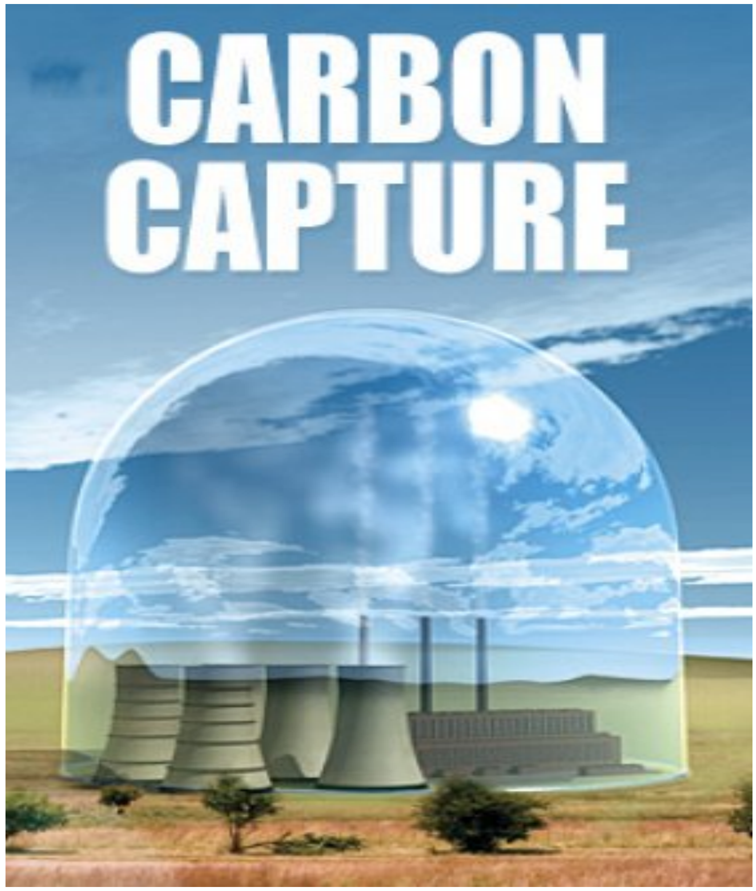

The Rotterdam Climate Initiative: Carbon, Capture & Solved?

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Executive summary

The RCI focuses on the ambition to reduce the CO_2 emissions in the Rotterdam area to 12 Mton in 2025, while ensuring and increasing economic growth. The 12 Mton is based on a 50 per cent reduction of 1990 emissions. To calculate the CO_2 emissions the source or local attribution is chosen.
This ambition is largely dependent on carbon capture and storage (CCS). The RCI aims at developing a CCS hub in the Rotterdam port to facilitate their demand for CCS and to serve the market. By serving the market the CCS hub can ensure and increase economic growth for the Rotterdam area.

The weakest point in the RCI is the lack of development of CO_2 capturing capacity. CO_2 transport and storage are developed following the capturing of CO_2. The storage fields currently developed will not last very long after 2025, but there are enough other storage locations available. The capturing of CO_2 is the real problem. Only the ROAD project will be realised in time, leading to a realistic forecast of 3.25 Mton annual capturing capacity. In the most optimistic scenario the current developed projects lead to a maximum capturing capacity of 5.75 Mton annually. For the RCI goal of 17.5 Mton CO_2 should be captured and stored on a yearly bases. The importation of CO_2, displayed in some RCI studies, does not fulfil the need of local attribution and therefore should not be part of the calculation.

The low prices on the CO_2 allowances market, the EU ETS market, make the marginal benefits of CO_2 emission mitigation low. The marginal benefits of CO_2 emission mitigation would reflect the marginal costs of CO_2 emissions for society in an optimal market situation. Although there is little consensus among scholars on the costs of CO_2 emissions, literature shows that these costs are substantial. The discount rate is of large influence on these costs. Although the choice is arbitrary this thesis and some recent papers show that a low discount rate is economically and morally desirable. This would make the costs of CO_2 emissions much higher than the costs of CO_2 mitigation options.

This thesis concludes that the RCI will almost certainly fail to fulfil its ambitions in terms of CO_2 emissions. On the other hand the potential for CCS in Rotterdam will become much bigger after successful demonstration projects like ROAD. They will show the possibility and create infrastructure where other, future, projects can benefit from. When, or if, the CO_2 emissions prices then are set at a level reflecting the marginal societal costs by international politics the port of Rotterdam can reap the benefits of the RCI. As is felt by the author and the interviewees and is reflected by literature doing nothing is far more expensive than investing now to solve the problem.

Preface

The struggle between economic development and sustainability has been a topic of interest for the last decade, also for me. The RCI gave me a possibility to combine this with the Port of Rotterdam, which attracted my attention during my bachelor studies. Resulting in the choice for the master UPTE at the Erasmus University and the RCI as topic for my thesis. Especially the 'soft approach' of sustainability in a hands-on, polluting environment as the Port of Rotterdam attracted my attention.

I would like to thank my thesis supervisor dr. Bart Kuipers and co-reader of my thesis prof. dr. Harry Geerlings, who participated from the beginning of the writing process of this thesis. I really appreciated the meetings and the useful input that I could gather at them. They gave me new insights into the problem and pointed out the way to solve some of the problems encountered in this thesis.

The interviewees were an important source of information; their expertise gave new insights and showed other insights to be useless. I would like to thank them sincerely for making time for me in their stuffed agenda's. I really enjoyed the conservations and they were very useful for understanding and analysing the problem.

A big thanks goes to my partner, parents and brother for all their support during my studies. Their continuous support helped me to both do my studies and enjoy the student life.

A special thanks goes to all the people who supported me during this master. Personal circumstances took the focus away from studying during this master. The help and support fellow classmates, friends, relatives and acquaintances were overwhelming and made it possible for me to finish my studies.

List of abbreviations

CCI	Clinton Climate Initiative
CHF-23	Fluoroform (CHF_3)
Cintra	Carbon in transport
DCMR	Dienst Centraal Milieubeheer Rijnmond
DEF	Deltalinqs Energy Forum
ETS	European Trading scheme
EOR	Enhanced Oil Recovery
EU	European Union
GHG	Green House Gas
Gton	Gross ton
HIC	Haven Industrieel Complex – Harbor Industrial Complex
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
Kton	Kiloton
Lowex	Low Exergetic
LPG	Liquefied Petroleum Gas
MB	Marginal Benefit
MC	Marginal Cost
Mton	Megaton
MTA	Mton annual
NAP	National Allocation Plan
NOGEPA	Nederlandse Olie en Gas Exploratie en Productie Associatie
OCAP	Organic Carbondioxide for Assimilation of Plants
PoR	Port of Rotterdam
R3CP	Rotterdam CO_2 Common Carrier Pipeline
REAP	Rotterdamse Energie Aanpak
RCI	Rotterdam Climate Initiative
VAT	Value Added Tax
UNFCCC	United Nations Framework Convention on Climate Change
ZEPP	Zero Emission Power Plant

Table of content

1. Introduction

1.1 Background

Over the last decades the world got more interested in sustainable development and the effects of the increasing energy consumption. The film ‘ An Inconvenient Truth’ made by Al Gore in 2006 fuelled this debate and brought CO_2 reduction to the agenda of politicians and citizens. A year earlier former U.S. President Clinton had launched the `Clinton Climate Initiative` (CCI), which benefitted from the publicity of Al Gore’s movie. In the CCI cities are considered promoters and catalysts of sustainable development. This led to an agreement between 40 cities to cooperate with the aim to reduce CO_2 emissions. The idea behind the program is to encourage national, regional and municipal governments to follow the example of the leading, climate friendly, cities. The city of Rotterdam wants to play a leading role in the process of climate impact reduction and climate change adaptation. This ambition of Rotterdam led, together with the visit of former U.S. president Clinton to Rotterdam, to the voluntary adaptation of the CCI. In the goals of the city of Rotterdam green factors and CO_2 emission goals are key assets, which has been formalized in the Rotterdam Climate Initiative (RCI). Green factors of the RCI focus on improving the living climate in Rotterdam; examples are noise reduction and the construction of more green areas like parks. The Port of Rotterdam has committed itself to the Rotterdam Climate Initiative together with the municipality of Rotterdam, DCMR Milieudienst Rijnmond and Deltalinqs (the lobby group of the logistical and industrial companies in the Rotterdam port and industry area). This must lead to 50% less CO_2 emissions in 2025 compared to 1990 in the Rotterdam municipal land (RCI, 2007).

1.2 Relevance

In the Netherlands a lot of money is invested in promoting greener technologies for cars, industry and energy consumption. The Rotterdam city council invested 31 million euro between 2007 en 2010 in the RCI, aiming at the attraction of another 319 million euro in investments for the RCI in this period. The Rotterdam area can be considered as a large polluter in The Netherlands, because about 25% of CO_2 pollution in The Netherlands originates from the Rotterdam area (RCI, 2011). Therefor it is logical that politicians like to pay attention to this area. In total, the costs of goals formulated for national sustainability by the Dutch government were estimated between 3 and 9 billion euro a year in 2020 (Energieportal.nl, 2007). So although the Rotterdam area is a large contributor to pollution and CO_2 emission, a relatively small portion of the budget is invested in Rotterdam.

Energy consumption, waste energy and pollution have become topics of interest the last decades. Not only in car usage and housing these topics are relevant, but also in industry and transport the energy consumption and pollution are becoming more important (Sims, 2003). The nature of industry, especially the power generation industry, makes it a logical target for greenhouse gas (GHG) mitigation, because of a limited number of centralised, large greenhouse gas emitters.
A striking figure is that in the Rotterdam area over 85% of CO_2 emission is industry related (RCI, 2011), this is over 20% of the total national CO_2 emission. The CO_2 emission of the (Rotterdam) industry is relatively under presented in policy measures and levies aiming at reducing the global footprint of The Netherlands (Battjes, 2000). The industry therefore has still options for cost-efficient ways to realise the national targets for renewables and the reduction of GHG emissions.

Like every port, the Port of Rotterdam is operating in the society it is serving, which means that ports can be considered as nodes of energy consumption and pollution; due to the transport activities and the port related industries. Perhaps becoming more durable is even more important for the Port of Rotterdam than for most ports, since among the lists of most polluting places in the world Rotterdam ranks top markings. In terms of CO_2 emissions per capita Rotterdam is even the highest ranked city in the world (Hoornweg, 2011). The Netherlands is forced to reduce greenhouse gas emissions with 20 per cent by EU regulation. This led the municipality of Rotterdam to join the Rotterdam Climate Initiative to increase health among its citizens[1], fight the image of being a polluted area and reduce the emission of GHG. The Port of Rotterdam committed itself to the goals to cut CO_2 emissions in half. A supportive public opinion is very important for the presence of one of the largest seaports of the world in Rotterdam, close to densely populated city areas. Meeting the goals of the Rotterdam Climate Initiative can help to create a greener image of the Port of Rotterdam and it's industries.

[1] The ambition to increase the health among citizens is reflected by improving the quality of the living environment. The creation of more green areas and noise reduction from traffic are examples, CO_2 emissions don't have a direct impact on health. Therefore the health aspects of the RCI are no topic in this thesis.

1.3 Problem statement

The Port of Rotterdam committed itself to ambitious goals, both out of corporate governance and because of goals of the municipality of Rotterdam, the main shareholder of the Port of Rotterdam. These commitments are formulated in end-term goals. The way and the process to achieve the goals are not formulated in formal agreements, so the stakeholders[2] of the RCI have to develop policy to meet the goals formulated in The Rotterdam Climate Initiative.

This leads to the following research question:

Can the Port of Rotterdam realize the RCI ambition of reducing CO_2 emissions to 12 Mton in 2025?

This research question will be answered by using the following sub questions:

1. What is the Rotterdam Climate Initiative (RCI)?
2. What is 'Carbon, Capture and Storage' (CCS)?
3. How is CCS implemented in the RCI?
4. What are the economic consequences of CCS?
5. How realistic are the goals for the Port of Rotterdam of the Rotterdam Climate Initiative in a competitive market?

The port of Rotterdam is a competitive port in the port range Hamburg – Le Havre. Since the RCI is a local project the ambitions of the RCI can incur costs for business partners of the port of Rotterdam, costs that wouldn't occur when the business partners shift their operations to other ports. The fifth research question will look into how realistic the ambitions of the RCI are when there is competition with other ports, reflecting the competitive environment in which the Port of Rotterdam is operating.

1.4 Methodology

This thesis is divided in two parts; the first part gives a detailed elaboration of the RCI, CCS in general and the positioning of CCS in the RCI. In this part the ambitions of the RCI are displayed and limitations to the RCI are outlined. CCS is introduced and technical details needed for an understanding of the last parts are explained. The correlation between the

[2] Stakeholders are: Deltalinqs, the Port of Rotterdam, the municipality of Rotterdam and DCMR, see also paragraph 2.3.

