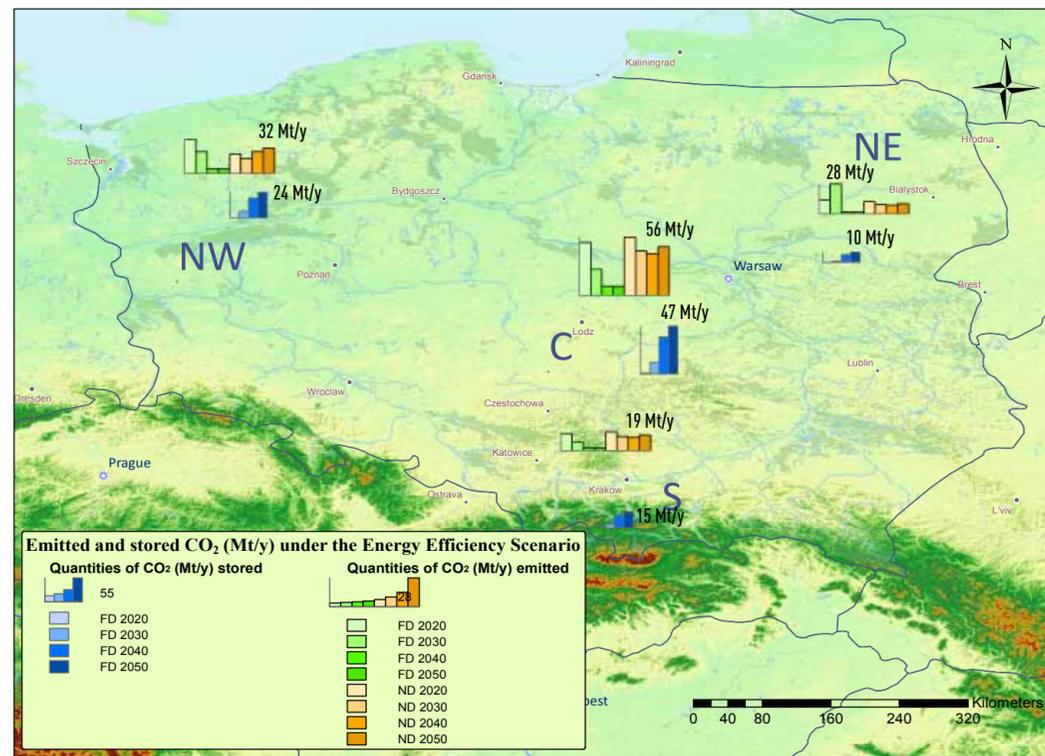


FIGURE A2 IMPACT OF CCS ON POWER SECTOR CO₂ EMISSIONS IN POLAND UNDER THE ENERGY EFFICIENCY TRAJECTORY
 Map of power sector emissions in Poland as a function of time under the Full Deployment scenario applied to the Energy Efficiency trajectory. The blue-turquoise graph shows the amount of CO₂ stored in a given region by 2020, 2030, 2040 and 2050 respectively, whereas the graph in green (Full deployment) and orange (No deployment) shows the amount of projected CO₂ emissions of this region calculated for 2020, 2030, 2040 and 2050



APPENDIX II - EU BIOMASS SUSTAINABILITY CRITERIA

Questions which are addressed in the European sustainability criteria relates to sustainability in production (land management, cultivation and harvesting), land use, land use change and forestry accounting (not indirect land use change), life cycle analysis and greenhouse gas performance and energy conversion efficiency.

- In the renewable energy directive, 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.

