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# Reducing $CO_2$ emissions from the European power generation sector – Scenarios to 2050

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**Abstract**

An assessment of the impact of the evolution of the European fossil-fuelled electricity generation technology mix to 2050 on the EU target to reduce greenhouse gas emissions by 20-30% compared to 1990 levels by 2020 has been performed. The influence of fuel and carbon prices, advances in carbon capture and storage technology and the share of non-fossil power sources in electricity generation have been evaluated. The policy target is only achieved in a carbon constraint environment, with the deployment of CCS technology, accompanied by a fuel switch to natural gas for a part of the fossil-fuelled capacity which reduces emissions to the desired level.


*Keywords:* Carbon capture and storage, $CO_2$ emissions, fossil-fuelled power generation

## 1. Introduction

Recognising the need to combat climate change the European Union (EU) has committed to reduce greenhouse gas (GHG) emissions by 20-30% compared to 1990 levels by 2020 [1]. Because of its pivotal position in the European energy system, the electricity sector has become one of the focal points of the European energy and climate change policies. Electricity meets 20% of the final energy consumption in the EU, which includes 30% of the needs of the industrial sector and 28% of services and households [2]. In order to achieve the above mentioned GHG reduction objective, $CO_2$ emissions from fossil-fuelled power generation will have to be reduced by at least the same, if not a greater, percentage to compensate for the smaller decrease in other sectors, such as transport, where available technology and economics do not favour emission reduction on a large scale within the given timeframe.

The demand for electricity has been increasing with an average rate of about 2% annually since the nineties [2] and projections of electricity demand in the EU foresee a continual increase in the future at a rate similar to that experienced today. The increasing demand for electricity can only be addressed by building new electricity

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generation capacity, especially since the potential for electricity imports from outside the EU is small. At the same time, the electricity generation infrastructure is aging and a large number of power plants will have to be retired in the near future. To this end, urgent decisions for the construction of new capacity need to be made, which will influence the GHG emissions of the EU power sector for the years to come.

Today half of the EU electricity demand is met through fossil fuel-based power generation, which is likely to remain the backbone of the electricity sector for the coming decades. A possible solution for the reduction of GHG emissions from the power sector is the introduction of carbon capture and storage (CCS) technologies in new power plants. According to the Zero Emissions Fossil Fuel Power Plant Technology Platform (ZEP ETP), plants with $CO_2$ capture could be commercially deployed on a large scale as of 2020, while first-of-a-kind plants could be operational around 2015 [3]. The utilisation of this technology could offer a temporary solution to the issue of having to use fossil fuels while avoiding further $CO_2$ emissions until carbon-free energy sources become the main source of electricity. However, power plants with CCS will be more expensive to build and operate than similar plants that do not capture $CO_2$ making it more difficult for them to enter and become established in a competitive electricity market.

This paper assesses the impact of alternative scenarios for the evolution of the European power generation sector on the EU policy goal of reducing GHG emissions. This is achieved by assessing how the future fossil fuel electricity generation technology mix may evolve in the EU up to 2050, in response to developments in fuel and carbon prices, and taking into account other deciding factors such as the advances in carbon capture and storage technology and the share of renewable and nuclear power sources in future electricity generation.

## 2. Methodology and Scenarios

The assessment presented here relies on a JRC in-house model based on the screening curve method for power generation capacity expansion planning [4, 5]. The time horizon of the study is the year 2050 and the baseline is set to the year 2010. Inherent to the limitations of the screening curve method, a key assumption of the study is that, the EU is treated as one control area with a single electricity market, without electricity transmission constraints, or constraints in the supply of coal and natural gas. Furthermore in the implementation of the method, a 20% reserve margin for electricity generation capacity has to be maintained, and the existing fleet is not decommissioned before it has reached the end of its technical lifetime. Thus – except for peaking capacity requirements, which are always fulfilled – it is assumed that new plants are only built in a given period when a capacity gap exists, even if the existing technologies do not represent the optimal solution in economic terms at that given time. These assumptions do not describe a liberalised competitive power market, but rather provide indications of the sensitivity of the EU fossil-fuelled power sector to various underlying factors. Hence, this paper should be considered as a broad assessment for policy purposes rather than a capacity planning study.

