Free of charge

-A valuation of the carbon sequestration services provided by Swedish forests

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“Free of charge”
-A valuation of the carbon sequestration services provided by Swedish forests

“Kolinlagring på köpet”
-En värdering av kolsänketjänster i svensk skogsmark

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Abstract

This thesis examines the value of Swedish forests as carbon sink in the perspective of increases in greenhouse gas concentration in the atmosphere, sometimes referred to as "global warming". This environmental problem would be even worse if our ecosystems did not absorb large amounts of carbon dioxide (CO_2), taking it away from the atmosphere for a longer or shorter time. The forests in Sweden are a sink for CO_2 from the atmosphere. This thesis tries to estimate the value of this service that is provided for free; it combines forecasts for the sink with cost for reducing CO_2 emissions and derives a value of the service. The estimated value of a carbon sink of 15 Mt/year range from 2.6 to 7.1 billions/year, depending on the assumptions made. The value of a 2 Mt sink/year could vary from 0.54 to 1.7 billions/year. The main factors that influence the value of the sink are: the size of the sink, the national emission target, the forecasted emissions, the shape of the cost curves, whether trading with emission permits is allowed and if trade is allowed, the market price of permits.

Key terms: Carbon sink, carbon sequestration, forest, valuation, Sweden, ecosystem service

Sammanfattning

Denna uppsats undersöker värdet av den svenska skogen som kolsänka i samband med ökande koncentration av växthusgaser i atmosfären vilket ofta benämns ”global uppvärmning”. Om inte våra ekosystem hade bundit upp koldioxid från atmosfären för kortare eller längre tid hade detta miljöproblem varit ännu allvarligare än det är idag. Den svenska skogen är en sänka för atmosfärisk koldioxid. I uppsatsen värderas denna ekosystemtjänst, som idag tillhandahålls gratis, som en biprodukt av dagens skogsbruk. Uppsatsen kombinerar prognoser för kolsänkan med kostnader för att reducera koldioxidutsläpp och ger sänkan ett värde för den reningstjänst skogen utför. En årlig sänka på 15 Mt kan värderas till mellan 2,6 till 7,1 miljarder kr beroende på vilka antaganden som görs. En sänka på 2 Mt per år värderas på samma sätt till mellan 0,54 och 1,7 miljarder kr per år. Olika faktorer som påverkar sänkans värde är: sänkans storlek, det nationella utsläppsmålet, de framtida utsläppsprognoserna, marginalkostnaderna för utsläppsreduktion, huruvida handel med utsläppsrätter tillåts och, om handel är tillåten, priset på utsläppsrätter.

Nyckelord: Kolsänka, skog, ekosystemtjänster, värdering, kolinlagring, Sverige

Abbreviations

C: Carbon
CO_2: Carbon dioxide, the most common greenhouse gas
CO_2 eqv: Greenhouse gases equivalent to 1 amount of carbon dioxide
EU: The European Union
Gt: Giga tonnes, 1x10^9 tonnes, 1x10^12 kg
GDP: Gross Domestic Product
GHG: Greenhouse gas
m^3sk: Forest cubic meters: Volume above the stump, including tree top and bark
MC: Marginal Cost
Mt: Mega tonnes, 1x10^6 tonnes, 1x10^9 kg
USD: US Dollars
SEK: Swedish kronor
Öre: 1/100 of 1 Swedish krona

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1 Introduction

1.1 Problem background

Global warming is an environmental issue that gains a lot of attention in Sweden and worldwide. For example, a search on "global warming" on the Google search engine in the end of Mars 2009 gave around 61 million hits. There are many different opinions about the severity of the problem, but today there is consensus among scientists about the fact that human activities affect the earth's climate, making it warmer, although to what degree is still debated. The Intergovernmental Panel on Climate Change (IPCC) states that (IPCC 2007, s 39): *"Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations"*.

The online dictionary Encyclopædia Britannica states that *"…the influence of human activities has been deeply woven into the very fabric of climate change"* (Internet, EB a). Although emissions of greenhouse gases (GHGs) are increasing globally, there are also processes in nature that bind carbon for a longer or shorter time (Stavins & Richards, 2005). This sequestration of carbon in nature is an ongoing process both in the oceans and on land. Without these processes the concentration of GHGs would be greater than today. More information about global carbon flows is found in *Appendix 1*.

Because the effect on the climate is global, there is need for international cooperation. Such action has been taken, leading to mainly the creation of the Kyoto protocol that goes on from 2008 until 2012 (Internet, UNFCCC a). During that period, a number of industrialized countries are supposed to stabilize their emissions to a level being roughly 5 % lower than the emissions in 1990. The total emission reduction will probably be lower since the USA has declared that they will not ratify the protocol (Internet, UNFCCC b).

The Kyoto protocol allows the use of a flexible economic instruments to achieve the emission targets set up in the treaty (Internet, UNFCCC c). This includes trading of emission rights, the right to finance abatement (emission reduction) projects in other countries and credit the emission reductions to the founder, and finally and most important for this thesis: the creation of carbon sinks. Carbon sinks and Swedish carbon sinks in particular are described in section 3.

1.2 Aim

The aim of this thesis is to value the carbon sequestration services provided by Swedish forests. This valuation of a service which is a by product of modern forest use and "is for free" could be important when making decisions regarding forest use in the future. The study is done because there are today, to the author, no known valuation studies for these services.

The question that this thesis is trying to answer is: How much is the sequestration service provided by the Swedish forest worth in the year 2010?

1.3 Problem and delimitations

In other countries, many studies regarding costs for using forest land for carbon sequestration have been conducted. For example, during the period 1990-2003 there was at least 11 different studies made in the US, providing very different cost estimations (Stavins & Richards, 2005). This is not the case for Sweden; no studies of costs for using Swedish forest land as a carbon sink is known to the author. However, this thesis is not an attempt to estimate costs for creation and use of forest land as carbon sinks. Rather, it analyzes the existing carbon sink in Swedish forests as a by-product of modern forest use.

The EU carbon trade program started in January 2005 but it did not include the right to credit carbon sinks as emission reductions. The EU program only included CO_2 and only large-scale industries. According to the National Institute of Economic Research (NIER) (2003), the Swedish trading sector's share of the total Swedish CO_2 emissions is around 30 %. So data used in this thesis builds upon the special characteristics of the EU market for CO_2 emission trade. The calculations in this thesis builds mainly upon a study called *Economic Effects for Sweden of Limited Carbon Dioxide Emission Trade within EU* made by NIER (2003), which is a paper that examines the costs for fulfilling a specific emission reduction target, namely -4 % from the 1990 level. The -4 % target is set by the Swedish Riksdag. The model used in NIER's study is the EMEC (Environmental Medium Term Economic Model)[1]. NIER's study only examines effects on Sweden, no possible foreign effects of Swedish emission reduction are included. NIER's study also examines a specific year when the target needs to be fulfilled. 2010 is the ending year for the analysis and that may affect the result depending on if, for example, 2010 is predicted to be a turning point for predicted emission paths.

In NIER´s study, a reference scenario is used to calculate the cost for achieving a specific emission target. The cost of achieving a target is the difference in costs between the two scenarios. Carlen (2004) claims that not all costs for achieving emission reductions are included in NIER´s study. Carlen claims that since the reference scenario contain taxes on emissions, these costs or at least parts of them should be counted as costs for achieving the emission targets set up by the Swedish parliament. This discussion arises from the question whether emission taxes should be regarded as a source of income for the government, and thereby not be credited as a specific cost for emission reduction, or if emissions taxes are introduced just to reduce emissions and therefore should be regarded as a cost for reducing emissions. In this thesis, the emission taxes in NIER´s (2003) reference scenario are regarded as a source of fiscal income and thus not as a cost for achieving emission targets.

In NIER (2003), the area under the MC curves does not reflect the total GDP effect of emission reductions. This is pointed out by Carlen (2004). Therefore, this thesis only take the directs costs into account when evaluating the carbon sink. That is because the total effect on the economy may be both larger and smaller than the direct cost due to "interaction effects" (Carlen, 2004 p 17 & 24). For example, the direct cost of reducing emissions to a level of -4% of 1990 emissions without emission trading is 4.74 billion SEK (Carlen, 2004) while the GDP loss is 8.4 billion SEK. On the other hand, the effect of the same reduction target with emission trading at a price of 6 USD is 2.7 billion SEK according to the calculations in *Figure 16* while the GDP loss is 2.2 billion SEK (NIER, 2003).

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[1] Since NIERs study the model has been updated and is now named EMEC 2.0. More info regarding the EMEC model can be found at NIERs website:
http://www.konj.se/sidhuvud/inenglish/environmentaleconomics/cgemodeling.4.2479068e10b3f7b60b980003617.html

The carbon sink is valuated by comparing the costs for reducing CO_2 emissions from NIER's study, putting them together with predictions of the size of the carbon sink, and then counting the sink as emission reduction. The value of the sink is the amount of money that is saved when a certain amount of carbon dioxide, for example 15 Mt CO_2, is embedded into growing biomass for free, which has the same effect as reducing emissions by 15 Mt.

In this thesis sequestration in forests is regarded in the same way as other means of emission reduction. This may not be fully accurate since the carbon in forest soil and in trees eventually will be brought back to the atmosphere, either naturally or as a consequence of human interaction. This will be discussed more in the chapter

7 Uncertainty regarding numbers and assumptions.

2 Economic theory for valuation of carbon sinks

The value of the carbon sequestration services provided by the forests is calculated by comparing the cost of two different strategies of achieving a specific emission target. Both strategies are assumed to be cost effective. The only difference between the two is that one of the strategies includes the forest sink as emission reduction, and the other does not. By comparing the two strategies, the total cost for achieving the same emission target for the value of the sink will be derived from the difference in cost between the two. The sink value is determined mainly by the following variables: the size of the sink, the emission reduction target, the forecasted emissions, whether trade is allowed, the price of emission permits (if trade exists) and the shape of the marginal cost (MC) curve. The content in *Chapter 2* and its subsections are based on quite general environmental economic theory which can be found in a number of publications, e.g. Perman et al (2003).

The value of the sink may differ substantially between a case where trade is allowed compared to when trading with emission permits is introduced. And if emission trading exists the market price of emission permits may also affect the the value of the sink. Section *2.1. Sink value without trade* presents the theory for valuating the sink when emission trading is not allowed. Section *2.2 Sink value with trade* then presents the theoretical background for valuating a carbon sink when emission trading exists and the price of permits changes from a high level to a lower lever.

2.1. Sink value without trade

The concept of marginal cost is fundamental in economic theory. The shapes of an MC curve often determine the structure of the market at issue. In environmental economics it is often the cost of abatement, or cleaning, which is important.

The most common case is a curve that becomes steeper with increasing activity. In our case the cost per unit of abatement of CO_2 most likely increases with the quantity abated. This is because the cheapest activities are used in the beginning and as more cleaning is needed more expensive methods are used. In *Figure* 1 below we can see the marginal cost increasing as the abatement efforts increases. The exact shape of the curve could vary. It could even become vertical in the end if extremely high cost methods must be used.

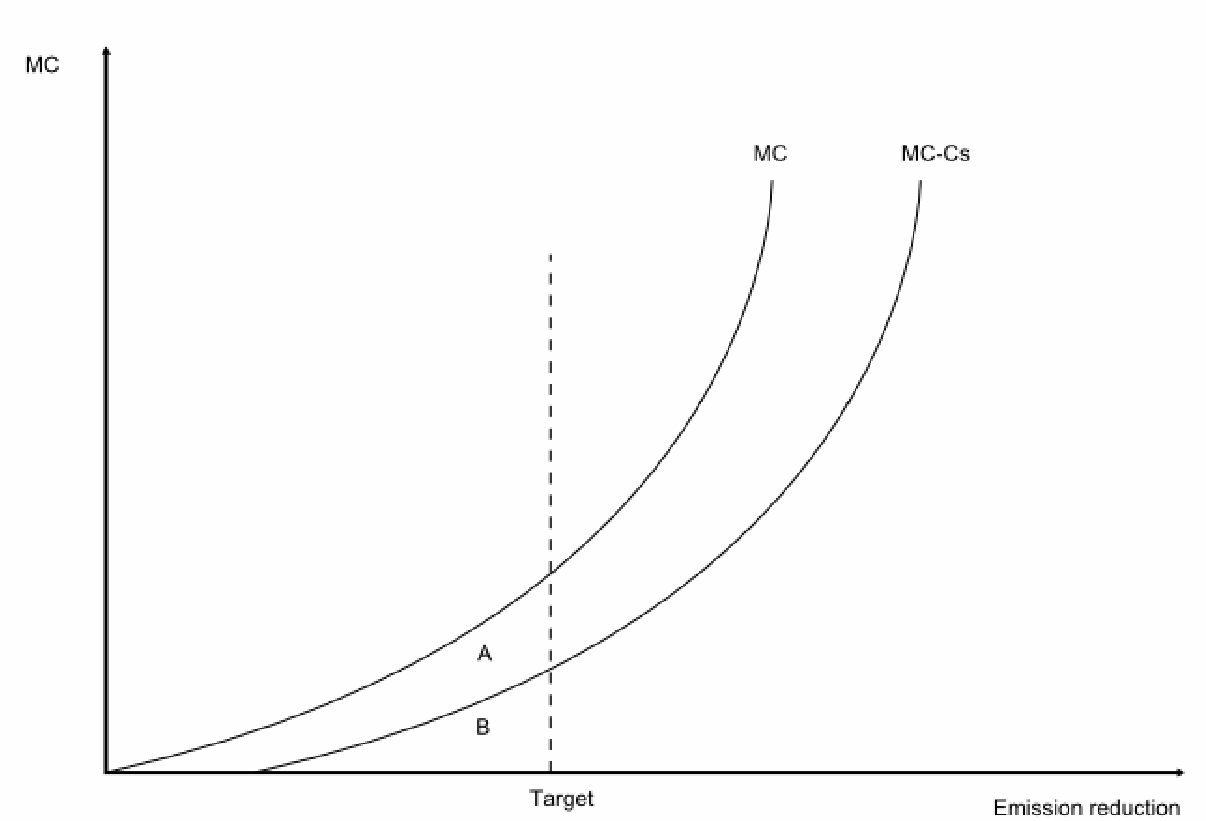

Figure 1. ***Sink value without trade.***

With traditional cleaning methods we have the MC curve to the left, as illustrated in *Figure 1*. But if we include the carbon sink provided today by the forests (for free), we get a shift in the curve (from MC to MC-Cs), which is the same as to say we get an amount of free cleaning. The assumption that the sink is provided for free could be controversial. But, as we later will see, we have a carbon sink in Swedish forests without aiming for it in forestry management. Therefore the forest sink is viewed as a free by product of forest management.