RCI and CCS is recognised and there is reviewed who are the different actors and stakeholders. The main sources for this first part of the study are academic literature, articles and policy documents.

The second part of this thesis is based on a literature study on what has become known as carbon economies and environmental policy and competition. Environmental policy measures and therefore CO_2 have become industries on itself because of the involved capital streams and technology. In this part literature is combined with qualitative research.

In this thesis the choice for qualitative research is made on the basis that there are a limited amount of key stakeholders. The outcome of the RCI is largely dependant on the decisions and dedication of these stakeholders. A survey or other quantitative research, which often creates more robust findings, was not chosen because of the limited amount of key actors and the required detail in questions. The interviews give a chance to gain information about the (political) processes in the RCI, which goes beyond the official statements on the websites of the organizations.

The interviewees were chosen in a way that their interests reflect the relations in the port of Rotterdam. Multiple government actors and industrial actors were interviewed, reflecting the tension between government and industry interests in the RCI.

1.5 Outline of the thesis

This thesis contains seven chapters with subparagraphs. Chapter two is a detailed oversight of the RCI and the ambition it promotes. The third chapter is a literature review and explanation of carbon, capture and storage (CCS) and in the fourth chapter the role of CCS in the RCI is presented. Chapter five deals with carbon economies, to explain what the costs are of CO_2 emission into the atmosphere and explores legal and political issues. Chapter six gives an insight in economical policy and the consequences for competitiveness. Finally, in chapter seven conclusions are drawn.

2. The Rotterdam Climate Initiative

2.1 Introduction

In this chapter the Rotterdam (RCI) will be explained. In the second paragraph the ambitions of the RCI are presented and reviewed. In the next paragraph the stakeholders will be presented with their responsibility to the RCI ambition. The fourth paragraph will shortly introduce the three pillars the RCI focuses on to reach the goal to cut CO_2 emissions.

2.2 The ambition of the Rotterdam Climate Initiative (RCI)

The RCI has the ambition to reduce the CO_2 emission in the Rotterdam area by 50% in 2025, based on 1990 reference while ensuring and increasing economic growth.
To analyze this ambition of the RCI it is split in different parts. The first subparagraph deals with CO_2 and the greenhouse effect associated with green house gasses GHG. The second subparagraph looks at what is meant with the Rotterdam area in the RCI. Subparagraph three and four look at respectively the reference year 1990 and the year 2025. The last subparagraph deals with the 'while ensuring and increasing economic growth' part of the ambition.
This sub-division is chosen because each of this parts of the RCI ambition has different implications, of which some are not or poorly displayed on the website of the RCI.

2.2.1 CO_2 emission

There are multiple green house gasses responsible for the heating of the earth via the greenhouse effect. The greenhouse effect can be split into two types, natural and human caused effects. The effects of the two types are the same, the radiation of the sun travels through orbit to the earth, where it meets the earth's atmosphere, here part of the radiation is reflected, the rest is absorbed by the atmosphere or the earth's surface or reflected by the earth's surface. This causes the earth to heat up. Because the earth heats it starts to emit infrared radiation. This partly passing through the atmosphere and partly reflected back to the earth. This is

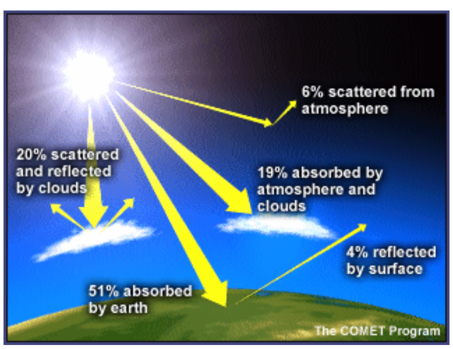


Figure 1 Greenhouse effect (UCAR, 2012)

the natural greenhouse effect of the earth, resulting in a climate favourable for life, as we know it. Figure 1 graphically shows this process. Because of human caused GHG emissions the amount of infrared radiation that passed from the earth's surface outwards to space is lower, causing extra heating up of our atmosphere. This is the greenhouse effect leading to global warming.

The most recent list of the IPCC gives 18 gases responsible for the heating of the earth (IPCC, 2007)[3]. Of this list CO_2 is the most important of human caused global warming gasses (Forster et al, 2007), because the impact of CO_2 is the largest of al GHG (Jansen et al, 2007).

CO_2 is an important gas on earth. It is part of the greenhouse effect, which gave earth a climate, which facilitates live as we know it. CO_2 is also important to facilitate the growth of vegetation. This process involves photosynthesis and follows the following reaction: $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$, where H_2O is water and O_2 is oxygen. Thus CO_2 and water become plants and oxygen with the energy of the sun in photosynthesis. This leads to a short and a long CO_2 cycle. In the short cycle the plants rot or are digested and the captured carbon is conversed again to CO_2. This cycle is of little influence towards the climate, although deforesting leads via this way to increased CO_2 levels.

In the long cycle the ecosystem fails to break down the vegetation material, often in a situation with a lack of CO_2. If the material gets locked in underground cavities the carbon is taken out of the short cycle, reducing CO_2 concentrations in the air. If these layers are pressurized, which often happens if ground layers form over the cavities the captured carbon can form, among other things, fossil fuels. Therefore fossil fuel resevoirs can also be regarded as storage sites of carbon. Because we harvest these fossil fuels and burn them to meet our energy needs the carbon is introduced into the short cycle again, in the form of $CO_{2.}$

An important note is that in the climate change debate air quality is also often used, however CO_2 is not considered in air quality (Leeuwen, 2000). The differentiation between gasses considered in air quality and GHG is important because the focus of the RCI and this thesis is climate change and not air quality. Air quality is more commonly used in the debate about health issues arising from air pollution, like for instance fine dust or chemicals. Global warming and thus GHG are also linked to health risks, but more in the sense that higher temperatures can be dangerous to ill and/or elderly people. This effect is beyond the scope of this thesis.

[3] The following GHG are listed by the IPCC: CO_2, CH_4, N_2O CFC-11, CFC-12, CFC-113, HCFC-22, HCFC-141b, HCFC-142b, CH_3CCl_3, $CCl_{4,}$ HFC-125, HFC-134a, HFC-152a, HFC-23, SF_6, CF_4 (PFC-14) and C_2F_6 (PFC-116) (IPCC, 2007).

There are two ways to calculate CO_2 emission for a region.

1. Source or local attribution. This means the amount of CO_2 that is exhausted in the area is calculated. For instance the total CO_2 exhaust of a power plant located in the Rotterdam area is attributed to Rotterdam, regardless of where the power is consumed.
2. User attribution. Here the CO_2 exhaust is attributed to the user. For instance the power used in Rotterdam by consumers or industries in Rotterdam is attributed to Rotterdam. In the previous example where a power plant is situated in the Rotterdam area, only the CO_2 exhaust for the electricity consumed in the Rotterdam area is attributed to the Rotterdam CO_2 exhaust. If the power is consumed elsewhere the CO_2 for the generation is attributed to the area where it is consumed.

In the 'Nulmeting uitstoot CO_2' the source or local attribution is chosen, because this is the national and international most used way of calculating and displaying the CO_2 exhaust for an area (Verhey, 2007). This way of calculation and displaying local CO_2 exhaust will also be used in this thesis. The 'Nulmeting CO_2 uitstoot' is described more detailed in paragraph 2.2.3 'The 1990 reference'. The setback of this way of calculating is that shifting polluting activities away from the local area to other, even neighbouring, area's will bring down CO_2 emission in the calculations, while there is of course no real (environmental) gain in this kind of policies. On the other hand because of this way of calculation the RCI stakeholders can be fully held responsible for the CO_2 emissions, without the possibility of blaming other, not RCI involved, parties of not cooperating. The outcome of the "Nulmeting uitstoot CO_2' is further displayed in paragraph 2.2.3.

2.2.2 The Rotterdam area

There is no definition of 'the Rotterdam area' to be found on the RCI website, giving room for two interpretations. The broader interpretation is used on the site of the municipality of Rotterdam, here 'The Rotterdam Area' is used for Rotterdam and it's 15 neighbouring municipalities (Rotterdam, 2009). This is also known as the 'Stadsregio

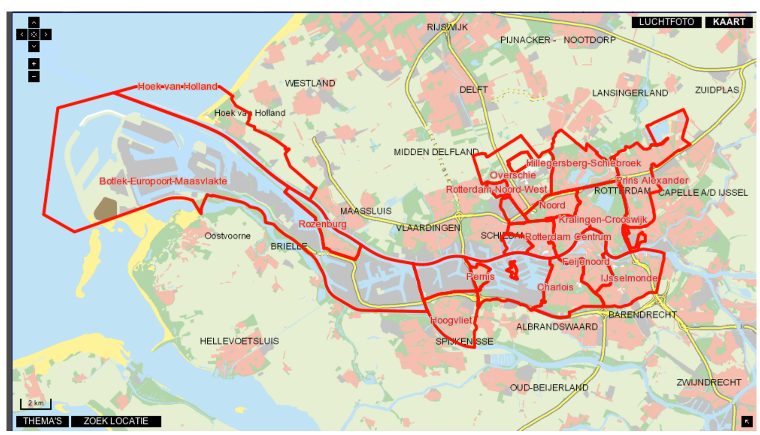


Figure 2 The Rotterdam area (Rotterdam, 2012)

Rotterdam[4]' in The Netherlands. The second interpretation is used in 'Nulmeting uitstoot CO_2' (Verhey, 2007), the reviewed area is the Rotterdam municipal territory. As is displayed by figure 2, this contains the Rotterdam city area and the Rotterdam port area, including 'Maasvlakte 2'. Because the data of the RCI are based on this definition and this thesis focuses on the industry of Rotterdam, the definition of 'Nulmeting uitstoot CO_2' will be used. So when the Rotterdam area is mentioned in this thesis this refers to the municipal territory of Rotterdam, as is displayed in figure 2.

2.2.3 The 1990 reference

The climate goal of the RCI is clearly formulated: reducing CO_2 exhaust with 50% in 2025 compared to 1990. The 1990 reference is the same as the Kyoto protocol reference year. The Kyoto protocol is a binding agreement between 37 industrialized countries and the European community for reducing GHG emissions (UNFCCC, 2012). Although the Kyoto protocol was formulated in 1997 the base year 1990 was chosen. Sceptics of the Kyoto protocol argue that this helped some countries to benefit from CO_2 reductions, which already were realised in the period between 1990 and 1997. Examples are the mitigation from Midlands coal to North Sea gas and oil in the UK. Germany was unified again in 1990, but the highly inefficient East-German industry was still in operation, while in 1997 these factories were out of order. For the Rotterdam area there is no data available of the CO_2 emissions of 1997, for The Netherlands the CO_2 emissions (dark blue) and the other GHG are displayed in figure 3. The figure shows a small rise in CO_2 emissions and a small decrease in other GHG emissions. The rise in CO_2 emissions is mainly attributable to the energy sector and in less extent to refineries (Statline, 2012). Based on this information the assumption can be made that CO_2 emissions in Rotterdam were higher in 1997 compared to 1990. The comments made on the reference year of the Kyoto Protocol therefore don't appeal to the RCI

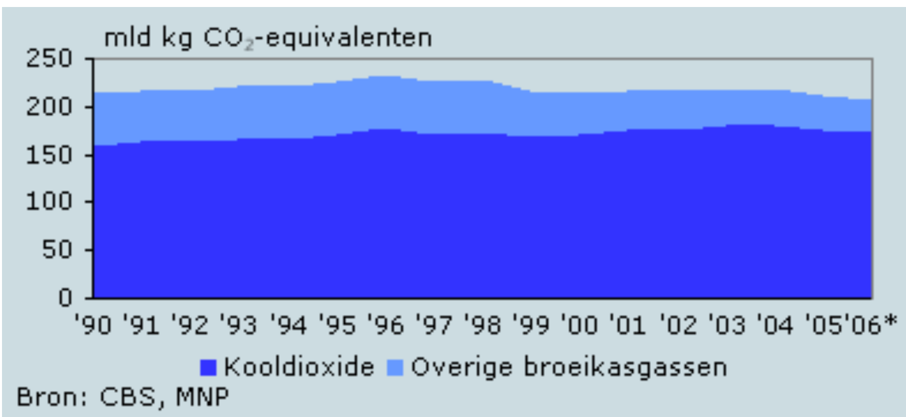


Figure 3 CO2 equivalents (CBS, 2006)

[4] 'Stadsregio Rotterdam' is also used for the Rotterdam area and it's fifteen neighbouring municipalities. This definition is not used for the RCI nor in this thesis.

reference year. The Netherlands and most likely the Rotterdam area would have had lower reduction goals if the reference year 1997 was chosen.
Of course this calls for a quantification of the Rotterdam area CO_2 exhaust in 1990. In the 'Nulmeting uitstoot CO_2' this quantification is set at 24 Mton. The Dutch name for this report is a bit pretentious, implying in 1990 there was an actual measurement of CO_2 exhaust for the Rotterdam area. In fact most of the figures were derived from national or more recent figures (Verhey, 2007). Nevertheless the 'nulmeting' is checked by ECN on the method, objectivity and completeness and judged as positive (Verhey, 2007).

