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Carbon sequestration and climate policy: an economic analysis

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Ministère de l'Écologie, du Développement durable, des Transports et du Logement

in partnership with

Toulouse School of Economics

This publication summarises the conference organised by the General Directorate for Sustainable development (CGDD) and the Toulouse School of Economics (TSE), held on 19th September 2011 at the Ministry of Ecology, Sustainable Development, Transport and Housing, on the subject of "Carbon Sequestration and climate policy: an economic analysis" It is based on the presentations of Gilles Lafforgue, André Grimaud and Michel Moreaux, researchers at the Toulouse School of Economics. The programme of this conference is given in the appendix.

This publication is the first issue of a series which will summarise conferences co-organised by the CGDD and TSE. This series presents summaries of the recent findings of economic research. It is aimed at academics, economic stakeholders, and public decision-makers to encourage dialogue between them.

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CONTENTS

Summary

In September 2011 the General Directorate for Sustainable Development and Toulouse School of Economics jointly organized a conference on "Carbon capture and storage (CCS) and climate policies: an economic analysis". This paper presents an overview of the main results of the conference concerning the optimal energy mix and carbon emission path in the presence of CCS, the superiority of a policy mix combining an environmental tax with R&D subsidies, as well as the intergenerational equity-efficiency trade-off. It is based on presentations by Gilles Lafforgue, André Grimaud and Michel Moreaux, researchers from the Toulouse School of Economics.

This overview confirms that a climate policy is more effective if it combines several instruments (tax and subsidies) and if it is quickly implemented.

Introduction

In the fight against climate change, a wide range of technological options need to be implemented to achieve the ambitious goals regarding the reduction of greenhouse gases (GHG): promote energy efficiency, fight deforestation, increase the use of renewable energies, etc. These options are of varying costs, of variable technical maturity and are likely to be implemented within different time frames. Among the different technological options, scientists, industrial players and decision-makers have been showing increasing interest in carbon capture and sequestration[1] (CCS) over the past several years. CCS involves capturing CO2 emissions at their source, at industrial sites, and injecting and sequestrating the carbon thus captured in impermeable geological substratum (depleted hydrocarbon deposits, etc.)[2]. The potential development of CCS in the future enhances the traditional economic analysis of non-renewable energy resources and raises concrete questions on the environmental policy instruments to adopt.

This document aims to study the economic consequences of CCS in terms of energy mix, the rate of extraction of resources and the choice of environmental policy instruments. It is structured as follows. The first part presents CCS from a technical point of view and its potential as a cost-effective way of fighting global warming. The second part analyses the consequences of the introduction of CCS on the relative competitiveness of energy resources and the rate of extraction of non-renewable resources. Lastly, the third part analyses the relative place of an environmental tax and a subsidy to CCS in the optimal mix of environmental policies aimed at reducing GHG.

1. Carbon Capture and sequestration/recycling (CCS): a technique to mitigate greenhouse gases

1.1. CCS technology

Carbon capture and sequestration (CCS) is one of the techniques being considered to reduce greenhouse gas emissions into the atmosphere, particularly CO2 emissions. Moreover, this solution is recommended by the Intergovernmental Panel on Climate Change (IPPC) in a technical report devoted to this technology (IPCC, 2005). The basic idea behind this mitigation technique is to capture the CO2 at its source, before it is released into the atmosphere and then, after reduction, to inject it either into natural reservoirs (saline aquifers for example), or into former mine sites, or even into hydrocarbon deposits being extracted, as the Norwegian firm Statoil does in the North Sea.

Total carried out an experiment involving the capture and sequestration of CO2 at the Lacq and Rousse sites in the south of France[3]. This experiment aimed to capture and trap about 120 tonnes of CO2 over a two-year period, which corresponds to the quantity of CO2 released by the exhaust pipes of 40 cars during the same period. This type of experiment would have to be carried out 100,000 times in order to achieve the capture and sequestration scenario presented by the International Energy Agency (IEA)[4].

1.2. An economically efficient solution to fight climate change?

According to the IEA, CCS could reduce a considerable proportion of CO2 emissions from thermal power plants (reductions of up to 19% of the world's annual CO2 emissions, i.e. more than the amount attributable to all the renewable energy channels). The IPCC suggests that this technique could deal with 20 to 40% of the world's CO2 emissions by 2050. CCS could be a cost-efficient solution for industrial sites powered by coal and gas (MIT, 2007). Results of modelling conducted in the framework of the Trajectories 2020-2050 committee[5] also show the importance of taking account, or not taking account, of CCS. However, as well as its technical aspects, the cost of capturing and storing CO2 is also a challenge: its cost in terms of economics and

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[1] In English CCS: Carbon Capture and Sequestration.