TABLE A1 PLANNED FUTURE INVESTMENTS IN THE POLISH POWER SECTOR

| Location | Capacity (MW) | Commencement of Operations | Investor | Fuel |
|-----------------------------|---------------|----------------------------|--------------------|----------------|
| Bełchatów | 858 | 2011 | PGE | lignite |
| Jaworzno 3_A | 50 | 2012 | Tauron | biomass |
| Dolna Odra – Szczecin | 88 | 2012 | PGE | biomass |
| Połaniec | 190 | 2012 | GDF Suez | biomass |
| Płock | 460 | 2012 | Orlen | gas/oil |
| Bielsko Biala | 50 | 2013 | Tauron | coal |
| Stalowa Wola | 400 | 2014 | Tauron + PGNiG | gas |
| Włocławek (Anwil) | 460 | 2014 | Orlen | gas |
| Tychy | 55 | 2015 | Tauron | coal + biomass |
| Opole blok 5 | 800 | 2015 | PGE | coal |
| Dolna Odra (Nowe Czarnowo) | 854 | 2015 | PGE | gas |
| Rybnik | 900 | 2015 | EDF | coal |
| Kozienice | 2000 | 2015 | ENEA | coal |
| Rafineria Gdańska | 200 | 2016 | ENERGA | oil |
| Dolna Odra - Pomorzany | 244 | 2016 | PGE | coal |
| Włocławek | 446 | 2016 | GDF Suez | gas |
| Turów | 460 | 2016 | PGE | lignite |
| Opole blok 6 | 800 | 2016 | PGE | coal |
| Połaniec | 833 | 2016 | GDF Suez | gas |
| Żarnowiec-Gdańsk-Grudziądz | 860 | 2016 | ENERGA | gas |
| Jaworzno 3_B | 900 | 2016 | Tauron | coal + biomass |
| Police | 1432 | 2016 | GDF Suez | coal |
| Lublin | 1600 | 2016 | GDF Suez/PGE | coal |
| Opalenie k. Gniewu | 1600 | 2016 | Vattenfall | coal |
| Puławy | 1660 | 2016 | Vattenfall | coal |
| Pelplino | 2000 | 2016 | Elektrownia Północ | coal |
| Ostrołęka | 1000 | 2017 | ENERGA | coal + biomass |
| Gubin | 2400 | 2018 | Enea | lignite |
| Pruszków | 70 | 2020 | Vattenfall | biomass |
| Żerań | 400 | 2020 | Vattenfall | gas |
| Siekierki | 480 | 2020 | Vattenfall | coal |
| Jaworzno 3 | 910 | 2020 | Tauron + KGHM | coal |
| Kędzierzyn Koźle/Błachownia | 910 | 2020 | Tauron | coal |
| Dolna Odra (Nowe Czarnowo) | 1600 | 2020 | PGE | gas |

TABLE A2 OPERATIONAL FOSSIL POWER PLANTS IN POLAND, AS OF 2010

| Plant name | Region | Industry sector | Main product | Power capacity (MW) | Heat capacity (MWt) | City | Latitude | Longitude | Primary fuel | CO ₂ emission (tonnes/yr) |
|--|--------------------|--|----------------------------|---------------------|---------------------|------------------|-----------|-----------|--------------|--------------------------------------|
| PGE Elektrownia Bełchatów S.A. | łódzkie | Heat and/or power | Electricity | 4 440,00 | | Rogowiec | 51.267903 | 19.264956 | lignite | 28 322 000 |
| BOT Elektrownia Turów S.A. | dolnośląskie | Production of electricity | Electricity | 2 088,00 | | Bogatynia | 50.948611 | 14.913056 | lignite | 12 900 000 |
| Elektrownia Kozienice S.A. | mazowieckie | Production and distribution of electricity | Electricity | 2 820,00 | 266,00 | Kozienice | 51.65 | 21.46667 | Coal | 10 000 000 |
| Elektrownia "RYBNIK" S.A. | śląskie | Production of electricity | Electricity | 1 775,00 | | Rybnik | 50.13334 | 18.533335 | Coal | 8 120 000 |
| Zespół Elektrowni Pątnów-Adamów - Konin S.A., Elektrownia Pątnów | wielkopolskie | Production of electricity | Electricity | 1 200,00 | | Konin | 52.305487 | 18.231726 | lignite | 7 070 000 |
| PGE Elektrownia Opole S.A. | opolskie | Production of electricity | Electricity | 1 492,00 | | Brzezie | 50.751825 | 17.881965 | coal | 6 910 000 |
| PGE Zespół Elektrowni Dolna Odra S.A. | zachodnopomorskie | Heat and/or power | Electricity | 1 772,00 | 64,40 | Nowe Czarnowo | 53.205776 | 14.466333 | Coal | 5 550 000 |