Figure 1 highlights the advanced age of the current European power plant fleet. Almost half of the fossil-fuelled power generation capacity is older than 25 years, and approximately 10% of the fossil-fuelled power plants are more than 40 years old. The currently operational fossil-fuelled power plant capacity in the EU27 is 430 GW; and a further 104 GW are under construction or in an advanced planning stage and expected to enter the power plant park by 2015. However, due to the advanced age of a large part of the fleet it is estimated that only 260GW of the fleet operating or under construction at present will be available in 2030, while this figure drops further to 30GW in 2050. It is clear that a significant investment is needed to replace and expand the retiring fleet in order to meet the future electricity demand. The technologies likely to compete in the future fossil-fuelled electricity sector along with their techno-economic characteristics are adopted from previous modelling exercises [4, 5], while the price scenarios influencing the sector have been defined in line with the latest estimates for future trends in fuel and carbon markets.

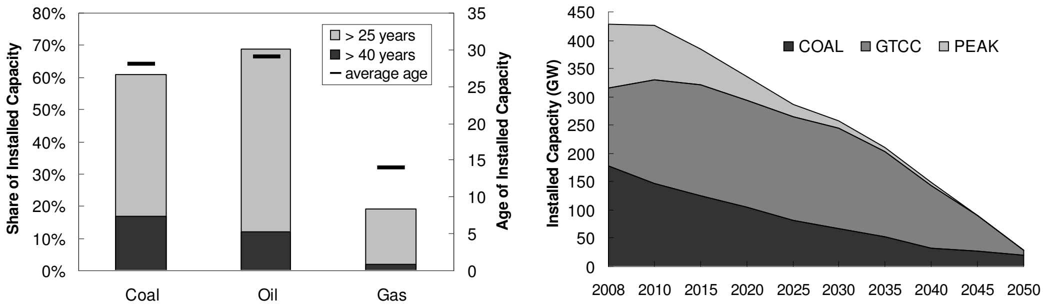


Figure 1 (left) Age and (right) evolution of the currently installed fossil-fuelled capacity in the EU assuming a 25 year technical lifetime for gas turbines and a 40 year technical lifetime for all other technologies, and taking into account new plants already under construction.

Two alternative cases are considered for the contribution of the non-fossil fuel power plant technologies (nuclear and renewables) to the European energy system: the business-as-usual (BAU) and the non-fossil fuel policy (policy) case. The BAU case is based on the Baseline scenario as described in the European Energy Outlook [6] and reflects implemented policies rather than policy targets, not assuming that the latter will necessarily be met. In the policy case gross nuclear power generation remains stable, while renewable electricity generation increases at higher rates than in the BAU case achieving the policy goals set by the European Commission [1,7]. Furthermore in the BAU case research, development and deployment of CCS technology is left entirely to market forces while in the policy case the introduction of the technology is assisted by demonstration plants, 5 GW of which will be operational by 2020. This figure is comparable with the Flagship Programme for the demonstration of the CCS technology, as proposed by the ZEP-ETP [8]. In both cases, CCS technology is allowed to grow by up to 30% per year over the already installed capacity, also assuming that there are adequate storage sites to accommodate this growth.

Additionally high and low price environments are considered for the developments in the fossil fuel and carbon markets, resulting in a total of 8 different scenarios, the particulars of which are summarised in Table 1. Both the fuel and the $CO_2$ prices are exogenous to the modelling process, i.e. they are not calculated but imposed to the analysis. It is assumed that power plants pay a penalty (that could be a tax or a permit) for each tonne of $CO_2$ emitted. In the case of CCS this penalty is avoided for the quantities captured, however, a cost of €10 is incurred per tonne of $CO_2$ captured to account for transport and storage.

Table 1: Overview of the combination of parameters that make up the 8 different scenarios examined.

| **Parameter** | | **Case** | **2010** | **2030** | **2050** |
|---|---|---|---|---|---|
| **Fossil Power Generation [TWh]** | | BAU | 2000 | 2520 | 3240 |
| | | Policy | 1900 | 1830 | 1750 |
| **Carbon capture availability** | | BAU | market | | market |
| | | Policy | demo (2020) | | market |
| **Fuel Price [€/GJ]** | High | N.Gas | 7.0 | 14.2 | 21.7 |
| | | Coal | 2.4 | 4.6 | 6.9 |
| | Low | N.Gas | 6.2 | 7.6 | 9.2 |
| | | Coal | 2.1 | 2.5 | 2.9 |
| **$CO_2$ price [€/t$CO_2$]** | | High | 20 | 60 | 80 |
| | | Low | 20 | 24 | 30 |

