# *INVESTMENT IN ZERO CARBON TECHNOLOGIES UNDER UNCERTAINTY ABOUT FUTURE CLIMATE POLICY*

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## Overview

Parties to the Paris treaty restated their commitment to the 2$^0$C target, and agreed to pursue efforts to limit the temperature increase to 1.5$^0$C. In order to keep global warming below the 2$^0$C target, a third of oil reserves, a half of gas reserves, and more than 80 percent of coal reserves must stay in the ground (McGlade and Ekins, 2015). These estimates, combined with the IEA prediction of a 50% growth in total energy demand in the next 25 years, implies that production of zero carbon energy must increase dramatically in the coming years.

In this paper, we study investment and R&D in zero carbon technologies under uncertainty about future climate policies. Zero carbon energy technologies differ with respect to their properties. Renewables are typically decreasing returns to scale technologies. For example, locations may differ with respect to average wind and sun conditions, and due to the intermittent character of their energy supply, system costs per kwh produced are likely to increase the larger the share of these technologies. Coal and natural gas power with carbon capture and storage (CCS), on the other hand, are constant returns to scale technologies, that is, the output of such a power station is constant and independent of natural conditions. However, the full cost of these technologies exceeds the full cost of traditional coal and natural gas power, and hence, and investor will not choose these technologies as long as climate policy is not significantly tightened.

We pose the following research questions: I) How do the different properties of renewables and CCS technologies affect the investment decisions of private firms under uncertainty? and II) Does the market outcome depart from the first-best outcome?

## Methods

We analyse two types of uncertainty: Either, there is uncertainty about the marginal damage of green house gas (GHG) emissions, or there is uncertainty about the ability of the politicians to impose a stringent climate policy. For the first type, we assume that the climate policy will be optimal, that is, if the marginal damage of GHG emissions is low, the emission tax will be low, and if the marginal damage of GHG turns out to be high, the emission tax will be high. For the second type, we assume that the marginal damage of GHG emissions is known to be high, but we do not know whether the future emission tax will be equal to the true marginal damage of GHG emissions or lower.

We first set up a theory model. Here, there are two zero-carbon electricity technologies; renewable energy, for example wind power, and fossil-based electricity production with carbon capture and storage (CCS) with no emissions. In addition, there is a conventional fossil-fuel based technology.

Under uncertainty in the model in the sense that when investing in R&D and power production capacity, neither the government, nor the private actors, know the stringency of future climate policy. For the government, the uncertainty could be due to either uncertainty about the stringency of future climate agreements, or the harmfulness of the climate change problem.

Our model has three periods. In the first period, a representative power producer decides under uncertainty the level of R&D for the two types of zero-carbon technologies. In the second period, the power producers invest under uncertainty in power capacity in the three electricity technologies. Finally, in the third period, the uncertainty (carbon tax) is revealed, and then production and consumption of electricity are determined (the electricity market clears).

We compliment the theoretical analysis by establishing a simple numerical model for the European electricity market in 2030 that builds on the theory model. We mainly use parameters and variables from the numerical energy market model LIBEMOD, see Aune et al. (2008; 2015) and LIBEMOD (2015), to determine the parameters in the numerical model. LIBEMOD determines simultaneously investment, extraction, production, trade, transport and consumption of eight energy goods, including electricity, in 30 European countries. In addition, the model determines prices and quantities of energy goods traded globally, and emissions of CO2 by sectors and countries.

We use the 2030 reference scenario in Aune et al. (2015) as the starting point of picking parameter values. Here, the LIBEMOD model is run for 2030 under the assumption that the EU targets of i) a 40 percent reduction in GHG emissions relative to 1990, and ii) a renewable share in final energy consumption of 27 percent, are reached. In the benchmark scenario, these targets are accomplished by imposing an EU-wide quota price on CO2-emissions in the ETS sector, an EU-wide price on CO2-emissions in the non-ETS sectors, and an EU-wide subsidy on renewable energy.

## Results

We use the theory model to derive conditions for existence of five regimes. In all regimes, there is investment in renewable electricity capacity; the regimes differ with respect to whether there is investment in conventional fossil electricity capacity and/or investment in CCS production capacity. We show that there is investment in fossil electricity, but no investment in CCS electricity, if, and only if, the expected total unit cost of the conventional fossil-fuel technology is lower than the expected total unit cost of the CCS technology.

We show that if there is uncertainty about the marginal damage of green house gas emissions, and the current government can commit the future government to implement an optimal carbon-tax policy, then the market solution will yield the first-best social outcome.

In the numerical application, there is no investments in CCS in the benchmark scenario. This result changes if future demand for electricity is much higher than in the benchmark scenario. Then R&D investment in CCS is profitable if the expected future tax level is sufficiently high. However, the equilibrium R&D in CCS is rather moderate.

If, alternatively, the uncertainty with respect to the future carbon taxes is caused by the ability of the future government to impose a carbon tax equal to the social value of carbon, we show – in the theory model - that private R&D levels will in general be non-optimal from a social welfare perspective.

Turning to the corresponding numerical application, we show that in the benchmark case, where demand for electricity reflects that the 2030 non-ETS emission goal of the EU is reached by imposing a uniform non-ETS tax, there will be no investment in the CCS electricity technology. The current government will adjust its R&D investment in renewable electricity (relative to the level supporting the first-best social outcom), but the adjustment is moderate.

If demand for electricity is higher, for example, because the 2030 non-ETS emission goal of the EU is reached by electrification, there are equilibria with CCS investment if the low tax is at least 50 percent of the true social cost of carbon.

## Conclusions

Our results suggest that investment in CCS electricity in Europe by 2030 requires a level of demand for electricity that is higher than most predictions. However, a substantial electrification in the end-user sectors may be sufficient to trigger profitable CCS investment. Also, if GHG emissions are to be reduced substanatially after 2030 as part of a strategy to reach the $2^0$C target, it might be socially optimal to invest in CCS electricity.

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