| Elektrownia Połaniec Spółka Akcyjna ? Grupa Electrabel Polska | świętokrzyskie | Production of electricity | Electricity | 1 600 | | Zawada | 50.438088 | 21.336805 | coal | 5 140 000 |
| Południowy Koncern Energetyczny S.A., Elektrownia Łaziska | śląskie | Production of electricity | Electricity | 1 155,00 | 196,00 | Łaziska Górne | 50.133694 | 18.846472 | Coal | 4 900 000 |
| Zespół Elektrowni Pątnów-Adamów -Konin S.A., Elektrownia Adamów | wielkopolskie | Production of electricity | Electricity | 600,00 | | Turek | 52.305448 | 18.231382 | lignite | 4 110 000 |
| Elektrociepłownia Siekierki | mazowieckie | Production and distribution of electricity | Electricity | 622,0 | | Warszawa | 52.18333 | 21.08333 | coal | 3 420 000 |
| Zespół Elektrowni Ostrołęka S.A. | mazowieckie | Production and distribution of electricity | Electricity | 674,00 | | Ostrołęka | 53.104331 | 21.613111 | Coal | 3 250 000 |
| Południowy Koncern Energetyczny S.A. Elektrownia Siersza w Trzebini | małopolskie | Production of electricity | Electricity | 666,0 | 36,50 | Trzebinia | 50.158755 | 19.469404 | Coal | 2 970 000 |
| Elektrociepłownia EC Nowa Sp. z o.o. | śląskie | Production of electricity | Electricity | | | Dąbrowa Górnicza | 50.344229 | 19.277735 | coal | 2 690 000 |
| Elektrociepłownia Żerań | mazowieckie | Production and distribution of electricity | Electricity | 334,0 | | Warszawa | 52.294688 | 20.990989 | coal | 2 470 000 |
| Południowy Koncern Energetyczny S.A., Elektrownia Łagisza | śląskie | Production of electricity | Electricity | 1 060,0 | 425,00 | Będzin | 50.348856 | 19.144535 | Coal | 2 360 000 |
| Elektrociepłownia "KRAKÓW" S.A | małopolskie | Steam and air conditioning supply | Hot water and conditioning | | | Kraków | 50.054166 | 20.006944 | coal | 1 790 000 |
| Elektrownia SKAWINA S.A. | małopolskie | Production and distribution of electricity | Electricity | 490,0 | 511,00 | Skawina | 49.96667 | 19.8 | Coal | 1 670 000 |
| Dalkia Poznań Zespół Elektrociepłowni S.A., Elektrociepłownia EC II Karolin | wielkopolskie | Heat and/or power | Electricity | 275,5 | | | 52.437883 | 16.984992 | coal | 1 560 000 |
| Elektrociepłownia Chorzów "ELCHO" Sp. z o.o. | śląskie | Production of electricity | Electricity | 238,4 | | Chorzów | 50.308293 | 18.968577 | Coal | 1 220 000 |
| Elektrownia "Stalowa Wola" S.A. | podkarpackie | Production of electricity | Electricity | 330,0 | | Stalowa Wola | 50.550717 | 22.077606 | Coal | 1 210 000 |
| Zespół Elektrociepłowni Wrocławskich KOGENERACJA S.A. - Wrocław | dolnośląskie | Heat and/or power | Electricity | 263,00 | 812,00 | Wrocław | 51.125102 | 17.02729 | Coal | 1 104 136 |
| Dalkia Łódź S.A. Elektrociepłownia nr 4 | łódzkie | Production of electricity | Electricity | 218,0 | | Łódź | 51.746323 | 19.53824 | Coal | 1 070 000 |
| Elektrociepłownia Bydgoszcz II | kujawsko-pomorskie | Steam and hot water supply | Electricity | 227,00 | 627,00 | Bydgoszcz | 53.105001 | 18.088496 | Coal | 1 010 000 |
| Zespół Elektrowni Pątnów-Adamów - Konin S.A., Elektrownia Konin | wielkopolskie | Production of electricity | Electricity | 193,00 | | Konin | 52.284166 | 18.271111 | lignite | 968 000 |
| Południowy Koncern Energetyczny S.A., Elektrownia Jaworzno III - Elektrownia III | śląskie | Production of electricity | Electricity | 1 345,00 | 50,60 | Jaworzno | 50.204553 | 19.20054 | Coal | 906 000 |
