Final ACCESS report

Clean Coal Technologies and Carbon Capture and Storage in Kazakhstan

Reflections and ACCESS project results

Assistance in Clean Coal & Environmentally Sound Storage Solutions

"The contents of this publication are the sole responsibility of the ACCESS project team and can in no way be taken to reflect the views of the European Union."

Publisher

Royal Belgian Institute of Natural Sciences
Geological Survey of Belgium
Jennerstraat 13
1000 Brussels
Belgium
Tel. +32 2 788 76 54
Fax +32 2 647 73 59

ISBN 9789089130259

Team of authors

Nesladek, M.[1], Helsen, S.[2], Piessens, K.[3], Van Passel, S.[1], Gaydardzhiev, S.[4], Kryukova, V.[5], Myngheer, S.[2], Janssens, R.[3], Welkenhuysen, K.[3], Compernolle, T.[1], Mathieu, P.[4], & Dusar, M.[3]

Editors

Myngheer, S.[2], Janssens, R.[3], Welkenhuysen, K.[3] & Compernolle, T.[1]

Project team

[1] Hasselt University
www.uhasselt.be

[2] Ecorem n.v.
www.ecorem.be

[3] Royal Belgian Institute of Natural Sciences - Geological Survey of Belgium
www.naturalsciences.be/geology

[4] University of Liège
www.ulg.ac.be

[5] Climate Change Coordination Centre
www.climate.kz

Project website: www.access-kazakhstan.eu

This project is funded by the European Union

Acronyms and abbreviations

ACCESS	Assistance in Clean Coal and Environmentally sound Storage Solutions
C4	Climate Change Coordination Centre
CBM	Coalbed methane
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCT	Clean coal technology
CHP	Combined heat and power
CO_2	Carbon dioxide
CO_{2eq}	Carbon dioxide equivalent
ECBM	Enhanced Coal Bed Methane
EIA	Environmental Impact Assessment
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gases
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
kWh	kiloWatt-hour
LHV	Lower Heating Value
MAC	Marginal abatement cost
MACC	Marginal abatement cost curve
MoU	Memorandum of Understanding
Mt	Million tonnes
NGCC	Natural Gas Combined Cycle
PM	Particulate Matter

Contents

Executive summary

Kazakhstan is the leading industrial country in Central-Asia with, amongst others, important coal, oil, gas and uranium reserves. The energy production of Kazakhstan is currently based on these resources, of which coal plays a central role. It is expected that economic growth will lead to a further increase in power production. Despite the potential for sustainable energy production, traditional coal-based energy sources will remain important in Kazakhstan.

Coal-based energy production has a significant environmental impact on human health and ecosystems, both on a local and global scale. These adverse effects urge the need for a more sustainable power sector in Kazakhstan, enabling this sector to grow but without a corresponding increase in environmental pressure. Clean Coal Technologies (CCT) and Carbon Capture and Storage (CCS) are part of the solution to achieve this transition.

The findings of the ACCESS project are the result of different techno-economic analyses on both macro (country) and micro (company) level. Also the workshops, meetings and discussions with different stakeholders from the power industry led to important insights necessary to conduct the analyses presented in this report.

Clean coal technologies can be implemented at many different levels within the power production process. Coal mining, coal treatment, coal combustion and emission abatement are for instance all eligible to the adoption of clean coal technologies.

From the project, it appeared that CCT and CCS are indeed very promising technologies in Kazakhstan. Clean coal can be implemented at many different levels in coal based industries. The project showed that the treatment of coals, the combustion of coal and the abatement of the associated emissions into the atmosphere are all eligible for the implementation of clean coal technologies. Concrete options have been developed in the project. One of the main general findings of the ACCESS project is furthermore the need for an integrated approach in the implementation of the clean coal technologies, because an important link exists between the different coal-based industries. Overall, the ACCESS project contributed to the increased interest given to this challenge by researchers, authorities and industrialists, and gave rise to recommendations for next steps in the transition towards a sustainable coal sector.

The results have been welcomed by the stakeholders at the concluding high-level meeting of the project on October 24, 2012.

The ACCESS project is as a first step towards a continuing collaboration between the EU and Kazakhstan and concrete implementation of technologies and legislation in Kazakhstan in the field of CCS and CCT, covering coal mines, coal combustion, associated environmental technologies and policy, energy research, etc. Furthermore, concrete challenges for the Kazakh industry that need to be taken a step further were also identified. More detailed and often site-specific studies and actions are needed in order to accelerate the transition to a green and low-carbon economy.

Clean Coal Technologies and CO_2 Capture and Storage

Clean Coal Technology (CCT) covers technological approaches that aim to reduce the environmental impact of coal combustion, for example, through a better coal preparation, efficient combustion techniques, and emission abatement technologies. These different technologies can be applied at one or more different stages of the process, starting before combustion of the coal, during the combustion stage and at the end of the process.

CO_2 capture and storage (CCS) is in fact a type of CCT. The technology comprises in its most basic concept three main steps (fig. 1), referred to as (1) 'capture' of CO_2 at a main industrial facility or 'source' (power plants / heavy industry), (2) 'transport' by pipeline and (3) 'geological storage' in deep geological reservoirs, called 'sinks'. By storing the CO_2 permanently deep underground, the CO_2 is prevented from entering the atmosphere and will no longer contribute to climate change.

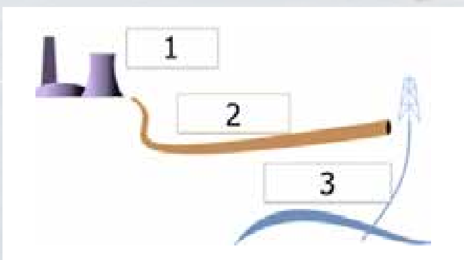


Fig. 1. The basic Carbon Capture and Storage scheme, with indication of the main steps (conceptual drawing, not to scale).

1 Introduction

This document is the final report of the ACCESS project which stands for Assistance in Clean Coal and Environmentally sound Storage Solutions. The project primary objective is to build capacity on the use of clean coal technologies (CCT) and carbon capture and storage (CCS) in Kazakhstan. It further aims to identify the different actions Kazakhstan can take in response to the environmental effects caused by climate change. Focus of the ACCESS project is put on the power production in Kazakhstan. As this power production is mainly coal-based, it puts pressure on all aspects of the environment and public health.

During the course of the ACCESS project, different workshops were held in order to exchange knowledge on possible applications of Clean Coal Technologies (CCT) and Carbon Capture and Storage (CCS). Besides capacity building, these events also allowed the ACCESS partners to come in contact with different stakeholders of industrial sectors such as the power industry and metallurgy, governmental institutes, scientists, etc. These contacts resulted in the identification of different specific case studies which made it possible to show how theory can be put into practice within the technical, economic, and environmental context specific for Kazakhstan. Although a broad range of topics are identified during the workshops, the ACCESS partners selected four of those topics to study in depth, namely: coal beneficiation, coal-fired power production, air quality, and CCS. The other themes that were identified during the workshops are only briefly scrutinized and considered as possible subject to further study.

Both the close contact with the different stakeholders and the results of the conducted studies leads to conclusions and recommendations upon which the ACCESS partners wish to reflect in this report. These reflections should be considered as a first evaluation of the different actions that can be taken to deal with the environmental issues that Kazakhstan faces. More detailed and site specific studies are required in order to define the optimal means to start the transition to a green and low-carbon economy.

First, this report describes the different challenges that Kazakhstan faces (Chapter 2). Next, the report presents the ACCESS project (Chapter 3) and the different capacity building actions (Chapter 4). In Chapter 5 the four selected topics are discussed and reflections are presented. This covers coal beneficiation, issues regarding coal-fired power production, measures to be taken in order to improve local air quality and the adoption of CCS. The conclusions and recommendations resulting from these studies and the overall project are presented in Chapter 6.

International climate targets of Kazakhstan

Kazakhstan ratified the UN Framework Convention on Climate Change (UNFCCC) in 1995. In accordance with Articles 4.1 (c), (j) and 12 of the Convention, under which countries periodically submit reports on actions to address climate change to the Conference of the Parties, Kazakhstan has prepared and presented the first National Communication at the Fourth Conference of the Parties. At the same conference the voluntary quantitative commitments to reduce greenhouse gas emissions were announced. The Kyoto Protocol to the UNFCCC was signed by Kazakhstan in 1999 and ratified in March 2009. At the seventh Conference of the Parties in Morocco it was agreed that "Kazakhstan is a non- Annex 1 country under the Convention and in the case of ratification of the Protocol and its entry into force, Kazakhstan becomes Annex 1 country under the Kyoto Protocol". This decision came into force on September 17, 2009 after Kazakhstan became a Party to the Kyoto Protocol.

Since 2000, Kazakhstan has held an annual inventory of Greenhouse Gas GHG emissions. In May 2009 in Bonn, Kazakhstan had developed and submitted the Second National Communication to the UNFCCC. In the same year Kazakhstan announced its quantitative reductions of GHG emissions for the post 2012 period. A reduction by 15% by 2020 and by 25% by 2050 against the base 1992 and an inventory in the form for Annex I countries was submitted to the UNFCCC Secretariat.

In the Republic of Kazakhstan a series of laws and regulations aiming at climate change mitigation were developed and adopted with among them the Environmental Code of the Republic of Kazakhstan of January 9, 2007. Currently, the Ministry of Environment Protection of Kazakhstan is working to establish a National Greenhouse Gas Emission Trading System.

2

The challenge for Kazakhstan

Climate Change

As a result of natural factors, climate has varied continuously on all timescales and will continue to vary in the future.

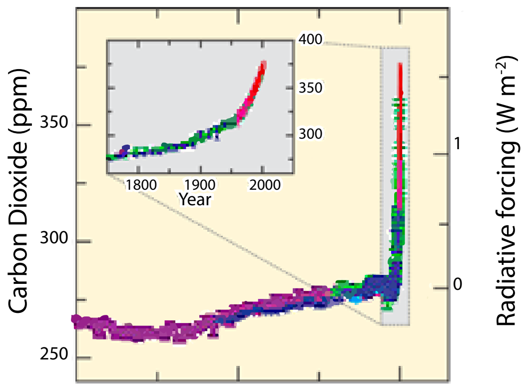


Fig. 2. Changes in CO_2 through time from ice cores and modern data [1].

Since the Western industrial revolution in the 19th century, also human activities have caused a change in the climate, which is significant and rapid Recorded data show that important greenhouse gas (CO_2, N_2O and CH_4) concentrations have increased considerably since the industrial revolution and now far exceed pre-industrial levels determined from ice cores spanning many thousands of years (fig. 2). The majority of the scientists link these increased emissions to the temperature increase observed in the last decades.

The global increase in CO_2 concentration is attributed to burning of fossil fuels and deforestation.

CO_2 is the most important anthropogenic greenhouse gas (GHG). The global atmospheric concentration of CO_2 has increased from 180 ppm (parts per million) some 650,000 years ago over a pre-industrial value of 280 ppm to 391 ppm in 2011. For the period 1992-2001 the average annual increase was 1.6 ppm per year while the past decade (2002-2011) knew an average annual increase of 2.07 ppm per year. An increase in the average temperature of the Earth's atmosphere and oceans of about 0.6°C is observed over the last century, particularly for the last decades. This trend, consistently observed worldwide, implies significant warming on a global scale. Model simulations predict a future global warming of about 2.5°C in 2100. Hot extremes and heat waves are expected to intensify and become more frequent worldwide. The amount of precipitation will very likely increase in the high latitudes and decrease in most subtropical regions. Continental areas far from oceans and seas are expected to become drier and a sea level rise of 0.1 to 0.2 m towards 2100 is expected.

With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow.

The situation in Central-Asia, and thus Kazakhstan, is even more problematic. After a steadily rising temperature in the 20th century (fig. 3), simulations estimate a temperature increase of 3.7°C and an annual precipitation decrease of 3 % (-13% in spring, summer and autumn) towards 2100. This means that more frequent dry spring, summer and autumn seasons can be expected which can cause a crop yield decrease of 30% [1].

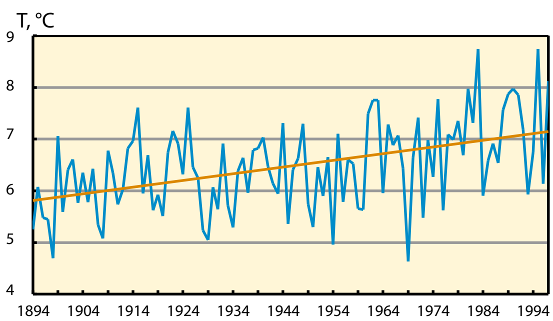


Fig. 3. Increase in the mean annual temperature of Kazakhstan during the 20th Century [2].

Economic development in Kazakhstan

During the Soviet period, Kazakhstan was an agrarian, raw materials supplier in the former Soviet economy. After Kazakhstan became independent in December, 1991, it started a process of reforms in order to transform its planned economy into a market economy. After a period of hyperinflation (1992-1994), the liberalization of prices, trade and currency has led to positive average annual growth rates, since 2000. The growth of the Kazakh economy was primarily due to increased foreign direct investments and increased exports. The increase in exports was the result of rising world prices for oil and metals, and also the economic recovery of the Russian Federation as its biggest trade partner [3, 4].

At present, economic growth in 2013 is projected to 6.5%, reflecting the slowdown expected in Europe and the Russian Federation. Although energy tariffs are set by the government of Kazakhstan, these tariffs are increasing to incentivise the investment in energy efficient power production and use [5]. The economy remains dependent on the export of oil, minerals, and metals which makes economic growth vulnerable to international price fluctuations. To diversify its economy, Kazakhstan needs to develop competitive projects based on its comparative advantages in agriculture, construction materials, oil and gas refining and infrastructure, metallurgy, chemicals, pharmaceuticals, defense, and energy development [6, 7]. However, the economic development of Kazakhstan also resulted in an increased carbon intensity. Kazakhstan produces 200% more CO_2 per unit of GDP than China [8].

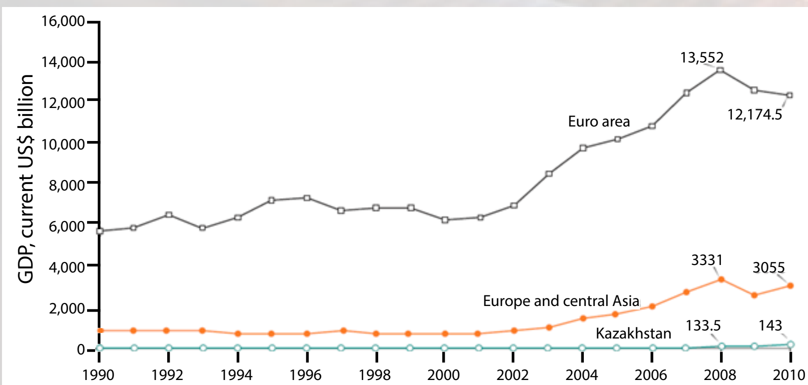


Fig.4. Kazakhstan's GDP evolution [9].

Power production in Kazakhstan

The electricity sector is worldwide one of the largest CO_2 and pollutant emitting industries due to the abundant use of fossil fuels. Kazakhstan, one of the leading industries in Central-Asia, is no exception. The republic's large coal, gas, oil and uranium reserves makes the Kazakh energy policy of great national and international interest. For example, Kazakhstan can rely on the country's rich coalmines for the increasing energy demand for over 100 years [15], even with a continuing economic growth.

Power production in Kazakhstan is mainly coal-based. Outdated power plants and transmission losses result in an inefficient power production.

Most of Kazakhstan's own power plants are outdated and inefficient which implies, seen the fast economic growth, that energy shortage can occur and that the negative influence on the environment will increase if no actions are taken [12].

Fig. 5. The Ekibastuz GRES-1 coal-fired power plant [13].

In 2011 Kazakhstan had an installed power generation capacity of 18.5 GW, 80% is coal fired, 12% is hydroelectric and the remaining 8% is generated through hydrocarbon combustion (mainly natural gas) [10, 11, 15].

Investments in small scale renewable energy plants can resolve energy shortages in the South and reduce transmission losses.

Most of the Kazakh power is generated by coal-fired power plants situated in the northern coal producing regions [15] (e.g. fig. 5). The electricity produced in these areas exceeds the region's demand, and part of it is transmitted to other regions. New projects combined with the technological upgrades of aging installations should match the increasing energy demand. However, insufficient transmission capability between the northern region and the other regions creates energy shortage in the South and West of Kazakhstan.

In the West, the installation of new coal-fired and gas-fired power plants should decrease the regions deficit while in the South plans were made for new hydroelectric power plants and wind turbines [12]. Remaining deficits should be resolved with a more extended electricity transmission network from the North towards the West and South. Now, Kazakhstan is forced to import electricity for consumers in the South from neighbouring countries. The excess electricity generated in the North is exported towards Russia.

The large territory of Kazakhstan, the transmission of electricity often towards remote consumers, and the associated problems in terms of management, maintenance and renovation causes a great deal of transmission losses (25 to 50%), which significantly decreases the efficiency of the overall system [12]. The estimated cost of power transport to rural areas may reach up to 0.04 €/kWh. This is about ten times more as in Europe (0.003 €/kWh in UK) [12, 14].

Transmission losses can be reduced if small scale renewable energy plants, such as wind turbines, concentrated solar power systems and photovoltaic solar cells, are installed close to the rural communities. The potential of renewable energy in Kazakhstan is exceptionally high. However, implementing this potential energy source needs a partial adjustment of the transmission lines and new policy measures.

Plans exist to construct a new nuclear power plant, which might be a logical step for the future energy strategy seen the large principal uranium reserves.

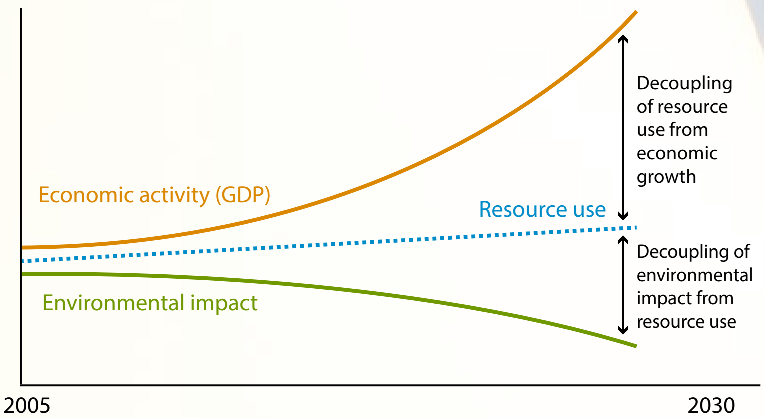
Sustainability and acceptability

'Sustainable development' is defined by the Brundtland Commission of the United Nations in 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". To reach sustainability, **decoupling** is necessary: the ability of an economy to grow without corresponding increases in environmental pressure.