2.2.4 The year 2025

The RCI uses studies of autonomous CO_2 emission growth to develop present and future policies. The figures in the studies are used as the scenario how CO_2 pollution would develop for the Rotterdam area without intervention. So based on this autonomous CO_2 emission growth expectations for future CO_2 emissions are predicted. The difference between the predicted amount of CO_2 and the 12 Mton CO_2 emission ambitions is the amount of reduction needed from the RCI.

There are two scenarios the RCI is working with. The first one is the previously mentioned 'Nulmeting CO_2 uitstoot', which is also displayed at their site. The second scenario is a study by the ECN (Energieonderzoek Centrum Nederland) 'Verkenning CO_2-emissie Rotterdam HIC 2015/2020/2025' (Plomp, 2010), which is conducted by ECN on request of the DCMR, but is not mentioned on the RCI website, RCI publications, DCMR publications or the DCMR website. The 'Nulmeting CO_2 uitstoot' expects an autonomous growth to almost 46 Mton of exhaust annually. The 'Verkenning CO_2-emissie Rotterdam HIC 2015/2020/2025 - Update en precisering nulmeting RCI' is an update of this scenario on the basis of new information like, for instance, the economic crisis. However the scope is not the same, for 'Verkenning CO_2-emissie Rotterdam HIC 2015/2020/2025' the sectors energy and industry and freight transport are reviewed. In this scenario an exhaust of 31 Mton CO_2 is expected in 2025 for these sectors, the CCS of 4.0 Mton CO_2 is already included in this scenario. Freight transport will have a slightly higher CO_2 exhaust of 0.1 Mton in 2025. In total the 'Verkenning CO_2-emissie Rotterdam HIC 2015/2020/2025' finds a CO_2 exhaust for the reviewed sectors, which is 11 Mton lower, compared to the 'Nulmeting CO_2 uitstoot', of which 4.0 Mton consists of CCS.
Overall the needed CO_2 emission reduction based on the 'Nulmeting CO_2 uitstoot' is 34 Mton annually. Based on the 'Verkenning CO_2-emissie Rotterdam HIC 2015/2020/2025' the needed reduction is 27 Mton. As is displayed in figure 5, paragraph 2.5, this is in line with RCI presentations and their website. The underlying study is not presented but can be find at the ECN website, a weakness in the report is that it is partly based on the source:

‘Verheij, K., (2010): *Persoonlijke communicatie*. DCMR’ and it is not cross-referenced. Verheij is the ‘projectleader monitoring RCI’ of the DCMR. The way of acting of the DCMR makes the findings in the report less valuable.

2.2.5 Ensuring and increasing economic growth

This is the latter part of the ambition of the RCI. This aim means that the RCI should become an attributed value to the Rotterdam economy. The website of the RCI gives some information on a leading role in energy efficiency and CCS, which should make Rotterdam an interesting business environment for companies. The Deltalinqs Energy Forum (DEF) should enable companies to address energy efficiency together, enabling Rotterdam based companies to share information and create a leading position in energy efficiency.
The development of infrastructure for waste energy and CO_2 transport should make Rotterdam the place where these facilities are available at low costs for companies (interview with Van Huffelen, 2012).

The claim that despite all efforts to reduce CO_2 emissions, there is the guarantee to ensure and increase economic growth has significant implications for the RCI. First of all, the economic growth without the RCI has to be forecasted. This forecast can be used as the reference to compare the economic development with the RCI later. After this, the economic development has to be forecasted with the implementation of the RCI. In a later stage the economic growth has to be checked and than this situation has to be compared to a situation without the RCI. If the scenario without the RCI is robust the prediction without the RCI and the actual state with the RCI can be compared. Via this approach, the influence of the RCI can be reviewed. In a complex environment as a seaport it will be hard at best to establish the relation between economic growth or decline and the RCI due to all the influences on the economic growth of a seaport. Benchmarking with other seaports is the most suitable way to estimate the influence of the RCI for the Port of Rotterdam. Although European seaports are clearly non-homogeneous, they perform the same tasks and therefore can be compared for benchmarking purposes (Tongzon, 1995). A setback of benchmarking is that you need figures to compare; since the RCI ambition year is set at 2025 there is no data available yet. Because of the long-term investments and start-up times that the RCI involves it is possible to evaluate the business climate and the likeliness that the ambitions of the RCI are met. Evaluating the impact of the RCI by benchmarking can be done in future studies. A note for the Port of Rotterdam is that it has a very large share of petrochemical related activities compared to other ports. Since the RCI is especially targeting the energy and petrochemical industry for CO_2 reduction emphasis has to be paid to this aspect in the analyses. Not only the performance of seaports, but also the market performance of the petrochemical and energy industry has to be evaluated.

In the third chapter of this thesis there will be a more detailed exploration of the possible economic scenario's and impact with a review of the literature.

2.3 The stakeholders of the RCI

Four stakeholders founded the RCI with former Dutch Prime Minister Ruud Lubbers as its ambassador.

2.3.1 The municipality of Rotterdam

As main stakeholder of the Port of Rotterdam with 70% of the shares of the Port of Rotterdam and legal partner in the Rotterdam area, the municipality is a major player in the RCI. The goal to reduce CO_2 on such a large scale started in Rotterdam with an advice from the International Advisory Board, an advisory board to the municipality of Rotterdam, to the mayor and alderman of Rotterdam in June 2006. Rotterdam has the ambition to be a strong economy and an attractive place to live. The municipality has the ambition to be a leader in climate policy and sustainable economic growth. The municipality of Rotterdam displays these ambitions in the RCI, as well as in 'Stadsvisie Rotterdam 2030'.

2.3.2 Havenbedrijf Rotterdam N.V.

Since most of the Rotterdam area pollution originates from the Rotterdam port area it is logical that the ambitious goals of the RCI needs support from the port area. Over 85% of the Rotterdam area CO_2 emission is attributable to industry, of which most originates from the energy industry (RCI, 2009). The 'Havenbedrijf Rotterdam N.V.' or Port of Rotterdam (PoR) has the ambition to develop, maintain and exploit the port in the most effective and efficient way. This makes Rotterdam the most important industrial and port complex in 2030 in the vision of the PoR. This vision is displayed in the 'Havenvisie 2030', where the positioning of Rotterdam as a global hub and industrial complex is presented. Both the hub and cluster will be the forerunner in efficiency and sustainability. The main contributions of the PoR to the RCI are in facilitating, stimulating and developing projects that contribute to the fulfilment of the RCI ambition. For instance in the case of biomass the PoR stimulates trade by the realisation of a biomass marketplace and facilitates the production and use of biomass (PoR, 2010)

2.3.3 DCMR Milieudienst Rijnmond

The 'DCMR Milieudienst Rijnmond' is the organisation licensing and controlling business with regard to environment. The organisation works in the Rijnmond area on behalf of the province of Zuid-Holland and sixteen municipalities. The DCMR uses its legal instruments, knowledge and expertise to diminish the environmental impact of companies. As the environmental protection agency of the Rijnmond area, the DCMR was already before the RCI monitoring the environment and trying to persuade partners to minimize their impact on the environment. The ambition of diminishing the environmental impact of companies and knowledge gathered since the founding in 1971 make DCMR a logical partner for the RCI.

2.3.4 Deltalinqs

As is pointed out in 2.2.2 the main CO_2 emission source in the Rotterdam area is industry, Deltalinqs is the lobby group of the logistical and industrial companies in the Rotterdam port and industry area. The listing of the 199 Rotterdam based companies that Deltalinqs lists includes large companies like AkzoNobel, Shell, Stedin and Vopak but also smaller companies like J.Smit Bulldozerverhuur and J.C. Meijers B.V. (Deltalinqs, 2012). For these companies the RCI can influence the mandate and possibilities for their daily activities, so influencing RCI related policy can be a crucial factor for their success. For the RCI to succeed the private sector is important because these are both the actual companies the CO_2 originates from and is the driver behind economic growth.

2.4 The organisation of the RCI

This paragraph describes the structural organisation of the RCI and the processes that influence the activities of the RCI.

2.4.1 The organisation of the RCI

The organisation of the RCI is displayed in figure 4. The four stakeholders introduced in the previous paragraph carry out the daily operations of the RCI. The RCI management team takes the decisions and is accountable to the RCI board, which consists of directors of the four stakeholders of the RCI, chaired by Mayor Aboutaleb. The RCI council

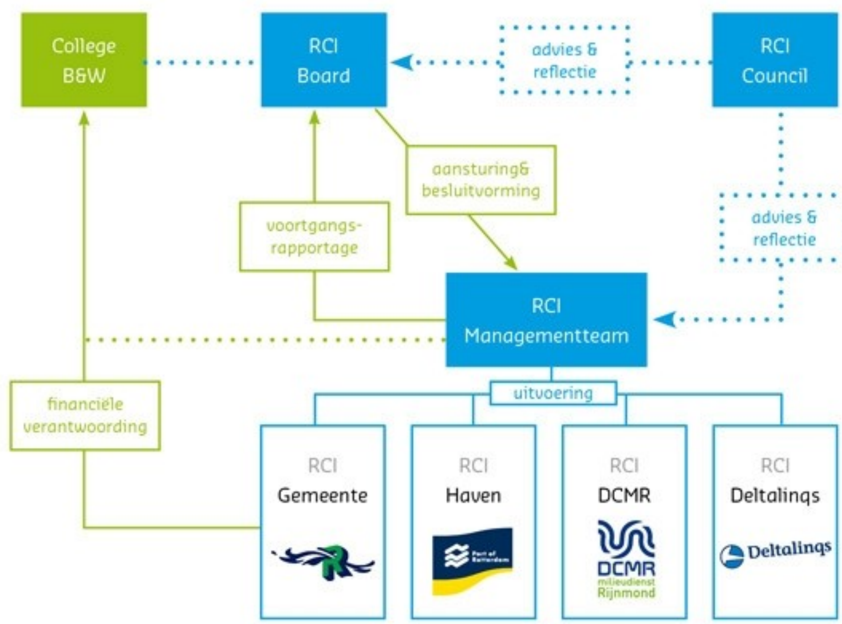


Figure 4 Organisation structure of the RCI (RCI, 2012)

provides advice and reflection to both the RCI management team and the RCI board. The RCI council is chaired by former Prime Minister Ruud Lubbers, who is also the ambassador of the RCI, applying his national and international network to lobby for the RCI.
As can be seen in figure 4, the financial responsibility of the RCI lies in hands of the board of Mayor and Alderman of Rotterdam. The municipality invests 31 million euros in a four-year period, aiming to attract another 10 euros of investments to the Rotterdam area for each euro they invest. Both the RCI management team and the RCI board report to the Rotterdam board of Mayor and Alderman, members of the board of Mayor and Alderman participate in both. The PoR invests in projects, which contribute to the achieving of the objectives. The investments of the PoR are not included in the 31 million euro of the city council, so the attracting of the extra funds can be both private and public investments.

2.4.2 Processes behind the RCI

All four stakeholders have a very limited or even marginal CO_2 emission in absolute terms. Therefore the CO_2 reductions have to be accomplished by companies operating in the Rotterdam area. Therefore the RCI signed letters of cooperation with some of the companies operating in the Rotterdam area.
This is one of the weaknesses of the RCI; the companies actually responsibly for achieving the CO_2 reductions are no stakeholders of the RCI. This means the RCI stakeholders have to continuously involve other parties to develop CO_2 reduction programs.
Another weakness is that the, except for the municipality of Rotterdam, government is not really committed to the RCI. In the case of CO_2 storage under the city of Barendrecht[5], located Southern of Rotterdam, it became obvious that when electoral pressure rose for national politicians they were not committed to the CCS project, although the national government initiated the CCS projects. The same can be argued for provincial politicians, who withdrew support from the project (Feenstra, 2010). Another interesting aspect is that DCMR tried to convince local residents of Barendrecht that CCS is a safe technology, while local politicians of the municipality of Barendrecht rose against the safety of the project and were the first to withdraw support to the project (interview with Van Heijningen, 2012). Especially because Barendrecht and the Province of Zuid-Holland are represented in the DCMR they fulfilled a dual role in the CCS project, lobbying for and against the CCS project at the same time.
Of course there is also the influence of global and European climate policy. The reduction

[5] The Dutch government commissioned the CO_2 storage project under Barendrecht. Shell, Linde gas and NAM worked together to realize the project. After concerns under local residents about the safety of the project a local political debate started. This debate gained momentum and led after a long process to the withdrawal of the project by the Dutch government.

schemes and tariffs of CO_2 reduction are decided on this level. The next global event is the Dohar Climate Conference in Qatar in November 2012, but expectations are low for an outcome. The European Union still relies on the emission-trading scheme (ETS), although prices of ETS rights are very low at the moment. The ETS is further discussed in chapter 5. For here it is important to recognise that for companies the ETS price is vey important in the decision to invest in CCS projects, because this would make CCS interesting in monetary terms. For the European interests of the RCI the support of Ruud Lubbers as ambassador and the support of former Mayor Ivo Opstelten are very important.