## 3. Results and Discussion

Figure 2 shows the evolution of annual $CO_2$ emissions from fossil-fuelled electricity generation according to the different scenarios examined, in the period to 2050. The policy target of a 20% reduction in $CO_2$ emissions by 2020 is only achieved in a carbon constraint environment (high $CO_2$ prices) combined with low fuel prices. High $CO_2$ prices encourage the deployment of CCS technology, which accounts for 28% and 61% of the installed capacity in 2050 in the BAU case for high and low fuel prices respectively. Similarly in the policy case the penetration levels of CCS capacity are 39% and 48% of the total in 2050 for high and low fuel prices and a carbon constrained environment, while if $CO_2$ prices are low CCS deployment is limited to the demo plans with no commercial follow-up. However this alone is not enough to sufficiently reduce emissions, if the fuel price and in particular the natural-gas-to-coal price ratio is high, since this also favours conventional coal technologies with high $CO_2$ emission factors. Conversely, when $CO_2$ prices are high but fuel prices are low, CCS deployment is accompanied with a fuel switch to natural gas for a part of the fossil-fuelled capacity which results in the reduction of annual emissions under the desired level. This is observed both in the BAU and policy case.

Apart from the two scenarios discussed above the results can be grouped in two sets according to the BAU and policy scenario for the contribution of non-fossil plants. The three scenarios in each set follow a similar trend until the year 2035. In the BAU case emissions increase by 17-25% by 2035, while conversely, in the policy case a reduction of 8-18% is observed. After 2035 there is a differentiation regarding the scenarios with high $CO_2$ and fuel prices where emission levels begin to drop sharply. In the BAU case this only means a return to current levels by 2050, in the policy case however significant reductions in annual emission levels can be achieved. This decrease in emissions is a result of CCS deployment in the form of IGCC CCS plants.

Figure 3 shows the cumulative $CO_2$ emitted and captured in each case in the period to 2050. The scenarios which achieve the policy goal for emission reduction (high $CO_2$ and low fuel prices) are also the ones with the overall lowest emission over the period studied. In total 39 Gt of $CO_2$ are emitted in the BAU and 31 Gt in the Policy case, while 14 Gt are captured. The annual capture rate for the BAU and Policy case by 2050 would reach 1.4 Gt and 0.8 Gt respectively.

The effect of CCS technology to annual emission levels and consequently cumulative emissions depends on the start date for the deployment of the technology which is in turn dependent on the techno-economic characteristics of the plants and how competitive they can prove compared to conventional technologies. Figure 3 also shows the effect of additional R&D efforts that would advance the technology so that lower costs and better performance would be achieved earlier (accelerated by a 5 year period). This achieves a significant emission reduction in the BAU case when both $CO_2$ and fuel prices are high; however the cumulative emissions for this scenario remain high.

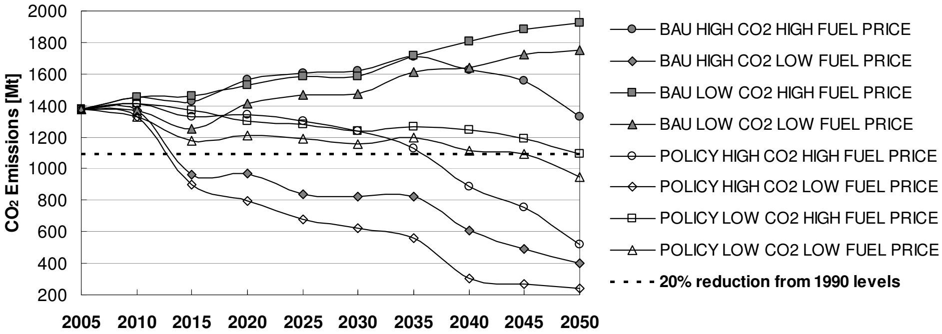


Figure 2. Projections for $CO_2$ emission levels from fossil-fuelled power generation in the EU for different fuel and carbon price scenarios and a transport and storage cost of €10/tonne $CO_2$.

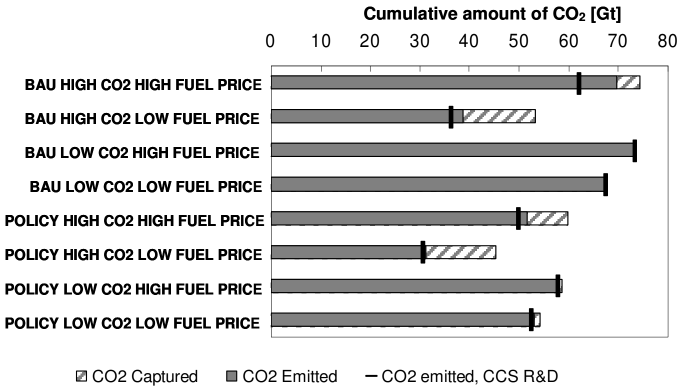


Figure 3. Projection of the contribution of carbon capture and storage to the reduction of $CO_2$ emission from fossil fuelled power generation in the EU for different fuel and carbon price scenarios and a transport and storage cost of €10/tonne $CO_2$. Time period 2010 – 2050.