Sustainability is a word with a very positive connotation that is associated with favourable effects on nature, climate and mankind. It seems to be something that we want all around us, and yet the strive towards a more sustainable world is a cumbersome undertaking. Sustainability seems to be a worthy principle, but too often not acceptable when it is actually to be implemented.

This paradox certainly holds when it comes to sustainable production of energy. When looking from afar, everything seems clear. Fossil fuels are dirty, represent a limited resource, and result in global warming that has been identified as a worldwide threat. Renewable energy is clean, cannot be depleted, and is climate neutral. The logical action is therefore to abandon fossil fuels, and embrace renewables.

The a-priori positive attitude towards renewable energy leads to a less critical evaluation of its potential, up to the moment when details need to be filled in for actual projects. It is then that practical difficulties are acknowledged, such as those associated with the conversion of an entire energy infrastructure, matching of production and demand, production costs, hidden emissions, limitations, etc. In certain countries, public opposition may locally become quite strong when decentralised renewable infrastructure is build close to local communities.



Environment and public health

To keep up with the economic growth of the country, energy production will need to increase further. And although Kazakhstan has a large potential for sustainable energy production from wind, solar and water, traditional energy sources will remain important.

Traditional coal-based energy production has a significant environmental impact on human health and ecosystems, both on a local and global scale. Emissions of atmospheric pollutants and of the greenhouse gas CO_2, release of pollutants to water, and generation of waste are main impact categories linked to coal combustion. The magnitude of these effects depends in general on the quality of the coal that is fired in the power plant, of the technology used for power production, and of power plant characteristics such as the age of the installation and the use of pollution control technologies.

Atmospheric pollutants

Emissions of pollutants to the atmosphere from coal fired-power plants cover mainly sulfur dioxides (SO_2), nitrogen oxides (NO_x), particulate matter (PM) or dust, and heavy metals.

Emissions of pollutants from coal-fired power plants can have a negative effect on human health and nature.

NO_x is formed under high temperatures (occurring during the combustion process in the boiler) out of the nitrogen present in the coal and in the combustion air. NO_x may form with other substances different compounds like nitric acid and ozone, which can both cause amongst others damage to the lung tissue. NO_x furthermore destroys the ozone layer in the stratosphere.

The emissions of SO_2 are in an important way related to the sulfur content of the coal. When SO_2 is oxidized to sulfuric acid, H_2SO_4, it contributes largely to the formation of acid rains.

During the combustion of coal, the mineral matter (inorganic impurities) converts to ash. An important part of the ashes (or otherwise called dust or particulate matter) leaves the boiler as fly ash and, without abatement, will be emitted to the atmosphere Especially small particles less than 10 micrometers in diameter pose the greatest health problems. Exposure to such particles can affect both the lungs and the heart.

During combustion heavy metals such as arsenic, cadmium, mercury and lead become volatile in the metallic form or by forming chlorides, oxides, sulfides etc. Most heavy metals condensate and can be collected with the fly ash. But when they are released in the environment (in the air, water, soil and the food chain) they can have toxic effects on men and nature.

Whereas atmospheric pollutants mainly give rise to local problems, the emission of CO_2 enhances the global problem of climate change as described in the previous chapter.

Water

Pollutants to water are mainly the result of the wet treatment of the flue gasses. By scrubbing the flue gasses, pollutants are removed from the air and dissolved in the water. When this water is not treated appropriately, the pollutants (sulfides, nitrates, heavy metals), can be released in the environment. Furthermore, power plant with open cycle-cooling use huge amounts of cooling water, decreasing fresh water stocks. Also this water is discharged at a relatively high temperature (> 30°C) which may affect the aquatic life. Closed cycle-cooling (by the use of cooling towers) limits the water uptake considerably and eliminates the discharge of warm water.

Waste

The part of the ashes that does not leave the boiler as fly ash remains as bottom ash or bottom slag (liquefied ash caused by high temperatures). Fly ash can (partially) be recovered from the flue gas through different techniques. Bottom ash, slag and the recovered fly ash give rise to an important quantity of waste. Whenever possible, this coal waste can be applied as additive in concrete industry, public works, etc., on the condition that the metals and other pollutants are immobilized.

Coal in the EU and EU policy

In the EU, coal adds to a diversified energy portfolio and contributes to security of supply. In 2010, coal use accounted for 16% of EU-27 total energy consumption and 25% of EU-27 electricity generation. EU is the fourth largest consumer behind China, USA and India (303 Mt hard coal and 415 Mt lignite in 2010).

Against this background, the European Union has adopted a number of measures at policy and instrumental levels, seeking to address challenges represented amongst others by coal use.

Under the Kyoto protocol, The European Union committed itself to a emission reduction of 8% compared to 1990 in the period 2008-2012. For the period after the Kyoto-protocol (2013-2020), the European Union formulated the "20-20-20" targets in its Climate and Energy package. One of the targets is the reduction in EU greenhouse gas emissions of at least 20% below 1990 levels by 2020.

In March 2011, the European Commission launched "A Roadmap for moving to a competitive low carbon economy in 2050". The roadmap lays out a plan for the EU to meet a long-term target of reducing domestic GHG emissions by 80 to 95% by 2050 against 1990 levels. This long-term target of reducing domestic emissions has been agreed by European Heads of State and governments. In December 2011, the European Commission adopted the Communication "Energy Roadmap 2050", which provides scenarios for achieving EU's decarbonisation objective while, at the same time, ensuring security of energy supply and competitiveness. It recognizes that long-term future of coal use requires the utilisation of CCS.

The EU takes leading position in the implementation of CCS and CCT through setting out a clear long-term vision, adapting its legislative and regulatory framework and funding of research and demonstration projects.

The ACCESS project

3

ACCESS: a joint EU-Kazakhstan collaboration

The adverse effects of traditional coal-based power production urge the need of a sustainable development of the coal-fired power sector in Kazakhstan, enabling the sector to continue to grow but without a corresponding increase in environmental pressure. Clean Coal Technologies (CCT) and Carbon Capture and Storage (CCS) are part of the solution to achieve this sustainable development.

The European Union is taking a leading position in the implementation and transfer of these technologies. In this light, the European Commission launched a call for proposals in 2010 (EuropeAid) on "Capacity building and studies on clean coal technologies and carbon capture and storage". The call was directed for the countries India, Indonesia, Kazakhstan, the Russian Federation, South Africa and Ukraine. The call is more precisely granted under the European Thematic Programme "Environment and sustainable management of natural resources, including energy No: EuropeAid/129199/C/ACT/TPS". Moreover, the project that was to be implemented in Kazakhstan is also part of the implementation of the EU-Kazakhstan Memorandum of Understanding on cooperation in the field of energy. This Memorandum, which was signed in 2006, has enhanced the EU-Kazakhstan cooperation for an improved coal value chain and a sustainable development of the energy sector in Kazakhstan.

The European Commission selected the "ACCESS" project in December, 2010 to be implemented in Kazakhstan. "ACCESS" is short for Assistance in Clean Coal and Environmentally sound Storage Solutions. The ACCESS project team is a joint collaboration between Kazakh and European partners and consists of a Belgian team of experts from the University of Hasselt, the environmental consultant Ecorem, the University of Liege and the Geological Survey of Belgium. The Belgian experts work together with the Kazakh partner Climate Change Coordination Center.

The ACCESS project is 70% funded by the EU, and has a total value of 687.000 Euro.

The ACCESS project is a capacity building project that intends to accelerate and deepen the exchange of EU knowledge and experience in the field of CCT and CCS towards Kazakhstan. The transition to a cleaner power production can enable an important economic development in the country based on novel technologies, including economic and environmental benefits. By developing this project, the vision of European and Kazakhstan policies on environmental and energetic challenges are brought together, acquainting both sides with the current state-of-the-art in these fields.

As such, the primary objective of the ACCESS project is to build capacity for the development of CCT as well as the identification of the potential for CCS in Kazakhstan.

The ACCESS project team together with Mrs. Alia Baidebekova (EU delegation project responsible), Mr. Klyakin (Deputy Director of the Power and Coal Industry Department of the Ministry of Industry and New Technologies) and some of the participants to the final ACCESS even that was held in Astana on the 24th of October, 2012.

Objectives of the ACCESS project

The objectives of the project cover different main topics:

- **CCT:** show the principles and the potential of the CCT technologies advanced coal washing techniques, new combustion technologies, end-of-pipe emission reduction techniques, with the ultimate aim to improve the efficiency and reduce the environmental impact of the coal industry;
- **CCS:** identify the potential for CO_2 capture, and storage for the power production sector in terms of economy and geology, and raise awareness on CCS on different stakeholder levels;
- **Health, Safety and Environment (HSE) and social aspects:** demonstrate the use of assessment tools such as air quality modeling and environmental impact assessments to prevent adverse environmental effects;
- **Air pollution monitoring:** demonstrate state-of-the-art CO_2 and other greenhouse gas monitoring strategies by using high-tech development technologies using real-time sensing;
- **Economics:** use sustainable economic assessment tools related to clean technologies and to health, safety and environment.

The capacity building objective is clearly a key component in each of these topics and has been, implemented through different actions that are presented in the following chapter. Furthermore specific case studies have been developed in the project to feed the capacity building mission and to provide specific solutions or pathways to solutions. The case studies are discussed in Chapter 5.

"I really liked the seminar, which I attended in November 2011 in Almaty. To my opinion the seminar had a good organisation and style of communication, a wide contingent of participants, high level of speakers and lecturers. JSC 'SevKazEnergo' is a direct user of natural resources and a power generation company.

We look for a mutually beneficial cooperation in international projects on greenhouse gas (GHG) emissions and the conducted seminar deepens and broadens discussed topics related to environmental issues and climate change, including the concept of carbon capture and storage in Kazakhstan, the efficiency costs associated with GHG. Our company has been involved in the ACCESS seminars from the first meeting and the project gives more opportunities for closer cooperation of JSC "SevKazEnergo" with the ACCESS team on reduction of greenhouse gas emissions and improvement of the air quality.

Given the legislative changes in GHG emissions and the introduction of the National Plan, these seminars are relevant and of interest to my work as the lead engineer on the environment at Petropavlovsk TETs-2AO SevKazEnergo."

Mrs. Anna Ajtikeeva

Lead engineer of the department of environment
at JSC "SevKazEnergo", Petropavlovsk and
participant to the ACCESS project workshops

"Capacity Building is the process in which a transfer of knowledge, experience and best practices takes place. The idea is to prepare Kazakhstan for the realization of projects that implement clean coal technologies and that capture and store carbon dioxide. The European Union is a lead player in these technologies and is the perfect partner for Kazakhstan to assist in the transition to a coal based economy with a low environmental and carbon footprint."

Mr. Norbert Jousten

Head of the EU Delegation to Kazakhstan in 2011

Capacity building in Kazakhstan

4

Introduction

A combination of different approaches was combined to reach a broad field of stakeholders such as politicians, industrialists, academicians and NGOs. Information between different partners and stakeholders was exchanged in order to work out country specific case studies from which the results were disseminated on different capacity building activities.

Project meetings,workshops and presentations

Project kick-off meeting

The kick-off meeting of the ACCESS project was held on the April 5, 2011 in Astana in the premises of the EU Delegation to Kazakhstan. About 30 participants from various Kazakh organizations were present (Ministry of Industry and New Technologies, Statistics Agency, the Institute under the Ministry of Education, mining companies and power plant companies, scientific and research institutes).

Fig.6. Kick-off meeting of the ACCESS meeting, Astana.

Mr. Klyakin, Deputy Director of the Department of electric power and coal industry development (Ministry of Industry and New Technologies) presented the current trends of the coal industry and its future perspectives till 2020. In addition, the project partners presented the ACCESS project with its main objectives and the intended work plan which was followed with an interesting discussion. Topic related discussions were continued in separate group sessions divided according CCS, CCT and environmental/social/ financial issues.

The participants showed a keen interest to cooperate closely with the project. Several concrete areas of interest were pointed out and discussed.

Renewables and CCS Symposium

The October 23, 2012, a symposium on "Renewable energy systems and CCS in Kazakhstan" was organised at the Nazarbayev University in Astana. The symposium aimed at giving mainly scientific researchers the floor to propose different technological solutions and outlooks, and their (theoretical) relevance for Kazakhstan. This symposium was well attended with over 30 participants and delegations from other universities, as well as from several industrial companies.

Fig. 7. Renewables and CCS symposium, Nazarbayev University.

Renewable research in Kazakhstan, Nazarbayev University, Astana

During the Renewables and CCS symposium on the 23th of October 2012, the Energy Research Centre of the Nazarbayev University presented some of their current research on energy modeling and renewable energy systems. Furthermore, the research is an indication of a growing interest in alternative energy production from Kazakh side.

The NU Energy Research Centre is, inter alia, active in the field of wind-solar power research and energy system modeling. Their aim is to foster research in these fields and to be involved in the education towards students. The NU Energy Research Centre works with state-of-the art laboratories, photo voltaic (PV) fabrication facilities and experimental renewable power systems (RPS) near the University. This RPS consist of a variety of wind turbines and solar cells and is aimed to answer research questions such as:

- Is it possible to successfully produce the renewable energy in climate conditions, typical for Kazakh steppes?
- Is the produced renewable energy sufficient for human activity, especially in the typical Kazakh agriculture sector?
- Is the RPS capable to be connected to a global power grid?

Fig. 8. Renewable system (RPS) test ground at Nazarbayev University (picture by NU)

The energy system modeling research is done with the TIMES model which, just as the PSS III simulator, simulates possible outcomes of the energy portfolio, emissions, costs, etc. over a long term, multi-period time horizon in Kazakhstan. The model input consists of the energy production portfolio comprising conventional technologies and renewables.

Final ACCESS event

The final ACCESS event was the closing event of the project in Kazakhstan and was held on October 24, 2012 in Astana, at the premises of the hotel "Imperia G". The event enabled to bring the main stakeholders of the project together and to make a clear statement about the main project results and the need for a continued progress to reach a low-carbon and environmentally sound Kazakh society. The meeting was amongst others attended by the Head of the EU Delegation to Kazakhstan, Mrs. Ambassador Aurelia Bouchez, Mr. Vladimir Klyakin, Deputy Director of the Power and Coal Industry Department of the Ministry of Industry and New Technologies, Mrs. Ainur Sospanova, Director of Green Technologies and Attraction of Investments Department of the Ministry of Environment Protection and Mr. Ermagambet Bolat, Expert, JSC "The National Science and Technology Holding Company Parasat".

The high-level speeches and presentations provided by different experts were focused on two main topics: (1) the future visions and policy direction of Industry, technology, environment and energy and (2) technological and environmental aspects of CCT and CCS. Here, the main results of the ACCESS project's case-studies were presented which showed that different possible green development tracks exists and that continued collaboration between the EU and Kazakhstan can be of mutual interest.

Fig. 9. Final ACCESS event in Astana.

Workshops

Different workshops were organised by the project team in Kazakhstan. The workshops are a key component of the ACCESS project and covered in general the subjects CCS, CCT, environment, health and safety and clean-tech economics.

Training week from July 11 till 14, 2011:

- 11 and 12 July: training sessions held in Ekibastuz;
- 13 and 14 July: training sessions held in Astana, in the premises of the Nazarbayev University.

Training from November 1 till 3, 2011:

- Training session held in Almaty in the offices of CAREC, The Regional Environmental Centre for Central Asia.

The workshops were an excellent opportunity to understand the precise needs and problems of the Kazakh coal fired power production from Kazakh experts on different fields. In addition, the ACCESS project team pointed out the existing problematic concerning climate, health and environment and their associated solutions, both political as technical.

Fig. 10. Workshop in Ekibastuz.

ACCESS News Letter

1ST EDITION SEPTEMBER 2011

ACCESS

IN THIS EDITION

"This publication has been produced with the assistance of the European Union. The contents of this publication are the sole responsibility of the ACCESS project team and can in no way be taken to reflect the views of the European Union"

Presentation of the ACCESS project

"Assistance in Clean Coal and Environmentally sound Storage Solutions" (ACCESS) is a project funded by the **European Union** that aims to achieve capacity building in Kazakhstan on Clean Coal Technologies and Carbon Capture and Storage. The project is designed in the light of the framework of the '**Memorandum of Understanding** on Co-operation in the field of Energy' between the European Union and the Republic of Kazakhstan, signed in December 2006.

Clean Coal Technologies (CCT) and **Carbon Capture and Storage (CCS)** are part of the solution to achieve significant emission reduction goals. CCT covers technological approaches that reduce the environmental impact of coal combustion, through for example coal beneficiation, efficient combustion techniques, etc. CCS involves capturing CO_2 produced by industry and storing it permanently in the deep underground.

The main objectives of the ACCESS project are to **build capacity** for the development of CCT and CCS in Kazakhstan and to identify the potential in Kazakhstan for CCS. The focus lies on the transfer of knowledge and experience in the field of **technology, economics, health, safety and environmental and social** impacts of these advanced technologies. The project is implemented by a Belgian team of experts (Hasselt University, Ecorem nv, Liège University, the Geological Survey of Belgium) with support of the Kazakhstani partner Climate Change Coordination Center.

Workshops in Kazakhstan, July 2011

The most important tool to build capacity in Kazakhstan on CCS and CCT is through **trainings and workshops.**

A first series of workshops was given in Ekibastuz and Astana from 11-14 July 2011.

Representatives from electricity generating and mining companies, other industry, universities, authorities, environmental organisations, etc. were present.

Different topics were covered, such as coal washing technologies, geological storage, clean economics and environmental impact assessment. The presentations are available on the ACCESS website in English and Russian.

The 14th of July a press conference on the project was given at the Nazarbayev University in Astana. The press conference included speeches of Mr Norbert Jousten, Head of the EU Delegation to Kazakhstan, Mr Bukenbayev Zhakyp, Director of Electricity and Coal Industry Department of the Ministry of Industry and new Technologies, and Silvie Myngheer, ACCESS project engineer.

Workshop in Ekibastuz

Some of the discussed subjects are listed below:

- CO_2 Capture technologies;
- Geological storage of CO_2;
- The management of mining waste;
- Legislative approaches to emission control;
- Benefits and challenges in the framework of mining operations;
- The importance of CCS for Kazakhstan until 2050 and CCS potential of Kazakhstan;
- CO_2 monitoring;
- (Environmental) investment decision taking;
- Climate change and environmental problems;
- Environmental Impact Assessment: introduction, disciplines and procedures;
- (Stock) externalities;
- Economics of clean technologies;
- Coal washing technologies.

The comments and visions on these subjects of the Kazakh experts were used to orient the actions and studies of the ACCESS project.

Project presentations

General ACCESS project presentations were presented at occasions where new interested parties were present. These presentations gave the opportunity to sketch the current climate, environmental and public health concerns in Kazakhstan and explained the importance of CCT and CCS as possible solutions. As such, the project and its contents gained a more broad interest whereby capacity building was strengthened. Some important events in which the ACCESS project has been presented are listed below:

- December 2011: Cleantech meeting ExeQutes Group, Gent (Belgium);
- October 2011: “How sustainable is Cleantech?” at the 2011 Innoventivity day, University of Hasselt;
- June 2012: Donor coordination meeting on energy, organised by the EU delegation to Kazakhstan, Astana;
- June 2012: EU member states diplomatic meeting, Astana;
- September 2012: “Through Green Economy to Sustainable Development Seminar” at United Nations Development Programme (UNDP), Astana.