2.5 Pillars of the RCI

There are multiple ways to reduce CO_2 pollution; the RCI approach recognises three main principles to diminish the amount of CO_2 that is released to the atmosphere, these themes are also displayed on their website.

- Energy reduction: less consumed energy means less CO_2 exhaust
- Renewable energy: if there is no pollution it doesn't have to be cleaned
- CCS: if we can capture CO_2 we can re-use it

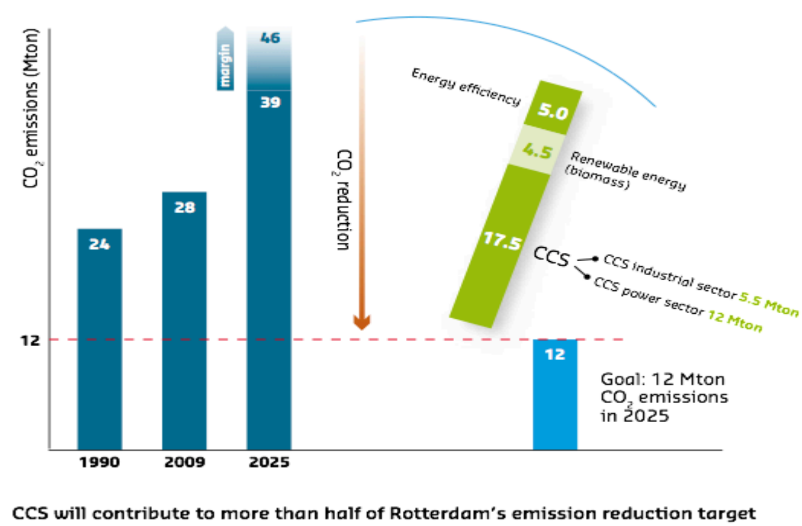


Figure 5 RCI CO2 capture and storage in Rotterdam (RCI, 2011)

2.5.1 Energy reduction

CO_2 emissions are directly linked to energy consumption, especially when the energy is generated with the usage of fossil fuels. When the energy consumption is reduced, the amount of CO_2 originating from energy production will also be reduced. The RCI aims to realize a reduction of the energy consumption by making the government more energy aware as well as stimulating energy efficiency in new buildings and industry. Other topics are the behaviour of citizens and transport. The paragraphs 2.6.1, 2.6.2 and 2.6.3 explore different ways of energy reduction more detailed. The total CO_2 emission reduction of this pillar is 5.0 Mton.

2.5.2 Renewable energy

Renewable energy sources like solar power and wind power don't emit CO_2 when creating energy. This pillar is also a theme in the RCI and explored in paragraph 2.6.4. The total CO_2 emission reduction of this pillar is 4.5 Mton.

2.5.3 CCS

The most important pillar in terms of CO_2 reduction is CCS. The energy sector and industry will need to realize large CO_2 reductions by capturing CO_2 and making it available for storage. CCS is further introduced in paragraph 2.6.5 and described in more detail in chapter 3. The total CO_2 emission reduction from this pillar is 17.5 Mton.

The three pillars introduced above and displayed in figure 5 led to five themes to reduce the exhaust of CO_2 (RCI website, 2012).

2.6 Themes

The RCI contains five themes; some of the themes are more oriented towards making the Rotterdam area a better living environment and making the area 'climate proof'. Making the area climate proof is about the adaptation of the city to the results of climate change. There is a lot of discussion of the results of climate change in literature, which goes beyond the scope of this thesis, but some adaptations to climate change in the Rotterdam area are implemented in the RCI and therefore introduced in this chapter. The themes sustainable city, sutainable mobility and energy efficiency in the industry together account for a 5 Mton annual reduction of CO_2 emissions. Renewable energy accounts for another 4.5 Mton annual reduction of CO_2 reductions and CCS, 17.5 Mton on a yearly base, will realize the largest part of CO_2 emission reductions.

2.6.1 Sustainble city

Rotterdam has the ambition to make the city more durable by the 'Rotterdamse Energie Aanpak' (REAP). This means that new and existing buildings are made energy neutral or made more energy efficient. According to researchers this is the cheapest way of CO_2 mitigation, a large setback is that the CO_2 reduction amount is limited (RCI website, 2012). In the REAP buildings and neighbourhoods are no longer looked upon as single objects, but as entities of a larger, complex, network. In this way waste streams can be harnessed and used in the network as well. Climate, land and environment are seen as key assets of the network. By using primary energy more efficient and thus only for the most high-grade functions (Dobbelsteen, 2008) and use waste heat for lower-grade functions (by a low-exergetic system (Lowex, 2012)). Altogether this can lead to a six times more sustainable

city, far more than most currently undertaken programs (Tillie, 2009).
A good example of waste stream management is the implementation of shopping areas, working areas and living areas in one project. The energy needs for cooling and heating of these different types of buildings is completely different and by harmonizing waste streams and demand energy consumption be reduced.
The impact in terms of CO_2 reduction is limited, energy efficiency in the built environment, companies and institutions accounts for a reduction of 0.4 Mton.

2.6.2 Sustainable mobility
The aim of this theme is to create a strategy for a sustainable mobility and accessibility for transport in Rotterdam. Sustainable mobility in the RCI is the ambition to make transport cleaner by three main strategies: clean use, clean vehicles and clean fuels. There are multiple pilots with clean, silent and efficient vehicles and transport demand projects. The RCI recognises three strategies to improve the sustainability of transport.
'Clean use' is a demand driven strategy, improving spatial planning, kilometre reduction and influencing behaviour. The project transport avoidance in the rush hours, when it's not necessary, reduces congestion. Congestion is a big source of pollution because the performance of vehicles is poorer when they travel slow and have to pull up and stop in sequences. Improving the transportation network and giving relevant information to drivers can achieve kilometre reduction. For instance cruising for parking, or driving around searching for a parking space accounts for between 8 and 74 per cent of urban traffic, dependent on available parking space (Shoup, 2006). These kilometres are polluting, congesting and are using valuable resources without adding value. Altogether this can diminish the demand for polluting transport.
'Clean vehicles' is about promoting cleaner and more efficient vehicles, this leads to a more efficient use of energy sources, leading to less pollution.
'Clean fuels' targets a change of energy source of vehicles. Instead of the current polluting fossil energy sources renewable source are promoted. The RCI believes that electric cars on renewable energy and biofuel or biomass fuel powered cars can substitute for the current fleet and contribute to reducing the CO_2 exhaust (RCI, 2012).
In terms of CO_2 reduction the influence of sustainable mobility is limited with 0.6 Mton.

2.6.3 Energy efficiency in the industry

Over 85% of the CO_2 exhaust in the Rotterdam area originates from industry (RCI, 2012). The Deltalinqs Energy Forum[6] (DEF) aims at a 2% annual increase in energy efficiency. This way the Rotterdam industry can realise a CO_2 exhaust decrease of 3 to 4 Mton in 2025. Where possible DEF cooperates with the program for SMEs (small and medium sized enterprises) of DCMR.

Deltalinqs is also involved in Technopark an initiative to stimulate the implementation of new, cleaner and more efficient process technologies. By providing pilot projects research can be done at full-scale, real life projects. Together with the energy platform 'Ketenenergie' (chain energy) and knowledge centeres pilot programs are set up to form business cases for energy consumption reduction. This way Technopark is maintaining and strengthening the position of the Rotterdam industry, the infrastructure, the business climate and labour market of Rotterdam as well as the knowledge economy of The Netherlands (RCI, 2012). A crucial factor in the success of creating more energy efficiency in the Rotterdam area industry is the realisation of a more unrestrained process of licensing so projects can be started. Deltalinqs, the RCI and other parties are lobbying for flexible licensing and regulation. Of course this can also become an asset for the Rotterdam area in terms of industry establishment and attraction.

Creating a network or networks to share waste streams of energy and/or commodities are a good way to promote energy efficiency in an industrial zone/network. In Rotterdam these networks are the CO_2 pipeline system, which is being developed and upgraded, and a steam pipeline network. This will make it easier and cheaper to share waste products that still have value for other industries. If this industry ecology is successful the amount of resources that are extracted from the earth will be diminished, in the case of fossil fuels this will also reduce CO_2 emissions.

Energy efficiency in the industry accounts for 4.0 Mton of the RCI ambition to reduce CO_2 emsissions.

2.6.4 Renewable energy

The name renewable energy is used for energy derived from energy sources that are continually available all over the world. Renewable energy sources are available abundantly and their use or capture does not inflict any damage on the environment (ACORE, 2012). The two main streams of renewable energy that are considered in the RCI are biomass and wind energy. Solar energy is also implemented in project development, but because of the

[6] The Deltalinqs Energy Forum is a platform where the companies involved in Deltalinqs can develop and share energy efficiency schemes. If the information is commercially sensitive it is made anonymous before it is shared with other companies.

limited potential in the port environment and high costs plays a minor role in the RCI.
Wind generated energy and solar power have a CO_2 emission of 0[7], by using these energy sources to generate energy the energy needed from energy sources leading to CO2 emissions will be reduced. Another durable energy source is the co-firing of biomass in coal-powered energy plants. The amount of CO_2 that is emitted into the air by the burning of the biomass is the same as that was captured when growing the biomass crops. The calculated amount of CO_2 emissions from biomass is 0[8], when the biomass products are grown in a sustainable way (Verhey, 2007).
Renewable energy reduces CO_2 emissions with 4.5 Mton in the RCI.

2.6.5 Carbon Capture Storage
The third pillar, and in terms of CO_2 emission reduction the most important, is carbon capture and storage (CCS). The ambition of the RCI is to capture CO_2 at energy plants and the petrochemical industry. A small portion of the captured CO_2 can be re-used in the beverage industry and horticulture. For the major part the captured CO_2 will be stored in depleted oil and gas wells in the North Sea. To make CCS a success, there are still major technical and political challenges. For instance the capture of CO_2 has to become more efficient to be able to capture enough CO_2. Secondly, a network has to be realized to transport the captured CO_2 to the storage locations and finally long-term storage has to be realized (RCI, 2012). The political challenge is to develop the right legislation for CCS to become legally possible, and to create a market for CO_2 emissions so the CCS becomes economically interesting.

A more detailed analysis of CCS is in chapter 3. Still it is important to state that CCS is believed to contribute for almost two thirds of the reduction in CO_2 emissions, 17.5 of the 27 Mton annual (MTA) reduction of CO_2 (RCI, 2012).

2.7 Political and economical changes since the start of the RCI

Since the start of the RCI in May 2007 there have been some changes in the economic prospects of and the political climate in The Netherlands influencing the RCI.
When the RCI started financial prospects were good. The word economic crisis wasn't used

[7] [7] The claim that renewable energy sources have a CO_2 emission of 0 is arguable. The discussion about the calculation of CO_2 emissions from these sources is a scientific, political and societal discussion. In this thesis the consensus is used that there are no environmental impacts or CO_2 emissions of renewable energy.

for a long time, but shortly after the launch of the bold RCI ambitions American bank Bearn Stearns announced two of its hedge funds, both investing in mortgages, needed extra capital. In retrospect this announcement in June 2007 has become the start of the mortgage crisis in the US. The crisis didn't use long to spoil over to Europe, in July 2007 the German bank IKB announced that it came in financial distress because of the US mortgage crisis, the second bank of Germany Commerzbank issued a profit warning. This last week of July 2007 and the beginning of August 2007 the US mortgage crisis turned into a credit crisis. The fall of the Icesave bank in October 2008 almost bankrupted Iceland and intensified the crisis. This process continued developed into the European crisis, which we are facing now.
The political climate also changed. The Netherlands was regarded as a political stable environment (Boogers, 2003), but now has one of the least predictable and most volatile electorates (Mair, 2003). Pim Fortuyn was the first politician to deport a more populist style of politics, which is now more common in Dutch politics (Korsten, 2011). Another important aspect is that since the cabinets of Kok (1994-1998 and 1998-2002) there is no cabinet that served its entire term.
The economic and political situations have multiple impacts on the RCI. In the media climate change has become less important. After the period around 2006, where climate change was a major topic in the news, the economic crisis overtook this position.
The economic situation made it harder for companies to plan huge investments, partly because financing has become more difficult and partly because in the current economic market future profits are highly insecure. Political instability contributed to these insecurities, a recent example is the threat to withdraw the ROAD CCS project by E.ON if the 'coal taxes' proposed by politicians are adopted.
The economic crisis also influences political choices, when the RCI started there was no recession; nowadays politicians have to defend investments to a background of budget costs and rising unemployment. The decision of national politics to withdraw from the storage project became a topic of elections in 2010, after the fall of the Balkenende IV cabinet. After the elections the project was stopped. Van Heijningen argued that the political will and courage missed to defend the importance of CO_2 mitigation in the national politics. The signal from the abandonment of the project to companies interested to develop CCS projects in The Netherlands was clearly negative (Van Heijningen, 2012).
From the industry there is still interest to develop CCS projects, but the monetary terms are very important. The ETS prices are too low to redeem investments, so companies are dependant on an increase in prices to develop CCS (interview De Wit, 2012).