| Dalkia Łódź S.A. Elektrociepłownia nr 3 | łódzkie | Production of electricity | Electricity | | | Łódź | 51.798318 | 19.420266 | Coal | 882 000 |
| Południowy Koncern Energetyczny S.A., Elektrownia Jaworzno III - Elektrownia II | śląskie | Production of electricity | Electricity | 190,00 | 321,00 | Jaworzno | 50.204553 | 19.20054 | Coal | 847 000 |
| Południowy Koncern Energetyczny S.A., Elektrociepłownia Katowice | śląskie | Production of electricity | Electricity | 135,5 | | Katowice | 50.285308 | 19.053876 | coal | 739 000 |
| PGE Zespół Elektrowni Dolna Odra S.A., Elektrownia Pomorzany | zachodnopomorskie | Production of electricity | Electricity | 134,2 | | Szczecin | 53.39221 | 14.525685 | coal | 738 000 |
| Elektrociepłownie Wybrzeże S.A., Elektrociepłownia Gdyńska, | pomorskie | Steam and air conditioning supply | Hot water and conditioning | 122,44 | 454,77 | Gdynia | 54.555017 | 18.47012 | coal | 734 000 |
| Elektrociepłownia Gdańska, Elektrociepłownie Wybrzeże S.A. | pomorskie | Steam and air conditioning supply | Hot water and conditioning | 220,6 | 741,23 | Gdańsk | 54.377414 | 18.643284 | coal | 734 000 |
| Elektrociepłownia Białystok S.A. | podlaskie | Production and distribution of electricity | Electricity | 203,5 | | Białystok | 53.13333 | 23.16667 | coal | 704 000 |
| Dalkia Łódź S.A. Elektrociepłownia nr 2 | łódzkie | Production of electricity | Electricity | | | Łódź | 51.742443 | 19.447646 | coal | 579 000 |
| Spółka Energetyczna "Jastrzębie" S.A., Elektrociepłownia "Zofiówka" | śląskie | Production of electricity | Electricity | 64,0 | | Jastrzębie Zdrój | 49.964307 | 18.626783 | coal | 562 000 |
| Elektrociepłownia "Będzin" S.A. | śląskie | Steam and air conditioning supply | Steam and air conditioning | | | Będzin | 50.302045 | 19.137115 | coal | 544 000 |
| Elektrociepłownia "Zielona Góra" S.A. | lubuskie | Production of electricity conditioning | Electricity | 221,4 | | Zielona Góra | 51.952148 | 15.489349 | Coal/oil/gas | 533 000 |
| Elektrociepłownia "Lublin-Wrotków" Sp. z o.o. | lubelskie | Steam and hot water supply | Hot water | 246,5 | 592,00 | Lublin | 51.216673 | 22.558298 | Coal | 493 000 |
| Elektrociepłownia Gorzów S.A. | wielkopolskie | Production of electricity | Electricity | 97,50 | 270,00 | Gorzów Wlkp. | 52.750841 | 15.268099 | Gas | 475 753 |
| Zespół Elektrociepłowni Wrocławskich KOGENERACJA S.A., Elektrociepłownia Czechnica | dolnośląskie | Steam and air conditioning supply | Steam and air conditioning | 100,00 | 247 | SIECHNICE | 51.125129 | 17.027135 | coal | 428 000 |

| Plant name | Region | Industry sector | Main product | Power capacity (MW) | Heat capacity (MWt) | City | Latitude | Longitude | Primary fuel | CO ₂ emission (tonnes/yr) |
|---|---------------------|--|----------------------------|---------------------|---------------------|-------------------------|-----------|-----------|--------------|--------------------------------------|
| Energetyka Dwory Sp. z o.o. | małopolskie | Steam and air conditioning supply | Hot water and conditioning | 84,3 | | Oświęcim | 50.036084 | 19.254742 | coal | 421 000 |
| Południowy Koncern Energetyczny S.A., Zespół Elektrociepłowni Bielsko-Biała, Elektrociepłownia Bielsko-Północ EC2 | śląskie | Production of electricity | Electricity | 55,00 | | Czechowice-Dziedzice | 49.875487 | 19.028793 | Coal | 420 000 |
| PGE Zespół Elektrowni Dolna Odra S.A., Elektrownia Szczecin | zachodnopomorskie | Heat and/or power | Electricity | | | Szczecin | 53.411271 | 14.585981 | Coal | 395 000 |