Field visits

Kazakh delegation visit to Europe

In June, 2011 a delegation from Kazakhstan consisting of representatives from the Ministry of Industry and New Technologies, the Ministry of Environmental Protection and industrialists visited Belgium and Germany to share experiences and knowledge with European experts and colleagues.

Fig. 11. Visit RWE power plant & coal mine, Germany.

The program included workshops, varies study visits to: the “Minerals Engineering and Recycling” Research Unit of the University of Liège, the coal fired power plant and open pit mine of RWE (Cologne), the Institute of Materials Research of the Hasselt University and the mine reconversion sites in the Limburg Region. Associated cases and topics were presented during the visits by Ecorem and the Geological Survey of Belgium (e.g. coal mine rehabilitation).

Visit of the Kazakh delegation to Belgium and Germany

The 4-days visit of the Kazak Delegation to Belgium and Germany was considered as an important event in the process of exchange of information and expertise between Europe and Kazakhstan. The Kazakh delegation was consisted of Mrs. Nina Gor of the Ministry of Environment Protection, Mr. Vladimir Klyakin and Mr. Sayat Issatov of the Ministry of Industry and Trade, Mr. Sergey Zaparin of the Bogatyr Comir Coalmine and Mr. Kalyk Saparov Yevgeniy and Mr. Ivankin of the Karagandagiproshakht company.

On the first day, the issue of coal and CCS related policy in the EU was the central theme of the meeting organised at the Museum of Natural History at Brussels. High level EU stakeholders, representatives of the European Commission as well as the project partners contributed to the interesting discussions. Amongst the main speakers were Mr. Brian Ricketts of EURACOAL, Philippe Paelinck of the Zero Emissions Platform ZEP, Mrs. Marion Wilde of DG Energy, Mrs. Beatrice Coda of DG Clima and Mrs. Claudia Marenco of DG RTD.

Fig. 12. Coal related policy sessions.

The following day a visit was made to the research unit Minerals Engineering and Recycling of the University of Liège. The research unit focusses on advanced mineral separation techniques, which can be applied to ferrous and non-ferrous minerals. Also the workshop by Prof. Philippe Mathieu on CO_2 capture technologies received a major interest of all participants.

The participants also had the occasion to visit the German opencast mine coal mine at Garzweiler and the lignite-fired power plant at Niederaussem, both exploited by the company RWE. All participants were impressed by the level of advanced technologies being used at both sites.

Fig. 13. Rehabilitated mine site, Limburg (Belgium).

On the last day, the group was invited at the University of Hasselt where ongoing research activities related to clean technologies and material research where presented. Also the subject of mine site rehabilitation was on the agenda, for which the environmental consultant Ecorem presented its international experience in this domain. Issues such as social rehabilitation, phytoremediation, groundwater modelling, etc. were covered. A visit to the Belgian former underground coal mining site of Winterslag at Genk, now called "C-mine", illustrated a good example of mine site rehabilitation.

Field visits in Kazakhstan

Different field visits in Kazakhstan enabled the project team to get a better insight in the Kazakh coal related sectors, the coal mining operations. The visits also contributed to expand and intensify the project network, and to identify the needs in these sectors.

The Lenin Mine of ArcellorMital, Karagandy

Following the project kick-off meeting in April 2011, the project team visited in the coalmine named after Lenin of JSC "ArcelorMittal Steel Temirtau" in the Karagandy region. The visit provided several useful insights in the coal mining operations and the coal sector in general in Kazakhstan.

Fig. 14. Visit to the Lenin mine, Karagandy.

The Ekibastuz Power Plant (GRES-1)

In April, 2011, the project team also visited the power plant GRES-1 located in Ekibastuz. The team had furthermore the opportunity to have a round table discussion with the head of engineering. The discussion covered, amongst others, the environmental issues that concern the power plant, such as the upcoming CO_2 emission trading system and investments plans The discussion and visit provided useful insights in the power production sector.

Fig. 15. Ekibastuz Power Plant GRES-1.

The Bogatyr Komir mine

One day of the July 2011 mission was devoted to the visit of the Bogatyr mine, which comprises four concessions of the Ekibastuz coal field. The field visit itself focussed on environmental and logistic themes. The general environmental aspects of coal mining were explained as well as the approach taken in this mining region. Particular attention was given to the infrastructural planning that is required for the excavation and transport in the open pit mine of the huge amounts of coal and overburden.

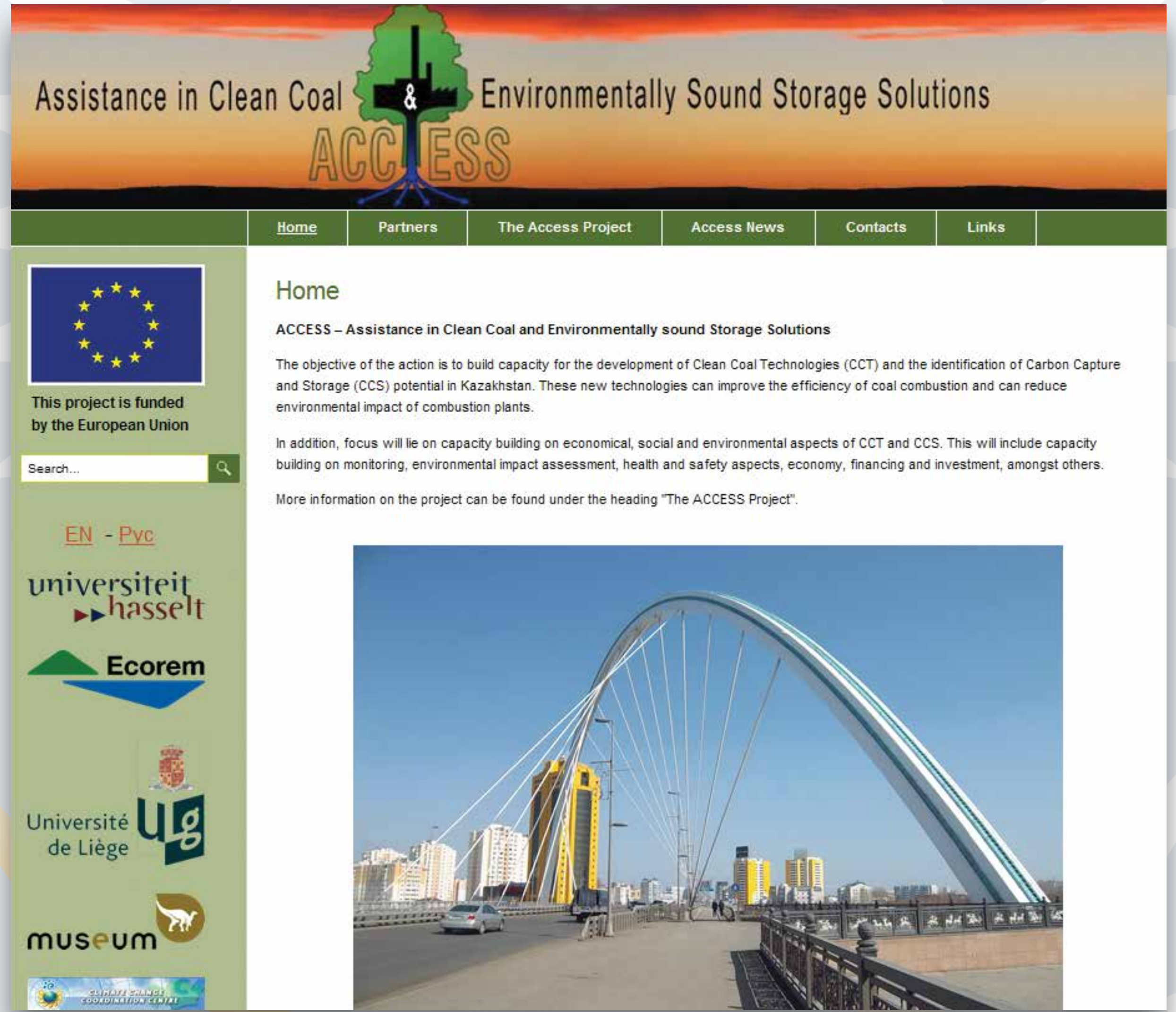
Fig. 16. Visit to the Bogatyr Komir mine.

Visit to the Karagandy coalmine liquidation company

From October 31 to November 2, 2011, a delegation of the project team met with the Karagandy Coalmine Liquidation Company, represented by Mr. Evgeniy Ivankin. Following subjects were discussed: abandoned and buried mines, methane monitoring, reclamation of disturbed lands, the levels of flooding in mines, dumps, waste heaps. Some of these topics were accompanied by a field visit (e.g. the 'Kirovskaya' Coalmine).

Fig. 17. Meeting with Karagandy Coalmine Liquidation Company.

ACCESS website: www.access-kazakhstan.eu



Communication actions

In addition to the ACCESS capacity building, communication actions played an important role. Dissemination of information was, depending on the objective of the action, directed to different target groups. The main goals of the communication actions were to rise general awareness on the subjects covered in the ACCESS project and to highlight the role of European expertise in the field of CCT and CCS.

A variety of communication actions have been held throughout the project. For this purpose, different tools and approaches have been used. The main communications approaches in the project are the project website, the publication and distribution of a newsletter, press releases, a press conference, publications in magazines and the creation of posters for the case studies.

All communication actions were performed both in English and in Russian.

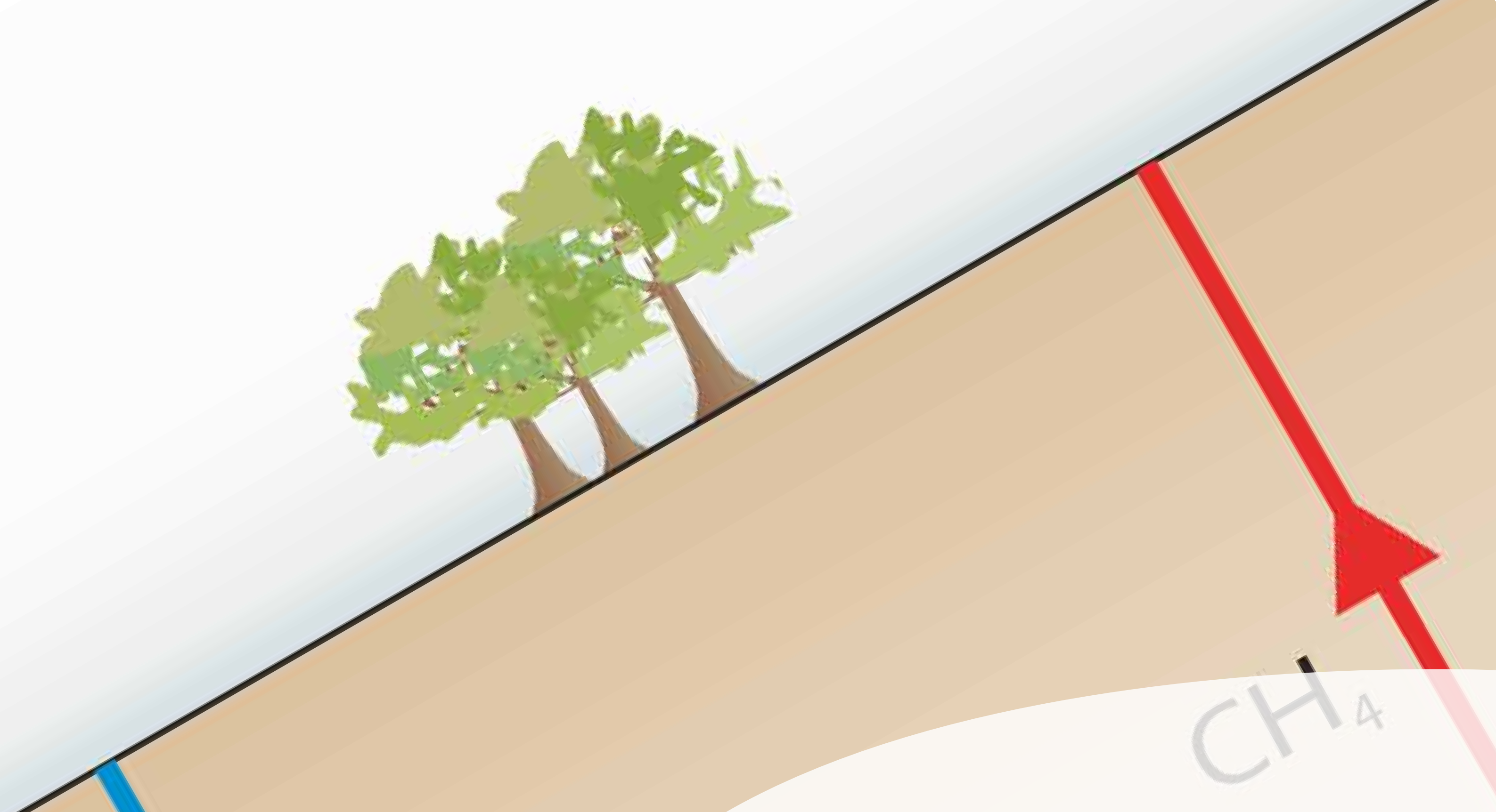
Fig. 18. Press conference in Astana.

Publications appeared in the magazine MilieuDirect (Belgium), Greenhouse News (UK), Ecologist KZ (Kazakhstan) and World Finance Review (UK). Publications in magazines, information on the project website and public dissemination ensured a necessary sharing of experience between the partners, stakeholders and the broad audience.

Fig. 19. Dissemination of the case study results through poster sessions.

Specific collaboration with stakeholders

Through the capacity building actions, different contacts from a diverse group of stakeholders were made. The collaboration with these stakeholders made it possible to work out the different case studies. The most important and profound collaborations are highlighted.



E-course CO_2 capture and geological storage

A good way to get an in-depth insight in CO_2 capture and geological storage (CCS) is an active participation in a specialized course. The ACCESS partners chose to set-up an online E-learning course where the scientific, technological and policy aspects of CCS are discussed. This E-course provides in-depth understanding of the role of CCS in the climate change mitigation portfolio, the technical approaches on CO_2 capture and transport, the science behind geological storage and site selection. Furthermore, the energy situation and the possibility of implementing CCS in Kazakhstan is dealt with in the course. Here the potential of CCS-based power production will be compared to that of other renewable energy technologies.

The course is made possible with the help of the European Federation of Geologists. A team of European experts is formed to guide the participants through the chapters and an active discussion board will be available. The course is of interest to students, scientists, engineers, managers and policy makers working in the area of energy, and especially those involved in strategies for climate change mitigation.

The Nazarbayev University (NU) in Astana

Apart from the logistic support in the organisation of meetings and the co-organisation of the Renewables and CCS symposium the NU Energy Research Centre uses the TIMES techno-economic simulation which is complementary with the PSS III simulator used within (and specifically extended for) the ACCESS project. A technical comparison of the two simulators, the input data, and a comparison of the simulation results for Kazakhstan was made and a future collaboration will start in which the exchange of published material, as well as non-published data and results, will lead to a joint high impact factor publication in 2013.

Furthermore, from the end of August until early September 2012, Mr. Diyar Tokmurzin, a PhD student from the NU, visited and followed the research activities during two weeks in the Material Physics Department, Organic and Nanostructured Electronics & Energy Conversion research group of the University of Hasselt in Belgium. During his stay, also other topics such as the mine rehabilitation were covered, for which a meeting with expert in this domain Mr. Paul Boutsen was arranged. Also meetings with the department of Environmental Economics of the University of Hasselt were included in the programme.

The K. Satpaev Geological Institute in Almaty

The collaboration with the K. Satpaev Geological Institute in Almaty started in the margin of an ACCESS project workshop in Almaty. Although information on geological storage options could not readily be provided, it was agreed to draft a Memorandum of Understanding (MoU) between the Geological Institute and the Geological Survey of Belgium. Herein, the common interests and possibility for cooperation between both institutes are formulated in the field of sustainable development and geological storage of CCS.

The power plant JSC Sevkazenergo

As air quality has been identified throughout the project as one of the major environmental topics, the ACCESS project devoted a case study on this subject. In line with the overall ACCESS project air quality has been studied from a coal-fired power plant's perspective. Through the positive participation of the power plant JSC Sevkazenergo in the project kick-off meeting and the first workshop, the contact had been made and a fruitful collaboration was set up. An open and interesting exchange of information took place, leading to a valuable case study. Furthermore, the collaboration between the power plant and the consultant Ecorem will be continued after the project.

The positive role of clean coal technologies in power production

The main goal of clean coal technologies in power production is to provide a more sustainable and healthy human environment, whilst securing the growing need for energy. These efforts should be balanced with their costs to allow for further economic growth. Finding this balance is not easy because the impact of externalities from power production cannot easily be expressed as a monetary value. There are different interlinked pollution effects to mitigate, including climate change and its consequences, other environmental effects and human health. Pollutants that can be drastically reduced using clean coal technologies include fly ash, fine dust, SO_X, NO_X and CO_2.

Additional costs for installing clean coal technologies can also partly be justified by the higher efficiency of new, lower waste-handling costs, and in general future-proofing the energy economy, since at the moment the electricity prices in Kazakhstan only include operational costs as most installations are depreciated power plants from soviet times [15].

Because of these old installations, clean coal technologies have a huge potential for emission reduction in Kazakhstan, both by renewing current power plants, and building new ones with modern technology. For these technologies be successfully implemented, government incentives are important.

Reflections and case studies

5

Introduction

Evolving to a climate and environmental friendly and thus green Kazakhstan is only possible when necessary steps are taken in the coal fired power sector.

A case study offers the possibility to deepen a specific problem or challenge, and to identify specific solutions or pathways leading to solutions. Case studies therefore are a perfect way to complement a more general approach of capacity building.

The selected case studies deal with technological, environmental and economic aspects of the industrial coal sector and coal-based power production in Kazakhstan. More precisely, the following case studies were conducted throughout the project:

- **Air quality through clean coal technologies at the Sevkazenergo power plant, Petropavlovsk:** Modeling the impact on air quality and cost-benefit analysis of end-of-pipe emission abatement technologies in a coal-fired power plant
- **The role of CCS** in the greenhouse gas mitigation portfolio of Kazakhstan:
- **Cost effectiveness analysis** of implementing capture technologies in power plants
- Potential for **improving coal treatment technologies** for the Kazakh coals through coal beneficiation

The case studies form furthermore the basis for future joint collaboration to achieve mutual benefits.

The results of the case studies have been incorporated in a more general reflection in the subsequent pages.