2.7 Summary

The ambitions of the Rotterdam Climate Initiative are bold with a CO_2 emission reduction of 27 MTA in 2025. CCS is an important aspect of this ambition, accounting for two thirds of the needed CO_2 emission reduction. This makes the RCI completely dependent on CCS.

The stakeholders of the RCI might not be the right ones to fulfil these CO_2 reduction ambitions; neither of them is in the position to solve the problem, because industrial companies are responsible for the CO_2 emissions and have to reduce the,. They committed themselves to a huge ambition and now need the help of companies, the national and European politicians to realize their ambition.

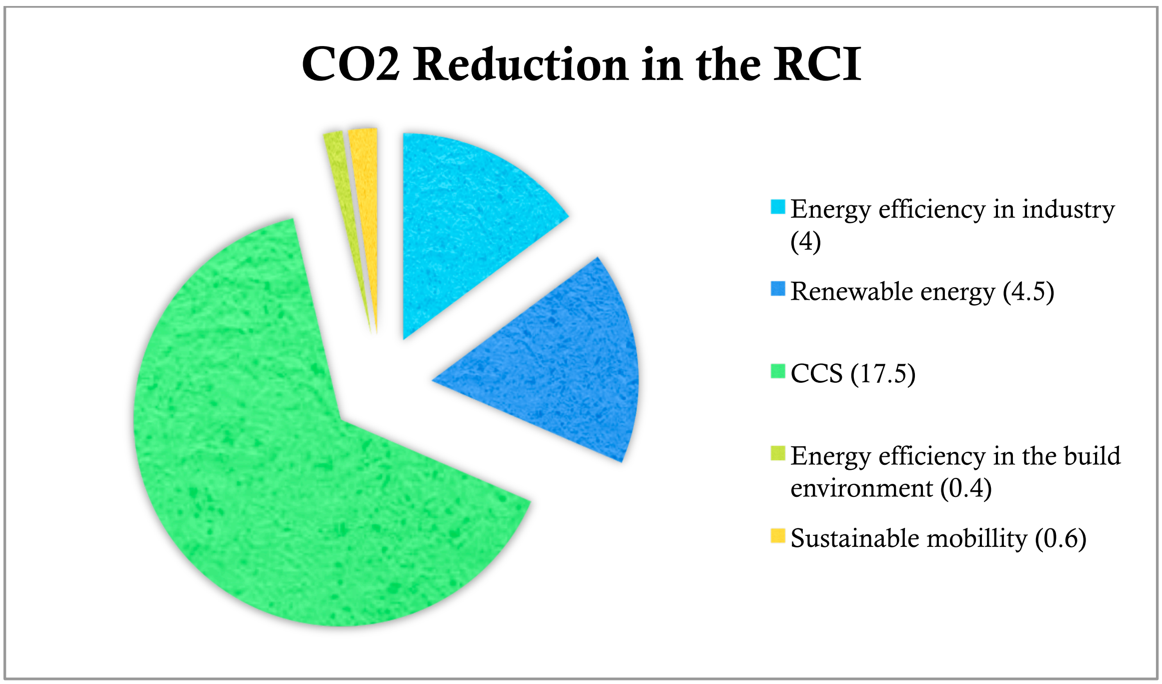


Figure 6 CO2 reduction in the RCI (Rotterdam, 2011)

3. Carbon, Capture and Storage

The first three paragraphs describe the different steps in CCS: capturing, transporting and storing. The different methods are identified and the costs of the steps, obtained from literature, are presented.
The fourth paragraph describes the future of CCS and places the costs of CCS, described in the previous paragraphs, in the context of other CO_2 reduction methods and legislation.

3.1 The capture of CO_2

There are three ways to capture CO_2 from power plants: pre-combustion, post-combustion and oxy-combustion. Each has different characteristics and efficiency rates.

3.1.1 Pre-combustion capturing of CO_2

Pre-combustion technology captures CO_2 before the combustion in the energy plant, resulting in a cleaner fuel in the combustion process and hence, less CO_2. Pre-combustion is mainly used in new power plants, because it is relatively expensive to adapt existing infrastructure (Huang, 2008). The pre-combustion process converts the initial fuel into H_2 and CO by gasification or reforming. After this step the CO is converted in CO_2 by a water-gas shift process. The CO_2 can be extracted before the combustion of the H_2. In new coal fired power plants equipped with an Integrated Gasification Combined Cycle (IGCC) the efficiency reductions are around 8.5 percentage points (IEA, 2008).

3.1.2 Post-combustion capturing of CO_2

Post-combustion technology aims at capturing CO_2 after the combustion process of a power plant. There is CO_2 in the residue gas after the combustion, called flue gas. The CO_2 can be taken out of the flue gas by absorption, adsorption, cryogenic distillation, membrane separation and solidification (Figueroa, 2008). The post-combustion capturing of CO_2 can be integrated in new plants, for existing plants the adaptation is relatively cheap because only the flue processor has to be adapted for the CO_2 capturing. The efficiency reductions for a coal fired power plant are around 9 percentage point and for a natural gas fired power plant around 6 percentage point, both for a amine-based CO_2 capturing system, the most frequently used system (IEA, 2008).

3.1.3 Oxy-combustion capturing of CO_2

Oxy-combustion is based on the principle that if a power plant is fired with high-purified oxygen instead of air the flue gas is mainly composed of CO_2 and H_2O. Condensing the H_2O

can then separate the H_2O and CO_2. There are technical challenges in the adaptation of existing plants because the heat transfer characteristics can change (Jordal, 2004) and the purification of oxygen on a larger scale might not be up to the standards for a media oxy-combustion plant (Bolland, 2009). At the moment, with cryogenic air separation techniques, the efficiency reductions are around 10 percentage points (Fu, 2010). By heat integration between the air separation unit and the CO_2 compression and purification unit to less than 8 percentage points and expectations are that in the coming five years the efficiency loss can be reduced to 4.7 percentage points (Tranier, 2009).

An important aspect of the feasibility of CCS is the costs incurred, the costs of capturing CO_2 at power plants vary according to different factors between 30 to 100 $ (US Dollar) per tonne avoided CO_2 (IEA, 2008).

3.2 The transportation of CO_2

Transportation of CO_2 can take place with CO_2 gas or liquefied CO_2. Road transport is always liquefied; ship and pipeline transportation can be both gas and liquefied transport. At the moment solid transport is not feasible because of the high costs and energy consumption.

3.2.1 Liquefaction of CO_2

CO_2 can appear as a liquid, gas or in solid state. The state CO_2 is in depends on the temperature and pressure. In figure 7 the different states are displayed. The triple point is very important, transport in ships will be done close to this triple point at around 6.5 bar and minus 50 degrees Celsius. This makes it possible to use the criteria for the ships that are identical to the criteria for LPG carriers (Aspelund, 2006). Pipeline transport can be both liquefied and gaseous. The desired state of CO_2 can be achieved by using a gas compressor or by refrigerating CO_2 first and then compress it to the right pressure with pumps. The latter method makes use of liquid compressors instead of gas compressors, which need less power and are less expensive (Baldwin, 2009).

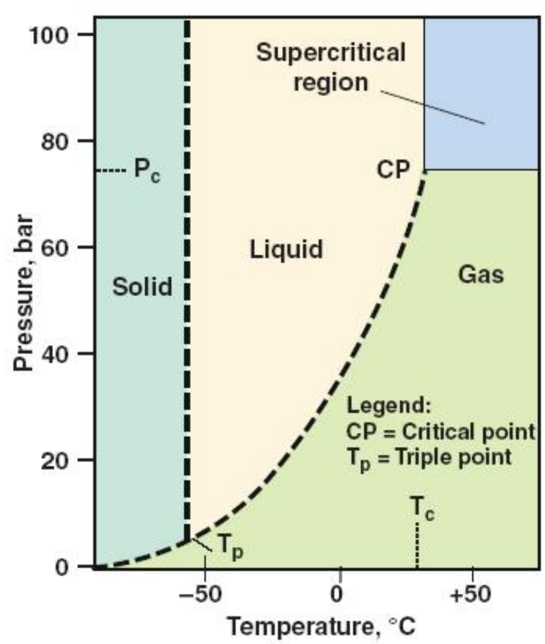


Figure 7 Aggregation states of CO2 (Chemical engineering, 2010)

3.2.2 Pipeline transport of CO_2

Dehydrated CO_2 can be transported through steel pipelines, because CO_2 does not corrode steel. For the small parts before the dehydration facilities a corrosive resistant alloy is used instead (IPCC, 2005). Pipeline transportation is already tested in practice for small quantities in this way, at the moment there is 50 Mton transported over a network of 5,600 km of long-distance pipelines in total (Gale, 2002). There are no explosion or fire risks from CO_2 transportation. The main risk comes from the nature of CO_2; it is heavier than air and therefore can accumulate in low-lying areas. This might cause high concentrations of CO2 leading to injuries or be fatal. Up to 2006 CO_2 has a lower leakage per km of pipeline compared to gas pipelines and there have been no recorded injuries due to CO_2 leakage (IEA, 2008b). The case of the Cortez pipeline shows that CO_2 transportation by pipeline is possible on bigger projects, the capacity of the Cortez network is 30 Mton annually over 800 km. For Europe to create a CCS network simulations suggest the need for between 30,000 and 150,000 kilometres of pipelines (IEA GHG, 2005). There are different studies of the costs to transport CO_2, depending on distance and volume. Fu et al. find a cost range between 4 and 12 US$/tonne 100 km (Fu, 2012), Svenson et al. find a range between 1 and 6 US$/tonne 100 km for a demonstration plant scenario (Svensson, 2004), while the IEA finds a rate between 1 and 6 US$ per 100 kilometre. They also make the important note that prices are largely dependent on steel prices as well as labour costs in the oil and gas sector (IEA, 2008b).

3.2.3 Ship transport of CO_2

Ship transport can add flexibility to the transport of CO_2 because capacity can be adapted to well capacity. Current ships suitable for CO_2 transportation are compressed natural gas carriers or CO_2 can be transported in semi-refrigerated tanks. Capacity of these ship carriers ranges between 10 and 50 kton. The total costs of ship transport, including harbour fees and temporarily storage, are 15 US$ for 1,000 kilometre and 30 US$ for 3,000 kilometre per ton of CO_2. (IEA GHG, 2004).

3.3 The storage and re-usage of CO_2

There are four ways to store CO_2 of which only one has the potential capacity without negative side effects. All four ways of storage are introduced, but only geological storage is introduced further in this paragraph. The reason is that geological storage is the only way of storage, which is valued realistic in literature and by policy makers. If liquefied CO_2 is injected into the deep ocean, minimum 3,000 metres, the CO_2 is denser than the surrounding ocean water and therefore trapped (IPCC, 2005). The injection into the deep sea will change the hydrogen ion concentration (pH) possibly leading to adverse biological and physiological effects. Therefore deep-sea storage of CO_2 is currently viewed as unrealistic and undesired (IPCC, 2005). Mineral carbonisation and industrial utilisation capacity is much smaller than deep-sea and geological storage and is valued as insufficient. On top of that most industrial utilisation is temporally storage. Therefore only geological storage is regarded as a realistic option (Fu, 2012). There is a huge variability in the storage capacity estimates among studies; up to two magnitudes is no exception. In Europe geological storage capacity is estimated between 1 and 2,499 Gton (Bradshaw, 2006). The different ways of geological storage are described in the following two paragraphs.

3.3.1 Non value-added storage capacity

Non-value added sites are depleted oil and gas reservoirs, deep aquifers and salt caverns. These reservoirs are available for storage, but there is no economic benefit other than the avoidance of CO_2 pollution.