If we set the emission target at "Target" in *Figure 1*, we will have a total cost of area A+B under the MC curve. If we account for the sink we will have a total cost of only area B under the MC-Cs-curve. So without the sink we have a total cost of area A+B and with the sink we have a total cost of area B. The value of the sink is then the avoided cost equal to area A.

If we set a more strict emission reduction target, then the value of the sink, and at the same time, the total cost will increase more than linear, because of the increasing slope of the MC curve. This is because more expensive cleaning methods must be used as we increase cleaning efforts.

Changes in the size of the sink of course change its value, as does changes in the shape of the MC curve. If trading with emission permits exists, then the valuation gets more complicated, as we will se in section 2.2.

2.2 Sink value with trade

If the CO_2 cleaning from a carbon sink is accounted for as reduction in emissions, the MC curve will shift to the right as we have seen above. However, when there is the option to trade emission rights, the value of the sink cleaning differs from the no trade case. How much the value differs depends on how high the market price is.

Assume that, in *Figure 2* below, Sweden is given the right to emit the amount IR (Initial Rights), which then equals the target of emission reduction. Sweden is assumed to be a price taker, that is, not able to influence the market price in any way. Sweden will then clean until MC for cleaning is the same as the market price, *p*. So the cleaning in Sweden will be larger than the target demands, the additional cleaning is done because Sweden has an opportunity to make profit by reducing more than demanded and then selling the additional cleaning to other actors in the market which have higher costs for cleaning.

In the case where there is no accounting for cleaning from the sink we will follow the MC curve until point A* on the X-axis. When reducing emissions until point A*, Sweden will sell an amount of emission rights equal to the distance between A* and IR. In the case where the forest sink is accounted for, the other MC curve, labelled "MC-Cs", will instead determine the amount of emission reduction, which then corresponds to A*Cs on the X-axis. When cleaning until A*Cs, Sweden will sell an amount of emission rights according to the distance between A*Cs and IR. The increase in emission rights sale then correspond to the distance between A* and A*Cs.

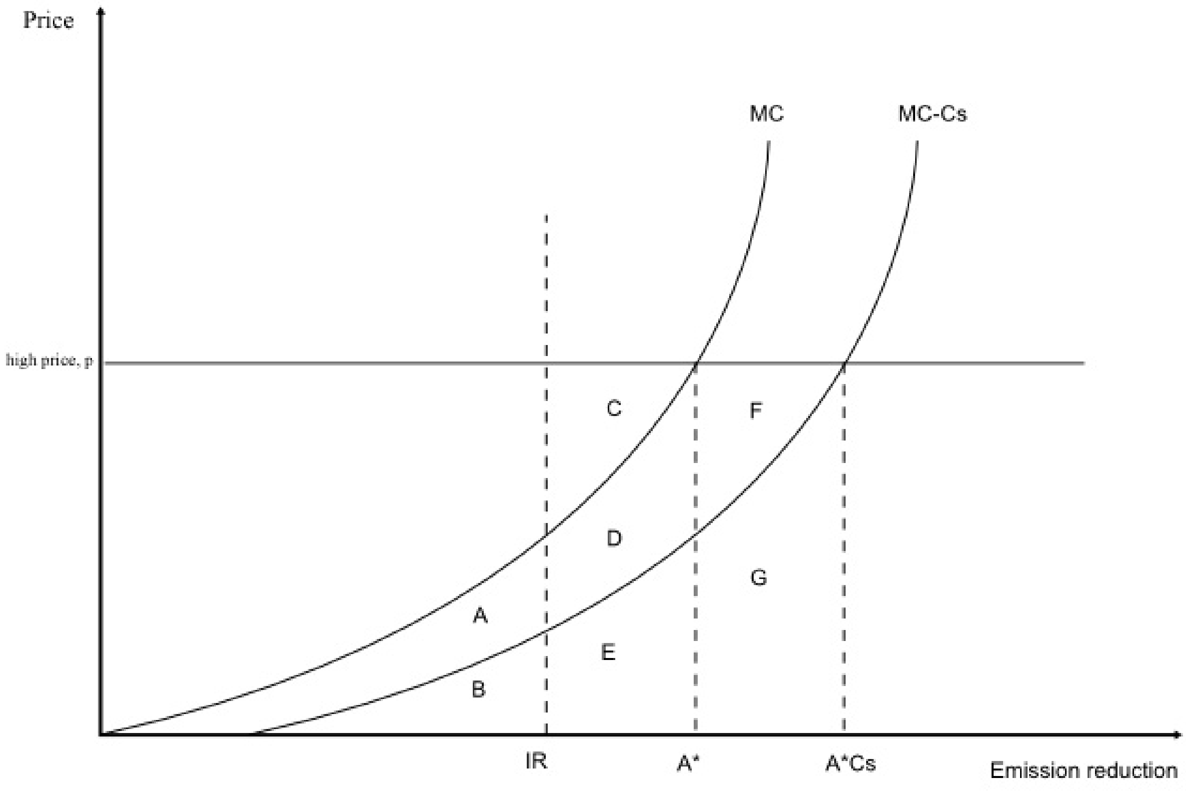

Figure 2. ***Effects from sink cleaning in emission trade with high price.***

In both of the cases above, Sweden will be a net seller of emission rights. This is all due to the high price; the effect of a lower price will be examined later, in *Figure 3*. It should be pointed out that individual firms with high cleaning costs could still be net buyers, but this thesis examines the aggregated national level and not the detailed national market structure. The effects of the choice to account or not account for the sink are shown in *Table 1*.

Table 1. ***Effect of sink, high price***

	Cost, from cleaning	Benefit, from selling	Net cost	Sink value
No sink	A,B,D,E	C,D,E	A+B-C	A,D,F
Sink	B,E,G	C,D,E,F,G	B,-C,-D,-F	

Finally, the sink case compared with the no sink case shows that with the sink, the cost of area A is avoided at the same time as the benefit from area D and F is gained.

With the same assumptions and initial rights as above, but with a lower market price, Sweden will now be a net buyer of emission rights. This is shown in *Figure 3*. The breaking point when Sweden starts to buy permits is reached when each curve intersects the price line. Without the sink Sweden will clean until A* and then buy permits until the "target" IR is reached. This is done because buying permits is cheaper than further reducing emissions. The amount of permits bought corresponds to the distance between A* and IR. With the sink cleaning, Sweden will reduce emissions until A*Cs and after that point buy permits according to the distance A*Cs-IR.

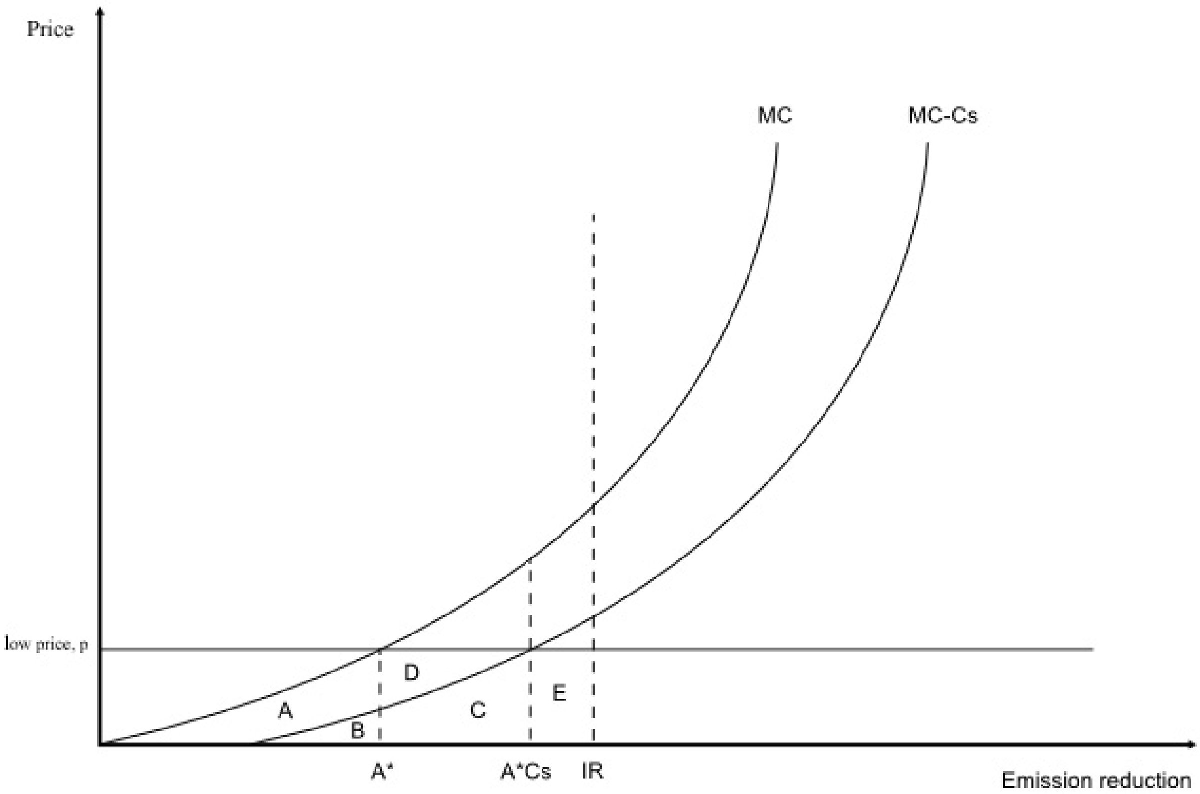

Figure 3. Effects from sink cleaning in emission trade with low price.

In this case, with a lower market price on emission permits than in *Figure 2*, the cleaning in Sweden will be lower than in the former case with a high market price. When allowing for carbon sink as a cleaning measure, purchases of permits decreases by an amount corresponding to the distance between A* and A*Cs. In the same way as above, the effect of accounting for the sink is shown in

Table 2.

Table 2. ***Effect of sink, low price.***

	Cost, from cleaning	Cost, from buying	Net cost	Sink value
No sink	A,B,	C,D,E	A,B,C,D,E	A,D
Sink	B,C	E	B,C, E	

In this case, the sinks have reduced the total cost by an amount reflected by areas A and D.

When comparing the no trade case with the case with a low price on emission permits one can say that the introduction of trade lowers the value of the sink. But at a certain emission permit price level, the value of the sink becomes higher than the no trade case as it becomes more and more profitable to increase domestic abatement and sell emission permits at a high price. When comparing the two cases where trading is allowed, one can see that the value of the carbon sink increases when the price of emission permits rises. To derive a value of the Swedish carbon sink, the amount of CO_2 that is sequestrated into the ground must be known. Predictions of the future size of the carbon sink are presented in the next section of this thesis.

3 Carbon sinks in Swedish forests

The definition of a carbon sink is: “Forests and other ecosystems that absorb carbon, thereby removing it from the atmosphere and offsetting CO_2 emissions” (Internet, EEA a). The amount of carbon in a forest over time is determined by a number of variables, some by nature such as forest fires and temperature and some by human hand, mainly the felling of trees and soil scarification (LUSTRA, 2008). As mentioned above, it is the possible annual Swedish sink around the year 2010 that is interesting for this thesis. That is because it is the year that is examined in the work by NIER (2003), which predicts the cost for reducing emissions of CO_2. The following sections presents facts about the Swedish forests and predictions about the Swedish carbon sink around 2010.

3.1 Growth in Swedish forests

Forests can act as both sinks and sources for CO_2 emissions. If the Swedish forests will be a sink or a source is a result of many different variables, and this complex system has been analyzed by the Swedish research project LUSTRA (Lustra, 2002). LUSTRA was a research project aiming for reducing GHG-emissions from the land use in Sweden. According to LUSTRA, Swedish forests mostly work as carbon sinks. However, there are exceptions. If, for example, clear cutting is used then the ground could act as a source until new trees bind enough carbon to compensate the loss from the ground. Another exception is trees on peat land that seem to be a source of CO_2 emissions even if there are trees growing on the ground (LUSTRA, 2006). So the Swedish forests in total act as a sink for carbon, and that is mainly because we have a growth in tree biomass (Johansson, 2003). The growth in tree biomass also produces more forest litter, which increases the carbon in the ground. We will now see two figures explaining this more thoroughly.

In *Figure 4* below, we can see how mainly forest management (Riksskogstaxeringen, 2001) has affected the forest tree biomass in Sweden. In the period for which data is available we can first see that growth in the forest exceeds drain, with the exception of about five years in the end of the 1960s and the beginning of the 1970s. The curves below total drain show what the total drain consists of. The difference between total felling and total drain is explained by natural drain. A rapid increase in final felling, which reaches its peak in 1973, and two storms, one in 1967 and one in 1969, explains why growth and drain almost equaled in the years around 1970. The most interesting fact for this study is that there seems to be an increase in the stock of timber, and therefore presumably a carbon sink in the forest.

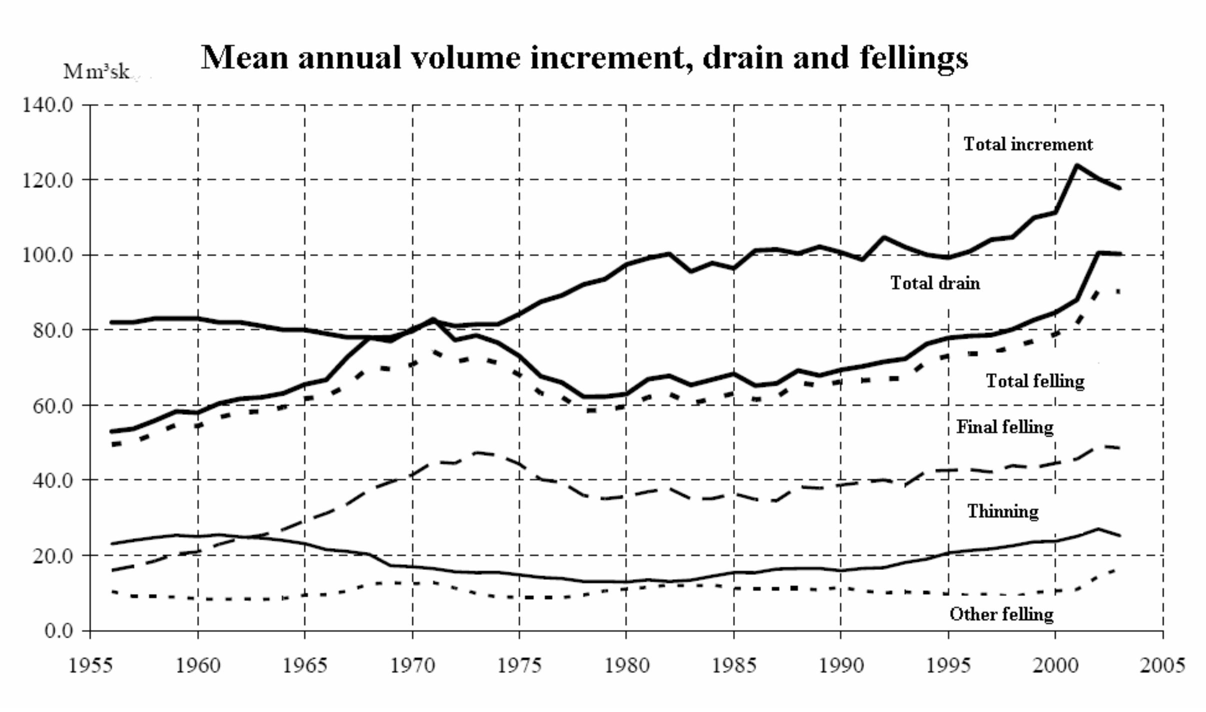

Figure 4. Annual growth, drain and felling in Swedish forests 1955-2002, translated from Internet, Riksskogstaxerigen a.