Coal beneficiation in Kazakhstan

Essential in the national challenge of Kazakhstan to increase the efficiency of the electricity production and the reduction of the environmental impacts, is the beneficiation of coal.

During the first stages raw material such as coal can be treated before the combustion takes place. This process is called coal beneficiation and different technologies exist to reduce the harmful content such as ash and sulfur in the flue gas. Some types of coal may require other kinds of beneficiation technologies.

Coal characteristics

Kazakhstan possesses coal resources of various types – from lignite to coking and high calorific bituminous coal. Ash content varies from deposit to deposit and in some seams it could reach 55%. Hard coal, which is used as pulverized fuel, has disadvantage of high ash content but at the same time the low moisture is an added benefit for coal transportation over long distances during extreme cold seasons. Kazakh coal does not freeze in contrast with imported coal. Some of the coal also has low risk of self-ignition due to high content of particulate matters. Earlier studies of some Kazakh coals have shown that reducing the ash content is very difficult. These findings were compared to possibilities that the newest coal beneficiation technologies bring, and the environmental and economic benefits that beneficiation could bring.

Coal treatment

Regarding the possibilities for the treatment of some high-ash coal for the purposes of ash reduction, research studies undertaken by different organizations have led to the conclusion that the coal under consideration is almost impossible to process efficiently. Nevertheless, there is no information whether the available techniques have been tested.

Kazakh coal properties

Coal properties of the major coal producing companies of Kazakhstan [16].

#	Company	Rank of coal	Technical characteristics			
			Thermal conductivity kcal/kg	Ash content %	Moisture content %	Volatile matter %
1.	"ArcelorMittal"	Coking, bituminous	7000-8300	34	9	27-28
2.	"Nefrit-2030"	Coking, caking	4103-4125	34.5-38.9	7.3-9.9	29.5-31.1
3.	"Batyr"	Coking, caking	5100	21.1-30	8-9	26.7-27
4.	"Rapid"	Coking, caking	6400	19	7	27
5.	"BogatyrKomir"	Coking, caking	4018	42.2	4.3	25-30
6.	"Vostochnyi"	Coking, caking	4018	42.2	4.3	25-30
7.	"Borly"	Coking, bituminous	3600	41-46	5-6	27-29
8.	"Shubarkol-Komir"	Long-flame	5200-5800	5-16	15	44-46
9.	"Karajira LTD"	Long-flame, Lignite	4500	18.1	16.7	47
10.	"Angressor"	Coking, caking	3562-4344	42.3	4	
11.	"Maikuben-West"	Long-flame, Lignite	3900-5200	15-18	19-20	27-40
12.	"Gamma"	Lignite	3356-3500	30-34.5	23	40
13.	"Kambar"	Lignite	5600	12-15	16-19	49-50
14.	"SatKomir"	Lignite	5600	27-28	17-20	47-50
15.	"Saryarka"	Long-flame, gas	5600-7670	5-15	4.7	46
16.	"On-Olzha"	Gas, bituminous	4994-6371	17.3-31.2	4.3-5.9	34.3-39.3
17.	"Kulan-Komir"	Gas, bituminous	3948-4295	37.7-40.6	2.36	35.8-38.1
18.	"Transkomir"	Coking, caking	5520-8040	26.7	3.8	28.5
19.	"Zapadnaya"	Coking	5330	26	8	28
20.	"Berkut"	Lignite	3600	3.8-12.5	7.8	33
21.	"Saikan"	Lignite	5030-6050	9.8-24.6	15.2-41.8	38.2-48.9
22.	"Priozernyi"	Lignite	2900	24.8	37	50.7
23.	"Kulan TB"	Gas, bituminous	4100	36	8	25-27
24.	"Edelveis"	Coking	4500	35-45	7.5-9	20-34
25.	"Esep"	Coking, caking	5100	24-25	9.7	31-38
26.	"KazVtorProm"	Coking, caking	5100	26	10	26-28

If future research studies in the direction of ash removal are to be envisaged, it is important to address the question about the needs of the end consumer, i.e. up to what extent of ash/sulfur content in the coal could the existing furnaces operate efficiently. It is by no doubt clear that any further research on coal quality improvement should take into consideration the specific requirements regarding ash toleration of the coal-fired boilers to be implemented. Once these needs are identified, an experimental program should be developed (encompassing testing various techniques) to evaluate the feasibility of achieving the reduction targets for the components in the coal under consideration. These issues are highly relevant to the coal extracted in Vostochnyy and Ekibastuz mines. For Shubarkol Komir a feasible direction could be the introduction of more efficient coal drying techniques, for example microwave drying; after air jig separation, the low grade coal subjected to microwave drying could generate heat which could lead to a decrease in the moisture of the coal. Further on, testing of more efficient binders for briquette fabrication or a binder-less technology could be envisaged in view of improving the mechanical properties of the briquettes.

The beneficiation of coal presents an essential national challenge for Kazakhstan in order to increase the efficiency of electricity production and to reduce the environmental impacts. Earlier studies done with these coals have shown that reducing the ash content is very difficult. It is feasible that slight modifications (in the current beneficiation scheme, installation of equipment, reagent changes, etc.) could lead to the desired improvement in coal separation efficiency [17, 18].

Different meetings were arranged with the Karaganda and Ekibastuz coal mines to discuss different technologies and subjects such as coal extraction methods, coal quality and end-user requirements, needs and opportunities for implementation of coal washing installations for improving the quality of coal and perspectives for introducing technological innovation. Data was received from the coal mines of Vostochnyi and Shubarkol Komir.

The ash content of the Kazakh coal can reach 55% which makes it almost impossible to use the coal efficiently.

The different parties agree that it is worthwhile to consider looking into beneficiation, but that evaluation of the techniques and the upscaling of the methodology will take time. Cooperation between Kazakhstan and the European Commission would be an important, even necessary stimulus to develop and implement advanced coal beneficiation technologies, which constitutes a key technique on the roadmap to clean coal technology.

Two possible solutions to treat high ash Kazakh coal have been presented in the project. The flow sheet pictured on figure 20 is based upon the different response to crushing of coal and the coal-associated stones (high ash rocks). It involves screening at 25 mm with the oversized subjected to selective crashing. The selective crushing is based on the fact that the impacts from the rotor hammer are adjustable, so that the brittle coal can pass into the undersize fraction while high ash rocks will stay in oversize one as less amenable to fragmentation. The undersize fractions are always "contaminated" with high ash particles and for the sake of efficiency increasing, second stage of separation by X-ray sorting is proposed. Preparatory operation is screening at 6 mm with the oversized material fed into TOMRA sorter. The material is passing through a chamber equipped with pneumatic air injectors controlled by computer. Particles are left to pass or rejected based on the captured information for their X-ray transparency. The more transparent fraction is collected together with -6 mm undersized and form a dry low-ash coal fraction able to meet market requirements. The high ash stone fraction is stored at heaps for further utilization.

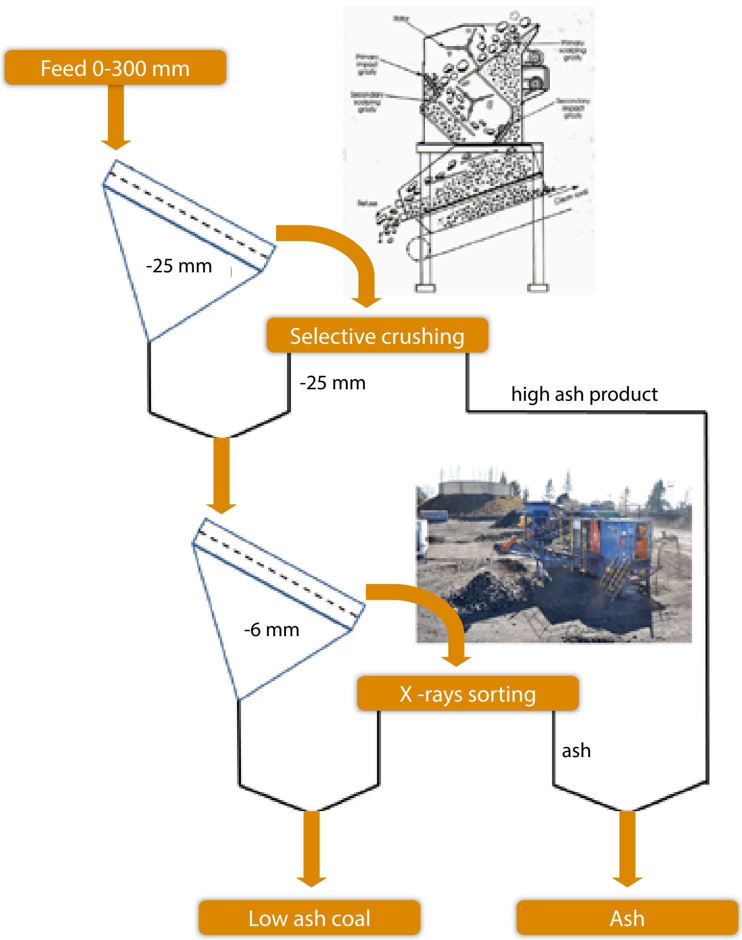
Another possible solution uses FGX Separation. The FGX separator seen at figure 21 represents a sort of

General info on coal washing techniques

Coal washing techniques are applied at the pre-combustion stage by treating the coals without destroying their physical identity. They are mainly applied at the supply source of the fuel and not at the power plant. The objective is to render the coal to burn more efficiently by removing unwanted matter like sulfur, ash and minerals. This removal takes place through fractioning and subsequent washing of the coal. A variety of "classical" techniques is available worldwide, like flotation, gravity and heavy media separations. Every coal washing case is specific however. Nowadays the recent advances in mineral processing technology have enabled large spectra techniques to emerge and to be used either as stand-alone basis or in combination when designing coal washing plants. Some of the established and the emerging techniques are listed below:

- automatic control and characterization systems **for fraction identification** and determination of the degree of fractions liberation during coal preparation;
- **coal petrology instrumentation** (implication to coal preparation and cleaning);
- **gravity separation equipment** for coal with minimal dust generation (jigs, dense medium cyclones, centrifugal concentrators);
- **dry coal processing equipment** (X-Ray and color NIR sorters) within the context of water resources preservation and for improved de-shaling and de-stoning;
- **electrostatic separation** units as a challenge for separation of ash-forming minerals from high ash non-coking coals;
- selection of optimal binding agents for **coal agglomeration** (i.e. briquetting installations) (importance of physical and surface properties of materials);
- strategies for selection of **flotation reagents** based on coal characteristic – usually non-polar collectors are used
- improving pyritic sulfur rejection in **froth flotation**;
- removal of pyritic sulfur by **biological means**;
- **processing of ultrafine particles** generated during classical coal washing processes (selective flocculation, HGMS);
- **dewatering** of lower rank coals for calorific value improvement. The appropriate coal washing techniques to be used depend on number of coal characteristics among them ash and moisture content are of primary importance. Sulphur content and its form of occurrence should be considered as well. Further, the repartitioning of the above mentioned characteristics within the grain size fractions and some physical characteristics of the coal (hardness) are important considerations when choosing the appropriate treatment route.

shaking table with fluidizing air where the particles are segregated in accordance to their specific gravity. By the aid of adjustable splitters the run of coal mine is separated into three fractions: clean coal; light weight fraction; middlings which are returned at the feed and discard (heavy fraction). The requirements for the normal operation of this equipment are the following: 10 to 20% yield of class – 6 mm in the feed as autogeneous medium and less than 7 % surface moisture. The separator is equipped with a bag filter and dust cyclones for capturing the fine coal particles from the up-stream air flow. This technology is already well established in practice and at present more than 500 FGX separators are in operation in China.



< Sorting could be realised for example using a « PRO Secondary XRT Chute » equipment from Tomra Sorting Solutions, Germany

Fig. 20. Selective crushing followed by X-rays sorting.

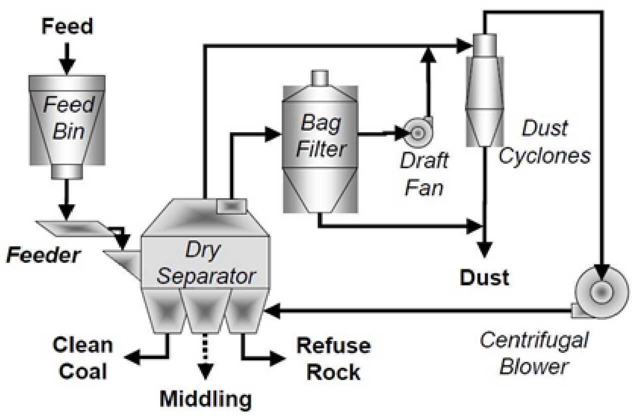


Fig. 21. FGX Separation.

Coal-fired power production

In fig. 22 the net electric efficiencies and the specific CO_2 emissions (gCO_2/kWhe) for different power plant technologies are presented. The full purple line represents the specific CO_2 emissions and the net electric efficiency of power plants firing 100% coal as fuel. This curve is developed for a specific average coal quality.

The dashed lines present coal-fired power plants with a fraction of biomass co-fired; respectively 10% and 20%. For a same efficiency of a power plant fired with 100% coal, the specific CO_2 emissions decrease when a fraction of biomass is added.

From the graph it is shown that coal-fired plants have specific CO_2 emissions of about 850-950 gCO_2/kWh, when their efficiency is in the range 35-40%. The relationship between an increase in efficiency and a decrease in CO_2 emissions is not linear but hyperbolic. An increase of the efficiency by 15% (from 40 to 46%) decreases the CO_2 emission by around 11% (from 850 to 760 g/kWh).

With respect to the investment costs of a coal-fired power plant, this cost amounts around 1560 €/kW and the cost of electricity produced is 48 €/MWh for a coal price of 2.4 €/GJ, and, with a 46% efficiency, the specific CO_2 emission are 760 gCO2/kWh or 4.2 MtCO2/y in base load [14].

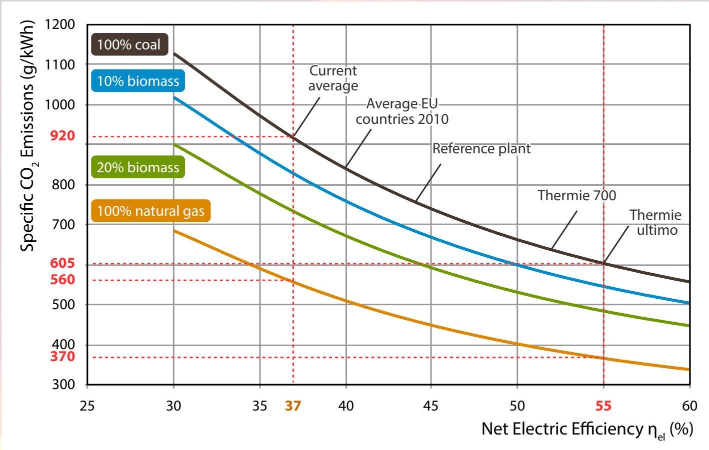


Fig. 22. Net electric efficiency and specific CO_2 emissions (g/kWhe) for different power plant technologies.

Switching in fuel and/or technology

Treatment of the raw fossil fuels before combustion is an important investment when trying to reduce pollutants and toxics from entering the environment. But another primordial step of a reduction strategy is to increase at the maximum possible the conversion efficiencies of power plants firing these coals.

Increasing the efficiency of power plants can amongst other be achieved by a switch in technology and/or fuel. This switch can be performed by upgrading or retrofitting power plants (changes to existing power plants) or by building new power plants. The high number of old coal-fired power plants in Kazakhstan (older than 30 years) makes that most Kazakh power plants are not in the best conditions neither to be retrofitted and upgraded nor to switch the fuel from coal to natural gas.

To reduce CO_2 emissions, the conversion efficiencies of the power plants should be increased to the maximum possible.

Natural gas

Switching from coal to natural gas is today a popular choice in western countries since natural gas is a cleaner fuel and emits less CO_2 per energy unit generated. Unfortunately, it is much more expensive than coal and its price is volatile and expected to increase continuously in the future. Building new natural gas combined cycle (NGCC) plants instead of coal-fired plants leads to dividing the specific emission by a factor 2, being typically 350-400 gCO_2/kWh for NGCC versus 850-950 gCO_2/kWh for coal-fired plants depending on their efficiency (fig. 22).

Fig. 23. Sleipner gas-field platform of Statoil, Norway. The installation CO_2-rich natural gas is produced from this platform and re-injects the stripped CO_2 into sandstone-layers beneath the gas reservoir © Statoil.

If natural gas is abundant and available at low price on an internal market, Kazakhstan could phase out its old coal plants and replace them partly by the most advanced NGCCs whose efficiencies are currently in the range of 55-58%. This efficiency can even rise to 60% and more thanks to gas turbine technology advances in the future.

Coal

Coal prices are the most stable in the world because the fuel is the most abundant and cheapest available. Kazakhstan could replace the current and in-future phased-out coal-fired power plants with new ones using the best available technologies on the market. Different coal (hard coal or lignite) based technologies are currently available or in development, i.e.

- Thermal power plants: subcritical, supercritical or ultra-supercritical steam cycles
  - Fluidized bed
  - Pulverized coal
- Integrated Gasification Combined Cycle (IGCC).

Integrated Gasification Combined Cycle

The figure below schematically shows an Integrated Gasification Combined Cycle (IGCC) process without and with capture of CO_2. The process steps that are added to obtain capture of CO_2 are in the dashed frame. The process starts with the coal preparation step depicted in the left upper corner of the figure. After gasification of the coal with oxygen and steam, the resulting syngas, i.e. a mixture of CO and H_2, is cooled, cleaned-up and feeds the burners of the gas turbine combustion chamber. When capture is applied, an additional step to shift the syngas CO+H_2 with steam towards a mixture CO_2 and H_2 is added, after which the CO_2 is removed and subsequently compressed for its transport to a storage site in a liquid or supercritical state. The H_2 is the new fuel for the gas turbine producing electricity. A second electricity production stage occurs by the use of a steam turbine in a so-called combined cycle.

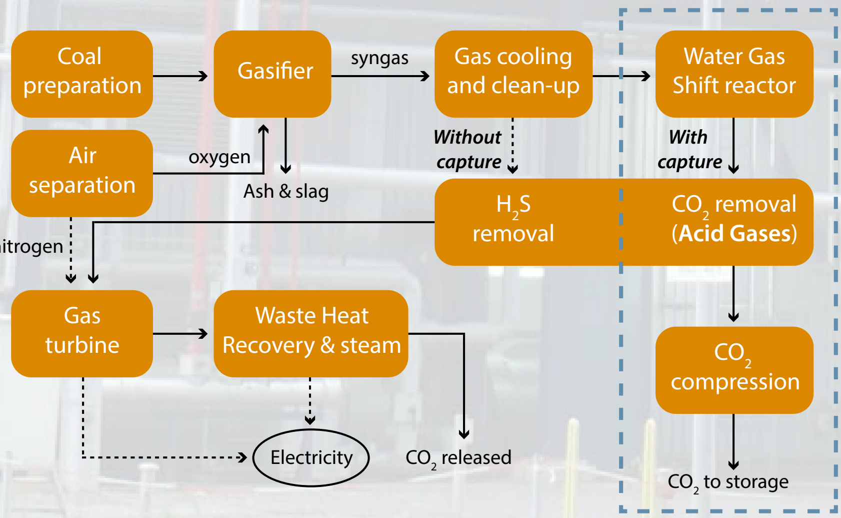


Fig. 24. Block diagram for the IGCC process with and without CO_2 capture [19].