Saline aquifers are the most promising solution for long term CO_2 storage (IEA, 2009). In this type of storage the CO_2 is injected into the pores of sedimentary rocks, where it is trapped or the CO_2 reacts with minerals also trapping it (IPCC, 2005). There is 30 Gton of saline aquifers capacity available at a price of 10-20 US$/ton (IEA, 2008). Total worldwide capacity estimates range from 2,000-20,000 Gton of which 30-577 Gton is situated in Europe (IEA, 2008).

Depleted oil and gas fields are also capable of trapping or holding CO_2; the principle is the same as saline aquifer storage. CO_2 is injected into the old wells trapping it, taking it out of the carbon cycle in the atmosphere. In Europe there is around 5 Gton of capacity available for storage of CO_2 at a price of 10-25 US$/ton (IEA, 2008).

3.3.2 Value-added storage capacity

For these storage options there is another economic benefit in the form of enhanced recovery of different fossil fuels like oil, gas and coal. Enhanced recovery techniques uses injection methods to 'press' out more fuel than would be possible without injecting into the well. CO_2 can be used for the injection; next to the benefit of the CO_2 storage there is also the benefit of increased fuel recovery.

Enhanced oil recovery (EOR) with CO_2 can help to increase the yield of an average oil field with 50% (IEA, 2008). CO_2 enhanced oil recovery is bust suitable for oil with a density lower than 910 kg/m^3. Higher densities can be recovered with CO_2-immiscible, but the economic conditions are rarely favourable (Green, 1998). Capacity for the North Sea oil fields is 4-5 billion incremental barrels or around 2 Gton CO_2 storage capacity at an investment of 60 billion US$ (Holt, 2007), this is almost the entire European capacity (Khatib, 2006 and Kuuskra, 2006).

Carbon sequestration with enhanced gas recovery (GSEGR) is the process where depleted gas fields are re-pressurised with CO_2 to increase gas recovery. CO_2 is in any state denser than natural gas (Methane, CH_4). If CO_2 is injected in a depleted gas well it will pressurize it again and the Methane will stay on top of the CO_2 making it possible to recover it. GSEGR gives a recovery rate of 0.03-0.05 ton recovered Methane per injected ton of (dense-phase) CO_2. Because of this low yield compared to CO_2 injection the realisation of GSEGR is largely dependent on CO_2 prices, at a price of 120 US$/ton CO_2 worldwide capacity is 800 Gton and at a price of 50 US$/ton CO_2 global capacity is 100 Gton (Stevens, 2000).
CO_2 enhanced coal-bed Methane (ECBM) recovery is a way to harvest Methane from coal layers, which cannot be mined because of their depth or thinness. By injection CO_2 the Methane, which is absorbed in the coal is pressed out. Coals can absorb up to two mole of CO_2 for every mole of Methane it consisted. Recent studies in the US even found low rank coals that can store 5 to 10 times more CO_2 than the amount of Methane they consisted. Worldwide ECBM has the capacity of storing between 146 and 228 Gton of CO_2, of which between 5 and 12 Gton is located in Europe (Gale, 2004 and Reeves, 2003).

3.4 Legal and political issues with CCS

3.4.1 Legal issues with CCS

Pipeline systems in Europe are mostly in use for natural gas transport, law and regulations on pipeline transport therefore focus on open and non-discriminatory access to pipeline systems (Coninck, 2008). This is not beneficial for CCS projects, because ownership rights might be under represented. New regulation is demanded weighing the interests of ownership and wider participation. In this regulations safeguards have to be implemented to make it interesting for parties to develop techniques and infrastructure (Coninck, 2008).
From a legal perspective it is not clear whether captured CO_2 is an industrial product or waste, if it is being classified as waste this would have implications for storage, because it falls under the permitting regime for European waste law. For storage in offshore locations the London Protocol would be applicable, limiting storage facilities and places. If classified as industrial product these issues would not arise. In the current debate the application of CO2 in EOR and usage in the beverage industry and horticulture shift CO_2 from waste to industrial product (Van Tongeren, 2012)[9].
Long-term effects of CO_2 storage also raise legal problems. Environmental liability is captured in the Environmental Liability Directive (Directive 2004/35/EC) but this directive has some shortcomings regarding CCS. Climate liability is not addressed, sub-seabed

[9] Van Tongeren was interviewed for this thesis, see the appendixes

geological formations are not covered and liability is limited to 30 years. The European commission addressed these issues in the proposed Directive on the geological storage of CO_2 (European Commission, 2008).

3.4.2 Development of an international standard

At the moment there is no real international legal framework for CO_2 pollution or CCS, national governments can determine the standards the industry has to adopt in their country. The differentiation between countries adds extra costs because different standards have to be developed and adopted for each country. Therefore, international standards have to be developed concerning capturing of CO_2, transport facilities, storage facilities and handling facilities to reduce the costs of developing CCS technology and infrastructure. Together with long–term CO_2 reduction policies and regulation the uncertainty and costs for the development of CO_2 emission reduction programs can be reduced.

Fiscal and trading frameworks have to be developed giving reliable prices for CO_2 emissions. This will give the industry opportunities to invest in CO_2 reduction in general and CCS especially. The Kyoto protocol is ending in 2012 and there still is no new agreement replacing it. It is highly unlikely that there will be an agreement in time according to Christiana Figures, Executive Secretary of the UN Framework Convention on Climate Change (UNFCCC, 2011). Along with the withdrawal of Canada in 2009 support for the Kyoto protocol and its successor is becoming less. The Kyoto protocol is almost reduced to an European treaty, joined by some other small countries. The Dutch government also contributed to the discussion about climate policy by buying obscure emission rights from HFC-23 installations. For companies these emission rights will be banned from 2012 because of claims the greenhouse gas HFC-23 is produced, with the sole purpose to be destroyed again. The only benefit of this scheme is the gain of emission rights, which can be sold on the emission market. Denmark lobbied to ban these emission rights also for national governments; the Netherlands decided to buy HFC-23 emission rights for 7 Mton anyway, at an estimated cost of 70 million euro (Volkskrant, 2011). This undermines the goals of the Kyoto protocol even further, damaging the interests of CO_2 reduction schemes and projects. For large-scale CO_2 reduction projects, like CCS investments in industry, a solid price of CO_2 is a key factor; climate legislation should be aimed at providing a stable CO_2 emission price at a level where CO_2 emission reduction is economically interesting (Azar, 1999).

3.4.3 The European Emission Trading System

In 2005 the EU launched the European Trading System (ETS), which is a 'cap and trade' system for CO_2. This means there is a limit to the total amount of CO_2 emission rights, the 'cap' and there is a possibility to trade these emissions rights on the ETS market.

The main idea behind this trading mechanism is that investments in CO_2 reduction are done where they reach maximum CO_2 reduction; there is no discrimination in emission rights. Because it is possible to chance the 'cap' or the total amount of CO_2 emissions it becomes easier for governments to set environmental goals. The government sets a goal, and limits the amount of CO_2 allowances. At the end of the year companies must surrender enough CO_2 allowances to cover their CO_2 emissions. If they fail to do so there are penalized with a high fine.

A first problem is the allocation of the CO_2 allowances. There have been national allocation plans (NAPs) for two periods, 2005-2007 and 2008-2012. In this scheme national governments obtain the CO_2 allowances, which they can redistribute to companies. Most commonly this was done free of charge. From 2013 the majority of CO_2 allowances will be auctioned. This makes the process easier and fairer, because the old system favoured incumbents with higher CO_2 emissions in the past.

A second problem is fraud with CO_2 allowances. Like any other easy to transfer, high value object fraud is a serious risk. In the ETS there have already been: VAT fraud, theft of allowances and recycling of used CO_2 allowances. The VAT fraud was possible because the seller reported VAT. In cross-border transaction within Europe VAT is excluded in EU VAT rules. The buyer didn't have to pay VAT on the transaction, after which it sold the CO_2 allowances with VAT added on the domestic market. This VAT was never paid to the State and the fraudster would disappear. After discovery of VAT fraud there is no VAT on carbon market transactions anymore. The theft of allowances involves phishing; the ICT system is improved to enhance security. The recycling of used allowances was made possible by a Hungarian mistake. The CO_2 allowance registration system is changed to prevent the re-appearance of used allowances on the market (CDC Climat, 2011).

The third problem is the price-level of CO_2 allowances. CO_2 emission rights have kept decreasing in price. This led to a minimum price below six euro (Bloomberg, 2012). There are critics of the system that this leads to a failure of CO_2 mitigation projects, because it is cheaper to buy allowances. They claim that the EU should intervene on the market to reduce the 'cap', the total allowed CO_2 emissions or install a minimum price. They argue that there is a backdoor in the system for the issuing of extra CO_2 allowances, when prices are rising to high, which should be also used if prices fall below a desired level. On the other hand the market asked for a reliable and stable scheme for CO_2 reduction. If the government intervenes too much on the ETS market it might become less reliable. An important argument is that the EU set the 'cap' to their environmental ambition. Whether these ambitions are realised because of climate mitigation projects or lower industrial outputs because of the economic crisis is of little relevance.

In my opinion the problem should be solved when the new CO_2 allowances for 2013 are auctioned. Next to the 'cap' there should also be a minimum price for CO_2 emission rights. This way the government can protect investments in climate mitigation, fixed bottom prices for CO_2 emissions helps projects keep their value. A minimum price can be set at a level where it reflects externalities of CO_2 emissions; the current prices are nowhere near this level which undesirable from an environmental point of view.

3.5 The future of CCS

CCS is a technology that, with the exemption of EOR, has only negative aspects for industries. CCS reduces efficiency, adds costs and lowers energy output for power and industrial plants. Even with the current carbon legislation in Europe, which incorporates some of the externalities in the price of CO_2 emitting, CCS is a cost factor for industries (IEA, 2008). With a higher CO_2 price CCS becomes economically viable.
The general interest however is served with CCS. Emitting CO_2 into the atmosphere creates costs, which are not well reflected in prices, CCS cancels out this negative effect.
For the public interest there are benefits from CO_2 emission reductions, which CCS can realize at the lowest costs at the desired scale (Praetorius, 2009). The industries that have to implement CCS cannot reap the benefits of CCS. The negative financial outlook makes companies reluctant to invest in CCS. For CCS, except EOR, to become (financially) attractive to companies negative external effects have to be incorporated in the price of CO_2 emission. Another way of stimulating CCS is by legislation, tax schemes and/or subsidies, but these are likely to have negative side effects, like reducing the effectiveness of the ETS scheme.
At the moment the carbon price is 15 US$/ton, not enough to cover CCS costs. Expectations are that the carbon price will continue to raise to 30-40 US$/ton after 2020, while at the same time CCS prices are expected to decrease, making CCS more interesting (Fu, 2012). Even without carbon prices EOR is already profitable and therefore can help to develop business cases and early projects for CCS. EOR can play an important role in the further technical and economical development of CCS (IEA, 2008).
Another issue with the implementation of CCS is the legislation. CO_2 transport has to meet different requirements in different countries and there is still uncertainty about liability for underground storage. These problems can be tackled if there is political will and consensus. Because of the long-term investments and consequences of CCS the market is especially served with long-term legislation and policy, making it possible to redeem the costs of CCS (IEA, 2008). The ambition of the EU to keep costs less than 20 Euro/ton of avoided CO_2 might be overambitious (European Commission, 2001). Literature suggests that at a price of 30 US$/ton avoided CO_2 is more realistic in terms of legislation and costs for CCS (Fu, 2012 and IEA, 2008). 30 US$/ton avoided CO_2 is still less than other CO_2 mitigation options. Further detail of the economic consequences will be given in chapter 5.

4. The RCI and CCS

The latter way of CO_2 emission reduction described in chapter two, is to capture the CO_2 and store it. This is a solution for the effects of CO_2 as a greenhouse gas, because if CO_2 is not emitted into the atmosphere there is no greenhouse effect (Nordhaus, 1991). Climate targets can be met at lower marginal costs when CCS is implemented in the mitigation options (Praetorius, 2009). There are some setbacks. First of all the capacity of storage is not endless, most of the time CO_2 storage is used in combination with the extraction of the last gas in active gas fields or CO_2 is stored in depleted gas fields. At the moment CO_2 emissions originate from the use of fossil fuels, so putting back the captured CO_2 in the original place can be a solution. However the transport of CO_2 to the (abounded) fields causes CO_2 and other greenhouse gas emissions as well.
This chapter follows the structure of chapter 3. The different steps of CCS are described in the paragraphs: in paragraph one CO_2 capturing projects of the RCI are presented. The second paragraph displays projects for transportation of CO_2 in the RCI and the third paragraph describes storage projects in the RCI. The fourth paragraph describes how CO_2 can be regarded as a commodity, attributing value to the rest streams of CO_2 as an input factor.