The assumption from above that there is an increase in the stock of timber in the Swedish forests is confirmed by the curve in *Figure 5* below. It has a longer time horizon than *Figure 4* above; this is simply because standing volume has been recorded in statistics for a longer period of time than the more detailed statistics in *Figure 4.* From the mid 1920s until 2003, we see an increase in standing volume from 1,760 Mm³sk to over 3,200 Mm³sk, an increase of over 80 %. Except from the years around 1970 the stock increases steadily during this period of almost 80 years.

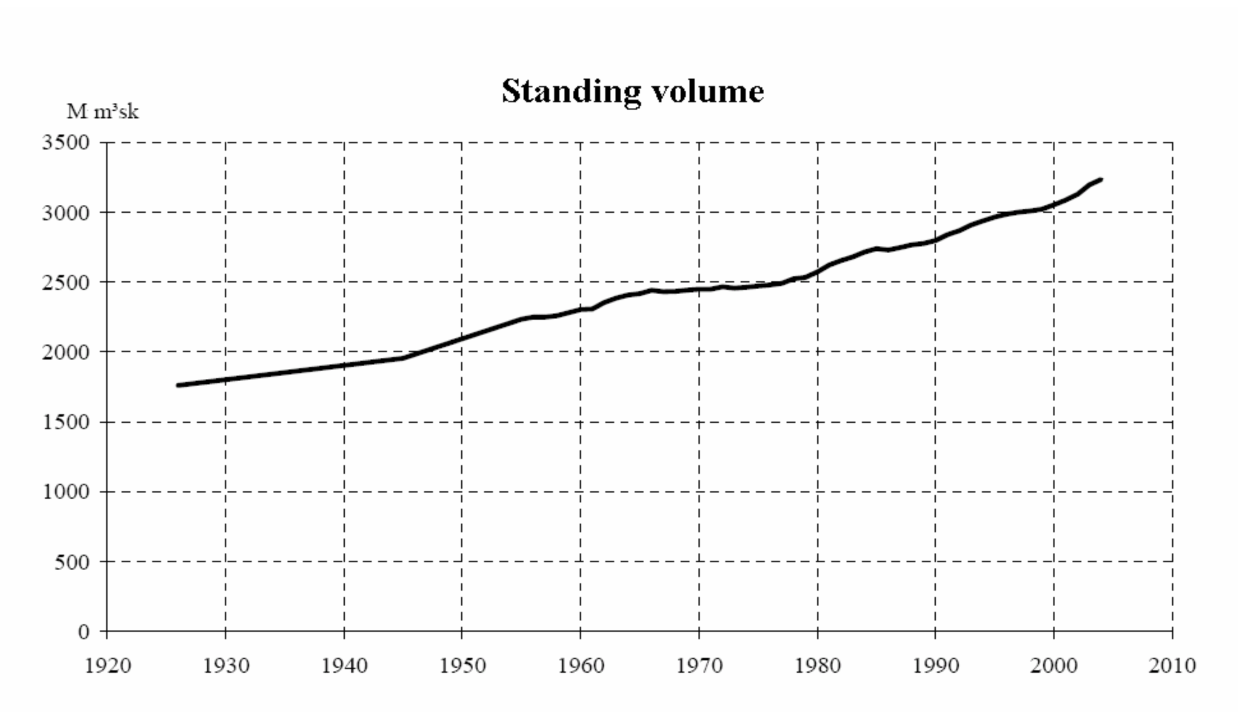

Figure 5. ***Standing volume, translated from Internet, Riksskogstaxeringen b.***

Although the curves and statistics above show growth in the biomass of Swedish forests, it does not show us the amount of carbon that has been sequestrated in the biomass. With statistics as the one above and with the help of different models, the LUSTRA project has come out with numbers for the carbon sink. The conclusion is that since 1920, 500 Tg (500 Mt) of C has been accumulated into trees and ground. About 75 % of the carbon has been accumulated above ground and 25 % in the ground itself (LUSTRA, 2006). Furthermore, it is important for this thesis to estimate the size of the annual sink in the (near) future and this is what is done in the next part.

3.2 Sink forecast for Swedish forests

The Swedish Environmental Protection Agency (SEPA) states that the annual sink will probably not be lower than 4 Mt C/year (Natuvårdsverket, 2003). This size of the sink is also supported by the LUSTRA project. In its latest annual report they say that their research points towards an annual sink size in the near future of about 15 Mt CO_2 eqv, and that corresponds to about 4 Mt C (LUSTRA, 2006).

One way to compare these forecasts with historical data is to divide the 500 Mt C sequestrated from 1920 until 2003 by the number of years, which is about 6 Mt C/year (Internet, Riksskogstaxeringen b), and compare this with the 4 Mt/year from the forecasts from SEPA and LUSTRA. In comparison with this rather crude way of estimating the historical carbon sink, the forecasts from SEPA and LUSTRA are lower, but at least the numbers are in the same order of magnitude. So according to historic trends and to present research it is very likely that the Swedish forests will act as a carbon sink in the near future. Since it is the year 2010 that is at issue in this thesis, it is most likely that we will have a sink and that the size will be around 4 Mt C or expressed in CO_2-equivalents: 15 Mt. There is however another part of the carbon sink that is worth examining and that is the part that could be accounted for in international agreements. This is done in the following section.

3.3 Carbon sinks in international agreements

In an infinite time perspective all carbon atoms on earth are moving, but with a shorter, more "human" outlook on time, it is possible to define some of the carbon pools as permanently stored. This is the case in the Kyoto protocol (UNFCC, c). In the first period of the protocol, 2008-2012, countries affected by the treaty could choose to report creation of carbon sinks as emission reductions. Only sinks resulting from active measures in the agriculture and forestry sector could be accounted for.

However, it is not easy to say what is a result from an active measure and therefore some guidelines have been established. These guidelines and their implications for Sweden are presented in Boström (2003). It is stated that a country could include the lowest of the two following measures of sinks; 15 % of the annual sink or an amount of 3 % of the emissions in 1990. For Sweden, this would imply the possibility to account for a sink of 0.58 Mt C/year. This number is almost equivalent to the number from the National Allocation Plan (NAP). The Swedish sink size that could be accounted for is according to the NAP 2.13 Mt $CO_{2.}$ eqv /year (Näringsdepartementet, 2004). In the following chapter, calculations of the carbon sink will be made. The examined sizes of the annual sinks are 15 and 2 Mt CO_2. The 2.13 sink is rounded off to 2 Mt because of the quite crude graphical method used in the calculations. The method is described in the following chapter.

4 Method for the calculations

The calculations in *5 Calculation of the sink value* were all made in the same way, which is described theoretically in *Figure 1*. The aggregated Swedish MC curve for reducing CO_2 emissions at question was adjusted by parallel shifts to the right according to the size of the carbon sink examined. This transformed the single curve into two parallel curves, which was made with a computer graphics program. The value, area *A,* of the sink was calculated in two different ways because the methods themselves may influence the result. An explanation of the two methods follow below.

The first method were to simply select the area *A* and measure its size, this is called **Method 1**. *Figure 6* below illustrates this with area *A* marked with a broken line.

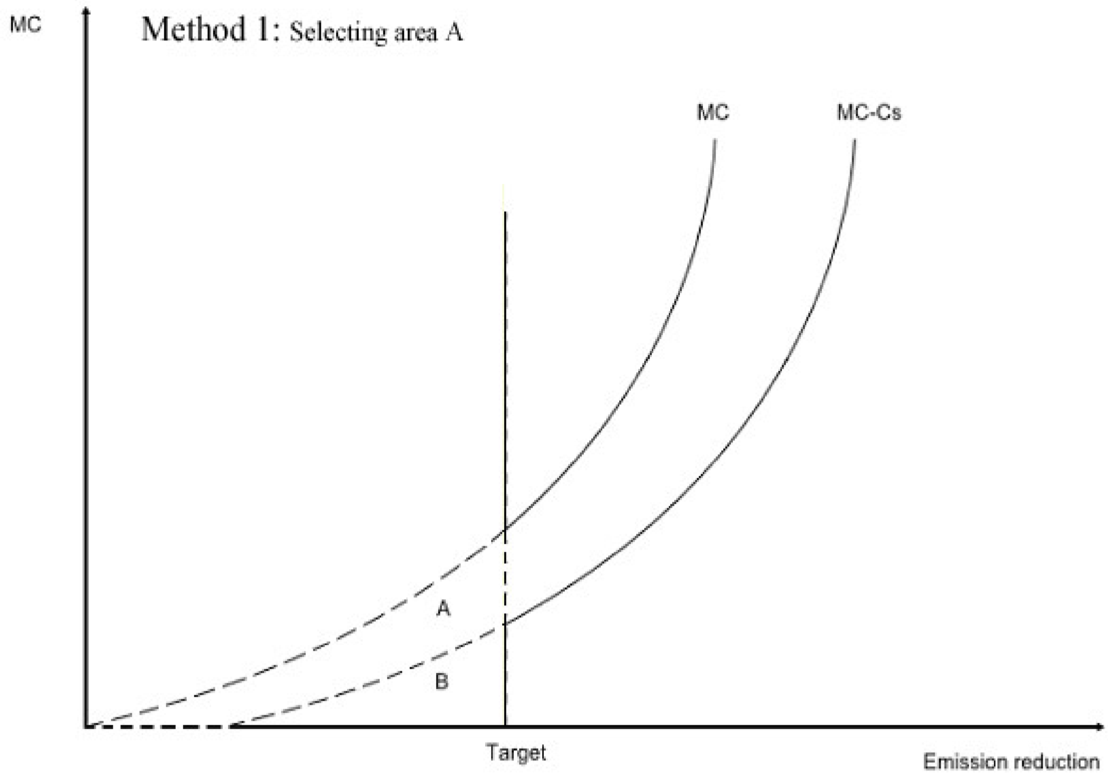

Figure 6. Illustration of Method 1.

The other method, named **Method 2**, is to first select both area *A* and *B* and then subtract area *B*. The "triangle" to the left encircled by the broken line, consisting of area *A* and *B*, is first selected. Then is area *B* selected and subtracted from the "triangle". The method is illustrated in *Figure* 7 below.

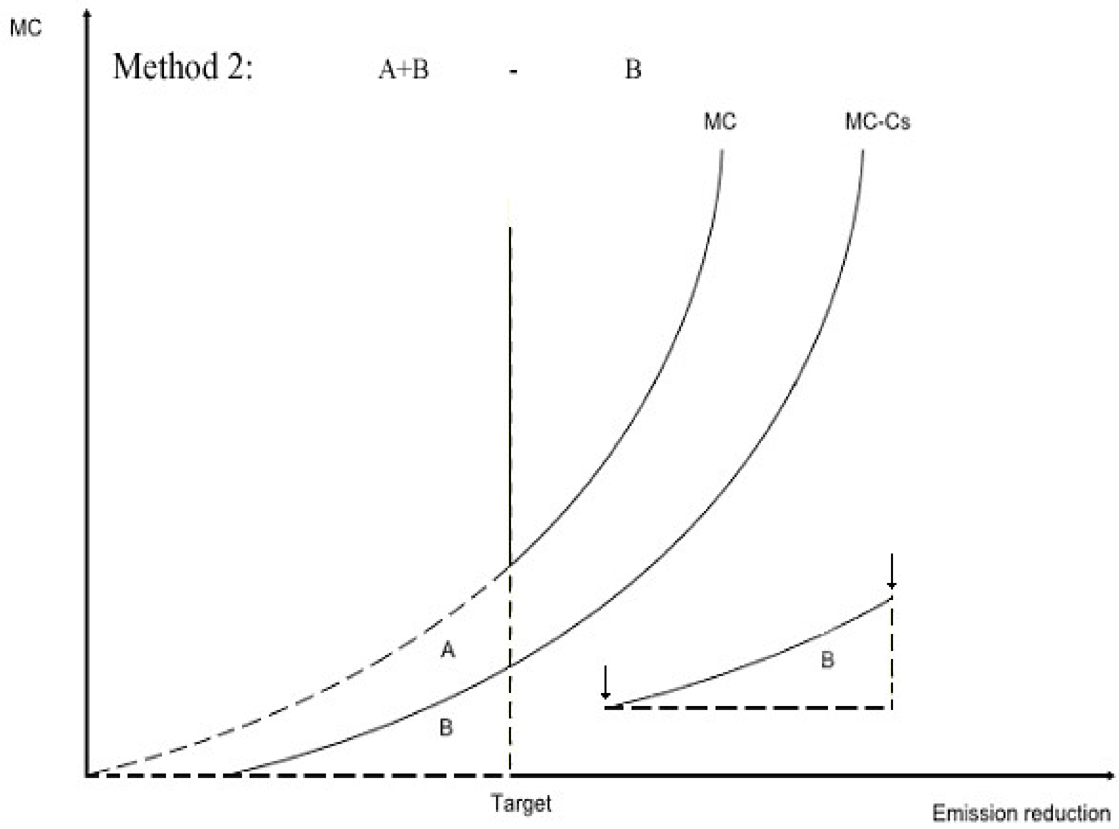

Figure 7. Illustration of Method 2.