| Elektrociepłownia Tychy S.A. | śląskie | Steam and air conditioning supply | Steam and air conditioning | 40,00 | 290,00 | Tychy | 50.106333 | 19.014333 | coal | 386 000 |
| Południowy Koncern Energetyczny S.A., Elektrownia Halemba | śląskie | Production of electricity | Electricity | 100,00 | 58,00 | Ruda Śląska | 50.234448 | 18.849698 | coal | 346 000 |
| Południowy Koncern Energetyczny S.A., Elektrownia Blachownia | opolskie | Production of electricity | Electricity | 165,00 | | Kędzierzyn Koźle | 50.35 | 18.283333 | coal | 336 000 |
| Elektrociepłownia Nowa Sarzyna Sp. z o.o. Elektrownia Blachownia | podkarpackie | Production of electricity | Electricity | 112,8 | | Nowa Sarzyna | 50.317472 | 22.323611 | coal | 329 000 |
| Zespół Elektrociepłowni Bytom S.A., Elektrociepłownia Miechowice | śląskie | Production of electricity | Electricity | 55,0 | | Bytom | 50.348664 | 18.843055 | coal | 279 000 |
| Elektrociepłownia Rzeszów S.A. | podkarpackie | Production of electricity | Electricity | | | Rzeszów | 50.061244 | 22.027373 | coal | 271 000 |
| “Elektrociepłownia Elbląg” Sp. z o.o. | warmińsko-mazurskie | Steam and air conditioning supply | Hot water and conditioning | 49,0 | | Elbląg | 54.181721 | 19.389308 | coal | 271 000 |
| Południowy Koncern Energetyczny S.A., Zespół Elektrociepłowni Bielsko-Biała, Elektrociepłownia Bielsko-Biała EC1 | śląskie | Production of electricity | Electricity | 77,00 | 275 MJ/s | Bielsko-Biała | 49.812 | 19.0525 | Coal | 265 000 |
| Elektrociepłownia Kawęczyn | mazowieckie | Production and distribution of electricity | Electricity | | | Warszawa | 52.269628 | 21.122246 | coal | 246 000 |
| Przedsiębiorstwo Energetyki Ciepłej - Gliwice Sp. z o.o. | śląskie | Production of electricity | Electricity | | | Gliwice | 50.292222 | 18.710833 | coal | 246 000 |
| Spółka Energetyczna “Jastrzębie” S.A., Elektrociepłownia “Moszczenica” | śląskie | Production of electricity | Electricity | 36,6 | | Jastrzębie Zdrój | 49.942079 | 18.569813 | coal | 234 000 |
| FENICE Poland Sp. z o.o., Jednostka Operacyjna Rzeszów | podkarpackie | Steam and air conditioning supply | Hot water and conditioning | 12,0 | | Rzeszów | 50.015668 | 21.990595 | | 221 000 |
| Toruńska Energetyka Cergia SA – EC1 | kujawsko-pomorskie | Production of electricity | Electricity | | | Toruń | 53.01667 | 18.55 | coal | 203 000 |
| Kompania Węglowa S.A. Oddział Zakład Elektrociepłowni, Elektrociepłownia Chwałowice | śląskie | Steam and air conditioning supply | Steam and air conditioning | 16,8 | | Rybnik | 50.069918 | 18.552176 | coal | 186 000 |
| Elektrociepłownia Kielce S. A. | świętokrzyskie | Steam and air conditioning supply | Hot water and conditioning | 10,8 | | Kielce | 50.897778 | 20.616389 | coal | 178 000 |
| Fortum Częstochowa S.A., Ciepłownia | śląskie | Steam and air conditioning supply | Steam and air conditioning | | | Częstochowa | 50.794252 | 19.142453 | coal | 175 000 |
| Elektrociepłownia Mielec Sp. z o.o. | podkarpackie | Production and distribution of electricity | Electricity | | | Mielec | 50.287584 | 21.423512 | coal | 170 000 |
| Energetyka Ciepła Opolszczyzny S.A., Zakład Energetyki Ciepłej w Opolu, Ciepłownia Centralna K-173 | opolskie | Steam and air conditioning supply | Steam and air conditioning | | | Opole | 50.684822 | 17.921907 | coal | 166 000 |