4.1 The capture of CO_2

4.1.1 Capturing projects in the RCI

There are different projects for the capture of CO_2 in the Rotterdam area.
'Rotterdam opslag en afvang demonstratieproject' (ROAD) accounts for capturing 1.1 MTA (million ton annually) and has a designed capacity of 1.5 MTA (RCI, 2011 and CINTRA, 2011). The decision on the project is postponed to September 2012, in this period ''E.ON Benelux and 'GDF SUEZ Energie Nederland' will make the investment decision for the needed hardware. A crucial factor in this decision is the allocation of subsidies to the project (interview with Schoenmakers, 2012).
The Air Liquide Green Hydrogen project has an obliged capacity of 0.4 MTA (CINTRA, 2011) and a designed capacity of 0.55 MTA (RCI, 2011) (ZERO, 2012). The final decision

will be taken end of 2012 when the NER300[10] subsidies are granted. The project is one of three CCS projects still under consideration for the subsidy.
The Zero emission power plant (ZEPP) of the Pegasus Project has a designed capacity of 2.5 MTA. However the realisation of this project is questionable and even if the project is realised it will be outside the Rotterdam area in IJmuiden (RCI, 2011).
Shell captures CO_2 at the refinery and petro-chemical plants of Pernis and Moerdijk. In total this accounts for 0.75 MTA. The CO_2 captured in Pernis can be counted for the RCI, because Pernis lies in the Rotterdam area. Moerdijk is no part of the municipal land of Rotterdam and therefore doesn't qualify for the RCI (Verhey, 2007).
Air Products will capture 70% of the total produced amount of CO_2, this will account for 0.5 MTA.

4.1.2 Calculation of capturing capacity in the RCI

The projects displayed by the RCI account in total for 5.75 MTA in the most optimistic scenario, assuming that all projects reach designed capacity. A more realistic, however still optimistic scenario is to exclude the Pegasus project. Total CO_2 capturing capacity goes down to 3.25 MTA in 2020. For the period after 2020 two extra CO_2 emitters are planned to be included, the existing E.ON and Electrabel coal fired plants. Both plants have an expected CO_2 capturing capacity of 4-5 MTA (CINTRA, 2011). Bringing expected CO_2 capturing capacity for the Rotterdam area in 2025 up to maximum 13.25 MTA.

4.2 The transportation of CO_2

For the large-scale storage of CO_2 there needs to be a network to transport CO_2 to the storage locations. At the moment there are two projects in the RCI focusing on the transportation of CO_2 and a third total project consisting of capture, transport and storage of CO_2.

4.2.1 R3CP

The first project is 'Rotterdam CO_2 Common Carrier Pipeline' (R3CP) of the Port Autohority, Organic Carbondioxide for Assimilation of Plants (OCAP), Gasunie and Stedin. This project aims at providing an efficient network in the Rotterdam Port Area, this means connecting all industries in the Rotterdam port area to the CO_2 hub. For 2025 the ambition is to have extended this network beyond the Rotterdam port area to sites such as

[10] The NER300 subsidy programme of the EU aims at promoting CCS projects around Europe. Projects can file for subsidy and are reviewed by the commission, aiming at developing CCS as an economic viable technology

Moerdijk and Antwerp. The goal with this project is to gather CO_2 and relocate it onshore to for instance greenhouses, the beverage industry and the CO_2 terminal for further transportation. The bulk of the CO_2 has to be transported beyond the hub to offshore CO_2 storage facilities; this is the focus of the CINTRA project.
The project is still in the study phase, reviewing two scenarios. The first is to extent the OCAP network; the other is to create a new network from between Air Liquide and Maasvlakte 2.

4.2.2 CINTRA

The CINTRA project is the development of a pipeline system or shipping infrastructure to ship captured CO_2 to offshore storage locations. It is a joint effort of Vopak, Antony Veder, Air Liquide and Gasunie, pooling their resources and expertise. The focus is to create a pipeline or shipping network from the Rotterdam CO_2 hub. In the policy documents of the RCI the capacity in 2015 will be 1.5 MTA and in 2025 a capacity of 10 MTA or more will be realised. The CINTRA knowledge sharing report 10 says capacity will grow from 1.6 MTA in 2016 to 18 MTA in 2025 (Tetteroo, 2011).
The project is still in the study phase; expectations are that the decision of this project will be made after the decision on the 'Road' project. The decision for this project is in September 2012. At the end of 2012 the decision on the Air Liquide Green Hydrogen project is due, this projects also aims at using the CINTRA infrastructure.

4.2.3 ZEPP

The third project is a Zero Emission Power Plant (ZEPP) where the gas is transported from the gas-winning platform to the ZEPP. In this plant the gas is used to generate electricity. All CO_2 is captured and transported back by pipeline to the platform where the gas originates. The CO_2 is pumped back into the gas well, resulting in a net CO_2 emission of zero. In the RCI policy documents is stated that The Pegasus Project is developing a pilot for this type of combustor in IJmuiden at the TATA plant, with a capacity of 2.5 MTA. The full-scale plant should be build from a grant from the NER300, a finance program of the European commission, European investment bank and EU member states for ' installations of innovative renewable energy technology and CCS in the EU (NER300, 2012).
In a blog by Derek Taylor of May 2011, where the entries for the NER300 grant are reviewed The Pegasus Project is missing (Taylor, 2011). There are no further details to be found, so the realisation of The Pegasus Project is questionable and even if the project is realized it doesn't comply with the calculation standard for the Rotterdam CO_2 emissions, because Ijmuiden is not located in the Rotterdam area.

4.2.4 Calculation of transportation capacity in the RCI

The transportation capacity is split in the transportation to and from the terminal. Of course a lack of capacity in one stream will constrain the total capacity since at the CO_2 terminal limited storage capacity is available for operational use. In the next tables the figures as presented by CINTRA are displayed.

Import	2016	2017	2020	2025
Onshore pipeline	1.5	1.7	1.7	3
Barge	0	1	6	15
Total import	1.5	2.7	7.7	18

Figure 8 Import of CO2 (CINTRA, 2011)

Export	2016	2017	2020	2025
Offshore pipeline	0	0	3	12
Ship	1.5	2.7	4.7	6
Total export	1.5	2.7	7.7	18

Figure 9 Export of CO2 (CINTRA, 2011)

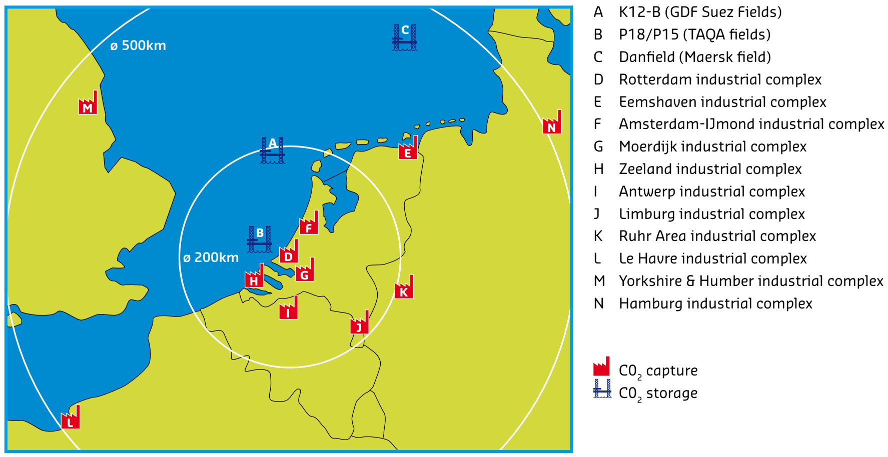
The import of CO_2 largely consists of barge import, in the knowledge sharing report is stated: ‘A significant portion of the hub’s volume growth on the mid term is envisaged to come over the river Rhine.’ And there is also a list of ‘non-Rotterdam emitters, post 2018’ consisting of Dutch power plants along the Rhine, the Antwerp region of Belgium and German power plants and steel mills in the Ruhr area and along the Rhine (CINTRA, 2011). Although this is beneficial from a CCS or environmental point of view these extra sources of CO_2 are irrelevant for the RCI ambition because the CO_2 emission reduction is based on the reduction of CO_2 sources located in the Rotterdam area.

The design and realization of CO_2 transportation infrastructure follows the development of CO_2 capturing capacity. With the postponement of the investment decisions in the projects regarding CO_2 capturing the decisions on transporting projects are also postponed.

Figure 10 Barendrecht (NWT, 2009)

4.3 The storage of CO_2

A problem is that, although carbon capture is becoming more popular, there are no relevant data for long-term storage. If the depleted gas fields start leaking the stored CO_2 still gets out in the air, leading to possible dangerous situations. In Barendrecht the local resistance to CCS was big enough to convince the national government to stop the project. In policy documents the government wants to develop CCS offshore now and possibly use the knowledge later for onshore storage. However it is arguable whether after the precedent of Barendrecht onshore storage of CO_2 is realistic. Policy makers seem to stay away from plans for onshore storage and in their capacity calculations onshore storage is no longer implemented as realistic. Now for the RCI sites in the North Sea are being considered. In the image below the current sites considered are



visualized.

Figure 11 CCS sites (RCI, 2011)

As is indicated by figure 11, there are three gas fields that are considered, the GDF Suez fields, TAQA fields and Maersk field. At the moment the TAQA fields are the closest to operation of the three.

4.3.1 TAQA fields

The RCI divides TAQA in two fields, P18 and P15 with capacities of 35 and 44 Mton, so 89 Mton in total. Carbon In Transport (CINTRA) however values the capacity of TAQA at 40 Mton CO_2 capacity. For the calculations we use the figures of the RCI, so we assume here that there is a capacity of 89 Mton. If this capacity is saved until 2025 it just lasts until 2030. When the, more logical, time path of implementation is used in 2025 there will be either no capacity or 1.5 Mton capacity left.

4.3.2 Maersk field

In the Danish North Sea gas field or Maersk field there are also opportunities to store CO_2. The RCI doesn't give any information about capacity. CINTRA thinks it is possible to store 300 Mton CO_2 in the old Danish gas fields. This will provide a basis for developing CCS and for the ambition to store 20 Mton CO_2 annually from the Port of Rotterdam. To also create a market for CCS from other CO_2 sources the capacity is limited for long-term goals.

4.3.3 ZEPP: The Pegasus Project

The last storage project is the ZEPP Pegasus. Here the CO_2 from the energy production is put back in the gas field where the gas originates. There is no detailed information available for this project regarding realisation and capacity. The last information on the RCI site is that the project will start if a NER300 subsidy is obtained, but the Pegasus project didn't apply for this subsidy.

4.3.4 Total storage capacity

In a presentation of DCMR Barend van Engelenburg presented a more complete oversight of North Sea fields considered. As is expressed by the map and column there are more fields available than reviewed in the RCI documentation. This presentation is based on the study 'Potential for CO2 storage in depleted gas fields at the Dutch Continental Shelf, phase 1' (NOGEPA, 2008). In this study there are different states of displaying technical capacity, starting with the theoretical capacity and ending with matched capacity. The matched capacity is the capacity that after all technical setbacks is available for storage. Although also here the numbers don't add up the study states there is 900 Mton capacity available in the Dutch North Sea area. The predicted total capacity is enough for the near future, even if all setbacks are taken into account and the matched capacity is calculated.

Company	Storagecapacity
1: Taqa	60 Mton
2: Wintershall	100 Mton
3: Wintershall	100 Mton
4: Gaz de France	155-200 Mton
5: Total	150 Mton
6: Wintershall	70 Mton
7: NAM	150 Mton
8: Chevron	100-150 Mton
Total	900-1000 Mton

Figure 12 CCS sites (DCMR, 2012)

4.4 CO_2 as commodity

Another way of dealing with captured CO_2 next to storage is re-usage; the captured CO_2 can be an input in other industries. Instead of emitting the CO_2 this way it can be captured in other products. To calculate the effect of using CO_2 as an input factor the efficiency is important, part of the CO_2 might still be emitted to the atmosphere. When this situation is compared to a situation without CCS the benefit of CCS can be calculated. In for instance horticulture CO_2 can be used to grow crops. The mainport Rotterdam is situated next to the greenport Westland-Oostland, CO_2 is abundant in the mainport while fuel is used to create CO_2 in the greenport. In 2009 the province Zuid-Holland started the project Mainport-Greenport where private companies from the mainport and greenport, municipalities and universities cooperated to try to create more synergies between the areas. The end rapport contained 45 ideas to cooperate where 24 already were explored. In the coming years it will become obvious which of the ideas will prove economically viable, in 2005 at least the carbon capture and usage in 550 greenhouse companies by OCAP started. At the moment over 300 kiloton or 0,3 Mton of CO_2 is reused in horticulture (OCAP, 2012) and OCAP started the collection of CO_2 at a second plant in Europoort. The ambition of OCAP is to increase the delivery of CO_2 to greenhouses up to 1 Mton annually.