The difference between the two methods is the thickness of the line between area *A* and *B*. The line is marked with two arrows at start- and endpoint to the right in *Figure* 7 where area *B* is displayed alone. This line may influence the results, especially if the area of the line itself is large compared to the other areas, *A* and *B*, which is examined. The influence will probably be larger when the sink is small and the MC curve is flat. This makes area *A* a long thin layer above area *B*. *Figure 25* is one example where the thickness of the line have a big impact on the final result, i.e. the value of the sink.

After the size of two different areas was calculated, the areas needed to be multiplied with a value per area unit[2] so that a sum in SEK could be derived in the end.

To get this value per area unit two things had to be made; first calculating the value of a known area, then measuring the number of area units in that area with the computer program. This is shown in *Figure 9* below. The total sum of a square, in SEK, was calculated by multiplying the MC with the amount of reduction. This was done by selecting points marked in the diagram. As an example the square marked below, 100 öre on the Y-axis and the 2 Mt on the X-axis, is 2 000 000 000 SEK. For each such known value the computer program may estimate different numbers of area units. This error has mostly to do with limited sharpness in the pictures. Ten different areas of different sizes were examined and the values per area unit ranged from 416 666 to 428 638 SEK. These were then added together and finally divided by ten, thereby resulting in the number 422 764 SEK per area unit.

[2] Area unit is the name of the squares used in the computer graphics program. When for example an area is selected, the size is presented in pixels which hereafter is named area units (au).

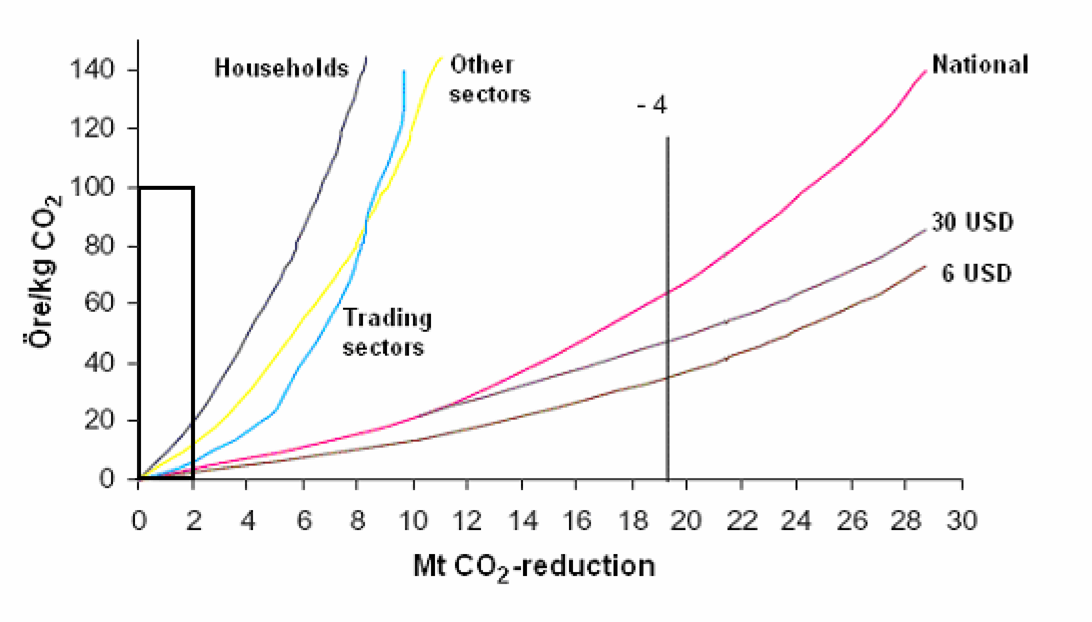

Figure 8. ***Marginal cost curves for Sweden, translated from NIER, 2003, p 19.***

In the next section, the value of the carbon sink will be calculated using the method described above together with the predictions of the sink size from chapter

3 Carbon sinks in Swedish forests.

5 Calculation of the sink value

The MC curves in *Figure 9* below show six different MC curves for reducing Swedish CO_2 emissions in 2010. To the left we have three curves that show the MC curves of households, “Trading sectors” (sectors that are allowed to trade with emissions permits) and “Other sectors”. The three other MC curves to the right are aggregated curves showing the total MC curves for reducing Swedish CO_2 emissions under different scenarios. The curve labeled “National” shows the Swedish MC curve when trade is not allowed. The other two curves labeled “30 USD” and “6 USD” show the Swedish MC curves when the trading sectors are able to trade with permits on the EU market at a market price of 30 USD and 6 USD per tonne respectively. In NIER’s study one USD is worth 10,3 SEK (NIER 2003, p 15).

The difference between the aggregated curves is explained by the trading sectors’ possibility to buy permits instead of performing domestic emission reduction. In the following figures, it is also assumed that any possible purchases of permits that Sweden does from the EU market are credited as domestic emission reduction. This is probably the cheapest way to reach the emission reduction target. In the end, this leads to a lower value of the carbon sink than if more costly ways to reach the target were to be used. If purchased permits are not included in domestic emission reduction, then households and non-trading sectors need to make further reductions corresponding to the purchased permits from the trading sector. This increases the total costs for reaching the national emission target.

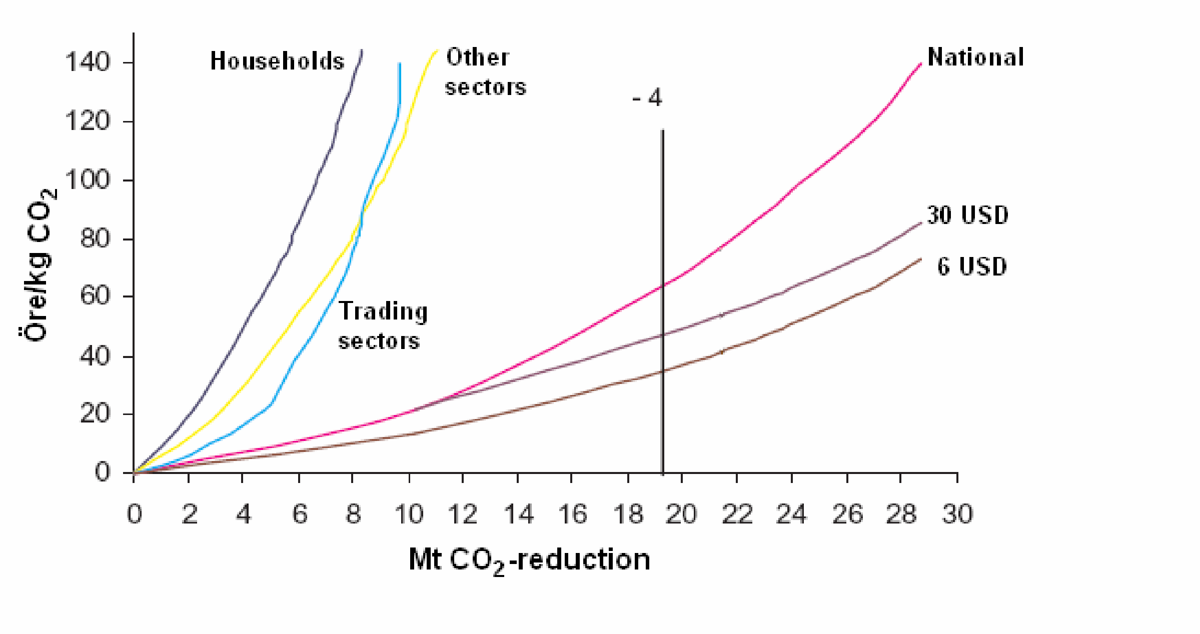

Figure 9. ***Marginal cost curves for Sweden, translated from NIER, 2003, p 19.***

The area under the aggregated MC curves shows the cost for reducing CO_2 emissions in 2010 according to the reference scenario mentioned above. However, it is important to point out that the MC curves used in the above and the following figures only reflect the direct costs of reducing CO_2 emissions and do not include interaction effects that spread in the economy and affect GDP. The total cost of reduction may therefore be higher (or lower) than what is reflected by the area under the MC curves in *Figure 9* (Carlen, 2004) & (NIER, 2003). This source of uncertainty is discussed more in chapter

7 Uncertainty regarding numbers and assumptions.

In *Figure 9* the line -4, located at around 19.3 Mt CO_2 emission reduction per year in the X-axis, represents the Swedish national target with a 4 % reduction from the emissions in 1990. The MC curves are calculated using a reference scenario with 62.794 Mt CO_2 emissions in 2010, 12 % higher than the 1990 emissions (NIER, 2003).

The calculations, whose results are presented in section *5.1 Results from calculations with original reference scenario* were done with the reference scenario from NIER (2003) mentioned above which uses a reference scenario of 62.794 Mt CO_2 emissions in 2010.

Section *5.2 Results from calculations with reference scenario 66.831 Mt CO2* uses a reference scenario with slightly higher emissions, about 4 Mt higher, taken from Capros & Mantzos (2000). The additional case, from Capros & Mantzos (2000), is included to show how the choice of reference scenario affects the final result, i.e. the sink value.

The calculations as a whole can be seen in *Appendix 2* and the following subsections present the results of the calculations. Two annual sink sizes and the annual value of them are examined; 2 Mt, roughly the size that could be credited in the Kyoto protocol and 15 Mt, which is the total size of the annual Swedish forest sink.

5.1 Results from calculations with original reference scenario

In *Table 3* the results of the six cases are summarized. The first number in each cell in *Table 3* is the value of the sink when *Method 1* is used and the second number is derived from using *Method 2*, the two methods were described above in section 4.

Table 3. ***Value of sink in billion SEK (10^9 SEK) with original reference scenario.***

Sink size, Mt	No trade	30 USD	6 USD
2	1.1/1.2	0.77/0.86	0.54/0.62
15	4.5/4.5	3.9/3.9	2.7/2.6

When rounding off to two significant digits, the mean value of a 2 Mt sink is 1.2 billion SEK when no trading is allowed. And when trading at at price of 30 USD is allowed the value decreases to around 0.82 billions, compared with the no trade case. Trading at a price of 6 USD makes the value of the sink decrease to somewhere around 0.58 billion SEK. In the same way, a 15 Mt sink is worth 4.5 billion SEK while a 30 USD price lower the value to 3.9 billion SEK, and finally, a 6 USD price makes the sink worth 2.7 billion SEK.

So the possibility to trade emission permits for 30 USD lower the value of the sink in the 2 Mt case with 29 % in comparison with the no trade case.[3] In the same way, the possibility to trade at 6 USD lower the value with 50 %, compared with the no trade case.

In the same way as above the possibility to trade at 30 USD lower a 15 Mt sinks value with 13 %. And a price of 6 USD lower the 15 Mt sinks value with 41 %.

[3] 1.15-0.815=0.335; 0.0335/1.15=0,291

5.2 Results from calculations with reference scenario 66.831 Mt CO_2

In this part another reference scenario with a higher emissions forecast was calculated. The higher emissions are derived by taking the predicted increase from 1990 until 2010 from the study made by Carpos & Mantzos (2000). In their study, the Swedish CO_2 emissions in 1990 are slightly lower than NIERs scenario and the forecast is a 19.2 % increase until 2010. Using that forecast together with the same 1990 emissions (56.066 Mt) taken from NIER (2003), the forecasted emissions in 2010 will be 66.831 Mt CO_2 eqv. This value is about 4 Mt (4.037) higher than the reference scenario used in section 5.1. This new scenario with higher increase from 1990 until 2010 gives us a new reduction amount since the total emission target is the same in the two cases. The target at question is to reduce the 1990 level of emissions by 4 %. Besides the higher prediction everything else is assumed to be the same in the two cases. The following subsections show the value of the sink under different scenarios regarding trade, price and sink size.

In the same way as in section 5.1 above, the first number in each cell in *Table 4* is the value of the sink when *Method 1* is used and the second number is derived from using *Method 2*. Like in the original scenario, the numbers referring to the 2 Mt sink value are more uncertain than the numbers from the 15 Mt sink.

Table 4. ***Value of sink in billion SEK, reference scenario 66.831 Mt CO_2***

Sink size, Mt	No trade	30 USD	6 USD
2	1.5/1.7	1.0/1.1	0.76/0.86
15	7.1/7.1	5.6/5.6	4.0/4.0

The mean value of a 2 Mt sink is 1.6 billion SEK without emission trading. The mean value of the 2 Mt sink is 1.1 billion SEK when trading at a price of 30 USD is possible. And a price of 6 USD makes the sink worth 0.81 billion SEK. Furthermore, a 15 Mt sink is worth 7.1 billion SEK when no trading occurs. The possibility to trade at 30 USD makes the sink worth 5.6 billion SEK while a price of 6 USD makes the sink worth 4.0 billion SEK.

The possibility to trade at 30 USD lowers the value of a 2 Mt sink with 34 %[4], compared with the no trade case. And when trading at a 6 USD price occurs the value decreases with 49 % compared with the no trade case.

Finally, compared to the no trade case, the value of a 15 Mt sink decreases with 21 % when the price of emission permits is 30 USD, and if the price of permits is 6 USD the sink value decreases with 44 %.

[4] 1.6-1.05=0.55; 0.55/1.6=0,34

6 Comparison of sink values in different cases

The question in the aim: "How much is the sequestration service provided by Swedish forest worth in year 2010?" is answered in *Table 5*. Values of the different sinks in the different cases and scenarios are shown in the different cells of *Table 5***Fel! Hittar inte referenskälla.**. As one might suspect, the value of the sink rises with increasing emission reduction and with higher prices on the EU market, and if trade is not possible the value rises even more. Again, it might be necessary to point out that the trade option studied here is probably the least costly method for Sweden to reach its reduction target. If permits bought in the trading sectors are not included as domestic emission reduction,. the value of the sink will increase along with the total cost for Sweden. This could for example happen if Sweden set a more ambitious target than demanded by international agreements. The difference in sink value between the trading and non-trading cases will then decrease. It is also important to remember that this is the value of the sink in one specific year, namely 2010.

Table 5. ***Sink values in billion SEK (10^9 SEK)***

Scenario	**Sink size**	**No trade**	**30 USD**	**6 USD**
Original(62.794 Mt)	2 Mt	1.1/1.2	0.77/0.86	0.54/0.62
	15 Mt	4.5/4.5	3.9/3.9	2.7/2.6
66.831 Mt	2 Mt	1.5/1.7	1.0/1.1	0.76/0.86
	15 Mt	7.1/7.1	5.6/5.6	4.0/4.0

How important the choice of reference scenario is can be seen when comparing each respective case from the original scenario with the higher emission scenario. The increase of just over 4 Mt raises the value of the sink considerably. For example, if we compare the value of the 15 Mt sink in the no trade case of both emission scenarios, we get 4.5 compared with 7.1, an increase with around 58 %. This considerable increase in sink value of just around 4 Mt increase in emission reduction is an effect of the fact that the MC curve gets steeper as emission reduction increases. Therefore, with increased total cost follows an increase in sink value.

