Abstract

This paper describes the process of scenario development under ECCO and presents six scenarios resulting from that process. The main objective of ECCO is to facilitate robust strategic decision making regarding early and future deployment of CO₂ value chains. The ECCO project strategy is based on critical evaluation of several case studies that will enlighten various aspects of CCS and point out the most promising CO₂ chain alternatives. Scenarios in ECCO help to define the background for the case studies. They describe the alternative future(s) in terms of political environment, public opinion, regulatory framework, technology and infrastructure development, and global economical situation.

Keywords: CO₂ value chain; CCS, scenario development

1 Introduction

European value chain for CO₂ (ECCO) is a collaborative research project involving 18 partners from 8 countries[1]. It was initiated in 2008 under EU’s Seventh Framework Programme (FP7). The main objective of ECCO is to facilitate robust strategic decision making regarding early and future deployment of CO₂ value chains. ECCO will build knowledge, methodologies and tools for analysing alternative options for carbon capture and sequestration (CCS) in Europe and the project will provide recommendations leading to implementation of the most promising EOR and EGR alternatives. The ECCO methodology was built around three key moments: scenario development, case study formulations, and techno-economical analysis of chain options.

The main idea of ECCO is to formulate and analyse various case studies in order to bring more insight on the key issues related to CCS chain realization. To evaluate the potential of various CCS chain options, a tool for techno-economical analysis will be developed in ECCO. However, a framework describing the non-quantifiable factors has to be developed also in order to define the background against which the chains can be studied. That is the role of scenarios in ECCO. Scenarios in ECCO should define the background for the case studies. They should describe the alternative future in terms of political environment, public opinion, regulatory framework, technology and infrastructure development, and global economical situation.

This paper presents the process of scenario development under ECCO and the preliminary story lines resulting from that process. The scenarios were developed through a series of workshops with the involvement of all project partners, including experts with background from power generation, oil and gas production and R&D relevant to all
aspects within a CO₂ value chain. The result is a set of plausible and representative stories depicting alternative scenarios for the European energy system by 2040 including various options for CCS deployment and EOR/EGR.

2 Methods

2.1 Scenario development - The Art of Forward Thinking

Scenario development or scenario analysis is a strategic planning method that some organizations use to make flexible long-term plans [2-6]. Scenarios combine known facts about the future, such as demographics, geography, military, political, industrial information, and mineral reserves, with plausible alternative social, technical, economic, environmental, educational, political and aesthetic trends which are key driving forces. Scenarios can be used to identify possible alternative futures modeled on uncertainties. Scenario planning helps policy-makers to anticipate hidden weaknesses and inflexibilities in organizations and methods. When disclosed years in advance, these weaknesses can be avoided or their impacts reduced more effectively than if a similar real-life problems were considered under duress of an emergency.

2.2 The scenario building process

The approach chosen in this study was a strategic scenario approach, or an intervention scenario approach developing both mini-scenarios and more global and holistic scenarios, aimed at strategic reasoning. The scenario development process applied here consisted of the following steps:

- Identifying major driving forces: The main actors and factors that would be shaping the future for CCS chains were identified. Actors were defined as all existing and future stakeholders that take an interest in CO₂ value chains for Europe and stakeholders who will be affected by this issue. Factors are described as the major trends that affect the development of CCS.

- Formulating mini-scenarios: 70 mini-scenarios (short stories) were developed, with each mini-scenario focused primarily around one actor or factor.

- Defining scenarios around governing axes: 5 main drivers, or the major uncertainties which significantly affect the CO₂ value chain, were chosen based on the key threads from previous discussions. These 5 axes were used to define the main features of each scenario.

- Drafting scenarios: Scenarios were developed by describing both the situation in 2040 - situational scenario, and the so called “how did we get there story” - corresponding development scenario. In creating the full scenarios, the groups were encouraged to incorporate the most “surprising” of the mini-scenarios that had been developed in order to produce deliberately distinct ideas. Based on the story lines, qualitative figures were derived showing the time evolution of key trends such as oil price, oil production, coal use/production, CO₂ value, and renewable and other power/energy production.