Fig. 25. RWE lignite-fired power plant at Nierderaussem, Germany, visit June, 2011.

New-built coal-fired power plants are currently no longer subcritical but have at least a supercritical steam cycle (i.e. a pressure of up to 250 bar and a superheat temperature of 580 to 600°C) which gives an efficiency of 42 to 45%. The steam parameters in an ultra-supercritical cycle go up to 300 bar and 600°C creating an efficiency of 45% to 48%.

But new materials withstanding high temperatures and corrosion are needed which increase the capital costs of this kind of power plant. Today, efficiency up to 52% is in view thanks to the improvement of the steam cycle (superheated steam of 700°C and 350 bar) together with the development of new advanced materials. The ultra-supercritical power plant is currently not yet available.

Another new technology for clean and efficient use of coal is the Integrated Gasification Combined Cycle (IGCC). It has been designed to make the primary mono-fuel (natural gas) NGCC more fuel flexible and able to use coal. In an IGCC, the gas turbine is fed with a syngas instead of natural gas. When coal is used as fuel, the coal is first converted into a gas in a gasification unit fed with pure oxygen and steam as gasification agent to form a synthetic gas ("syngas") made of carbon oxide (CO) and hydrogen (H_2). The hot syngas is cooled down and cleaned-up with a high removal rate of sulfur and nitrogen Current energy conversion efficiencies of IGCCs are around 42-45% and have the potential to rise up to 50-52% thanks to technology advances, in particular in gas turbine technology. IGCC is a rather new technology that received considerable attention lately due to its excellent environmental performance. The efficiencies of IGCCs and supercritical steam power plants are quite similar but the IGCC power plant is very flexible with respect to the fuel and is able to "swallow" all solid fuels that can be gasified, such as wastes, wood pellets and other mixtures of solids.

Efficiency increases can be realized by building NGCCs, or using the most advanced coal-based technologies.

Compared to coal-fired power plants, IGCCs, while being more environmentally friendly and more fuel flexible, are more complex installations that are dominated by chemical components, and are thus more expensive and less reliable and available. Furthermore, only a small additional step is necessary to allow for CO_2 capture. IGCCs are not at the same level of development as coal-fired power plants, which are commercially well established while IGCCs are currently still at the level of demonstration (250 MWe).

A third technology is the fluidized bed combustion where pulverized fuel is burnt in suspension in an air flow.

This allows a large contact surface between fuel particles and the oxygen in the air, which leads to a more complete combustion. The drawback is that the temperature of the bed is limited to some 850°C. That is why this technology has efficiencies limited to 40-42% but is cheap, simple to operate and environmentally friendly since sulphur can be removed by solvents in the bed itself. The highest asset is the flexibility of the technology with respect to the fuel, similarly to an IGCC which uses a fluidized bed to gasify the fuel. The technology can, similar to IGCC, use nearly any kind of solid fuels. It is therefore used for waste incineration, co-generation of electricity and heat and particularly for district heating.

Some advanced fluidized beds are currently available on the market such as the supercritical types (the Lagisza demonstration plant in Poland, 460 MWe; 43% efficiency) and the high temperature Winkler type.

Fig. 26. Brown coal mining activities at Niederaussem, Germany.

Fig. 27. Hard coal mining activities at Ekibastuz, Kazakhstan.

Biomass

Solid biomass, like wood pellets, can be co-combusted with coal in existing steam boilers and can be co-gasified with coal in existing gasifiers provided minor technical modifications are made.

Biomass can technically be co-combusted in an existing steam boiler without a need to redesign the boiler, provided the biomass fraction is limited to about 10 % in order that the resulting flame temperature and combustion kinetics remain compatible with the boiler design. For higher co-firing rates, the lower energy content of biomass per unit volume compared to coal leads to drop of efficiency and higher costs. It is today a popular choice in order to make coal-fired power plants more ecological. Following the European BREF document on Large Combustion Plants [20] one of the primary goals and achievements of the co-firing of biomass with e.g. coal is the reduction of acid oxides emissions such as SO_2 and CO_2. The combustion of biomass is indeed "CO_2 neutral" since the CO_2 released from the combustion is the one which was absorbed by the plants from the atmosphere during their growth through the photosynthesis process.

Two technical options can be proposed:

- the gasification of biomass in a fluidized bed and injection of the generated syngas in the boiler through separated burners;
- the mixing of pulverized wood and coal in the pipes feeding the boiler's burners.

In both systems, even if the wood comes as pellets, additional installations have to be built on the plant site for the treatment and the handling of the pellets. As an illustration, the handling zone is made of a truck or boat unloading station, conveyors, a train of oscillating screens, a chain of hammer mills, storage silos, pneumatic transport of wood dust. Since dusts of wood can explode, safety systems for firefighting are required.

In case of gasification, room has to be made for building a gasifier and new burners for the syngas feeding have to be made through the walls of the existing boiler. This latter must thus be in good state and have a sufficient remaining life to justify the investment.

Regarding the pollutants, the content of sulfur in wood is much less than in coal; however, the much higher content of alkaline leads to ash deposition and corrosion, leading to additional costs.

The price of biomass (wood) is generally higher than that of coal so that the cost of electricity is higher as well.

Again, for Kazakhstan, the key issue is the state of the boilers and the economic justification to retrofit or modify them given their age.

In general, a profound analysis of the power sector that leads to a strategy to refurbish and renew the power generating sector in Kazakhstan is needed.

Fig. 28. Rapeseed for biofuel production in Germany © Vincent van Zeijst.

The Sevkazenergo coal-fired power plant

The power plant JSC "SEVKAZENERGO" is located in the northeast industrial area of Petropavlovsk in the North of Kazakhstan. JSC "SEVKAZENERGO" is a vertically integrated company that includes all the sections of power supply to the North Kazakhstan oblast: generation, transportation and sales. The company also provides heat to the city of Petropavlovsk.

JSC "SEVKAZENERGO" has currently an installed electric capacity of 380 MW and an installed thermal capacity of 999 MW. The generated electricity is supplied to 650.000 people in North Kazakhstan oblast. The generated heat is supplied to 165.000 citizens of Petropavlovsk and 5.500 industrial and agricultural enterprises of the region. The investment program of the company for 2010-2015 foresees an increase of the installed electric capacity to 455 MWe.

The power plant is fired with pulverized coal from the Ekibastuz coal mine. The power plant has 11 boilers and operates under subcritical steam conditions. The installations are generally old. The investment plan foresees an upgrade of some boilers.

For flue-gas cleaning, the company has installed seven Venturi scrubbers and four battery emulsifiers to reduce particulate emissions. The application of these installations also leads to a reduction in SO_2 emissions. The term 'battery emulsifier' is unknown in Europe. However, it seems that this technique corresponds to a 'packed bed wet scrubber'. Both the Venturi scrubber and the battery emulsifier are a type of wet scrubber. Through the use of tertiary blast, 30% NO_x reduction is achieved.

Fig. 29. JSC Sevkazenergo.

Fig. 30. Turbine-generator unit.

Improving local air quality

Air quality is recognised as a significant environmental issue in Kazakhstan and is resulting both from urban and industrial emissions. Sectors contributing to the air quality are for instance the transportation sector, the housing sector and industry through the emissions of several pollutants in the atmosphere.

Power plants have important emissions of pollutants into the atmosphere, resulting from the combustion of coal. Air quality can be improved through the application of Clean Coal Technology measures such as coal beneficiation and modifications in power production and/or combustion technology. These types of measures should in fact be the first measures to be considered because they prevent the formation of pollutants. But a change in the quality of the coal used by a specific power plant and modifications in power production technology are technologies in generally needing an important change in the power plant. End-of-pipe abatement techniques can often more easily be added to an existing power plant. For power plants where significant modifications would be too costly, end-of-pipe techniques are often the best solutions to improve the environmental impacts fast.

End-of-pipe emission abatement technologies to improve air quality are effective and require only minor changes to the power plant.

Air emissions and air quality modelling

To evaluate whether end-of-pipe technologies should be added to an existing power plant, current emissions of the plant can be compared to national and international emissions standards. This gives immediately a good idea about the performances of a power plant with respect to air emissions.

In the ACCESS project, a collaboration has been set up with the company JSC SevKazEnergo in Petropavlovsk, Kazakhstan.

Based on the emission data received from the power plant, it can be stated that the power plant is currently not in compliance with the Maximum Permissible Emissions (MPE) imposed by the Kazakh authorities to the company, nor with the international standards of the International Finance Corporation (World Bank Group). However, the power plant will be in compliance whit the MPE for particulate matter when all remaining venturi scrubbers are replaced by battery emulsifiers, as planned.

It is noted that the imposed emission limits to the company for PM is significant less stringent than the international standard. For NO_x however, the Kazakh emissions standard is more stringent.

The impacts of these emissions on the surrounding air quality, can be assessed by the use of air quality modeling. On top on the emissions data, data such as meteorological conditions in the project area, land characteristics are needed to perform this analysis. When background air pollutant concentration are available (i.e. the concentration of pollutants in the area without the considered installation), the resulting air quality can be evaluated against health standards, such as set out in the EU directive on Ambient Air Quality (2008/50/EC). Without background concentrations, only a statement can be made about the contribution of the emission source to the local air quality.

Unfortunately in the case study, existing detailed air quality data for the city of Petropavlovsk is not available and therefore background concentration data cannot be estimated. The concentrations are therefore assumed to be zero. This implies that no conclusion can be made regarding the total air quality of the project area. Nevertheless, the analysis has provided valuable insight regarding the contribution of the power plant to the local air quality.

For the specific power plant under study, the model results show that for NO_x, the impact on the air quality is limited, but for SO_2 and PM, the impact is rather important. Combined with non-zero background emissions, PM and SO_2 emissions could exceed EU air quality limits and pose a threat to human health.

Credit: Christian Wagner

Environmental Impact Assessment

The practice of Environmental Impact Assessment (EIA) is becoming a standard worldwide, and can be a powerful environmental safeguard in any project planning process.

The idea behind an EIA is that the various possible environmental and socio-economic impacts of the proposed project are determined and evaluated. In the standard EIA practice, socio-economic aspects, physical aspects and biological aspects all need to be taken into consideration. Also all life phases (from construction, over exploitation to decommissioning) should be evaluated. Environmental or socio-economic actions to remediate possible negative impacts of the project need to be suggested. Based on the EIA, authorities can take well considered decisions whether to allow the project as it is proposed, in a modified way or simply to not allow its realisation.

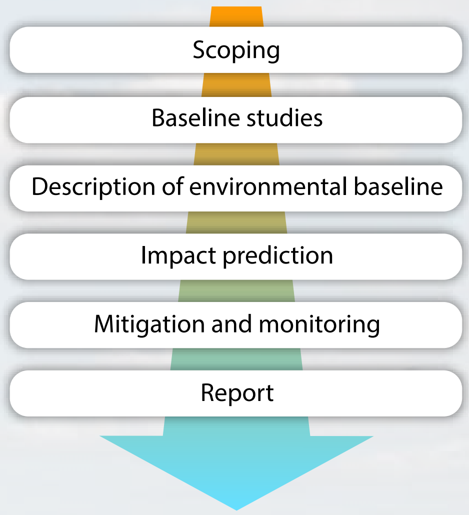


Fig. 31. Conceptual procedure of an EIA.

In case of the construction of a new power plant, one of the impact categories that is studied in the EIA will be the impact on the local air quality of the emissions of the power plant. Through the use of air modelling and based estimations of the project, this impact can be modelled and evaluated.

Fig. 32. Modelling results - maximum 1-hour SO_2 concentration values.

According to the EU directive Ambient Air Quality Directive, the limit for PM of 50 µg/m³ can be exceeded 35 times. In the current situation the power plant emissions give not rise to a non-conformance. But in reality, background concentrations make the final concentration likely to be higher than 50 µg/m³. When all venturi scrubbers are replaced by battery emulsifiers already a considerable improvement is noted.

Rank	Current scenario	Future scenario	Rank	Current scenario	Future scenario	Limit µg/m³
1	57.42	20.97	19	43.78	15.70	50
2	53.70	18.96	20	43.64	15.68	50
3	51.66	18.37	21	43.49	15.67	50
4	50.57	18.03	22	43.40	15.57	50
5	48.14	17.21	23	43.39	15.56	50
6	47.07	17.08	24	43.22	15.53	50
7	46.73	16.90	25	43.11	15.50	50
8	46.09	16.78	26	43.07	15.46	50
9	46.07	16.68	27	43.01	15.45	50
10	45.65	16.60	28	42.83	15.40	50
11	45.49	16.24	29	42.70	15.34	50
12	45.46	16.17	30	42.48	15.32	50
13	45.38	16.15	31	42.33	15.05	50
14	45.04	16.04	32	42.29	15.02	50
15	44.62	15.98	33	42.14	15.00	50
16	44.56	15.94	34	42.03	14.991	50
17	44.07	15.84	35	42.01	14.907	50
18	43.83	15.73				50

Fig. 33. Maximum 24-hour concentration values for PM as a result of the emissions of the power plant, in the current and future scenario.

Air quality modeling can not only be used to evaluate the current situation, but also to assess the improvement that the installation of end-of-pipe techniques can bring on the air quality. This is for example very useful in an Environmental Impact Assessment (EIA).

Furthermore, through air modeling the best localization and design parameters (stack height etc.) for a new facility can also be determined.

For the power plant under study the following possible techniques have been evaluated: a Selective Catalytic Reduction unit for NO_x, a Wet Lime Scrubber for SO_2 and the replacement of all venturi scrubbers by battery emulsifiers for PM. When the proposed future abatement technologies would be used, the contribution of the plant to ambient NO_x concentrations is rather limited. On the other hand its contribution to SO_2 ambient concentrations is quite significant. Results show that in the case that background SO_2 concentrations reach a value of only 10 µg/m³, the EU air quality limits will be exceeded. In the case of PM, the plant also has a significant contribution although not at such a high level that non-conformance can be taken for granted. A background value of around 30 µg/m³ is needed in order to exceed EU limits.

Air quality modeling can also be used when authorities establish emission limit values for specific installations. When authorities grant a permit to a (new) company that is an important source of air pollutants, it is essential for the authorities to know in which way the emissions of this company will contribute negatively to the air quality in the surroundings of the company. This is especially the case when a company is located in or nearby dense populated regions and/or valuable ecotypes. Through air quality modeling, authorities can gain these insights and may set the permitted emission limits of the company accordingly (with taking into account the level playing field of the concerned company when it is a competitive sector).

With respect to the Sevkazenergo Power plant for example, it is noted that the location in the North East of the city is well chosen because the prevailing wind direction is South-West oriented. As a result, maximum average concentrations appear to the west of the plant, which is away from populated areas.

End-of-pipe technologies to reduce the emissions of atmospheric pollutants

Treatment of flue gas aims to remove pollutants like NO_x, SO_x, dust and heavy metals from the formed flue gasses. This stage occurs just before emitting the flue gasses into the atmosphere and is often referred to as end-of-pipe. Different well known pollution abatement techniques are possible. Commonly applied techniques in coal-fired power plants are the following:

- Electrostatic Precipitators (ESP): removes particulates from emissions by electrically charging particles and then capturing them on collection plates;
- Fabric filters: one or more isolated compartments containing rows of fabric filter bags or tubes. Particles are retained by the fabrics when particle-laden gas passes through the fabric;
- Selective Catalytic Reduction (SCR): the SCR is used to eliminate nitrogen oxides from the flue gases. The SCR process comprises a selective reduction of NO_x with ammonia or urea in the presence of a catalyst. NO_x is converted to the harmless N_2 (fig. 34);
- Flue Gas Desulfurisation (also called "scrubbers"): removes large quantities of sulfur, other impurities and particulate matter from emissions to prevent their release into the atmosphere.

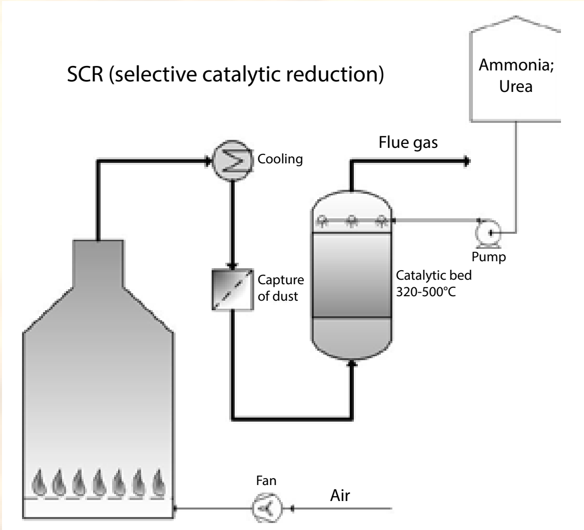


Fig. 34. Typical flow diagram of selective catalytic reduction [21].

Economic evaluation

When investing in end-of-pipe emission reduction techniques, economic considerations are to be taken into account. An economic evaluation of the opportunity of such an investment can be made from both a private as from a societal perspective. When the costs of the investment in the end-of-pipe technique are covered by the company, a private cost-benefit analysis can be made. Benefits for the company could result from reducing fines when a certain emissions standard is not reached. In a social cost-benefit analysis however, the environmental benefits of the air quality improvement resulting from the emission reduction efforts can be considered. The environmental benefits result in better health conditions and less damage to nature.

To abate SO_2 and NO_x emissions and achieve international standards, more extensive measures seem necessary. The option of a wet lime scrubber and a Selective Catalytic Reduction should be analysed further.

These social benefits are represented by external effects that are not directly reflected in the market. When the harms associated with negative externalities are not taken into account, excess production and unnecessary social costs are the results. This inefficiency can be remediated by encouraging the firm to reduce emissions. If the benefit of emission reduction is larger than its cost, it is economically feasible to invest in emission abatement technologies from a society's point of view.

The social cost benefit analysis should be considered as a decision support tool that can justify the investments in emission reduction technologies.

In the case study, the economic evaluation of different end-of-pipe technologies is performed based on the available cost data. The benefit of the emission abatement technologies is the avoided damage cost. Based on the available data and taking into account different assumptions, the social cost benefit analysis shows that the power plant should continue to replace the venturi scrubbers by battery emulsifiers to reduce PM emissions. Concerning NO_x and SO_2 emissions, the installation of a Selective Catalytic Reduction unit and a wet lime scrubber results in a positive net benefit. Hence, the power plant should be encouraged to invest in these emission reduction technologies.