Trading with emission permits has a major impact on the value of the sink, especially if prices are low. In the case with the 6 USD price, trade reduces the sink value to 55-60 % of the no trade value. With higher prices the sink value equals 80-85 % of the value of the no trade case.

Although the results are quite similar when comparing the two different methods used to calculate the sink value, there are uncertainties in the results. These are discussed in the next chapter.

7 Uncertainty regarding numbers and assumptions

When writing a thesis like this, a lot of decisions have to be made regarding which method to use and what assumtions that must be made. This section of the thesis tries to highligt how the result is affected by the assumptions and decisions. At first, some issues concerning the calculations are discussed and later issues about references and assumptions will follow. As in any thesis including aggregated analyses and data like MC curves concerning emission reduction, the results should overall not be looked upon as exact numbers, but rather give a hint on what the "real value" of the sink could be. NIER (2003, p 18) states that the knowledge of the MC curve is “far from extensive”.

As pointed out before, the quite rough graphical method used is the explanation to why this thesis uses a 2 Mt sink and not the exact number 2.13. The values of the 15 Mt sinks do not differ much between *Method 1* and *Method 2*. There is less than 1 % difference between the two numbers in all cases. The values of the 2 Mt sinks on the other hand show more variation, which is expected because small variations in absolute numbers give a large difference in percentage when small areas are measured. As mentioned before, it is the thickness of the curves themselves that affects the result more when the curves’ area is relatively large compared to the examined area (*A* and/or *B*) in the figures. One interesting aspect is that the 2 Mt sink cases also show larger absolute variations between the two methods compared to the corresponding 15 Mt case. This is probably connected to the graphical method that was used in the calculations.

One more thing that could affect the value of the sink is the question of what should be included in a model reference scenario. In this case, it is the question whether taxes should be seen only as a source of income for the government or if they should be regarded as a way to maneuver the economy into a different path when choosing to tax one activity/good and therefore making other activities/goods relatively cheaper. For this thesis, the uncertainty pertains to how large share of the CO_2 tax that is fiscally motivated and how large share that is imposed for environmental reasons. Carlen (2004) claims that all tax costs associated with emission reduction is not included in NIER’s study (2003). Carlen claims that some of the costs are hidden in the reference scenario, as the taxes assumed in the reference scenario are not just fiscally motivated. This kind of claim raises costs for achieving emission reduction goals and therefore also increases the value of the sink. Carlen claims that up to 20 % of the cost for achieving the emission target is “hidden” in the reference scenario. If some part of the CO_2 taxes in the reference scenario is fiscally and not environmentally motivated, the “hidden” percentage decreases.

As mentioned before, carbon sequestrated in biomass may not stay away from the atmosphere forever. Trees, for example, die naturally after some time if not felled before. If trees credited as a carbon sink are harvested or die naturally, then other biomass must take its place as a sink to ensure that the CO_2 stays away from the atmosphere. Since 2.13 Mt is the amount that Sweden could credit as a sink in the Kyoto protocol, sink sizes larger than that must be included in some kind of national emission right system. So if Sweden on their own would credit the 15 Mt sink as emission reduction then the value is more uncertain than the 2 Mt sink.

The fluctuation in currency exchange rates is also a source of unceratinty. The prices in NIER’s study are specified in USD, at the rate 10.3 SEK/USD (NIER 2003, p 15). As shown by *Figure 10.* the Swedish crown has grown stronger towards the US dollar during 2002-2008 but in late 2008 and 2009 the dollar has grown stronger. (Internet, Riksbanken a). Since lower prices on emission permits decrease the value of the carbon sink this will lower the value of the sink and vice versa.

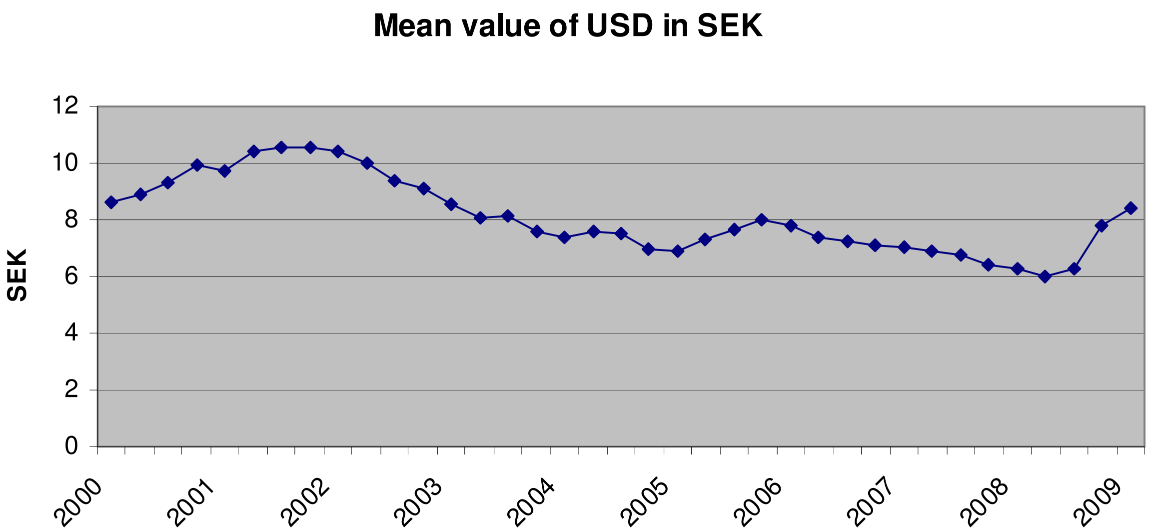

Figure 10. Exchange rate of USD in SEK. Mean value every quarter 2000-2009 (March). (Internet, Riksbanken a).

One more thing that could affect the carbon sink value is the price of permits. Alberola et al (2008) identifies mechanisms behind price changes in the emission trading market. The price fall in April 2006 occurred due to news that more permits than the amount in a "business as usual scenario" had been distributed among the countries participating in the European emission trading. Since then, prices on the spot market have fallen almost to zero, but the market for future emission permits show a higher price because of hints from the EU that distribution in future periods will not be as genereous as before.

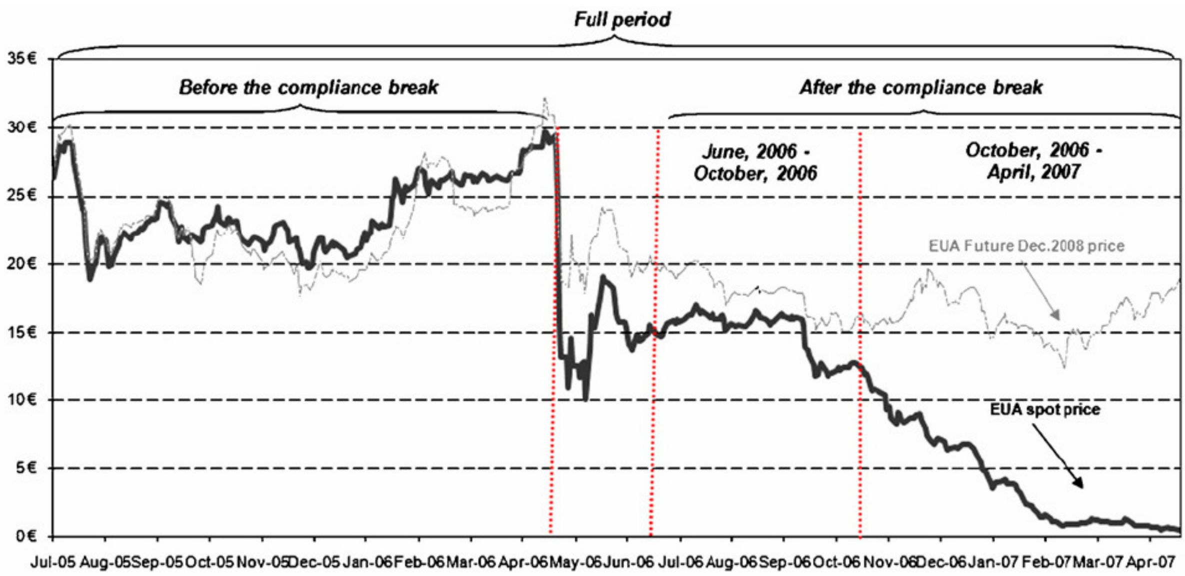

Figure 11. Spot prices and Future prices on the EU market. Alberola et al (2008), p 788.

At the time of writing this thesis (2009-05-07), the permit prices of 30 USD and 6 USD that is used in NIER's (2003) calculations seem to correspond to about 22 Euro and 4.5 Euro (Internet, Xe a). The price span NIER uses seems to be quite reasonable since the graph of future prices lies between 23 and 4.7 euro. If the anticipations regarding prices that is revealed in the "Future price curve" above prove to be correct, then NIER´s prices are a good estimation of coming permit prices.

8 Conclusions

The estimated value of the carbon sink in the Swedish forest ranges from 2.6 to 7.1 billions/year for a 15 Mt sink. For a 2 Mt sink the value is between 0.54 and 1.7 billions/year. The study has shown that there are a lot of factors that affect the value of the sink, some are easy to estimate and quite obvious, others are much harder to estimate. Below is a list of factors that decrease and increase the value of the Swedish sink in 2010. Often one factor, such as the price of permits, can both decrease and increase the value. Higher prices on the emission rights market increase the value of the sink and lower prices decrease the value of the sink. The following is an overview of the factors that affect the value of the sink:

Increases the sink value:	**Decreases the sink value:**
Higher reduction targets	Lower reduction targets
Larger sink	Smaller sink
Higher price on permits	Lower price on permits
Weaker Swedish currency vs USD	Stronger Swedish currency vs USD
	Trading possibility

Carbon sinks on forest land will not stop global warming. But they will delay the release of CO_2 for a while which may be beneficial. This is based on a belief that knowledge about global warming probably will increase over time and therefore it may be cheaper to store some of the emissions and deal with emission reduction later, when the increase in knowledge results in better technology which makes emission reduction cheaper. But if the increase in greenhouse gas concentration is to be halted, the usage of carbon sinks must be combined with reductions of CO_2 emissions.

An interesting idea for further research could be to value the carbon sink and include all interacting effects from emission reduction, and thus get a more complete view of how the emission reduction affects the economy. Another study could also include different assumptions about reference scenarios and how large share of the emission tax that is environmentally motivated and how large share that is fiscally motivated. Finally and perhaps most important, further research could examine emission reduction scenarios with other years than 2010 as the examined year.

References

Literature and publications

Alberola, E., Chevallier J., Chèze B., 2008. *Price drivers and structural breaks in European carbon prices 2005–2007.* Energy Policy 36 (2008) 787–797.

Boström, B. 2003. Kyotoprotokollet styr kampen mot klimatförändringar. *Miljötrender, 3, 5.*

Capros, P. & Mantzos, L., 2000. *The Economic Effects of EU-Wide Industry-Level Emission Trading to Reduce Greenhouse Gases – Results from PRIMES Energy Systems Model.* Institute of Communication and Computer Systems of National Technical Unviversity of Athens

Carlen, B., 2004. *BNP-effekter av svensk klimatpolitik - en kommentar.*
ITPS: Institutet för tillväxtpolitiska studier, Östersund. (ISSN 1652-0483)

IPCC, 2007. *"Climate change 2007 –Synthesis report".*

Johansson, M-B. 2003. *"Så kan skogsbruket motverka klimatförändringar.*" Miljötrender, 3, 12-15.

Lindholm, E-L & Berg, S., 2002. *SkogsForsk - Resultat nr 13 2002: Skog, skogsprodukter, kol och politik.* ISSN: 1103-4173

LUSTRA, 2006. *LUSTRA årsrapport 2005.* SLU/Repro, Uppsala (ISBN: 91-576-6891-4) (Available at: http://www-lustra.slu.se/rappotermm/pdf/2005.pdf)

LUSTRA, 2008. *Kolet, klimatet och skogen – Så kan skogsbruket påverka.* SLU/Repro, Uppsala (ISBN: 978-91-85911-16-5)
(Available at:
http://www.mistra.org/download/18.61632b5e117dec92f47800041300/LUSTRAS%C3%A5KanSkogsbruketP%C3%A5verka2008.pdf)

National Institute of Economic Research, (Konjunkturinstitutet), 2003. *Economic Effects for Sweden of Limited Carbon Dioxide*
Emission Trade within EU. (ISBN: 91-618-1186-6)

Naturvårdsverket, 2003. *Begränsad klimatpåverkan - Underlagsrapport till fördjupad utvärdering av miljömålsarbetet.* Rapport 5316 (ISBN 91-620-5316-7.pdf)

Naturvårdsverket, 2005. EU: Utsläppsmål sätter press på "handlande sektorn". *Klimataktuellt, 4* (Available at:http://www.naturvardsverket.se/Documents/publikationer/620-8217-5.pdf)

Perman, R., Ma,. Y., McGilvray, J., Common, M.,. 2003. *Natural Resource and Environmental Economics.* Pearson Education

Stavins, R., N. & Richards, K. 2005. *The cost of U.S. forest-based carbon sequestration. Pew Center on Global Climate Change.* (Available at: http://www.pewclimate.org /docUploads/Sequest%5FFinal%2Epdf=)

Internet

EEA, European Environment Agency, http://www.eea.europa.eu

a. Carbon sink, 2009-03-31
http://glossary.eea.europa.eu/EEAGlossary/C/carbon_sink

Encyclopedia Critannica – The Online Encyclopedia, http://www.britannica.com

a. Global warming, 2009-03-31
http://www.britannica.com/eb/article-9037044/global-warming

European comission, http://ec.europa.eu/index_en.htm

a. Emission Trading Scheme, 2009-03-31
http://ec.europa.eu/environment/climat/emission.htm

Google, Google search engine, http://www.google.com

a. "Global warming", 2009-03-31
http://www.google.se/search?hl=sv&q=%22global+warming%22&btnG=S%C3%B6k&meta=

Riksbanken, (The Riksbank), http://www.riksbanken.se/

a. Currencies against Swedish kronor, 2009-03-31
http://swea.riksbank.se/sweavr/avanceradSokning.do?group.egenskapid=1&sprakid=sv

Riksskogstaxeringen, (The Swedish National Forest Inventory), http://www-riksskogstaxeringen.slu.se

a. Årlig tillväxt avgång och avverkning,
(Annual growth, drain and felling), 2008-10-23
http://www-riksskogstaxeringen.slu.se/Resultat/Figurer/TvA.pdf

b. Totalt virkesförråd, (Standing volume), 2008-10-23
http://www-riksskogstaxeringen.slu.se/Resultat/Figurer/VF_26-.pdf

UNFCCC, United Nations Framework Convention on Climate Change, http://unfccc.int/

a. Kyoto protocol, 2009-03-31
http://unfccc.int/kyoto_protocol/items/2830.php

b. Countries included in Annex B to the Kyoto Protocol and their emissions targets, 2009-03-31
http://unfccc.int/kyoto_protocol/background/items/3145.php

c. Kyoto Protocol, 2009-03-31

http://unfccc.int/kyoto_protocol/items/2830.php

Xe, http://www.xe.com

a. http://www.xe.com/ucc/convert.cgi, 2009-05-07

Appendix 1

The carbon cycle

The carbon on earth is a constant amount and is constantly moving around, at least if you look over infinite time. *Figure 12* from Stavins & Richards (2005) below shows the global carbon cycle in Giga Tonnes (metric) per year. The numbers indicate an increase in atmospheric carbon (CO_2) concentration. But they also indicate one increasing pool on land (1.2 Gt/year) and one larger in the oceans (2 Gt/year). If the change in land use had not been, the land sink would have been larger.