- Analysing scenarios and identifying new issues arising from the stories: The scenarios were cross-checked for consistency by use of a consistency matrix, in order to identify any inconsistencies in the stories and to suggest any additional scenarios that may be needed to encompass a wider range of possibilities. One additional scenario was developed as a result of the analysis.

3 Results

The scenarios were defined along a set of 5 main drivers as illustrated in Figure 1:

1. The degree of the influence of EU – the level of action set forth by EU regarding regulations for combating climate change.
2. The degree of globalization - level of coordinated worldwide efforts against combat change.
3. Economic growth – global economic changes
4. Fuel availability – a combined measure referring to high fuel consumption and low fuel price (“high” fuel availability means high fuel consumption and/or low fuel price; “low” fuel availability means low fuel consumption and/or high fuel price)
5. Degree of environmental changes - level of CO₂ emissions, weather changes, pollution and smog, etc.,
For each scenario the situation in 2040 and the development from 2010-2040 has been described with special attention given to address the following issues:

1) Environmental changes and public opinion
Here the following aspects are addressed: quality of global environment, awareness of environment quality, standard of living, public opinion and willingness to reduce CO₂ emissions.

2) Political and regulatory issues
This covers the issues related to political will and incentives to reduce CO₂ emissions, rules and regulations, international agreements and standards, ownership, national governments, EU, and situation in other regions outside Europe.

3) Global economy
In addition to economic growth, this category covers the following aspects fuel availability and prices, energy and steel prices, financial market, CO₂ market, financial, industrial and energy actors.

4) CCS technology and infrastructure
Issues related to: technology development, commercial availability and costs of technology, existence or non-existence and type of national and/or international CCS infrastructure, ownership and operation of the infrastructure etc. are discussed under this subtitle.

There is not enough space for presenting the full scenario stories in this paper; however the main ideas behind each scenario are briefly presented in the following paragraphs and examples of deduced trends for scenario 1 and 2 are shown as well.

**Scenario 1: “Happy Planet”**
The combination of high economic growth, low fuel availability and low degree of environmental change suggests that the climate changes were actively addressed by EU and on a coordinated worldwide basis leading to a reduction of greenhouse gas emissions. In order to achieve that, technology reducing the emissions must have been successfully implemented while fossil fuels use continued. That again was leading to depletion of the reserves and thus the increase in fuel prices. High prices of fossil fuels made the renewable and other alternative energy productions competitive.

1) Environmental changes and public opinion
Target emission reductions are reached. CO₂ concentration never reaches more than 450 ppm and world temperature declines after reaching 2 deg C increase. World Oceans do not acidify. The concentration of CO₂ in the atmosphere is now stabilized at the 2015 level and new scientific evidence supports the view that it will be effective in mitigation of climate changes.

