Journal of Environmental Economics and Management 74 (2015) 55–70

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Optimal abatement of carbon emission flows ☆

Michel Moreaux [a], Cees Withagen [b,*]

[a] Toulouse School of Economics (IDEI and LERNA), France
[b] VU University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 26 June 2014
Available online 1 September 2015

JEL Classifications:
Q32
Q43
Q54

Keywords:
Climate change
Carbon capture and storage
Adaptation
Non-renewable resources

ABSTRACT

We study optimal carbon capture and storage (CCS) from point sources, taking into account damages incurred from the accumulation of carbon in the atmosphere and exhaustibility of fossil fuel reserves. High carbon concentrations call for full CCS, meaning zero net emissions. We identify conditions under which partial or no CCS is optimal. In the absence of CCS the CO2 stock might be inverted U-shaped. With CCS more complicated behavior may arise. It can be optimal to have full capture initially, yielding a decreasing stock, then partial capture while keeping the CO2 stock constant, and a final phase without capture but with an inverted U-shaped CO2 stock. We also introduce the option of adaptation and provide a unified theory regarding the optimal use of CCS and adaptation.

Introduction

Carbon capture and storage (CCS) is generally expected to play a crucial future role in combating climate change. In a special report IPCC puts forward that "…the potential of CO2 capture and storage is considerable" (Metz et al. 2005). The European Union states "This (CCS) technology has significant potential to help mitigate climate change both in Europe and internationally, particularly in countries with large reserves of fossil fuels and a fast-increasing energy demand" (European Union, 2014). The Environmental Protection Agency argues "Carbon dioxide (CO2) capture and sequestration (CCS) could play an important role in reducing greenhouse gas emissions, while enabling low-carbon electricity generation from power plants… CCS could also viably be used to reduce emissions from industrial process such as cement production and natural gas processing facilities" (Environmental Protection Agency, 2014). And J. Edmonds (Joint Global Change Research Institute) puts forward: "meeting the low carbon stabilization limits that are being explored in preparation for the IPCC 5th Assessment Report are only possible with CCS" (Edmonds, 2008). The main rationale for this view is that the economy is still depending on the use of fossil fuels to a large degree and that it might be too costly to introduce renewables in the short to medium run. CCS would then offer the opportunity to keep on using fossil fuels while limiting the emissions of CO2 into the atmosphere.

CCS consists of several stages. In the first stage the CO2 is captured at point sources, mainly at coal-fired or natural gas-fired power plants, but also in the upgrading process of tar oil (see Shell's Quest project.[1]) Several technologies are available, including post-combustion capture, pre-combustion capture (oxidizing fossil fuel) and oxy-fuel combustion. In the second

☆ Withagen gratefully acknowledges financial support from FP7-IDEAS-ERC Grant no. 269788.
* Corresponding author.
E-mail addresses: moreaux.michel@wanadoo.fr (M. Moreaux), c.a.a.m.withagen@vu.nl (C. Withagen).
[1] http://www.shell.ca/home/content/can-en/aboutshell/our_business_tpkg/business_in_canada/upstream/oil_sands/quest/about_quest/

http://dx.doi.org/10.1016/j.jeem.2015.08.002
0095-0696/

phase the CO2 is transported to a reservoir, where in the third phase the captured carbon is stored in for example deep geological formations. A side effect of the latter could be the use of captured carbon for increasing the pressure in oil fields, thereby reducing the cost of future extraction, but at the same time increasing the profitability of enhanced oil extraction, with the subsequent release of carbon, unless captured[2]. As a fourth phase there is monitoring what is going on, once CO2 is in the ground. Each of these phases brings along costs. The economic attractiveness of capture depends on the cost of capture and storage and the climate change damage prevented by mitigation of emissions of carbon. Herzog (2011) and Hamilton et al. (2009) provide estimates of these costs and conclude that the capture cost are about \$52 per metric ton avoided (from supercritical pulverized coal power plants), whereas for transportation and storage the costs will be in the range of \$5 – \$15 per metric ton CO2 avoided. This leads to overall costs amounting to \$60 – \$65 per metric ton. These numbers are more or less confirmed in ZEP (2011). The International Energy Agency (2011) reviews several studies concerned with technologies used on a large scale and finds cost per metric CO2 avoided \$55 on average for coal-fired plants and \$80 for gas-fired power plants[3]. At the present state of climate change policy CCS is obviously not profitable, but with a carbon price at present of \$25 and rising by 4% per year, large scale CCS becomes a serious option before 2040. Nevertheless numerous obstacles remain and many questions are still unresolved. Some are of a regulatory and legal nature, for example the rights-of-way for pipelines[4], access to the formation where CO2 is injected[5], and how to make the transition from capturing megatons to capturing gigatons in the future in order to have capture at a level that is substantial enough to combat climate change. Moreover, in Europe the success of CCS also depends of the prevailing CO2 permit price, which is low nowadays, and has induced Eon and GDF Suez to postpone investments in an EU funded demonstration project near Rotterdam, The Netherlands.