As the benefits of end-of-pipe clean coal technologies accrue on a social (and not a company) level, it is recognized that mainly the regulatory framework should provide the incentive for a company to invest in emission reduction technologies. The competent authority can e.g. impose an emission standard or charge an emission fee.

In general, the study shows that air quality modeling and economic decision tools can be an important tool in industrial investment decisions (EIA, determining best design parameters of new units, selection of abatement technologies) and in policy making (in general air quality policy and in granting permits). But in order to develop its use, availability of air quality data is an important condition. A systematic monitoring program should therefore be implemented. On a more general scale, the use of air quality monitoring should also be further developed in Kazakhstan as it forms the basis for environmental policy in this field, a.o. through target-setting, determination of pollution abatement policy, assessment of achievements and effectiveness of the policy.

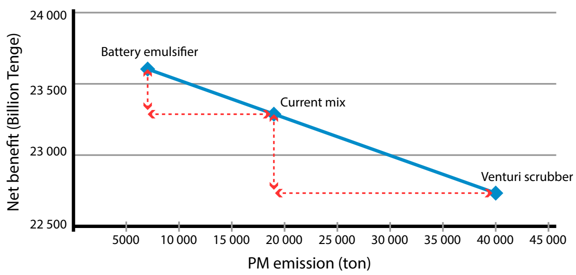


Fig. 35. Social cost benefit analysis of emission abatement technologies to reduce PM emissions.

Carbon Capture and Storage (CCS)

It has repeatedly been shown that reaching significant CO_2 emission reduction targets is at least more expensive (cf. [14, 22], or even technically nearly impossible, when CCS is not considered as part of the energy and industrial portfolio. Although a few CCS projects are currently in operation, it is much more difficult to implement than many of the renewable technologies. One obstacle is that economic CCS projects are necessarily large scale, while renewable projects such as wind or solar can start out small and gradually upscale with time. A second main concern is the economy of such large projects. Although they are likely to be cost competitive, and even more economic than other options, they only become economic because the costs for emitting CO_2 are avoided. In other words, the CO_2 price (in an emission trading scheme) or CO_2 tax should be sufficiently high. The level of such a price or tax indicates the national and worldwide ambition to tackle the climate issue, and it is currently uncertain how far that ambition reaches.

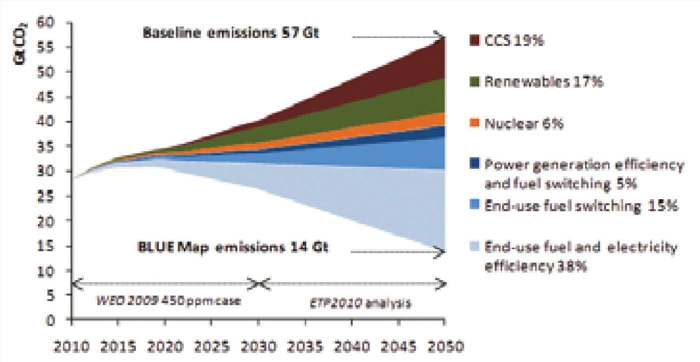


Fig. 36. Key technologies for reducing CO_2 emissions under the BLUE Map scenario in ETP 2010 [22].

Carbon Capture and Storage in Kazakhstan

CO_2 capture and storage (CCS) is internationally seen as an important technology to reach deep, worldwide climate targets. Europe in particular tends to take a leading role for enabling CCS in other countries, especially developing countries that rely largely on coal as a source of energy. Kazakhstan fits this profile. Yet, CCS is currently not really considered as an option in Kazakhstan.

In the ACCESS project, capacity building about CCS has been undertaken. Focus has been at the one hand on the process and economics of CO_2 capture, the most expensive step in a CCS project, and at the other hand on the place CCS could take in the portfolio of low carbon electricity production technologies.

CO_2 capture

Impact on power plants

CO_2 capture is the first step of the CCS chain, aiming at separation of the CO_2 in an as pure as possible CO_2 flow. There are several techniques to separate CO_2 from a gaseous mixture and three of them are already at pilot or demonstration stage. These are: (1) de-carbonization of the flue gas (post-combustion capture) where CO_2 is separated from nitrogen by using solvents, (2) the de-carbonisation of the fuel itself (pre-combustion capture) and (3) the oxy-fuel combustion where the fuel is burnt in pure oxygen instead of air. All three options are able to remove 90% of the CO_2 generated in the combustion process.

The three options are roughly equivalent regarding the penalty they produce on the performance of the power plant, i.e. a loss of efficiency of about 10% points. This means that additional fuel must be used to produce the same energy and consequently additional CO_2 is initially generated. At the same time, the installation of a capture unit increases the capital cost from by 60% and increases further O&M costs.

The efficiency penalty and additional capital and operation costs lead to an increase of the cost of the produced electricity by 40 to 70% per kWh. Facing such penalties, the efficiency of the coal-fired plant must be initially as high as possible to justify such a heavy investment, even if additional costs are expected to be cut by a factor 2 in the near future thanks to R&D projects in Europe and worldwide.

Cost effectiveness of different CO_2 capture options

To evaluate the economics of CO_2 capture on a company level, the cost effectiveness of different CO_2 capture scenarios can be determined. This kind of economic analysis defines the trade-off between the cost and effects associated with different investment scenarios. The calculation of the cost effectiveness involves the use of two different metrics. Concerning the different CCS options, the effectiveness of the investment is determined in Mt CO_2 emissions avoided, the cost of CO_2 capture is determined in Euro.

A cost effectiveness analysis can be performed on an average basis or incrementally. When an average cost effectiveness ratio (ACER) is calculated, the cost of each investment scenario is divided by the effect i.e. C/E. To determine the incremental cost effectiveness ratio (ICER) one of the investment scenarios is considered as a reference to which the other scenarios are compared. The ICER of an investment scenario is calculated as the trade-off between the difference in cost (ΔC) and the difference in effect (ΔE), i.e. ΔC/ΔE.

CO_2 capture leads to further CO_2 emission reductions. However, this investment is only feasible if highly efficient power plants are built.

Three different CO_2 capture investment scenarios are selected. A company can decide to: (1) build a new power plant without CO_2 capture (NoCCS), (2) build a new power plant including CO_2 capture which is put immediately in operation (CCS operational) or, (3) build a new power plant with the option to put CO_2 capture in operation in the future (CCS ready). Table 1 gives an overview of the cost and effect of each investment scenario. The data is based on EU cost structures.

Carbon capture technologies

Post-combustion capture

This technique, which is currently the capture technology closest to commercial deployment, can remove CO_2 from the flue gas both in coal and natural gas-fired power plants, boilers and furnaces and this both on existing (retrofit) and new installations. The fossil fuel is together with air injected in the combustion room where heat is generated to power steam turbines. The flue gas is pumped through a reactor where chemical absorption of CO_2 by a solvent happens (fig. 37a). The depleted flue gas is emitted into the atmosphere. The CO_2-solvent solution is treated (heated) in a separate reactor called the stripper or desorber to release the CO_2. Hereafter the CO_2 is compressed and dehydrated and ready for transport and storage. The consumption of heat for this decarbonisation of flue gas technique affects the overall performance. New solvents with lower regeneration energy, longer life time and lower corrosive characteristics are being developed to reduce this energy penalty and increase overall efficiency.

Oxy-fuel combustion

Oxy-fuel combustion is a combustion technology with pure oxygen which can be used in existing or newly designed boilers (gas, coal, biomass, waste…). In this process of oxy-fuel capture, pure oxygen instead of air is used to burn the fuel. The pure oxygen is generated with an air separating unit which separates the nitrogen from the oxygen in the intake air. The pure oxygen is injected in the boiler together with the fuel. The flue gas then mainly consists of H_2O (steam) and CO_2, which is re-circulated to control the boiler temperature and cooled. The steam and CO_2 can be separated by water condensation (fig. 37b).

Pre-combustion capture

The removal of carbon from the fuel after a process where natural gas is reformed or coal is gasified into a syngas (H_2 and CO) is called pre-combustion capture or decarbonisation of the fuel. The technique is based on integrated gasification technologies (IGCC), where solid fuels such as coal or biomass are gasified with pure oxygen from an air separation unit to form a syngas which is a mixture of H_2 and, CO. Steam is added to the syngas where it reacts with the CO to form CO_2 and H_2 (fig. 37c). The CO_2 is separated using physical adsorption to a solvent, compressed and dehydrated where after it is ready for transport and storage. The pure H_2 is burned to power turbines.

Fig. 37. (a) Post-combustion capture technique; (b) Oxy-fuel combustion technique; (c) Pre-combustion capture technique [23].

Also the results of the ACERs and ICERS are presented. Based on the calculation of the ACERs, the company should invest in the CCSbase scenario. because this investment involves the lowest cost per ton CO_2 avoided.

Table 1. Calculation of the ACER.

Scenario	No CCS	CCS oper.	CCS ready
Cost (M€)	3668	5094	3921
Effect (Mt)	0	184	115
C/E (€/t)	∞	28	34

To determine the ICER (see Table 2), the NoCCS scenario is considered as the reference scenario. Compared to the calculation of the ACER, the ICER provides a more nuanced conclusion.

In reference to NoCCS, the investment in CCS ready is more economical than the investment in CCS operational. The incremental cost for an additional unit of CO_2 emissions avoided is lower. In order to make correct recommendations, it is necessary to discount the effectiveness. Units of emissions avoided in the future are worth less than emissions avoided at present.

Table 2. Calculation of the ICER.

Scenario	CCS oper.	CCS ready
ΔCost (M€)	1425	253
ΔEffect (Mt)	184	115
Discounted Δeffect (Mt)	45.12	10.03
ΔC/ΔE (€/t)	31.58	25.18

The incremental cost of CCS ready is only economically justifiable if the benefit of the quantity of CO_2 avoided is at least 25.18 €/tonne. In order to make a decision, a company should only invest in CCS ready if the benefit of one ton CO_2 avoided is at least 25.18 €/tonne. This benefit could correspond to a CO_2 price due for each ton of CO_2 emitted.

In the case of Kazakhstan where the sub-critical coal-fired power plants have an efficiency as low as 33-35% a penalty of 10% points would bring down the efficiency to 23-25% and this is unacceptable from an economical point of view. Installing a capture unit is therefore out of question for low efficient power plants.

This is also indicated by the results of Table 3. It is shown that CCS ready for a less efficient power plant reduces the emission by 84 Mt. However, the cost is higher than when an efficient power plant is built. In order to justify the incremental cost, a CO_2 price of more than 93 €/tonne should be due. Hence, for a power company it is more economical to build a new highly efficient power plant without CO_2 capture than to retrofit a low efficient power plant.

Table 3. No CCS scenario compared to low efficient CCS ready power plant.

Scenario	No CCS (ηe=0.46)	CCS Ready (ηe=0.35)
Cost (M€)	3668	4350
Effect (Mt)	0	84
ΔCost (M€)		681
Disc Δeffect (M)		7.26
ΔC/ΔE (€/t)		93.80

Kazakhstan should phase out the inefficient old coal plants when they become uneconomic and build the most advanced new ones with at least 45% efficiency. Because of the long lifetime of power plants, new-built plants should already today be designed to be able to install a capture installation.

A comparison of Table 3 and Table 1 shows that building a high efficient power plant which is CCS ready is less costly than a low efficient power plant which is CCS ready. Compared to NoCCS, more emissions are reduced. Also these figures indicate that it does not make sense to retrofit existing inefficient power plants. If CO_2 capture would be considered, it is necessary to build high efficient power plants.

CCS in the EU and relevance for the EU

The EU recognizes that CCS will and should play an important role in the achievement of ambitions CO_2 reduction goals. This is stimulated by the clear and sustained intention of the European Commission to realise worldwide reduction of CO_2 emissions.

In order to make sure that CO_2 is safely and permanently stored in CCS projects across Europe, an EU wide directive (Directive 2009/31/EC) has been put into force in 2009, informally referred to as the CCS directive. In spite of its name, the CCS directive mainly deals with the storage aspects, since transport and capture are considered to be sufficiently covered by existing legislation and guidelines. The directive was published in 2009. As initially planned, the first review process will start in 2013. This was considered necessary in order to further detail and adapt the legislation according to the experiences gained from the demonstration projects.

Furthermore, from 2013 onwards, the environmentally safe capture, transport and geological storage of CO_2 will also be covered by the European ETS. The ETS directive post 2012 integrates CCS projects as follows:

Allowances will not need to be surrendered for CO_2 emissions which are permanently stored or avoided.

No free allocation is given to the capture, transport and storage of CO_2.

Through the ETS, the incentive for CCS arises thus from CO_2 allowances not being required to be surrendered when stored safely and permanently. If leakage of CO_2 would occur during transport and/or from the storage site, CO_2 allowances must be surrendered. Monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide are in place.

Also a financing program for commercial CCS demonstration projects and innovative renewable energy technologies has been established by the European Commission. The program is called "NER 300" and will provide project financing to several CCS demonstration plants.

In the European Union several industrial companies are technological leaders on different aspects of CCS. The EU has as such build up a technological lead placing it one step ahead of other developed regions. As such, it has both an economic and moral interest to involve Kazakhstan in this process.
In view of the vast natural resources and growing economy of Kazakhstan, this country is also likely to become a more important trade partner for the EU, meaning that also the economical footprint of the materials and products originating from Kazakhstan are of direct relevance to Europe.

Credit: Szymon (sinsin)

The role of CCS

Making different stakeholders such as authorities, industry, researchers, consider CCS as an important option to tackle climate change in Kazakhstan, asks not only for a technical-economic support. Explaining the technical concept of CCS needs to go hand-in-hand with demonstrating under which conditions CCS becomes a viable alternative to other greenhouse gas mitigation strategies, such as renewable energy and energy efficiency.

A study was started to objectively evaluate CCS compared to other traditional and renewable technologies for Kazakhstan and to determine a marginal CO_2 abatement cost curve. This latter can be used to compare the costs, potential and environmental benefits of CCS in Kazakhstan to other CO_2 mitigation technologies. As such a basic insight in country-specific investment strategies concerning CCS is given to Kazakh parties, which can get both Kazakh and potentially also European partners interested and involved. The results are a sound basis to initiate early research and development regarding CCS in Kazakhstan.

The PSS III simulator [24] was used to process and evaluate country-specific data combined with an up-to-date technological portfolio for electricity production. This technology portfolio consists of 22 technologies which meet EU standards, and comprise standard coal and natural gas based power plants, as well as those using biomass. Each of these technologies can also be installed in combination with CCS. Also included are concentrated solar, photovoltaic and wind energy. Hydropower and nuclear power installations are not evaluated.

PSS III simulation results

When the use of state-of-the art high efficiency installations in the energy sector in Kazakhstan is not mandatory (a so-called "irresponsive energy portfolio") and the average CO_2 price within the Kazakh emission trading system (ETS) is set to not exceed 5 €/tonne CO_2 emitted, the simulation shows that the energy production portfolio in 2050 will mainly be based on coal-fired power production.

This implies that the 2050 energy portfolio does not differ fundamentally from the 2012 portfolio (fig. 38). The plants are expected to operate at a slightly higher efficiency than the present ones but in general there is clearly an insufficient stimulus for low carbon energy production technologies to come into play.

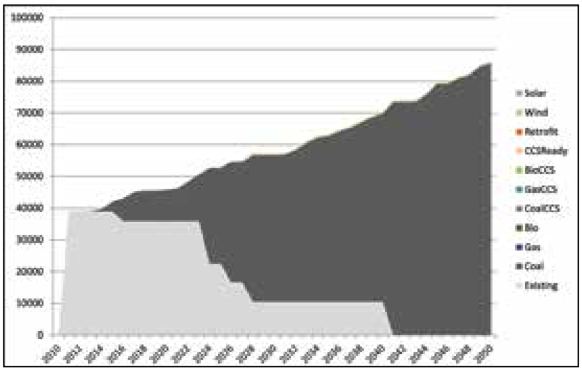


Fig. 38. PSS III prediction of the irresponsive energy portfolio with a low ETS-price. The total portfolio is dominated by coal technologies (grey part). Production (vertical axis) in GWh/y.

Even when the ETS price is increased up to around 40 €/tonne by 2050 an almost complete dependence for power production on coal is still simulated (fig. 39). Wind plays only a marginal role, although it grows slowly with time. It is the only low-carbon technology which is activated, and its share is too small to significantly decrease the CO_2 emissions from the power sector. The emissions increase by 1.1% annually.

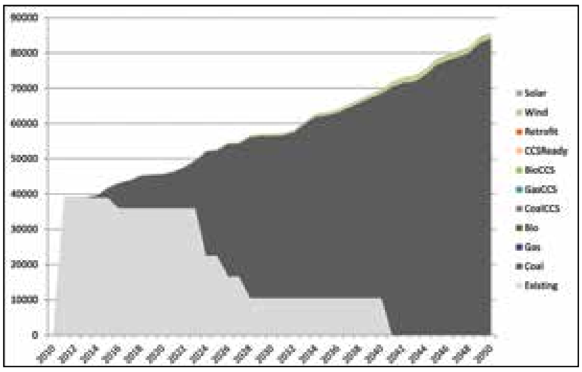


Fig. 39. PSS III prediction of the irresponsive energy portfolio with a high ETS-price. The total portfolio is dominated by coal technologies (grey part). Only wind energy (lime green) plays a marginal role. Production (vertical axis) in GWh/y.

PSS III simulator

The PSS III simulator is an ad-hoc techno-economic CCS simulator that can be used for detailed analysis of the implementation of CCS and was extended in the frame of the ACCESS project to include a series of renewable technologies. Future predictions of investment decisions on the CO_2 emitting industry are made up to 2050 to investigate the economic deployment of CCS for a region or country, next conventional and renewable technologies. The production technology (or energy mix for the power industry), location, pipelines and reservoir choices are simulated following a bottom-up approach. The simulations in this study are restricted to the power sector. Project investment options are considered using the Real Options Analysis method in combination with the Modern Portfolio Theory for making realistic, close-to-optimal investment decisions. The Modern Portfolio Theory itself provides the optimal investment decision based on the expected risk and return of different investment options.

PSS III matches power and industrial production (e.g. electricity in GWh) and demand, and uses a price on CO_2 emissions to make economically sound investment decisions with a choice of conventional (non-CCS), CCS-ready and CCS-operational technology options. Captured CO_2 is transported via the most optimal pipeline route and stored in a domestic geological reservoir or exported to neighbouring countries. The most optimal, in this case least-cost, pipeline route is calculated using different spatial cost grids and factors, such as land use, soil type and slope. If economically favourable, pipeline networks can emerge. Minimum and maximum CO_2 pressure will define pipeline diameter, the number of compression stations and cost. Several socio-economic parameters are grouped to define so-called "scenarios" which may reflect political decisions such as energy choices or climate targets.

The CO_2 price is a key parameter in the simulations since it is, apart from enhanced recovery of oil, gas or coalbed methane which are not considered in the current simulations for Kazakhstan, the main economic driver behind CCS deployment (CCS technology will always pose an additional cost compared to non-CCS production technologies).