There is public acceptance of all low-carbon-emitting technologies, including CCS.
2) Political and regulatory issues
Europe has implemented relatively tight emission regulations that encouraged a decarbonised economy and has reduced its dependency on fossil fuels.
There is high degree of cooperation between the countries that has led to a high degree of coordinated actions. There are international rules and regulations for CCS in place. Countries are sharing technologies and knowledge. Research is coordinated. China and India are developed with similar green economies; lifestyles are similar to Europe and North America.
3) Global economy
Costs of capital are medium to high and there are high investments, together with investment confidence. Significant technology innovation has occurred in the energy sector, as a consequence of appropriate economic environment. The fuel prices are high because the economic fossil fuels resources have been depleted.
4) CCS technology and infrastructure
In 2040, commercial CCS is a reality in all developed countries. Europe demonstrated and recognized existing CO2 infrastructures and is considered globally as a world leader. Other non-EU countries have continued though to rely largely on fossil-fuel electricity generation. However, regulations in these regions only permit they continue to use fossil fuels if CCS is implemented.
CCS technologies were successfully developed and shared internationally. Research institutes are well-founded and working for the common good. An international grid network was established for CO2 transport. High prices of fossil fuels triggered also the development of renewables and other alternative energy production technologies. The scenario definition diagram and the qualitative figure with deduced trends for important factors affecting CCS are shown for scenario1 in Figure 2.
Scenario2: “EU stands alone”
The combination of high economic growth, high fuel consumption and high degree of environmental change suggests that the climate changes, while actively addressed by the EU, were not addressed on a coordinated worldwide basis leading to a reduction increase of greenhouse gas emissions. However, fossil fuel use continued throughout the world with technology reducing the emissions successfully implemented in the EU. The high degree of environmental change kick-started all types of environmentally-friendly energy sources.
1) Environmental changes and public opinion
Europe has now met most of its goals for CO2 emissions reductions, mainly because CCS has been fully-implemented in fossil fuel plants. Now, 2040, after decades of using CCS as a bridging technology, the increase of renewable energy systems and nuclear energy production now nearly matches energy consumption and the need for CCS has declined along with the use of fossil fuels. The worldwide level of CO2 emissions has, however, continued to increase despite the strong reduction in developed countries (especially in Europe).
Even though most agree that something has to be done to mitigate climate change, the public opinion regarding CCS is still split in two main groups, those in favor of CCS as one of many solutions and a bridging technology and the other group against all technology promoting the use of fossil fuels.

Figure 3: Example of a diagram and time evolution of the oil price and production, coal production, CO2 value and renewable and other power production from present to 2040 for the “WU Stands Alone” scenario.

2) Political and regulatory issues
The EU focuses on economic growth with minimal environmental change and uses ETS as well as strict regulation to steer the development and minimize the environmental load of foremost the member countries but the commission has also managed to agree with non-EU members within Europe on several joint actions against climate change.

A solution to all global problems, including climate change, is difficult to reach due to a low degree of globalization. Governments in most developed countries focus on designing and enforcing policies that will not only promote a reduction in emissions, but resources are also used to develop new technologies for mitigating climate change. In contrast, several developing countries prioritize economic growth and believe that the developed part of the world should solve the climate change problems which where caused by them.

3) Global economy
Costs of capital are medium to high and there are high investments, together with investment confidence. Significant technology innovation has occurred in the energy sector, as a consequence of appropriate economic environment.

4) CCS technology and infrastructure
With economic growth naturally comes technological development and thus CCS technology and implementation is relatively affordable. Increased research and focused technology development along with the learning effect have reduced the capture cost of CCS. By 2040, commercial CCS is a reality in all developed countries, but still too expensive for the developing countries to implement fully.

A historic economic growth and high fuel consumption has made CCS an absolute necessity and is strongly regulated in Europe. The infrastructure and technology within Europe is well-developed and functioning with little cross-border issues or legality problems. Cooperation with countries and the use of storage sites and routes outside Europe however, is not functioning equally well.

The scenario definition diagram and the qualitative figure with deduced trends for important factors affecting CCS are shown for scenario1 in Figure 3.

Scenario 3: “Weak EU”
The combination of high economic growth, high fuel availability and high degree of environmental change suggests that the climate changes were not actively addressed by EU nor on a coordinated worldwide basis which lead an increase of greenhouse gas emissions. Therefore, technology reducing the emissions must not have been successfully implemented while fossil fuels use continued. Low prices of fossil fuels made the renewable and other alternative energy market pick up only after there was severe environmental change. Spider diagrams and time evolutions similar to those in Figure 2 and Figure 3 were constructed for this scenario, but are not shown here.
1) Environmental changes and public opinion
The level of CO₂ emissions has risen due to the high availability and usage of fossil fuels. Due to low EU influence on climate change, there are no incentives to increase to amount of CCS technology, as well as that of renewables, in the power plant portfolio.