[2] As it is possible to obtain very pure gases from fumes, storage can be replaced by recycling as raw chemical materials (e.g.: anti-sublimation)

[3] http://www.total.com/MEDIAS/MEDIAS_INFOS/3121/FR/TOTAL-CO2-FR-BasseDef.pdf?PHPSESSID=48f5e017cfb6bdb54bad7ee6199afb54

[4] http://www.iea.org/techno/etp/etp10/French_Executive_Summary.pdf

[5] This task force, chaired by Christian de PERTHUIS, professor of economics at the University of Paris-Dauphine, and supported by the Centre for Strategic Analysis (CAS) was set up by the Minister for Ecology, Sustainable Development, Transportation and Housing to develop a longer term strategy. It brought together environmental protection associations, businesses, labour organizations, climate experts and the ministries concerned. http://www.developpement-durable.gouv.fr/IMG/pdf/2011-10_Rapport_Comite_preside_par_M-_de_PERTHUIS_Trajectoire_2020-2050.pdf

energy[6]. Storing the CO2 is also a problem and this is currently being studied (a storage site is being sought in the North of France) and the transportation is another challenge.

2. CCS and relative competitiveness of energy resources

A mitigation option like CCS raises new types of economic trade-offs. The first trade-off concerns the use of the different types of primary energy. Indeed, assuming there is an implicit or explicit price for carbon, using CCS would have serious consequences on the relative competitiveness of different non-renewable resources. When stocks of fossil energy resources are still relatively high, CCS could allow the mining of these resources, without having to worry about the climate. Coal in particular, which is very polluting but very plentiful and which can be extracted at a low cost, could become much more competitive ("*King coal is back*", 2007). More generally, the relative advantage of fossil energies compared to renewable energies and nuclear energy would be greater.

The consequences of the introduction of CCS in terms of the rate of extraction of resources, technological choices and social well-being have been the subject of many recent studies (Chakravorty, 2006[7]; Lafforgue et al., 2008-a and 2008-b; Grimaud and Rougé, 2009; Grimaud et al., 2011; Amigues et al., 2010). These studies call upon the economic theory of natural resources to tackle these issues in the tradition of the founding model of Hotelling (1930). The goal is to determine the socially optimal temporal trajectory of the extraction of a non-renewable resource and the forming of its price at each period (Rotillon, 2005). In the case of climate change, as well as the problem of the rate of extraction of the non-renewable resource, there is the problem of environmental damage related to greenhouse gas emissions, in particular CO_2. There are two ways of integrating the externality of climate into the models. The first involves introducing a damage function, which reduces the production and/or utility for consumers, and which increases with the stock of atmospheric CO_2. The second involves setting a ceiling limit on this stock, which takes the form of an additional constraint in the planner's programme[8]. This constraint, when binding, changes the socially optimal trajectory of extraction[9] and may have other consequences which the series of studies mentioned above explores in detail.

This theoretical framework is particularly appropriate to analyse the consequences of introducing CCS. Lafforgue et al. (2008-a, 2008-b) analyse these consequences by characterising the optimal extraction paths; of a fossil fuel resulting in the accumulation of carbon in the atmosphere by considering that society wants to keep the development of this atmospheric stock below a given ceiling limit. These emissions can be captured and stored via CCS technology. The economy is composed of only one sector in which CCS can be applied. Two main results can be drawn from these studies. The first result shows that it is "never optimal to capture potential emission streams before reaching the atmospheric carbon concentration ceiling limit". The second result shows that "during the stage when the ceiling limit is reached, when it is optimal to make the mitigation, only part of the potential emission stream must be reduced".

One of the limitations of these studies lies in the hypothesis of one single economic sector, for which all the production units can call upon CCS technology. It seems more plausible to assume that CCS can only be used for the highest and most concentrated sources of emissions. A study underway by Amigues et al. (2010) removes this hypothesis and shows that this can have favourable consequences on the results obtained. Thus, considering two sectors which have different carbon capture capacities – one sector with concentrated emissions, able to call upon CCS, another sector with diffuse emissions which cannot call upon CCS - and considering that there is a GHG ceiling limit which must not be exceeded –, Amigues et al. show that there may be trajectories for which it is optimal to start to capture all the potential carbon emissions of the sector which has CCS even before the carbon ceiling limit becomes effective. This result favours an earlier introduction of CCS than was suggested in the previous results, which supposed one single economic sector.

Another very important aspect is the presence or absence of a non-polluting renewable resource as a potential substitute for the polluting non-renewable resource. According to the values of the cost parameters, the presence of such a resource in the models may lead to phases when the use of both resources follow each other or co-exist in an optimal manner. Chakravorty et al. (2006) analyse this problem and the results are summarised in table 1.

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[6] The energy performance of the different physical or chemical capture techniques varies a great deal.

[7] This article discusses mitigation in general, without specifying that this could be CCS.