PSS Explorer and the PSS III simulator both use brute force for most of their calculations, and about 100 PSS II Monte-Carlo iterations are typically needed to generate results for general statements, even more if higher accuracy is desired. This means these simulations are very time-consuming and are typically multiple-day and parallel calculations. The main added value of this stochastic approach is that next to the most probably outcome also an uncertainty envelope is calculated taking into account technical, geological and economic uncertainties of a given scenario. The foundations of PSS III is trying to predict investment decisions at project level, which is fundamentally different from the approach of optimisation models. Nevertheless, the input data is exchangeable and the most optimal results are obtained by using PSS III combined with e.g. Times.

The somewhat surprising conclusion for Kazakhstan is therefore that even a significant attempt to mitigate the emission of CO_2, by setting a high CO_2 price, gives only an extremely low variation in the future electricity production portfolio. The energy portfolio is there rather irresponsive and rather inefficient coal technologies remain the most economic technologies. This is explained by the fact that the price of coal is low in Kazakhstan.

Inefficient coal-based technologies in the energy portfolio combined with a very low coal price, annihilate the effect of a CO_2 price on industrial emissions.

When simulations are run in which only the most efficient supercritical power technology is allowed for coal-fired power plants (a so-called "responsive energy portfolio"), low carbon technologies do become an important investment option when ETS prices increase. This assumes that a policy is in place that not only sets a price on the emission of CO_2, but also implements rules preventing the construction of the less efficient coal-based power plants.

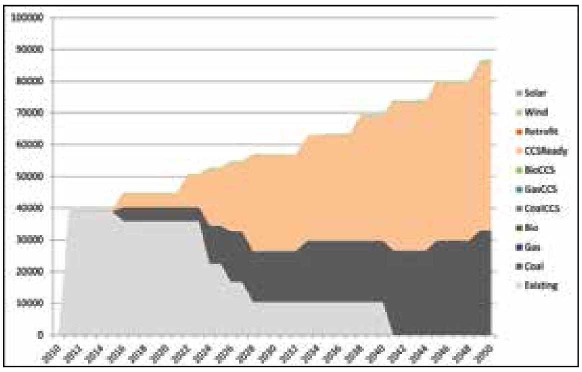


Fig. 40. The energy portfolio predicted by PSS III for the responsive energy portfolio (most efficient coal technologies only) in the case of a limited ETS-price (up to 5€/ton). The cost of emitting CO_2 is insufficient to affect the energy portfolio which means that coal fired power plants remain the most important power sources in 2050. Production (vertical axis) in GWh/y.

Simulations which take the responsive energy portfolio into account with a limited ETS price (up to 5€/tonne), show an energy portfolio in 2050 which consists mainly of classical coal-fired power, but also of CCS ready coal-fired power plants (fig. 40). This can be understood as a minimization of risks: building CCS ready power plants requires only a marginally higher investment cost, while the flexibility to switch to CCS operational in case the CO_2 price rises is an additional certainty for the investor. If the ETS price increases towards 2050 (up to 40 €/tonne) the coal portfolio is more dominated by CCS ready technology, of which part is effectively retrofitted to become CCS operational after 2040. Power from wind is gradually growing over time and natural gas based power is also visible in the portfolio (fig. 41). The fact that these options are chosen is also an indication that the CO_2 price is sufficiently high for the introduction of more carbon lean power technologies.

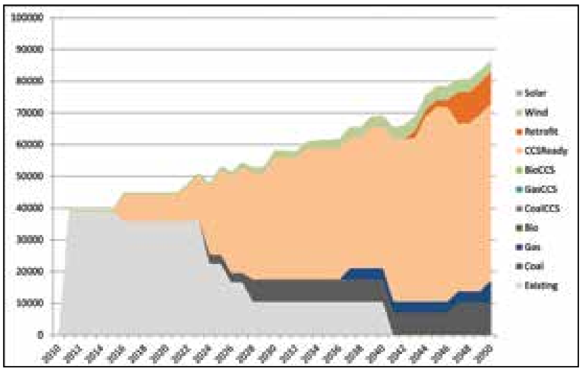


Fig. 41. The energy portfolio predicted by PSS III for the responsive energy portfolio in the case of an increasing ETS-price towards 2050 (up to 40 €/ton).Tthe cost of emitting CO_2 is important enough to effect the energy portfolio. Production (vertical axis) in GWh/y.

Marginal emission abatement cost curve

A marginal emission abatement cost curve (MACC) is set up as well. The marginal abatement cost represents the additional cost of an extra tonne CO_2 emissions avoided for each emission abatement technology. The MACC finally gives a ranking of these technologies based on their additional abatement cost for a unit of emissions reduced. PSS III calculated this for the 22 technologies available in the Kazakh specific simulations. The cost and effects of each abatement technology are compared with the current coal-based power production [25]. The selection of an emission abatement technology depends on the existing CO_2 price. If the CO_2 price is higher than 22 €/tonne, wind energy will be adopted. Technologies that reduce emissions at a relatively low cost are adopted first

Geological storage options

After capturing and transporting CO_2, it is injected in its dense or liquid phase into a geological suited formation where it is stored. Geological storage of CO_2 aims at permanently preventing the greenhouse gas from entering the atmosphere.

Various storage options exist. They include storage in deep saline aquifers, in depleted oil and gas fields and in abandoned coal mines. CO_2 can also be stored in active oil and gas fields by which it can be used to enhance the production of respectively oil (enhanced oil recovery (EOR)) and gas (enhanced gas recovery (EGR)). Injection into virginal (un-mined) coal fields is possible as well. In this case it can enhance the production of methane (enhanced coal bed methane recovery (ECBM)). All options can take place onshore and offshore. Figure 42 below shows the different storage options.

The carbon dioxide is generally injected below a depth of 800 meters, where the CO_2 will remain as a liquid or a supercritical fluid because of ambient pressures and temperatures. Coal-bed storage of carbon dioxide can take place at shallower depths, because the storage relies on the adsorption of the carbon dioxide on the coal.

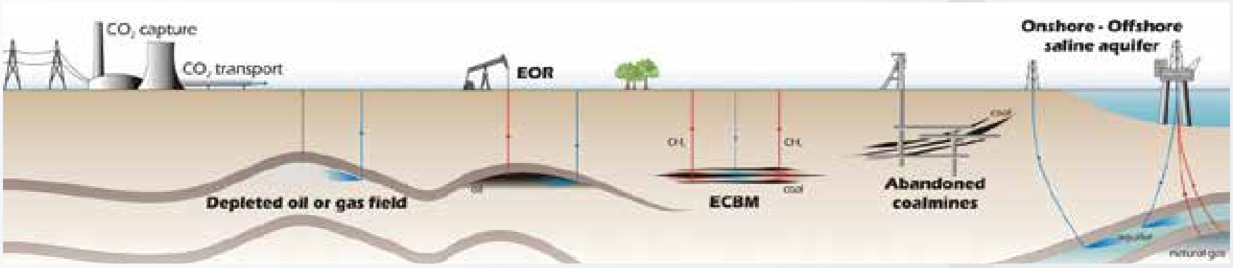


Fig. 42. CO_2 storage options [26].

(gas and wind). If regulations are more strict, CCS retrofit technologies that reduce emissions further but that require higher costs are adopted as well (fig. 43).

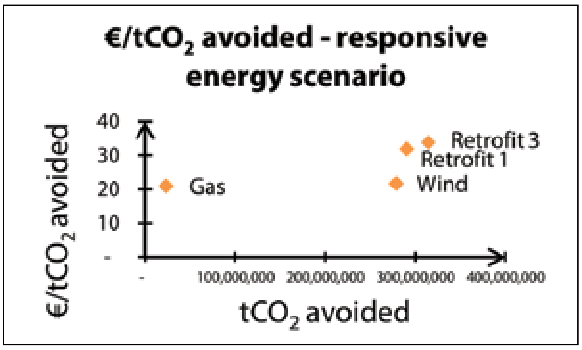


Fig. 43. Marginal emission abatement curve in the case of an increasing ETS-price towards 2050.

The future energy portfolio of Kazakhstan

Kazakhstan is a country with an explicit and quantified ambition to lower its CO_2 emissions over the next decades. Yet, it is also clear that a system which may work in e.g. Europe, such as sufficiently stringent ETS system, should not simply be copied to the Kazakh situation. The economic dynamics of each country warrants the proper analysis and quantitative projection of policy measures, and additional tailoring of policy measures in order to have maximum effect.

If the energy portfolio is reshaped and a carbon price is set, CCS will naturally take its place next to other technologies.

CCS is only one example in the portfolio of CO_2 lean technologies that is evaluated. The most important step is about building the correct and most efficient, yet economic portfolio of low-carbon technologies. In the specific situation of Kazakhstan, it is however demonstrated that coal will remain the basis of the power production until at least 2050 because it is easily and cheaply accessible. Still, renewables such as wind do have a huge potential, and when a level-playing field is created for all power options, it will no doubt claim a larger share than that is currently projected in the 'high ETS price, responsive energy' portfolio. However, for the coal-based power production, the current economic stimuli (access to cheap coal) have the undesired side effect that low efficiency power plants will preferentially be built. If this technology lock-in is prevented, e.g. by setting minimal efficiency standards for new plants, CO_2 emission reductions will be achieved, because the coal power plants will be more efficient, but also because natural gas power plants will be added to the portfolio, as well as (in a later stage) CCS operational power plants.

The way forward

The relatively straightforward scenario assumptions made above allow to formulate the following few recommendations, which can be used for guidance when planning the road ahead for CCS.

For Kazakhstan, CCS is an essential technology in any CO_2 lean energy portfolio. Given sufficient ambition, CCS becomes the dominant technology for reducing the CO_2 emissions. CO_2 emissions can only be brought down significantly by also phasing out the least efficient coal-based technologies. The low coal price strongly favours the use of low-efficient technologies. These low-efficient technologies will continue to exist unless they are phased out, or until the coal price is increased. All new power plants need to be CCS ready, but not yet CCS operational. CCS in Kazakhstan will become economic at the earliest within one to two decades. A fast introduction of CCS requires that CCS ready power plants are already being built. The Kazakh ETS system needs to reflect the international climate ambitions. Kazakhstan has the will to conform to the international climate targets. The outlooks of the domestic ETS system (and other measures) should be kept in line with international outlooks, and a CCS-enabling framework needs to be put in place. A stable legal framework for CCS is required for properly laying the foundations for CCS (e.g. CCS ready installations).

Although the statements above are robustly supported by the preliminary results of the ACCESS study, the techno-economic evaluation can and should be significantly detailed to obtain further insights, including early opportunities such as EOR.

How to stimulate CCT and renewable energy investments

Pricing reforms and energy efficiency policies

Electricity tariffs in Kazakhstan are still regulated and do not recover investment costs. Kazakhstan's tariffs are still among the lowest in the world and do not allow making the necessary investments to secure the future energy requirements of a growing country. At the demand side, the tariff level does not provide incentives for local companies or households to invest in energy savings [27]. Energy efficiency investments contribute to energy security, improve the competitiveness of the economy, and reduce CO_2 emissions. Increasing energy prices do not necessarily lead to higher energy bills for end-users because the saving potential is large. Market based energy pricing are a win-win option for economic development and the environment but it also entails adjustment costs, shifts in competitiveness between sectors, and the reallocation of labor and capital from high-emitting to low-carbon sectors. National policy should envisage gradual phase-out of certain energy intensive products, improve (building) standards, and labeling of energy efficient goods in order to make energy efficiency projects business-as-usual [28].

Renewable energy support instruments

Electricity is going to play an important role in the transition to a sustainable future. The development of renewable energy support instruments is necessary to stimulate activities that are valuable from a public perspective but are not adequately supported by consumer demand because they are competing with low-priced products that do not internalize external costs. Electricity support instruments can be categorized as price driven or quantity driven. Price driven support includes the use of feed-in tariffs, premiums, investment credits, and fiscal stimuli. When a feed-in tariff (TIF) is applied, a fixed price is offered to renewable energy generation. This price is paid by consumers that use power from standard electricity suppliers. A quantity driven approach is the connection of renewable energy quota obligations to the creation of tradable green certificates (TGC). Renewable energy quota imposed on standard electricity suppliers are translated into the number of certificates that must be delivered to the regulator in a given years. If the quota is to be fulfilled, the penalty on certificate shortfalls must sufficiently exceed the expected market value of the TGC. To decide which policy instrument to apply, each instrument should be evaluated on its efficacy, efficiency, equity and institutional feasibility [29].

Carbon price

A carbon price can be established by a cap-and-trade system, carbon offset mechanisms, an emission tax or command-and-control measures. Although there are some instances in which cap-and-trade is unable to operate effectively, it is considered as the most efficient method of achieving an environmental target. Setting a cap and allowing trading within that cap minimizes costs incentivizes investment in low-cost emissions abatement and optimizes improvements in carbon reduction investments [30]. Kazakhstan is considering to use an own trading scheme which can link up with the EU emission trading scheme (ETS) [28]. Kazakhstan needs to achieve Annex B status first in order to implement tradable compliance credits. In the meantime, the voluntary carbon market offers options to lay out the basis for the implementation of a sustainable low-carbon path [31].

Identification of prospective themes

The discussions during the different meetings, workshops and field visits resulted in the identification of case studies, but also in other themes that were considered equally important by most of the stakeholders. Within the framework of the ACCESS project these topics (named "prospective themes") have only be briefly discussed, but can be considered as possible work topics for the future.

Coal gasification

Different stakeholders have expressed an interest in coal gasification during the project. Coal gasification techniques have been developed in Germany in the 1940's and are applied at large scale in South Africa. The topic of coal gasification receives nowadays again a lot of attention, especially in China were projects have been set up recently.

Gasification is a chemical process by which coal, or other low-value hydrocarbons, are converted to a synthesis gas (syngas) by means of partial oxidation with air, oxygen, and/or steam. The resulting syngas is consequently cleaned by the removal of impurities such as nitrogen and nitrogen oxides, some mercury, sulfur oxides, etc., and is then used to produce electricity (see IGCC technology infobox p. 40) and/or converted into high-value products such as synthetic fuels, chemicals, and fertilizers. Production of syngas can also be combined with the capture of CO_2. A water gas shift reaction makes it possible to easily capture the CO_2 out of the syngas.

The technology seems very interesting for a country rich of coal such as Kazakhstan. It enables to exploit the coal resources in a carbon-neutral way and can complement the start-up period of renewable energies.

Recultivation of mining (waste) sites with biomass

Kazakhstan is the ninth largest country in the world by land area. Because of its thin population density (less than 6 people per square kilometer), land is generally widely available. In the coal regions of the country, the land is often used to spread coal mining wastes, which makes these lands less valuable.

The possibility to grow biomass on these lands has been suggested by project stakeholders, such as the mining liquidation company. Growing biomass on the soils of the Karagandy mining region could make the soils more stable and healthy, can provide work opportunities for the region and can deliver a renewable energy source or even, depending on the chemical composition of the soil, agricultural crops. With respect to the biomass as a renewable energy source, the biomass could be co-fired with conventional coal in existing power plants, making the coal-based power production more ecological.

Growing of biomass cannot only be done on soils mixed with coal mining wastes, but also on closed coalmines leading to the recultivation and rehabilitation of these lands.

This project could start with lab test followed by small scale experiments.

(Enhanced) coal bed methane extraction

Coal is formed from plant debris that is transformed in the underground during a process that takes millions of years. During this maturation process methane (CH_4) is produces which partly remains bonded to the coal as coal bed methane. This gas is better known as mine gas because it is released when coal is being mined and can cause explosions when not properly evacuated.

Coal bed methane is identical in composition to natural gas. It is therefore a valuable resource if it can be extracted in an efficient way. This can be done in relation to mining activities, where through a series of drillings the coal is degassed ahead of the excavation front. The compressor depicted below forms part of such a system which is in place in the Lenin mine in the Karagandy basin. Drillings are first used to fracture the coal beds through the injection of water, after which water and methane are being extracted and collected through a series of pipelines.

Mine site rehabilitation in Belgium

Closure of the Campine coal mine basin in Limburg province, Belgium was accompanied by a reconversion policy, starting with an environmental clean-up and reallocation of real estate properties for nature, housing, industry and community support. As the mines were closed in a period of cheap energy and strong industrial growth a socio-economic backlash could be avoided. The most iconic buildings and infrastructures reminiscent of the mining industry were preserved (fig. 45). Each mining site has been or is being developed along a complementary theme, depending on its accessibility and industrial history. These are for the six mining sites which were closed in the early nineties: geoheritage and mining museum, vocational training centre for the building industry, clean technologies campus, cultural economy centre, energy technologies campus, retailing and leisure centre. This way, both the cultural identity and economic fabric of the region are kept alive, which form invaluable assets for further prosperity of its people and contribution to the national economy.

Fig. 44. Historical picture of the coalmine site at Houthalen.

Fig. 45. The main building of the Houthalen coal mine today, redeveloped as a 'Cleantech' Campus Incubator & Network for materials and recycling, 20 years after closure of the mine. This development results from a partnership between the municipality, research institutes and the Flemish Minister of Innovation, initiated and managed by former coal mine personnel.

In Kazakhstan the coal properties are in general suited for coal bed methane extraction. A major obstacle are the harsh winter conditions, which poses challenges to the pipeline transport of the gas, which will still contain water that may freeze and block the pipelines. Also the proximity of users or major pipeline systems is an issue.

Collection of coal bed methane may be sufficiently interesting to also implement it where mining activities are not immediately planned. An option for optimizing the production from areas that cannot be mined is enhanced coal bed methane production. This involves the injection of usually CO_2 to enhance the production of methane. The CO_2 will bind to the coal, allow to store this greenhouse gas together with the production of CH_4.

Fig. 46. Methane capture installation on the surface of the ArcelorMittal coal mine in Karagandy.

Coal mine waste management

Mining of coal produces large amounts of waste, which may continue to increase by volume tremendously if no appropriate recycling measures are taken. Currently there is 22 billion tonnes of waste from the coal industry accumulated in Kazakhstan. Coal mining waste can be a "nuisance" for the mining companies, but also for the local population. However, a sustainable management can turn waste into economic interesting by-products that can be used locally or sold on the market.

As from the first ACCESS project meeting in Astana in April, 2011, it was motivated by the Kazakh stakeholders that the issue of waste management is an important environmental and social issue. During the subsequent June, 2011 visit of the Kazakh delegation to Belgium and Germany, and in the presence of DG ENER officials, "waste" was once more one of the main topics. The workshop and field visits in the Ekibastuz area of July, 2011 confirmed the need for additional measures and management practices.

It is clear that there is a close bound between both this prospective theme and "coal processing". Whereas coal processing has mostly been discussed to treat new minded coals, the coal mining waste issue reaches further as also existing mining waste deposits should be treated and managed sustainably.