| Miejskie Przedsiębiorstwo Energetyki Ciepłej Sp. z o.o., Wydział Ciepłowni Kortowo | warmińsko-mazurskie | heat | operational | | | Olsztyn | 53.74767 | 20.445793 | coal | 153 000 |
| Radomskie Przedsiębiorstwo Energetyki Ciepłej “RADPEC” S.A., Ciepłownia POŁUDNIE | mazowieckie | Steam and air conditioning supply | Hot water and conditioning | | | Radom | 51.356561 | 21.106024 | coal | 142 000 |
| Zakład Elektroenergetyczny H.CZ. “ELSEN” Sp. z o.o. | śląskie | Production of electricity | Electricity | | | Częstochowa | 50.795278 | 19.183056 | coal | 140 000 |
| Miejskie Przedsiębiorstwo Energetyki Ciepłej Sp. z o.o., Ciepłownia Wschód | kujawsko-pomorskie | Steam and air conditioning supply | Hot water and conditioning | | | Włocławek | 52.654772 | 19.098787 | coal | 139 000 |
| Energetyka Sp. z o.o., Wydział EC-1 | dolnośląskie | Steam and air conditioning supply | Steam and air conditioning | | | Lubin | 51.406765 | 16.198222 | coal | 138 000 |
| “Elektrociepłownia Marcel” Sp. z o.o., Elektrociepłownia Marcel | śląskie | Production of electricity | Electricity | 34,5 | | Radlin | 50.043415 | 18.484539 | coal | 135 000 |
| Ciepłownia Centralna | mazowieckie | Steam and hot water supply | Hot water | | 156,63 | Siedlce | 52.16667 | 22.3 | Coal | 125 000 |
| Elektrociepłownia Pruszków | mazowieckie | Production and distribution of electricity | Electricity | 7,1 | | Pruszków | 52.170787 | 20.798385 | coal | 123 000 |
| Zakład Energetyki Ciepłej w Lubinie | dolnośląskie | Steam and air conditioning supply | Steam and air conditioning | | | Lubin | 51.37969 | 16.18585 | coal | 116 000 |
| Miejska Energetyka Ciepła Sp. z o.o., Ciepłownia | świętokrzyskie | Steam and air conditioning supply | Hot water and conditioning | | | Óstrowiec Świętokrzyski | 50.947922 | 21.448386 | coal | 112 000 |
| Zakład Energetyki Ciepłej Sp.z o.o. | kujawsko-pomorskie | Steam and hot water supply | Hot water | | | Inowrocław | 52.767215 | 18.240995 | coal | 110 000 |
| Miejskie Przedsiębiorstwo Energetyki Ciepłej Sp. z o.o. | lubelskie | Steam and hot water supply | Hot water | | | Chełm | 51.13333 | 23.48333 | Coal | 109 000 |
| MPEC Sp. z o.o. Białystok - Ciepłownia Zachód | podlaskie | Steam and hot water supply | Hot water | | | Białystok | 53.132611 | 23.171368 | coal | 109 000 |
| Centralna Ciepłownia w Legnicy należąca do WPEC w Legnicy S.A. | dolnośląskie | Steam and hot water supply | Hot water | 190,96 | | Legnica | 51.234918 | 16.18829 | coal | 109 000 |
| Miejskie Przedsiębiorstwo Energetyki Ciepłej Spółka Akcyjna w Tarnowie | małopolskie | Steam and hot water supply | Hot water | | 153,40 | Tarnów | 50.03862 | 20.981998 | Coal | 107 000 |
| Energetyka Sp. z o.o. Wydział EC-2 Polkowice | dolnośląskie | Heat and/or power | Heat | 10,40 | 211,40 | Polkowice | 51.487209 | 16.06596 | coal | 105 000 |
| Kotłownia Rejonowa KR 1 | zachodnopomorskie | Steam and hot water supply | Hot water | 16,90 | | Słupsk | 53.722717 | 16.677783 | coal | 105 000 |
| MEGATEM EC- Lublin Sp. z o.o. | lubelskie | Steam and hot water supply | Hot water | 24,0 | | Lublin | 51.23333 | 22.56667 | coal | - |
| Energomedia Sp. z o.o. | małopolskie | Steam and hot water supply | Hot water | 7,5 | | Trzebinia | 50.16667 | 19.45 | coal | - |
| Energetyka Boruta Sp. z o.o, Elektrociepłownia ECIII i Ciepłownia ECII | łódzkie | Steam and air conditioning supply | Hot water | 36,3 | | Zgierz | 51.841111 | 19.394444 | coal | - |

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