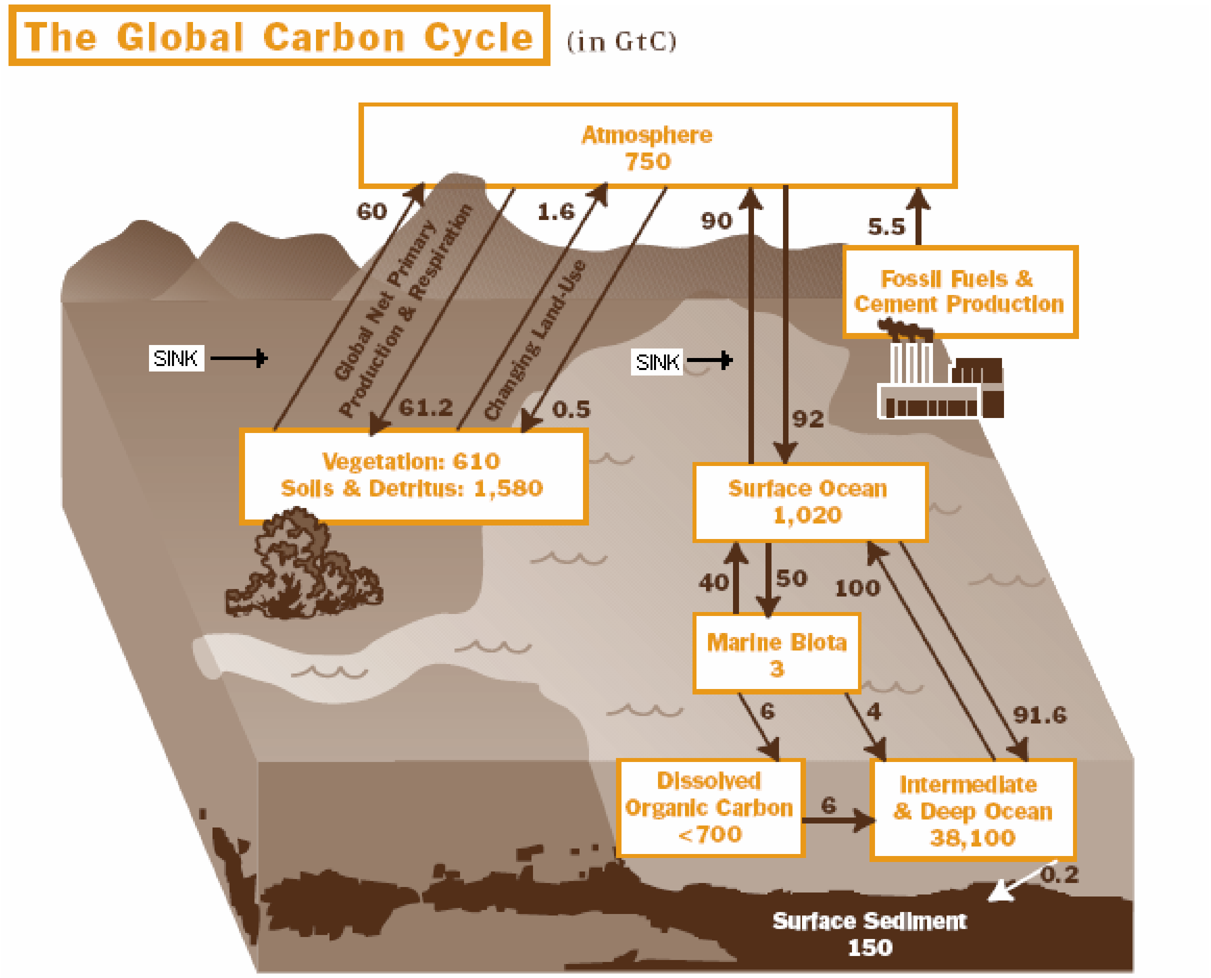

Figure 12. ***The global carbon cycle with sinks, (own version according to Stavins & Richards, 2005, 1)***

In *Figure 13* from Boström (2003), the different annual sources and sinks are shown in a diagram. The lines at the edges indicate the bias. As we can see, especially the size of the land sink is very uncertain. So perhaps the exact numbers in *Figure 12* above should be viewed with that in mind.

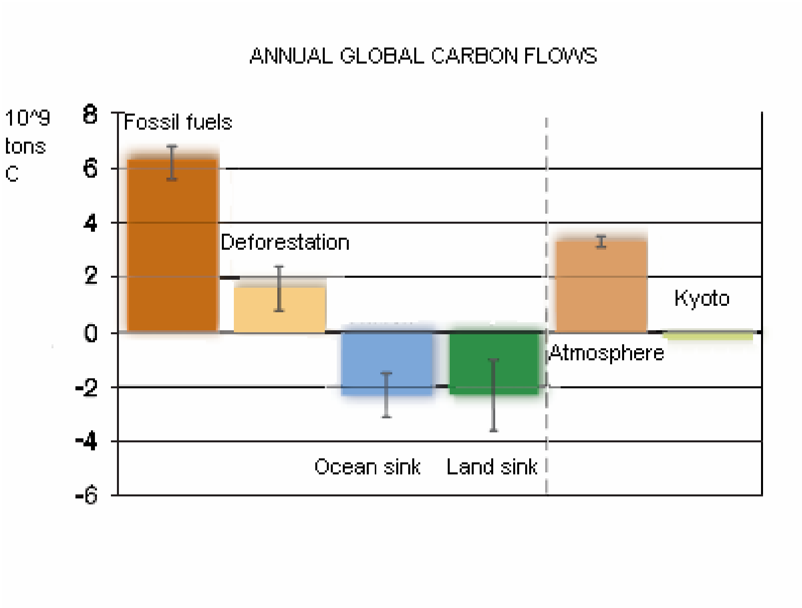

Figure 13. ***Annual global carbon flow. Translated from Boström, (2003, 5)***

The column "Atmosphere" to the right of the broken line indicates the net addition from all sources to the atmosphere every year, the one to the far right shows how large the reduction from the Kyoto commitment would be, which is about 250 Mt/year (ibid).

Appendix 2

Calculations with original reference scenario

5.1.1 Value of 15 Mt sink without trade

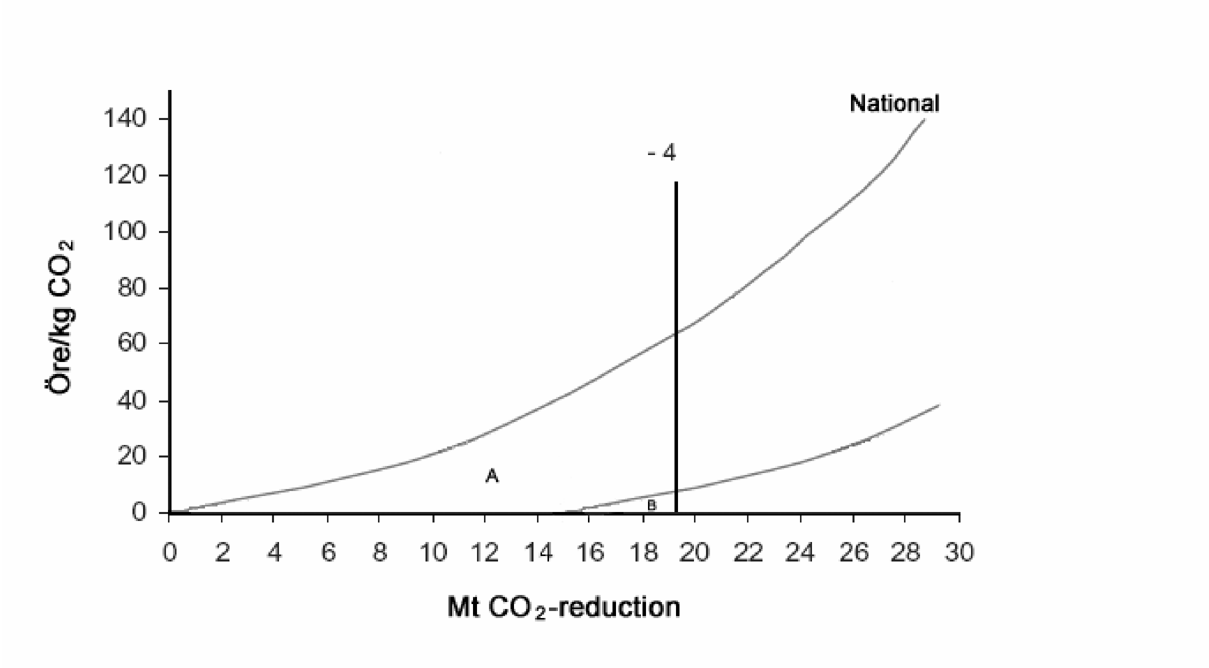

Figure 14. ***15 Mt sink, no trade, original ref. scenario.***

This following example from *Figure 14* above illustrates how the sink value is derived, all calculations under the different scenarios and cases follow the same practice. The number of area units (au) is first measured with a computer graphics program with *Method 1* and *Method 2*. Then the two areas are multiplied with the value per area unit, 422 764 SEK, to derive the value of the sink.

10 681 au with method 1 and 10 655 (11 017-362) with method 2. ⇒
10 681*422 764=4 515 542 284 is the value of the sink when using *Method 1*.
10 655 au*422 764 SEK=4 504 550 420 is the value of the sink when using *Method 2*.

Cost without sink, A+B: 11 017 ⇒ 4 657 590 988
Cost with sink, B: 362 ⇒ 153 040 568

5.1.2 Value of 15 Mt sink with trade, high price

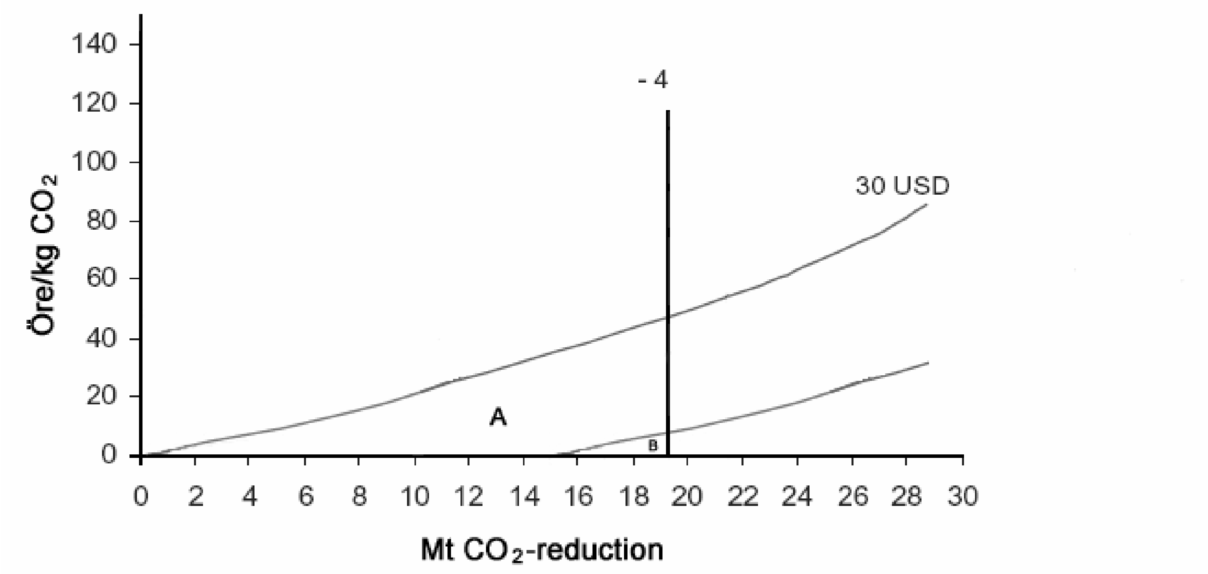

Figure 15. ***15 Mt sink, 3O USD, original ref. scenario.***

Sink value: 9 174 au / (9 588-356) = 9 232 au ⇒ 3 878 436 936/3 902 957 248
Cost without sink: 9 588 ⇒ 4 053 461 232
Cost with sink: 356 ⇒ 150 503 984