Sustainable mine liquidation and mine site rehabilitation

Mines may close for various reasons, also in Kazakhstan. The principal force is likely to be economic, but it may be geological, technical, or regulatory as well. Premature and planned mine closures can result in significant, adverse impacts to the environment and the community, and therefore, must be managed appropriately. Mine closure may impose risks which are identified as environmental, safety related, social, related to the final land use, legal, financial and technical. Sustainable mine liquidation and rehabilitation plans may address a number of problems and issues due to the decommissioning of the mines.

The need to provide a more important support to local authorities and mining companies, considering the main stakeholders opinions during the preparation of a sustainable mine closure and rehabilitation plan has been identified by the Kazakh and EU delegation through the field visits in both Kazakhstan and Belgium and Germany. The visit to the Karagandy region made this need clear. Examples of mine rehabilitation were included during the visit to Europe. For particular mines, it would be highly interesting to conduct pre-feasibility studies of the technical aspects of the mine liquidation and to develop a conceptual master plan for the rehabilitation of the mine site. By creating an example for a project in Kazakhstan, and setting general and specific guidelines for closure and rehabilitation measures, future discussions and negotiations can be facilitated.

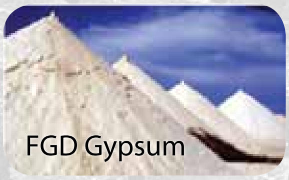
Coal combustion products (CCPs)

The products from coal combustion could find applications in various niches. This is due to their inherent physical (granulometry, density, porosity) and chemical characteristics. The areas could encompass their use in civil engineering (as additive to concrete, brick manufacturing, earthworks and landscaping), for soil amelioration (reduction of acidity), or for recovery of vanadium, germanium, gallium, etc. (the case of fly ash).


Fly Ash


Boiler slag


Bottom Ash


FGD Gypsum

Application of coal combustion products

Coal combustion and the treatment of the combustion gases lead to the production of different types of coal combustion products (CCPs). These products can be disposed of as waste, but may as well be applied in a useful way.

The average amount of CCPs produced in European power plants (EU 15) is annually about 56 million tonnes and in the EU 27 the total production is estimated to about 100 million tonnes per year. Most of the CCPs produced are used in the construction industry, in civil engineering and as construction materials in underground mining (54%) or for restoration of open cast mines, quarries and pits (36,5%). The use is regulated by REACH, the European Community Regulation on chemicals and their safe use (EC1907/2006), and many technical standards are published.

During the workshops, the issue about the possibilities in Kazakhstan for the use of CCPs was raised. Blending of the power plants ashes with soils and the potential for increasing the crop in agriculture appeared to be a topic that asks for further support.

Recommendations

6

The ACCESS team considers this project as a necessary first step in the transfer of knowledge on CCT and CCS and the development of Kazakh specific techno-economic analyses. During the seminars, by the analysis of different case studies, and through the close contacts made, the ACCESS team built up experience on the Kazakh mining industry, the energy sector, the economic system, and current environmental policy. From this experience, the ACCESS team proposes a list of recommendations which aims to reflect the vision of the EU, Kazakhstan and the ACCESS team on the actions necessary to successfully initiate the transition to a low carbon economy.

Clean coal technologies

R1: Coal beneficiation – further research required

The ACCESS project experts in the field of coal beneficiation had different contacts with coal mining companies and with the Ministry of Industry and New Technologies. It was discussed how the coal mining companies can face the challenge of treating coal with a high ash content. From these discussions, possible means to treat the coal were suggested.

Considering coal characteristics and the current beneficiation of the coal extracted from the Vostochnyy and Ekibastuz coal mines, reducing the ash content is difficult. That is why it should be investigated to which extent the ash and sulphur content should be reduced in order for the existing boilers to operate efficiently. Once these needs are identified, an experimental program should be developed (encompassing testing various techniques) to evaluate the feasibility of achieving the reduction targets for the components in the coal under consideration. In this context, dry coal preparation techniques should be preferably targeted view the harsh local climate conditions. This should be accompanied by focused characterization studies of coal and accompanying rock mass to deliver key characteristics (petrological, granulochemical, degree of coal liberation). As regards the coal from Shubarkol Komir, the introduction of more efficient coal drying techniques should be considered in order to reduce the moisture of the coal.

Because of the close link between the coal quality and the design of the power plant combusting the coal, the implementation of coal beneficiation technologies should not be a one-side action in the mining sector. Coal beneficiation technologies should be considered together with the refurbishment of existing power plants and the construction of new power plants. Both sectors have in fact an interest in a parallel evolution.

Coal beneficiation does not only improve the energy efficiency of power production, it also limits the formation of pollutants such as particulate matter, ashes, and slag. Hence, it can be considered as a preventive measure to environmental pollution. Furthermore, the beneficiated coal will be more easily suited for export as it can travel further because of its increased value per tonne. Coal beneficiation is therefore of both environmental and economic interest to Kazakhstan.

Because of the potential economic and environmental rewards, it is recommended to launch one or several ad-hoc studies to reduce the ash and sulphur content of coal from the Vostochnyy and Ekibastuz mines, and on moisture reduction of Shubarkol Komir coal, in combination with a technical cost-benefit study on the relation between coal beneficiation and expected efficiency and environmental improvements in power production.

R2: Coal combustion – to set minimum efficiency standards

The production efficiency in the power sector is in general low and there is an apparent lack of state-of-the art technologies. Most power plants are thermal sub-critical coal-fired power plants. These are highly inefficient leading to a rather extensive pressure on the local environment and on global warming. Inefficient old power plants should phase out and the most advanced new ones should be built.

However, the model results of the PSS III simulator indicate that the current access to inexpensive coal has the undesired side effect that the most economic new power plants to be built are less efficient than the state-of-the-art references. One obvious way to prevent this technology lock-in is by setting minimal efficiency standards for new plants.

Simulations show that a combination of phasing out existing power plants and setting state-of-the-art performance standards results in CO_2 emission reductions. This will be achieved, not only because the coal power plants will be more efficient, but also because natural gas power plants will be pulled into the portfolio, as well as (in a later stage) CCS active power plants.

These complex but fundamentally important interactions should obviously be well understood. It is therefore recommended that more detailed techno-economic evaluations are made, and to do this in close relation with the preparatory policy work on improving the energy portfolio. The specific technological problems related to using the domestic high-ash coal, and their technological implications (see R1), should explicitly be taken into account.

R3: to invest in state of the art emission abatement technologies

For the time being, and in anticipation of profound changes in the power sector, different measures can be taken to improve the environmental impact of coal-fired power production. End-of-pipe emission abatement technologies can be installed on existing power plants. Abatement technologies of atmospheric pollutants such as PM, SO_2 and NO_x can result in an important improvement of the local air quality. Investments in these technologies are justified by the avoidance of damage costs associated with the harmful impact of these emissions to human health and nature. Of course from a private investor's perspective, the investment decision in these technologies should take into account whether the additional removal efficiencies are worth the additional costs. Also the remaining life time of the installation and other possible site specificities should be considered.

To support these decisions, air quality modelling can be an important tool in industrial investment decisions (environmental impact assessment, determining best design parameters of new units, selection of abatement technologies) and in policy making (in general air quality policy and in granting permits). In order to develop its use, availability of air quality data is an important condition. A systematic monitoring program should therefore be implemented.

Even with the intention to profoundly modernize the power sector, existing infrastructure will remain operational for a significant time. Given the adverse health and environmental impact of the current installations, we clearly recommend an extensive evaluation, and successive implementation, of end-of-pipe abatement technologies. The rationale for these changes needs to be provided by air quality modelling and monitoring.

Carbon capture and storage

R4: to develop a framework that considers CCS as an intermediate step towards green energy production

In the mid-long term, carbon capture and storage (CCS) should be applied to reduce the emissions of CO_2 of power production further. Again, this technology only makes sense when high efficient carbon-based power plants are in operation. At the current low-efficient power plant, capture of CO_2 is not economically feasible. However, if the energy portfolio of Kazakhstan is reshaped by the introduction of state-of-the-art technologies (see R2), CCS will naturally take its place. As for any technology, the enabling framework needs to be timely in place. Hence, Kazakhstan should consider CCS within the portfolio of CO_2 mitigation options similar to the introduction of renewable energy production.

CCS currently appears be an overly expensive technology. Simulation of power production in Kazakhstan for the next decennia shows that CCS will become an important and economic greenhouse gas mitigation technology. This observation, together with the given complexity of CCS projects, leads to the recommendation to prepare the road for CCS by creating an enabling framework, as well as research activities to establish the geological knowledge base required for storing CO_2. It is at this stage too early to warrant pilot or demonstration activities, unless significant international support could be secured.

Environmental policy

R5: to have a vision on an integrated approach

Recent policies aim to increase the competitiveness and technical feasibility of the production and transmission of renewable energy, opening the green way forward. Furthermore, the emission trading scheme under development in which a carbon price is set, is a positive signal and will stimulate investments in CCS and renewable energy. Low energy efficiency in the Kazakh society is a general problem which cannot be addressed by the energy production industry alone. Also other sectors such as transport, housing and buildings need to contribute in order to reach a green economy. The emission reduction targets should therefore be set sufficiently low to be an incentive for all sectors to improve energy efficiency and to reduce CO_2 emissions.

It is clear that most issues are highly interlinked with each other, for which an integrated approached is needed. Many of the issues above have already been tackled or considered in Europe. Therefore, a collaboration between Europe and Kazakhstan is most useful, allowing for the exchange of knowledge and technology. Attracting investments and setting up structures for collaboration with research institutions can accelerate the necessary transition to a more sustainable coal-based power sector in Kazakhstan. The Kazakh energy sector faces important challenges, but has, on the other hand a major potential. The possibilities of economic growth, the abundance of space, the high level of education in the country and the political stability are some of the aspects that are in favour of this transition. And when the challenges overcome, Kazakhstan will occupy a more "powerful" position and serve as an example not only in Central Asia, but worldwide.

Conclusions

7

Kazakhstan is the leading industrial country in Central-Asia with, amongst others, important coal, oil, gas and uranium reserves. The energy production of Kazakhstan is currently based on these resources, with a particularly important role for coal. To keep up with the economic growth of the country, energy production will need to increase further. Kazakhstan has a large potential for sustainable energy production from wind, solar and water. Even so, traditional energy sources will remain important. Traditional coal-based energy production has a significant environmental impact on human health and ecosystems, both on a local and global scale. These adverse effects urge the need of a sustainable development of the coal-fired power sector in Kazakhstan, enabling the sector to continue to grow, without the associated increase in environmental pressure. Clean Coal Technologies (CCT) and Carbon Capture and Storage (CCS) are part of the solution to achieve this sustainable development. The European Union is taking a leading position in the implementation of these technologies through setting out a clear long-term vision, adapting its legislative and regulatory framework, and funding of research and demonstration projects. The government of Kazakhstan has also expressed its commitment to sustainable development, amongst others through the Green Bridge Initiative and its ratification of the UN Framework Convention on Climate Change and the Kyoto protocol.

The recommendations of the ACCESS project cover a strategy to decrease the environmental impact of burning fossil fuel by increasing coal quality, developing an air quality monitoring network and business cases for emission reduction equipment, and an onset towards the deployment of CCS in Kazakhstan.

Coal in Kazakhstan is characterized by a high ash content. For the Shubarkol Komir coal mines, the ACCESS project determines that the introduction of more advanced coal drying techniques can result in a significant efficiency increase. For the Ekibastuz and Vostochny mines, it is shown that reducing the ash content is very difficult. Therefore, it is important to identify to which extent the ash/sulfur content in the coal should be reduced for the existing furnaces to operate efficiently. In any case, coal beneficiation is an important preventive step and should be performed as far as (economically) possible.

Current sub-critical coal-fired power plants in Kazakhstan are inefficient, and have a large environmental footprint. The current economic stimuli (access to cheap coal) have the undesired side effect that less efficient power plants are chosen over the state-of-the-art references. Because of an energy penalty, CCS can only become an option when efficient, carbon-based power plants are installed. CO_2 emission reductions can be achieved by increasing efficiency, deploying CCS, and adding natural gas to the technology portfolio; even when maintaining economic growth. While still too expensive now, CCS will become an economic option in the next decades. The enabling framework needs to be timely in place for a successful deployment of CCS. The emission trading scheme under development, in which a carbon price is set, is a positive signal and can help to stimulate investments in CCS and renewable energy. For reducing other pollutants with end-of-pipe technologies, it is determined using an air quality model and economic framework that the investments that extensively reduce emissions of particulate matter, SO_2 and NO_X are justified by the avoidance of damage costs associated with the harmful impact of these emissions. In general, more ambitious end-of-pipe emission abatement technologies could and should be used in Kazakhstan to improve the air quality in Kazakhstan.

From the case studies and the different contacts that were made during the project, it appears that the role of CCT and CCS in Kazakhstan can be major. Furthermore, the set-up of a structural European – Kazakh technology network is suggested in the CCT-CCS respect. A collaboration between the EU and Kazakhstan will create added value to the realization of the priorities set out in the 'Plan of the Republic of Kazakhstan of the Transition to Low-carbon Development till 2050'.

Acknowledgments

The project team would like to express its gratitude towards Mrs. Alia Baidebekova (EU delegation to Kazakhstan), Mr. Andrey Zhelehovsky (JSC Sevkazenergo), Mr. Kanat Baigarin (Nazarbayev University Energy Research Centre), Mrs. Karlygash Jamankulova (EU delegation to Kazakhstan), Mrs. Marion Wilde (European Commission DG Energy), Mrs. Rasa Jautakaite-Tunaitiene (EU delegation to Kazakhstan), Mr. Vladimir Klyakin (Power and Coal Industry Department of the Ministry of Industry and New Technologies of Kazakhstan), and many others that contributed to this study.

References

[1] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] UNFCCC, 1998. Initial National Communication of the Republic of Kazakhstan under the United Nations Framework Convention on Climate Change, Almaty, Kazakhstan.

[3] Koch, L. and M.A. Chaudhary, Economic Transformation of Kazakhstan: Evidence from Liberalization Reforms. Journal of Academic Studies, 2002. 4(13): p. 135.

[4] Pomfret, R., and Anderson, K., 2001. Economic Development Strategies in Central Asia Since 1991. Asian Studies Review, 25(2): p. 185.

[5] CIF, 2009. Clean Technology Fund, Investment Plan for Kazakhstan, Manila, Phillipines.

[6] Farra, F., 2012. OECD PRESENTS… Unlocking Central Asia. Harvard International Review 33(4): p. 76-79.

[7] Hnanguie, C. and M. Nurseitova, 2012. World finance review. Kazakhstan: Economic trends and propsects for 2012.

[8] EBRD, 2011. Climate change. The low carbon transition.

[9] World Bank, 2011. Data and Statistics for Kazakhstan, Washington, DC, USA, September 2011. Available from http://www.worldbank.org.kz/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/KAZAKHSTANEXTN/0,,contentMDK:20212143~menuPK:361895~pagePK:1497618~piPK:217854~theSitePK:361869,00.html

[10] Asian Development bank, 2012. sd. CAREC Members Electricity Regulators Forum. Consulted on 9 April 2012 on the following website: http://www2.adb.org/projects/CMERF/kaz.asp

[11] United Nations Development Program (UNDP) Kazakhstan, 2011. Lessons learnt from the UNDP-GEF project "Kazakhstan – wind power market development initiative". Consulted on 9 April 2012 on the following website: http://www.undp.kz/library_of_publications/files/7075-25305.pdf

[12] UNDP/GEF, 2006. Report Prospective of Wind Power Development in Kazakhstan. Consulted on 9 April 2012 on the following website: http://www.windenergy.kz/files/1214226182_file.pdf

[13] Polyurban, 2005 Das Kohlekraft- werk Ekibastus, K-U Reitmann (selbst fotografiert, 2005) http://en.wikipedia.org/wiki/File:Kraftwerk_Ekibastus.jpg

[14] ZEP, 2011. The Cost of CO_2 Capture, Transport and Storage. European Technology Platform for Zero Emission Fossil Fuel Power Plants, 51p. http://www.zeroemissionsplatform.eu/downloads/811.html

[15] IEA, 2012: Oprisan, M.: Prospects for coal and clean coal technologies in Kazakhstan. IEA Clean Coal Center.

[16] Informative-Analytical Centre of Geology and Mineral Resouces of RoK, 1996. "Coal basins of Kazakhstan" handbook.

[17] Wills B., Munn-Napier T.J., 2006. Mineral processing technology: an Introduction to the practical aspects of ore treatment and mineral recovery. Seventh edition, Butterworth-Heinemann Ltd.

[18] Tomra Sorting Solutions – product catalogue

[19] Falcke, T. J., Hoadley, A.F.A., Brennan, D. J., Sinclair, S.E.,2011. The sustainability of clean coal technology: IGCC with/without CCS. Process safety and environmental protection, 89, 41-52

[20] Integrated Pollution Prevention and control (IPPC), 2006. Reference Document on Best Available Techniques for Large Combustion Plants.

[21] EMIS, 2009b. Technical factsheet. Selective Catalytic Reduction. Available from: http://www.emis.vito.be/techniekfiche/selective-catalytic-reduction?language=en

[22] IEA, 2008. Technology roadmap: Carbon capture and storage. 52p. http://www.iea.org/papers/2009/CCS_Roadmap.pdf

[23] CCP., 2004. CO_2 Capture Project Project Results. 17 p (www.co2captureprojectresult.org)

[24] Piessens, K., Welkenhuysen K., Laenen, B., Ferket, H., Nijs, W., Duerinck, J., Cochez, E., Mathieu, Ph., Valentiny, D., Baele, J.-M., Dupont, N. & Hendriks, Ch., in press. Final report PSS II & BeNe Policy Support System for Carbon Capture and Storage (phase 2) and collaboration between Belgium-The Netherlands (Final report PSS-CCS II & BeNe). Belgian Science Policy Office, Research Programme Science for a Sustainable Development contracts SD/CP/04b & SD/CP/803.

[25] Statistics Agency of the Republic of Kazakhstan, 2011. Energy output, Kazakhstan. http://www.eng.stat.kz/digital/Industry/Pages/default.aspx. Consulted in 2011.

[26] Welkenhuysen, K. and Piessens, K., 2008. CO_2 Capture and Storage. European Union Sustainable Energy Week, Brussels, Belgium, 28.01.2008-01.02.2008

[27] Lorenz, H. and Tokhayev, D., SD. Electricity tariffs, power sector modernization and energy efficiency investments.

[28] EBRD, 2011. Special report on climate change. The low carbon transition.

[29] Verbruggen, A. and Lauber, V., 2012. Assessing the performance of renewable electricity support instruments. Energy policy. 45(0): p 635-644

[30] Solomon, B.D. and Heiman, M.K., 2010. Integrity of the Emerging Global Markets in Greenhouse Gasses. Annals of the Association of American Geographers, 100(4): p. 973-982

[31] Climatefocus, 2010. Option review for Kazakhstan to participate in the international carbon market.

9 789089 130259