[8] The latter method has the advantage of allowing a more clear-cut characterization of the successive phases of the extraction of resources and the technologies used, thus facilitating the interpretation of the results obtained. In fact, this is a degeneration of the first approach because it is the same as considering a zero marginal damage function as long as the stock of atmospheric CO2 remains below the ceiling limit, and infinite when the latter is exceeded. This is a safety threshold which warns that extreme and irreversible damage will occur.

[9] The Quinet report (2008) gives a more detailed explanation of the joint analysis of the problem of extracting a non-renewable resource and the problem of damage related to GHG emissions.

Table 1: Use of resources trajectory *- Chakravorty et al. results (2006)*

Characteristics of substitute (*non-polluting renewable resource*)		Results
Cost	Availability	
High cost	Plentiful resource	The polluting resource is depleted before the use of the non-polluting resource.
Low cost	*No hypothesis on availability*	Both resources are used simultaneously.
No hypothesis on cost	Rare resource	The phase when simultaneous use may occur before the ceiling limit is reached

Generally speaking, it emerges that a subtle microeconomic model of technologies and sectors is needed to understand the economic trade-offs involved in the optimal trajectory of extraction of the renewable resource and its interactions with other technological choices.

3. CCS, R&D and the choice of economic instruments: tax and/or subsidies

3.1. The role of research and development (R&D) and subsidies

A second example of an economic trade-off raised by CCS is the orientation of long-term investments. The development of CCS is subject to the marked effects of the learning process, and requires considerable R&D efforts, so we are faced with the question of timing its implementation and structuring the investments required by this technique with other jobs, or other R&D sectors. The introduction of technical progress into the analysis leads to a new source of distortions in the economy, externalities related to research[10], which adds to the environmental externality of carbon emissions. A classic result of economic theory, the *targeting principle* (set out by the economist Tinbergen) is that there should be a dedicated instrument for each objective of economic policy. The introduction of an R&D sector with the impact of the learning process means we need to consider another instrument as well as the environmental tax to produce the externality of the learning process at its socially optimal level.

Grimaud and Rougé (2009), and Grimaud et al. (2011) show that subsidies for research into CCS, combined with an environmental tax, can increase social well-being in relation to a reference situation in which only one of the instruments is present. In other words, both instruments are complementary. In reality, is this complementary nature quantitatively significant? Grimaud et al. (2011) provide an initial answer using a calibrated model. They show that, firstly, the introduction of an optimal carbon tax does not result in a significant increase in CCS or in the proportion of renewable energies, and secondly, they show that, symmetrically, a subsidy for R&D does not reduce the extent to which fossil energies are used. The simultaneous implementation of these two instruments strengthens the effect of the tax on the use of fossil energies (i.e. reducing the proportion of fossil energies) and increases the proportion of carbon emissions stored (up to 4% of total carbon emissions in 2100) and the development of renewable energies.

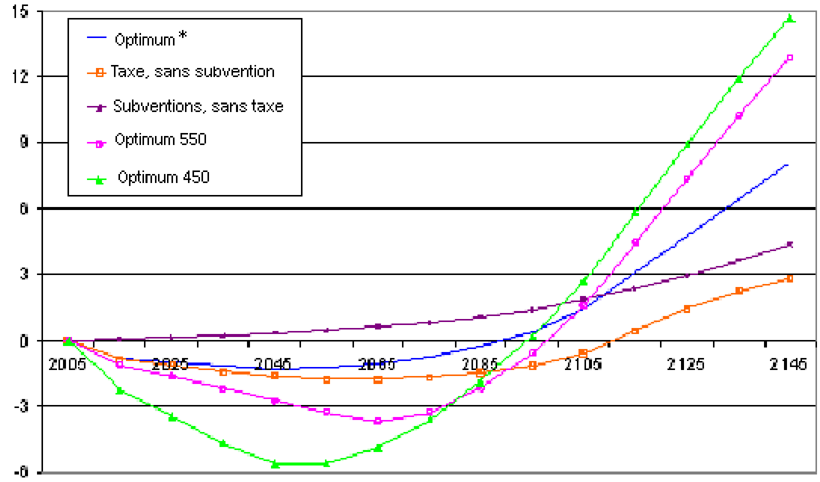
3.2. Intergenerational equity and social acceptability

In this framework, in the presence of two externalities, it is optimal to combine tax and subsidies for R&D, according to the up-to-date social well-being criteria. However, this criteria is not the only one that can be considered when choosing instruments. Social well-being includes inter-generational equity concerns via the discount rate, but the question of the acceptability of instruments, related to the cost for the present generation, can also be important. On this subject, Grimaud et al. (2011) show that choosing to subsidise CCS ensures that no generation, including the present generation, lose out. However, this acceptability is acquired to the detriment of the up-to-date social well-being. Figure 1 illustrates this phenomenon. This figure presents the variations in the level of production over time for different environmental policy scenarios, in relation to a reference scenario corresponding to laissez-faire: optimum scenario (with tax and subsidy), scenario with a tax but no subsidy for CCS, scenario with no tax but with a subsidy for CCS. We observe that the socially optimal production trajectory (blue curve) falls in the first period in relation to the laissez-faire, then recovers and exceeds the laissez-faire level, with an increasing