In the present paper we address not so much the development of the CCS technology but the optimal use of the technology once it is available. We only look at capture at point sources, and thereby abstract from geo-engineering, where carbon is captured from the atmosphere. We also assume that a storage technology is available, but that technology cannot be utilized for making fossil fuel reserves accessible at lower cost. The potentially limited availability of (costly) storage capacity (see e.g., Lafforgue et al., 2008a, 2008b) is not taken into account. Moreover, we neglect other important issues as well, such as the uncertainty surrounding the safety of storage over a very long period of time, due to the possibility of leakage. We consider both exhaustibility and non-exhaustibility of fossil fuels. British Petroleum (2013) estimates that world proved natural gas reserves at the end of 2012, 6614 trillion cubic feet, are sufficient to meet 56 years of production. Roughly the same holds for oil. For coal the global reserves-to-production ratio is much higher: 109 years. Since climate change is an issue that needs to be addressed in the long term, the assumption of exhaustibility seems warranted, even for coal. However, one could argue that the technically recoverable amounts of gas and coal are much higher and that large part of it will become economically viable due to higher prices or extraction lower costs. For example, the U.S. Energy Information Administration (2013) estimates the technically recoverable amount of gas are huge: 25,000 trillion cubic feet, of which around 30% is shale gas. Given the fact that backstop technologies are becoming cheaper over time, we account for the possibility that not all recoverable resources will be used up, so that from an economic perspective exhaustibility is not taking place.

The criterion for optimality that we use is discounted utilitarianism with instantaneous welfare being the difference between utility from energy use on the one hand and the capture cost and the damage arising from accumulated CO2 in the atmosphere on the other hand. In addressing optimality one needs to simultaneously determine optimal capture and storage of CO2. We make a distinction between constant marginal capture cost and increasing marginal capture costs (with marginal capture costs at zero capture zero or positive). Along the optimum a tradeoff has to be made between the direct instantaneous welfare of using fossil fuel on the one hand and the cost of capture and damage caused by the accumulated CO2 on the other.

The main contributions of the paper are twofold. First, we characterize the optimal use of CCS taking the exhaustibility of fossil fuels explicitly into account. The interplay between the atmospheric CO2 stock and the potential additional emissions through the existing fossil fuel stock is crucial. It is found that the stock of fossil fuels plays a crucial role in the degree to which it is desirable to employ CCS. For example, it could well be that initially there is no CCS, then CCS is only partial, whereas there is a final phase with zero CCS again. The possible optimal patterns of CCS also depend on the assumptions on capture and storage cost. The second contribution therefore is to show that different cost specifications lead to considerable differences in the combined optimal capture and storage and extraction regimes, in the case of abundant fossil fuel reserves as well as when reserves are limited. We identify cases where in the presence of the CCS it is still optimal to let the CO2 stock increase before partial capture takes place[6]. The core of the paper is Section Optimal capture with a finite resource stock, where we derive the optimum for the pivotal case of a finite resource stock and the availability of a CCS technology. There we show that it might be optimal to have full capture initially, then partial capture while keeping the CO2 stock constant, and a final phase with no capture but in which the CO2 stock increases initially, before decreasing eventually. Hence the CO2 stock is not inverted U-shaped, as in Tahvonen (1997). In addition to these main contributions we also

[2] Herzog (2011) points out that already decades ago capture took place, but then the objective was to enhance oil recovery by injecting CO2 in order to increase the pressure in the well.

[3] Remarkably, the costs for a project in China are much lower.

[4] See Jaakkola (2012) for problems that may arise in case of imperfect competition on the transportation network (offshore, in northwestern Europe).

[5] Feenstra et al. (2010) report on the public outcry when plans for storage in the village of Barendrecht (The Netherlands) were revealed.

[6] We are aware of the fact that CCS requires large upfront investments, for example in creating the capacity to transport and store CO2. We neglect such costs, although we do allow for high marginal costs of the first unit of CCS. Fixed cost is subject to future research.