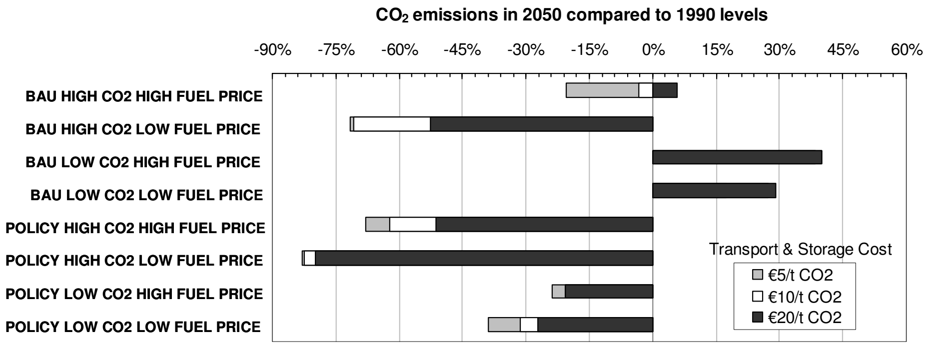


Figure 4. Sensitivity of the CCS implementation, in terms of $CO_2$ captured, and the $CO_2$ emission levels from fossil-fuelled power generation, in terms of reduction achieved compared to the 1990 reference value, to the cost of $CO_2$ transport & storage.

On the other hand $CO_2$ prices and costs seem to have a greater effect on the system as illustrated in Figure 4, which displays annual emission levels in 2050 relative to 1990 levels for three different $CO_2$ transport and storage costs. Note that all previous results are for a reference cost of €10/t $CO_2$. BAU scenarios with high $CO_2$ prices, where CCS technology is likely to have a role in fossil-fuelled power generation display greater sensitivity to transport and storage costs than the equivalent policy scenarios. When transport and storage costs are low (€5/t), the share of CCS capacity in the fossil-fuelled power generation mix by 2050 is 5-10% higher than in the reference case for high $CO_2$ prices, while it also achieves a 7-10% penetration for low carbon and fuel prices. Consequently, emission levels in 2050 could be 17% lower than the reference case. Conversely, high transport and storage costs (€20/t) translate to lower participation of CCS technologies in the power generation mix – only 20-35% of the total fossil-fired capacity by 2050. This in turn means that emissions in 2050 could be up to 18% higher than the reference case.

The policy scenario most sensitive to $CO_2$ transport and storage costs is where high carbon prices are combined with high fuel prices. A low transport and storage cost has the potential of reducing annual emissions in 2050 by a further 6% while a high transport and storage cost would mean levels 9% higher than the reference case. The policy scenario with low $CO_2$ and fuel costs would also be affected by a change in transport and storage costs achieving a further 4% reduction or an increase of 2050 emission levels by 8% for low and high costs respectively. It should be noted that the policy target of a 20% reduction in $CO_2$ emissions by 2020 can still be achieved by scenarios combining high $CO_2$ costs and low fuel costs even if $CO_2$ transport and storage costs are in the area of €20/t. However there would be a difference in the reduction achieved by 2050 especially in the BAU case.

## 4. Conclusions

In order to achieve significant reductions in $CO_2$ emissions from fossil-fuelled power generation the carbon price has to reach and maintain a value of the order of 55-60€/tonne $CO_2$. At the same time, the fuel prices in general and the natural gas-to-coal price ratio in particular have to be such as to enable part of the fossil-fuelled capacity to switch to natural gas in the near term. The effect of this switch is two-fold: natural gas plants have lower specific emissions thus effecting immediate reductions to the annual emission rates from fossil-fuelled power generation; and as these units have a shorter life span they can be replaced sooner by CCS capacity in the medium term if the technology is proven and competitive. On the other hand, under the assumptions of this study, the deployment of new coal capacity in the near term binds the sector to higher emission levels for a longer period and makes it difficult to achieve the policy goals concerning emission reduction without additional measures.

The evolution of the future technology mix is sensitive to carbon costs both in terms of $CO_2$ prices and in terms of the costs associated with the transport and storage of the $CO_2$ captured by the eventual deployment of CCS technology. On the contrary technology advances in CCS technology as long as they follow an ordinary learning curve seem to have a lesser impact on the competitiveness of the technology.

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