2) Political and regulatory issues
Individual Member States register a series of economic and technological developments and are able to act to perform effectively at a national level. The degree of influence of the EU has been weakened and this has weakened the EU’s leadership in the fight against climate change. There is a high degree of cooperation between countries and therefore high trade of goods and resources.

3) Global economy
There is a high degree of economic growth and of increase of standard of living. The economy is supported by low energy prices given the abundance of fossil fuel resources.

4) CCS technology and infrastructure
Under the circumstances of low fuel prices, no boundaries on CO₂ emissions, no regulation and incentives on CCS, no significant investment on CCS power plant technologies is expected. Though, there is public acceptance of low carbon technologies, including CCS off-shore as environment and climate change concerns rise. Research is driven by market forces, sponsored by the industry, and there is a large scale exchange of IPR. CCS technological progress is limited due to the lack of incentives. Technological developments in other sectors, such as renewables, oil production, and energy efficiency, do not improve the competitiveness of CCS and hence CCS opportunities are missed.

Scenario 4: “We told you so”
This scenario is characterized by a high degree of environmental change, high fuel prices and a high degree of influence by the EU. On the other hand the degree of globalization and economic growth is lower than by year 2000. These axes draw a picture of a split world society where the EU is trying to move forward on climate combat but the rest of the world is falling behind. These efforts in the EU lead to higher efficiency standards, higher reduction / lower carbon quota targets which can only be implemented if combined with more market barriers on products and services than today. Spider diagrams and time evolutions similar to those in Figure 2 and Figure 3 were constructed for this scenario, but are not shown here.

1) Environmental changes and public opinion
The EU has by 2040 reduced its overall emissions by forty percent (40%) but total global emissions have continued to increase such that CO₂ atmospheric concentrations have increased to 550 ppm or a fifty-five percent (55%) increase on 1990 concentrations. This is primarily due to the continued growth in global population, the higher standard of living achieved in a number of regions (i.e. China and India) through a reliance on fossil fuels and the overall lack of regulations toward significantly decreasing CO₂ emissions outside of Europe.

2) Political and regulatory issues
In 2040, EU still stands as a strong community with trading barriers against the rest of the world and with a high degree of technological development. In the past thirty years the EU has striven to lead the combat against global warming but the rest of the world has been reticent to follow and unenthusiastic about real CO₂ emission cuts. Globally there is a high demand for fossil fuels leading to high prices, but on the internal market of the EU the demand for fossil fuels is not as strong. Prices are still high however due to the extensive taxation of fossil fuels.

3) Global economy
As a result of the high prices on energy in and outside the EU, the economic growth was affected and therefore not as high as it was during the decades around year 2000. The high demand for fossil fuels outside the EU and the decreasing area of arable land has led to a number of regional conflicts, even war, over resources and arable land as the global warming effect was felt starting in 2020-2030.

4) CCS technology and infrastructure
In the EU, CCS is mandatory on all new fossil fueled thermal plants while it’s voluntary on new biomass plants. By 2040 CCS was implemented on sixty percent (60%) of the thermal plants, primarily fossil fueled but also some pure biomass plants. About fifty (50%) of the CCS plants are connected to a large common infrastructure in the North Sea where the other half is connected to local storage sites. Thirty percent (30%) of the CCS is related to EOR and EGR while the rest is aquifer storage. The value of fossil fuels has supported the EOR and EGR projects on a wider
scale and longer than originally anticipated but most of the small and medium sized oil and gas projects have now reached their technical and economic life and are just taking on CO₂ for storage.

**Scenario 5: “Competition”**
The combination of high economic growth, low fuel availability and high degree of environmental change suggests that the climate changes were not actively addressed by EU or on a coordinated worldwide basis which led an increase of greenhouse gas emissions. Therefore, technology reducing the emissions must not have been successfully implemented while fossil fuels use continued. This led to the depletion of the reserves and thus the increase in fuel prices. However, high prices of fossil fuels made the renewable and other alternative energy productions competitive. Spider diagrams and time evolutions similar to those in Figure 2 and Figure 3 were constructed for this scenario, but are not shown here.