[10] For example, the dissemination of knowledge beyond the person who was at its origin or imitations. These externalities usually prevent innovators from acquiring all the income related to their innovation, thus explaining the under-investment into R&D. According to empirical studies, this investment is 3 to 4 times lower than the optimal level for society.

relative gain over time. This fall in the level of production, followed by a recovery and a subsequent gain in relation to the laissez-faire is also observed in the case of the tax (orange curve). However, when the subsidy for CCS is used, in the absence of tax, the level of production constantly increases in relation to the laissez-faire, and this happens as soon as it is implemented. But this initial relative gain is offset by a lower relative gain in the long term, compared to the laissez-faire. In other words, compared to the tax, the subsidy for CCS can play a specific role, involving the inter temporal smoothing out of efforts to reduce carbon emissions.

Figure 1: Variations in the world's annual production level (in %) in relation to Laissez-faire.



* The optimum considered corresponds to a situation in which a tax and subsidy are implemented, without a ppm concentration objective.

Source: "Climate Change Mitigation Options and Directed Technical Change: A Decentralized Equilibrium Analysis", Resource and Energy Economics (2011), Grimaud, A., et al.

Note to the reader: Implementing the combination of tax and subsidy engenders annual production losses worldwide in the short and medium term in relation to laissez-faire but leads to significant increases in this production in the long term, exceeding the laissez-faire scenario in about 2095.

Conclusion

Sequestrating or recycling carbon is one of the technical options available to fight global warming. Its potential development requires a good understanding of the economic trade-offs it could cause. Planners trying to maximise social well-being face two major constraints: the non-renewable nature of some energy resources, and the climate constraint which puts a certain ceiling limit on GHG emissions in the atmosphere which must not be exceeded. Because it allows carbon emissions to be captured or stored (or recycled), CCS is a means of relaxing the climate constraint, at least temporarily. In some cases, this can lead to an increase in the pace of extraction of resources – which appears to be quite a paradoxical phenomenon. In the longer term, the growing shortage of non-renewable energy resources, and consequently their increased price, will be the main strength of the socially optimal carbon trajectory. A subtle microeconomic analysis allows us to highlight economic trade-offs between energy resources, and characterise socially optimal trajectories concerning the use of resources and carbon emissions. The inclusion of R&D enhances the analysis, particularly in the choice of environmental policy instruments, by highlighting the complementary nature of tax and subsidised CCS. This analysis should be completed by the integration of processes to recycle the different gases captured in suitable conditions.

Appendix

Programme of the conference on "Carbon sequestration and climate policy: an economic analysis", held on Monday 19 September 2011 from 2 pm to 5.30 pm at the Grande Arche de la Défense, Arche Sud, Room 2

Introduction
by Françoise Maurel, Head of the Department for the Economics, Assessment and Integration of Sustainable Development (CGDD/SEEIDD) and Pascal Dupuis, Head of the Climate and Energy Efficiency Department (DGEC/SCEE).

Presentation of the issue, by Gilles Lafforgue.

Presentation 1: *"Optimal CCS and air capture from heterogeneous energy consuming sectors*" by Michel Moreaux.
Discussants: Julien Hardelin, Nathalie Dubreu (CGDD).
Discussion with people in the room.

Presentation 2: "Carbon sequestration and an optimal climate policy" by André Grimaud.
Discussant: Daniel Delalande (DGEC).
Discussion with people in the room.

Presentation 3: "*Climate change mitigation options and directed technical change: A decentralized equilibrium analysis*" by Gilles Lafforgue.
Discussant: Lionel Perrette (DGEC).
Discussion with people in the room.

Conclusion by Françoise Maurel, Head of the Department for the Economics, Assessment and Integration of Sustainable Development, and Daniel Delalande, Head of the Greenhouse Effect Department at the (DGEC/SCEE).

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Abstract

In September 2011 the General Directorate for Sustainable Development and Toulouse School of Economics jointly organized a conference on "Carbon capture and storage (CCS) and climate policies: an economic analysis". This paper presents an overview of the main results of the conference concerning the optimal energy mix and carbon emission path in the presence of CCS, the superiority of a policy mix combining an environmental tax with R&D subsidies, as well as the intergenerational equity-efficiency trade-off. It is based on presentations by Gilles Lafforgue, André Grimaud and Michel Moreaux, researchers from the Toulouse School of Economics.

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