5.1.3 Value of 15 Mt sink with trade, low price

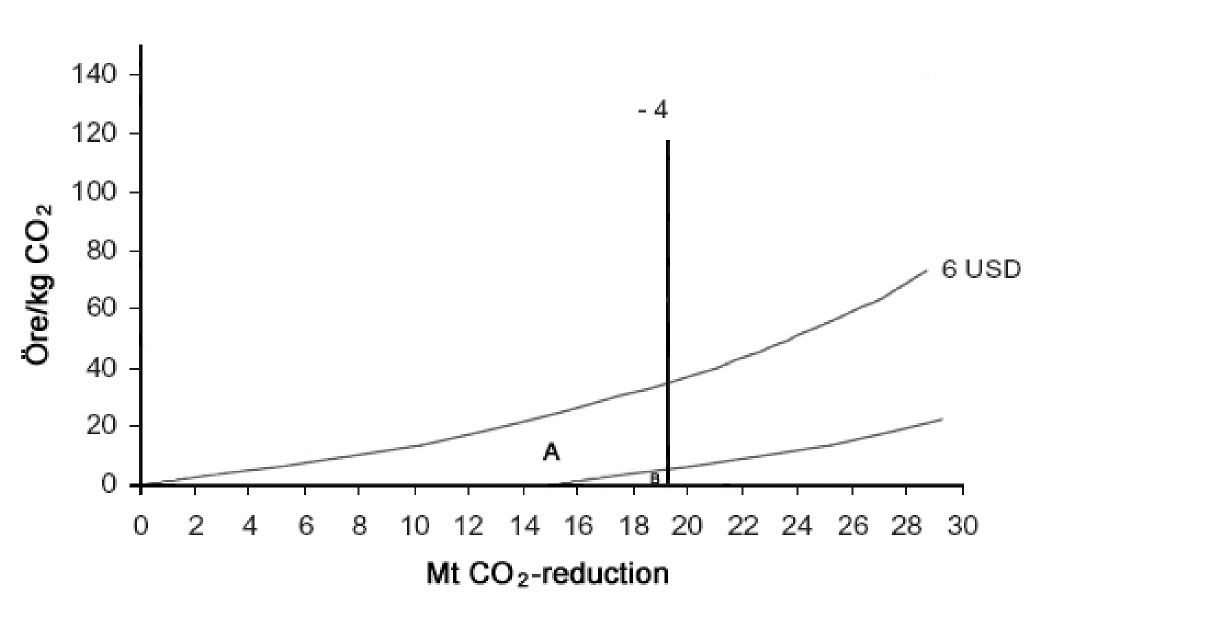

Figure 16. ***15 Mt sink, 6 USD, original ref. scenario.***

Sink value: 6 277 au / (6 496-245) = 6 251 au ⇒ 2 653 689 628/2 642 697 764
Cost without sink: 6 496 ⇒ 2 746 274 944
Cost with sink: 245⇒103 577 180

5.1.4 Value of 2 Mt sink without trade

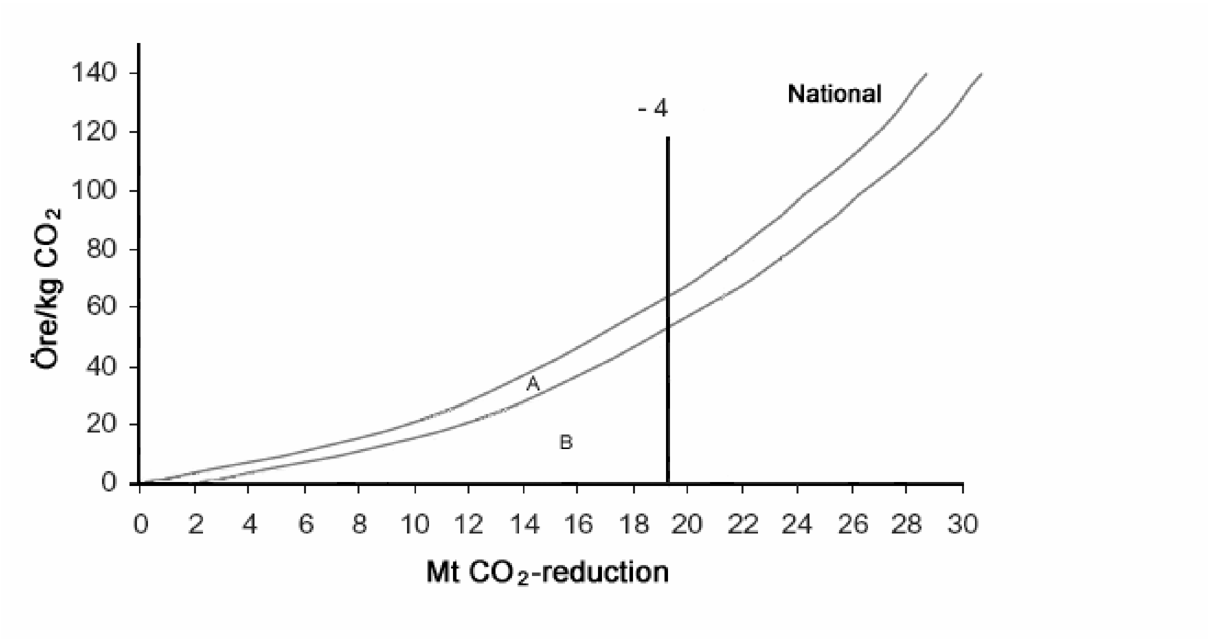

Figure 17. ***2 Mt sink, no trade, original ref. scenario.***

Sink value: 2 534 au / (11 016-8 242) = 2 774 au ⇒ 1 071 283 976/1 172 747 336
Cost without sink: 11 016 ⇒ 4 657 168 224
Cost with sink: 8 242 ⇒ 3 484 420 888

5.1.5 Value of 2 Mt sink with trade, high price

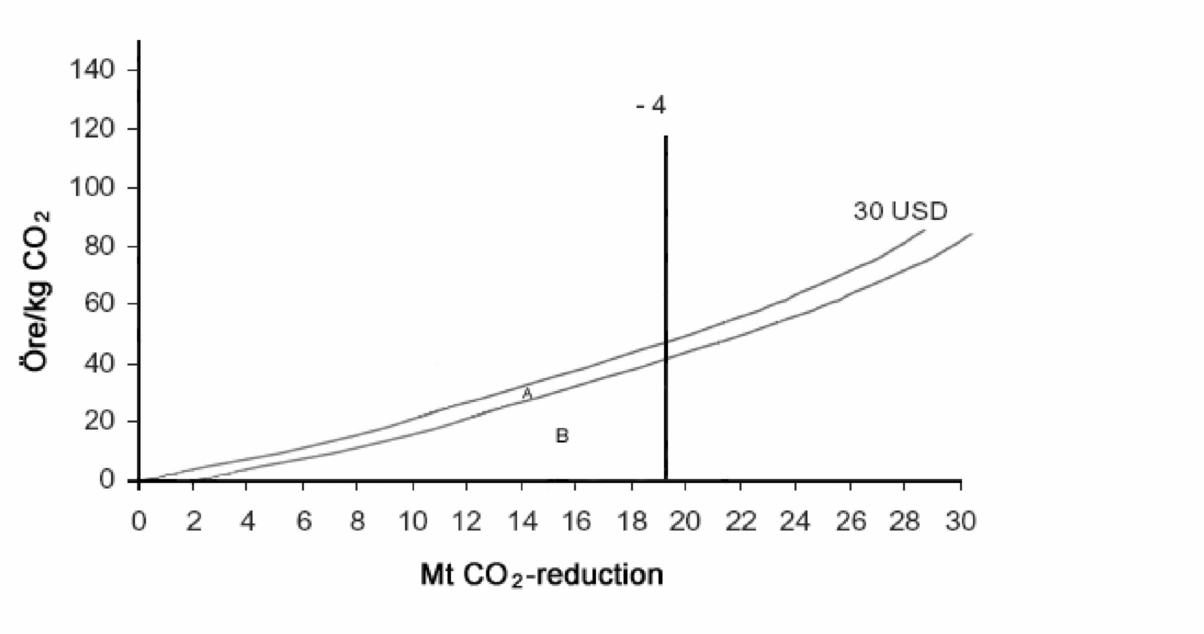

Figure 18*. 2 Mt sink, 30 USD, original ref. scenario.*

Sink value: 1 830 au / (9 544-7 516) = 2 028 au ⇒ 773 658 120/857 365 392
Cost without sink: 9 544 ⇒ 4 034 859 616
Cost with sink: 7 516 ⇒ 3 177 494 224

5.1.6 Value of 2 Mt sink with trade, low price

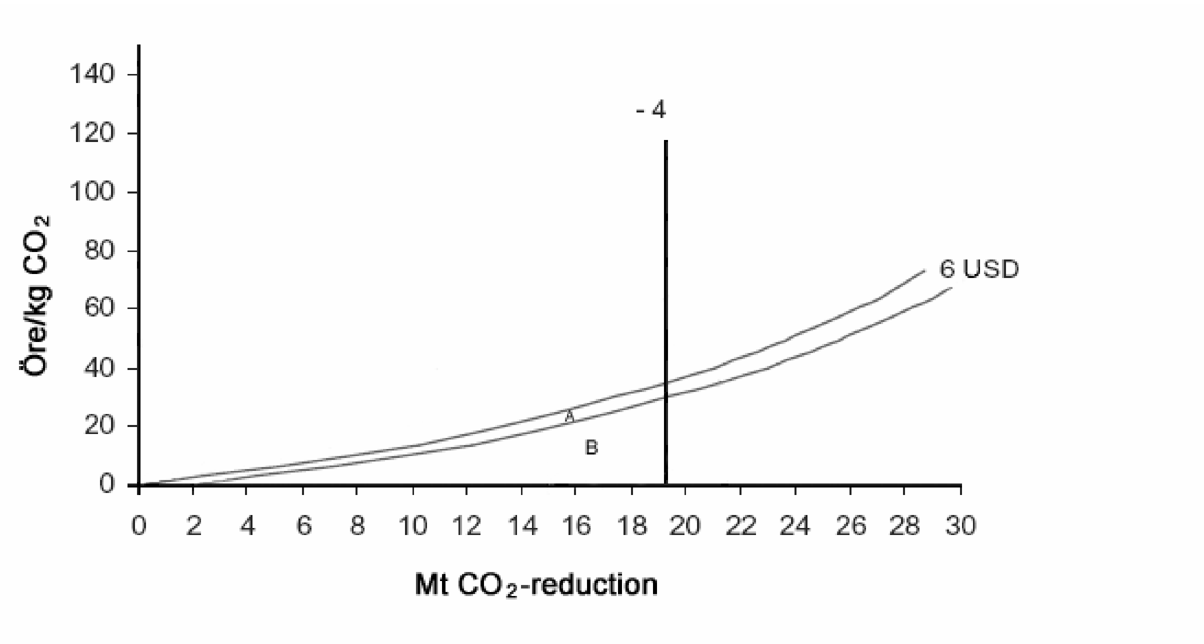

Figure 19*. 2 Mt sink, 6 USD, original ref. scenario.*

Sink value: 1 272 au / (6 490-5 019) = 1 471 au ⇒ 537 755 808/621 885 844

Cost without sink: 6 490 ⇒ 2 743 738 360
Cost with sink: 5 019 ⇒ 2 121 852 516

Calculations with 66.831 Mt reference scenario

5.2.1 Value of 15 Mt sink without trade, high emission scenario

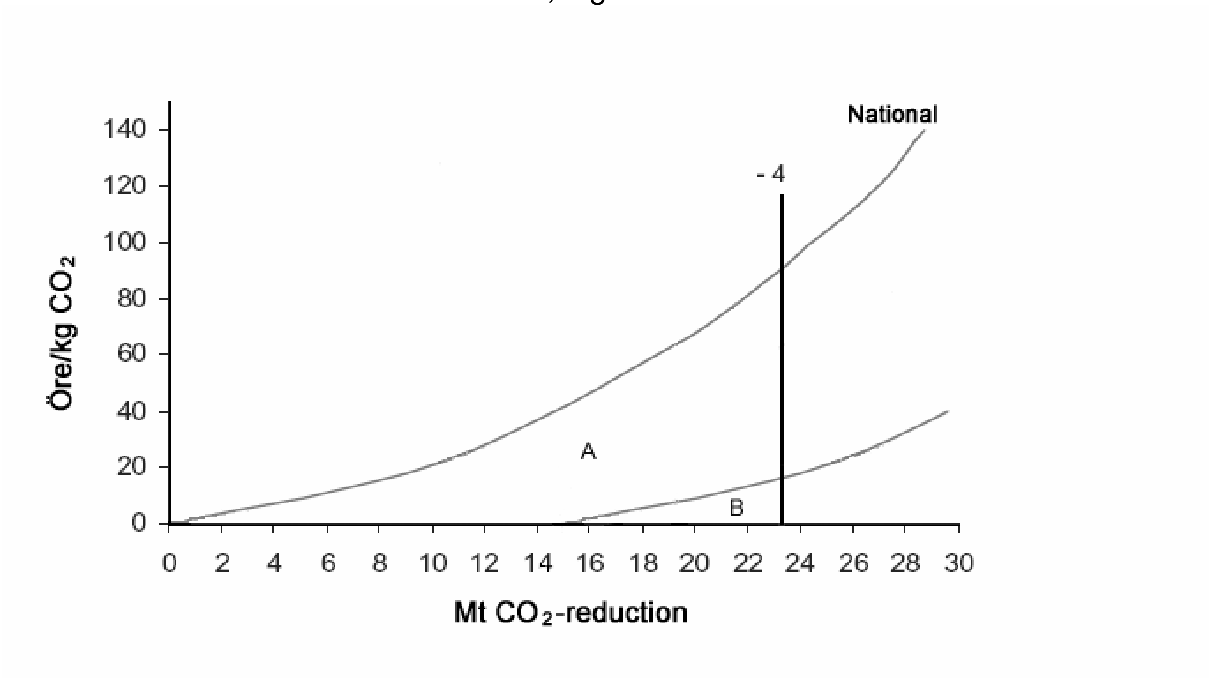

Figure 20*. 15 Mt sink, no trade, 66.831 Mt ref. scenario.*

Sink value: 16 887 au / (18 282-1 454) = 16 828 au ⇒ 7 139 215 668/7 114 272 592
Cost without sink, A+B: 18 282 ⇒ 7 728 971 448
Cost with sink, B: 1 454 ⇒ 614 698 856