1) **Environmental changes and public opinion**
The price of energy has come to the level to make clean coal economic, but not high enough to put people off using similar levels of energy with energy efficiency roughly balancing growth. Hence there is low impact on EU lifestyle except for growing impacts of global warming. Some actions are taken for environmental/climate change reasons and for energy supply reasons but more lip service than major initiatives.

2) **Political and regulatory issues**
There is no coordinated approach to CCS world-wide with competition emerging between global companies instead. Barriers to CCS are only overcome on a case-by-case basis, driven by individual corporations.

3) **Global economy**
Economic growth was significant and the energy demand continued to increase, as any reduction of living standards was not accepted. However, oil supplies have dwindled and oil companies are investing heavily in replacement technologies (EOR, coal-to-liquid, synthetic fuels, from gases, etc) but also in other energy sectors. CCS for EOR is seen as the only lucrative method. Globally increasing population has used a significant proportion of the remaining fossil fuel resources. Low fuel supply is driving energy prices up, thus enabling the competitive development of other, environmentally friendly energy sources, including EOR from CCS, cleaner coal, renewables and nuclear. Accelerated global economic development has greatly diminished the availability and consumption of relatively easy to extract hydrocarbons to meet the energy requirements of tiger economies to sustain continuous economic output. The current oil & gas price has led oil and gas majors to be considered previously abandoned oil & gas reservoirs for increase production using CO₂. The price of oil compensates for all the elements in the CO₂ value chain. Furthermore national law does not consider the environmental cost of CO₂ to be sufficiently high to offset the societal cost of reducing hydrocarbon usage. CCS is viewed only as a means of getting more hydrocarbons out. CO₂ emission prices remain low due to lack of cohesive political support and remain insufficient to fund CCS. Many large sources continue to emit unabated CO₂. Few financial actors find an interest in investing in CCS infrastructure/value chain because infrastructures are all privately owned to supply CO₂ for EOR

4) **CCS technology and infrastructure**
There was a general understanding that research is important and ample funding was made available early at the beginning of the time period. As research institutes were well-founded and working towards the common good, the CCS technology has been developed fully on the small scale, but capture technologies are still expensive and all infrastructures are privately owned.

**Scenario 6: The EU “New Energy Policy” scenario**
The EU “New Energy Policy” scenario was added to include a baseline scenario that describes an energy future which is compatible with the targets of the European energy and climate change policy, endorsed by the European Council in 2009. In particular, the “EU Stands Alone” scenario is based on the assumption that a low degree of globalization is combined with high economic growth and high degree of the influence of EU. The “New Energy Policy” scenario is an extension of the 2007 update of the European Energy and Transport Trends to 2030, published by the European Commission [7], and is derived using the PRIMES model. It takes into account not only the current trends and policies as implemented in the Member-States by the end of 2006, but it also assumes: (i) 20% reduction in GHG emissions in 2020 compared to the 1990 levels (since the model includes neither JI/CDM credits nor actions on other gases than CO₂, the scenario could also be made consistent with a 30% reduction by including those levers); (ii) 20% share of renewable energy sources in final energy consumption at EU
level by 2020; (iii) vigorous implementation of new policies to make substantial progress on energy efficiency for reaching other energy and climate targets.

4 Summary
A set of relevant scenarios that reflect possible variations in the environment for the European value chain for CO₂ in the next 30 years have been developed. The key features of each scenario are governed by the five main drivers or uncertainties for the future development of the CO₂ value chain in Europe. All scenarios are described with respect to a common set of important issues such as environmental changes and public opinion, political and regulatory issues, global economy and CCS technology and infrastructure. The set of scenarios cover a wide range of possible futures while maintaining a level of relevance and common understanding of the issues at hand. The scenarios have been written to describe alternative futures on background of which various CCS chain case studies would be analysed within the ECCO project.

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6 REFERENCES