5.2.2 Value of 15 Mt sink with trade, high price, high emission scenario

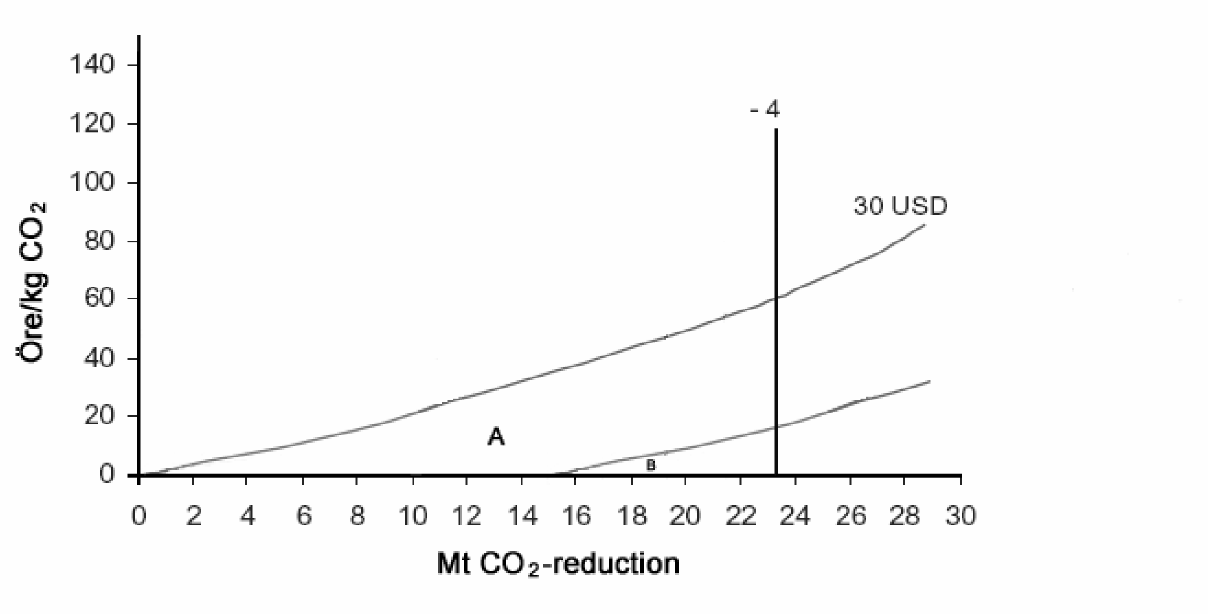

Figure 21. ***15 Mt sink, 30 USD, 66.831 Mt ref. scenario.***

Sink value: 13 228 au / (14 612-1 447) = 13 165 au ⇒ 5 592 322 192/5 565 688 060
Cost without sink: 14 612 ⇒ 6 177 427 568
Cost with sink: 1 447 ⇒ 611 739 508

5.2.3 Value of 15 Mt sink with trade, low price, high emission scenario

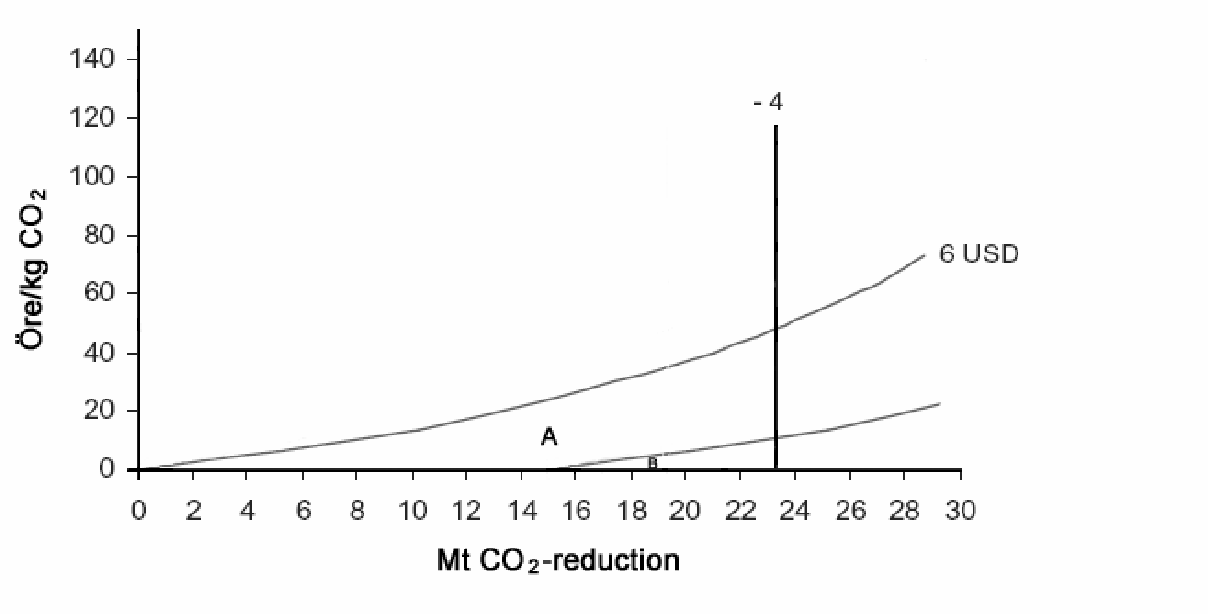

Figure 22. ***15 Mt sink, USD, 66.831 Mt ref. scenario.***

Sink value: 9 464 au / (10 381-969) = 9 412 au ⇒ 4 001 038 496/3 979 054 768
Cost without sink: 10 381 ⇒ 4 388 713 084
Cost with sink: 969 ⇒ 409 658 316

5.2.4 Value of 2 Mt sink, without trade, high emission scenario

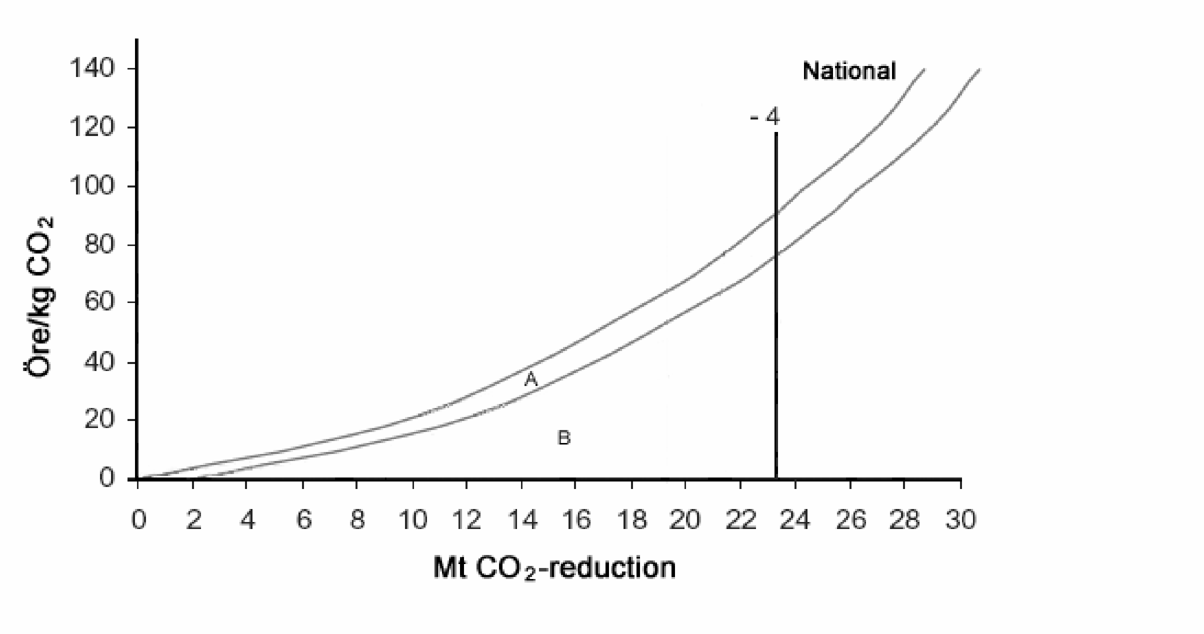

Figure 23. ***2 Mt sink, no trade, 66.831 Mt ref. scenario.***

Sink value: 3 650 au / (18 278-14 324) = 3 954 au ⇒ 1 543 088 600/1 671 608 856
Cost without sink: 18 278 ⇒ 7 727 280 392
Cost with sink: 14 324 ⇒ 6 055 671 536

5.2.5 Value of 2 Mt sink with trade, high price, high emission scenario

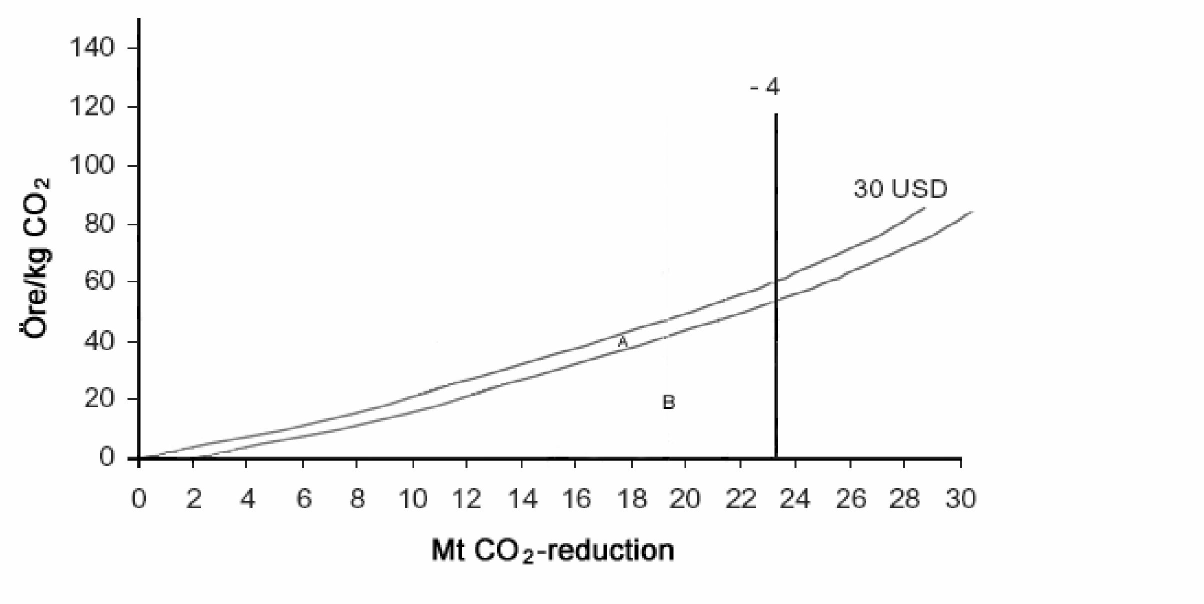

Figure 24. ***2 Mt sink, 30 USD, 66.831 Mt ref. scenario.***

Sink value: 2 355au / (14 620-12 010) = 2 610 au ⇒ 995 609 220/1 103 414 040
Cost without sink: 14 620 ⇒ 6 180 809 680
Cost with sink: 12 010 ⇒ 5 077 395 640

5.2.6 Value of 2 Mt sink with trade, low price, high emission scenario

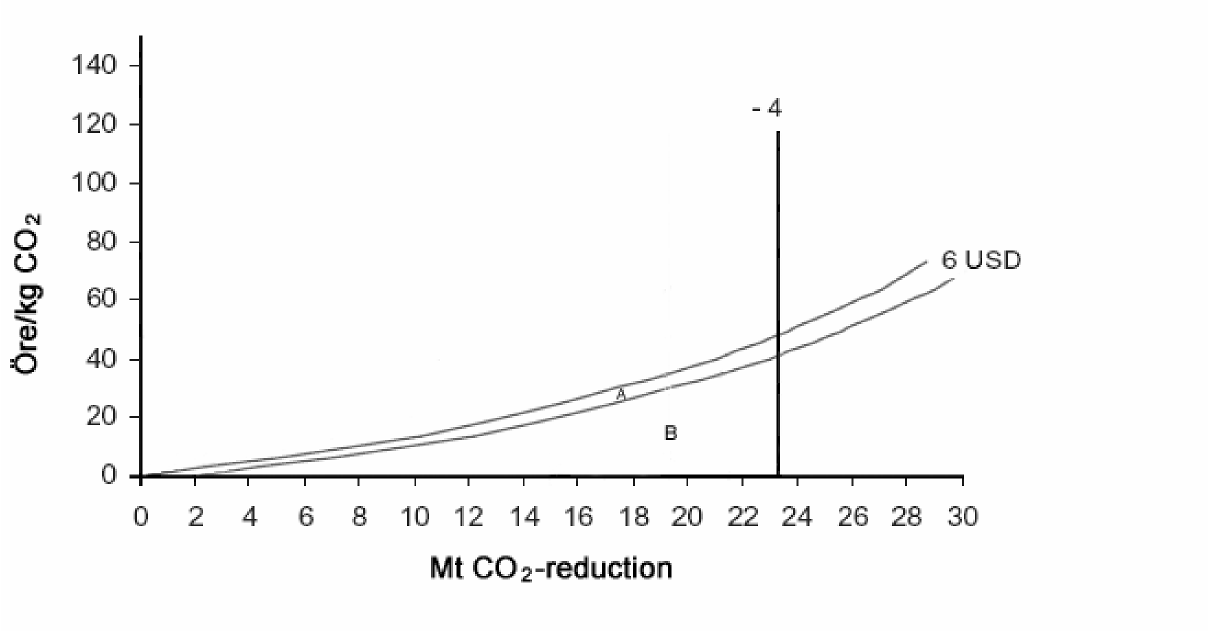

Figure 25. *2 Mt sink, 6 USD, 66.831 Mt ref. scenario.*

Sink value: 1 790 au / (10 374-8 334) = 2 040 au ⇒ 756 747 560/862 438 560
Cost without sink: 10 374 ⇒ 4 385 753 736
Cost with sink: 8 334 ⇒ 3 523 315 176

Appendix 3:

Percentual variation in numbers

The following tables are a complement to section 6.2 "Uncertainty regarding numbers". They show the percentual variation between the two ways of calculating the sink value.

Table 6. *Value of sink in billion SEK (10^9 SEK) and percentual difference between numbers*

Sink size, Mt	No trade	30 USD	6 USD
2	1.071283976/1.172747336 9.5%	0.77365812/0.857365392 11%	0.537755808/0.621885844 16%
15	4.515542284/4.50455042 0.24%	3.878436936/3.902957248 0.63%	2.653689628/2.642697764 0.42%

Table 7. ***Sink value change when trade is introduced, share of value with no trade case and percentual difference between numbers***

Sink size, Mt	30 USD	6 USD
2	0.6596971881/0.80031570 21%	0.45854361932/0.53028118 16%
15	0.8589083419/0.86644767 0.87%	0.58524482726/0.58911309 0.66%

Table 8. ***Value of the sink in billion SEK (10^9 SEK), reference scenario 66.831 Mt CO_2 and percentual difference between numbers***

Sink size, Mt	No trade	30 USD	6 USD
2	1.5430886/1.671608856 8%	0.99560922/1.10341404 11%	0.75674756/0.86243856 14%
15	7.139215668/7.114272592 0.35%	5.592322192/5.56568806 0.49%	4.001038496/3.979054768 0.55%

Table 9. ***Sink value change when trade is introduced, share of value with no trade case, reference scenario 66.831 Mt CO_2, lowest share/highest share, and percentual difference between numbers***

Sink size, Mt	30 USD	6 USD
2	0.5955993930/0.7150687 20%	0.4527061203/0.5589041095 23%
15	0.779593770/0.786070821 0.83%	0.5573518090/0.5623957435 0.90%

Pris: 100:- (exkl moms)

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