Another example of CO_2 re-usage is the joint venture between Shell and the beverage industry. The abundant CO_2 of one of Shells refineries is used to carbonize drinks. Although the 0.15 MTA used in the beverage industry is a rather small portion of total CO_2 emissions it are best practises of CO_2 re-usage. A big benefit of re-usage is the diminishing of created CO_2 and the low risks. The CO_2 would come in the atmosphere in the end anyway, so there are no risks of leakage.

4.5 Summary

The success of the RCI is largely, if not completely, dependent on CCS because the RCI relies for almost two thirds of the CO_2 reduction on CCS. Therefore the conclusions around CCS are important for the main research question whether the RCI is realistic.

4.5.1 Capture of CO_2

Even if all projects meet the planned capacity this will not be enough to meet the climate goals set in the RCI. The data projected by the RCI are too optimistic and are not in line with the studies regarding the attribution of CO_2 to an area, although the requirements are clearly and correct defined in the 'Nulmeting uitstoot CO_2'. From the data of CINTRA one can conclude that calculations are made with CO_2 originating outside the Rotterdam area, this is interesting from a CCS point of view, but irrelevant for the RCI. There are benefits to develop a CCS market and network for a region (IEA, 2008), but these CO_2 reductions cannot be added to the RCI. With a realistic prediction of 3.25 MTA capturing capacity in 2020 the ambition of the RCI, to reduce 17.5 MTA, becomes infeasible. Even if the two projects after 2020 reach maximum planned capacity the RCI needs to find projects contributing to CO_2 capturing capacity.

4.5.2 Transportation of CO_2

There is sufficient capacity to meet the goals of the RCI. For economic reasons it would be better if more capacity is developed because costs go down per ton CO_2 for pipeline transport. On top of this more transport capacity will also help to create a CCS market. From the information of CINTRA one can conclude that the ambition to create a CCS market is an underlying motivation for the development of infrastructure. This would mean that the CO_2 streams are competing with CO_2 originating from the Rotterdam area, because the development of transportation facilities is just enough to realize the RCI ambitions.

4.5.3 Storage of CO_2

The technology for CCS is still immature, especially for storage in offshore gas fields. This leads to a very unpredictable realisation of capacity (IEA, 2008). The fields currently developed by partners of the Port of Rotterdam, except for the Danish North Sea gas fields, will not last very long after 2025 or, if capacity is less then expected, won't last up to 2025. This makes the RCI largely dependent on the injection rate of the Maersk field. Literature shows there is enough capacity available, so it would make the RCI more robust if there are other storage locations explored.

5. Carbon economies

Carbon economies are economies in which carbon plays an important role in energy generation and therefore, in the functioning of the economy. Basically all current economies are carbon economies. In recent literature and debate the term ‘carbon footprint’ is often used. The academic definition of a carbon footprint is not quite clear; here the definition of Wiedman and Minx is used. "The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." (Wiedman, 2008). Reducing the carbon footprint of an economy, or reducing the CO_2 emissions, can lead to a low-carbon economy, or even a carbon-free economy.
In this chapter several ways of reducing the ‘carbon footprint’ of an economy are introduced. Paragraphs four and five deal with the monetary aspects of CO_2 mitigation.

5.1 Different ways of CO_2 reduction.

There are different ways to reduce CO_2 emissions from power generation. In the end, a large part of the decision how to reduce CO_2 emissions is a choice made in politics. In many countries there is a tactical desire not to be completely dependent on one source of energy. This can be because of energy needs, for instance wind energy and solar energy are dependent on weather conditions, or out of political needs. Countries are reluctant to become dependent on one supplier of fossil fuel, for instance in The Netherlands a dependency on Russian gas is regarded as undesirable. Therefore many countries develop a desired source of energy mix, which is used for granting permits.

5.1.1 CO_2 reduction in energy production

The following methods for CO_2 mitigation are found in the current literature:

1. **More efficient conversion of fossil fuels:** by increasing the power station efficiency less fuel and less pollution is needed. This is one of the pillars of the RCI in the form of energy reduction, also applying this strategy to industry and households (paragraph 2.5.1).
2. **Switching to low-carbon fossil fuels:** if cleaner and/or more efficient fuels are used, less carbon emissions are needed to generate the same amount of energy. For instance, switching from coal- to gas powered plants results in lower CO_2 emissions.
3. **Carbon, capture and storage:** if the fuel of plants is decarbonised, the resulting flue gas is less polluting. Another option is to filter CO_2 out of the flue gas. The CO_2 of these processes can be stored on long-term bases (paragraph 3.3).

4. **Nuclear power:** there is no CO_2 output from nuclear power installations. Of course there are other, very dangerous, waste materials and there is a safety hazard involved in nuclear power generation.
5. **Renewable energy sources:** if energy demand is fulfilled with renewable energy, there are no calculated CO_2 emissions (Verhey, 2007, paragraph 2.6.4).

5.1.2 The necessity for CCS

With regard to the five methods for CO_2 mitigation in the energy sector, there are some important remarks. Renewable energy is, with the exception of biomass, an unreliable energy source. Weather conditions influence the amount of generated power for solar power and wind energy. For hydro-electrical power, there have been environmental and societal constraints. The location and scale of hydro-electrical projects restrain the development in current market conditions at a commercial base (Sims, 2003). Except for biomass it is also difficult to match energy demand and supply. This problem is further explained below for nuclear power.

Nuclear power generation has a serious image problem since the Fukushima Daiichi nuclear disaster in 2011. Ever since, there is a lack of political and societal desire for the development of new nuclear plants. On top of this, serious technical problems will arise if too much energy would originate from nuclear plants. A nuclear plant is hard to steer in terms of altering energy supply. Since our energy demand over a period is not a flat line but rather a curve, there is a need to use sources that can be steered to match energy supply and demand. For example, last summer Germany was close to a blackout in the energy system because of the mismatch between supply and demand on the energy grid (interview with Schoenmakers, 2012).

Only fossil fuel- and biomass-powered energy plants can fluctuate their energy supply in a way that can adapt to the technical demand resulting from societies energy needs. Since biomass is not yet available and will not be in the nearby future on a scale to meet our energy needs, there remains a need for fossil fuels.

If we want to reduce our CO_2 emissions according to ambitions formulated in the RCI, or even for the six per cent reduction agreed upon in the Kyoto protocol we need to reduce the CO_2 emissions from fossil fuels. The first two options in paragraph 5.1.1, more efficiency and switching to low carbon fuels, are not enough to solve this problem. Therefore the need for CCS is high, without CCS the CO_2 reduction ambitions are impossible to fulfil (interview with Van Heijningen, 2012).

5.2 Climate change as a public good

CO_2 emissions cause a greenhouse effect as is described in paragraph 2.1.1. This greenhouse effect includes heating of the earth and climate change. This paragraph describes why climate change is a global public good. The characteristics of a public good influence the resource allocation and the decision making process.

5.2.1 Climate change as a global public good

A public good is a non-excludable and non-rivalry good. Goods in general can be divided on the basis of excludability and rivalry (Samuelson, 1954).
If a good is rivalry, the consumption of that good by someone will make it impossible for anyone else to consume the good. Consumer goods like cars are a good example. If someone buys the car, it is taken of the market and therefore not available for others anymore, note that of course they can buy another car. If a good is non-rivalry, the consumption of the good does not take it of the market. For instance a television show is non-rivalry. If someone consumes it (watches it), the opportunity for others to watch it, is not changed.
The excludability of goods is the second characteristic of a good. Excludable goods can be consumed without giving others access to the good. A car is again an example, you can lock it and other people cannot use it. Non-excludable goods are goods where people can get access; they cannot be excluded from consumption. National defence is an often-used example, but this excludes almost everybody. Only the inhabitants of the country enjoy this good. National availability is enough to fulfil the need for non-excludability in the theoretical concept of a public good. This aspect does not reflect the problems of climate mitigation and GHG emissions very well, because the climate and therefore climate change is clearly a global good.
This led to the definition of the global public good (Kaul, 1999). A global public good is a good, which is non-rivalry, non-excludable and is available worldwide. GHG emissions are an example of global public goods. For the allocation of costs and benefits, the global public good definition is most suitable in this thesis. It adds the layer of free riding at an international level. Free riding is introduced in the next subparagraph.

5.2.2 The free-rider problem and the tragedy of the commons

The non-excludability of (global) public goods leads to negative effects, like the free-rider problem and the tragedy of the commons.
The free-rider problem is the problem that the people benefiting of a public good can do so without paying for it. Because consumption cannot be excluded, people have an incentive to

pay less than the market value, or the value they would be willing to pay for the consumption (Marvell, 1981). This leads to less resources being allocated to public goods. In more recent research, there was even found that the existence or the perceived existence of free riders in a group led to less willingness to contribute by the other members of the group (Ostrom, 2000). This would even further reduce the contributions to public goods. For climate change this means people benefitting from climate change mitigation can do so without paying for the climate mitigation costs. The existence of free riders also reduces willingness of others to invest in climate mitigation. An example of this in CO_2 reduction is that the reluctance of the U.S. to adapt climate legislation leads to less willingness to invest in climate mitigation in other countries. For example, the Canadian environment minister commented that the Kyoto protocol without the commitment of China and the U.S. is no solution for Canada or the world, leading to the withdrawal of Canada from the Kyoto protocol (Guardian, 2011). This process, were the collective interest of avoiding climate change is not served, is described by Hardin in the tragedy of the commons.
The tragedy of the commons describes the problem that a shared limited resource will be over utilized and depleted by individuals, even when it is clear that this not in anyone's best interest (Hardin, 1968). The reason for this is that all individuals independently serve their self-interest rationally, not fulfilling their collective interest or even their long-term own interests. The planet is the ultimate resource and the climate can also be seen as a resource for production or production factor. The tragedy of the commons theory therefore can be applied to climate change and GHG emissions. The tragedy of the commons theory than predicts that the level of GHG emissions is higher than the optimum; this is also found in literature and explains the efforts to reduce CO_2 emissions in environmental acts.

5.2.3 Shirking in environmental economics

Shirking is an economic principle well studied in labour economics, but has drawn less attention in environmental studies. Shirking in labour economics describes workers on a job avoiding working to their best effort. The reason for this is that workers prefer to be lazy. The risk of shirking is being fired, so workers will try to avoid work (shirk) to the maximum amount without being fired. Shogren et al defined shirking in environmental economics as: 'Occurring when a firm provides a socially inefficient level of pollution control' (Shogren, 1992). So a firm will try to pollute as much as it can without being punished, or in terms of GHG emissions, a firm will emit as much GHG as possible without being punished. The punishment can be both in terms of legal action against the firm or punishment from the general public. For the RCI this would mean that firms co-operate with the RCI partners to the least extend possible. The RCI partners should therefore create incentives for, or force the firms in the Rotterdam area to cooperate.

5.2.3 Group decisions

Game theory literature is often based on a single rational person as a decision maker. From this assumption decision processes are monitored. However, group decisions are more important than single rational person decisions in climate mitigation, leading to the question whether groups make other decisions than single rational persons.

In questions where there is a demonstrably correct answer, groups perform better than individuals (Laughlin and Ellis, 1986; Blinder and Morgan, 2005). Unfortunately most decisions don't have a demonstrably correct answer. For climate change decision a more complex framework is better suited, because there is no obvious best answer.

When there is no obvious best answer it is easy to find studies that find different results for the influence of groups on decisions, some influences are displayed below.

Some negative effects of groups on decisions, compared to single rational persons, are a bigger influence of the winner's curse (Cox, 2006 and Sutter, 2008). This means that groups are more likely to overpay an asset. This mean that the price paid is higher then the value of the asset, or the asset is worth less than the group initially thought, but still higher then the price paid (Thaler, 1988). In the climate change debate this means that groups, like for instance the CCI, are more prone to overpaying to reach their goals. In the first scenario of Thaler this consists of a loss for the group, the latter leads to a lower profit.

The impact of the base rate fallacy becomes bigger when a group makes a decision compared to an individual (Argote, 1990). This means that groups are worse in taking base rates, often of a population, in account when making decisions and focus more on the test rates.

Another negative group decision is the amplification of individual biases (Kerr, 1999). Individuals will defend their irrational preferences and/or prejudices, trying to convince the group of them. This way individual biases are spread among the group, enlarging their infuence compared to a decision process where all members of the group take an individual decision. For instance in the Barendrecht CO_2 storage project the judgement unsafe was made, although experts valued the risk extremely low. The local municipality used the argument, and seemed convinced of it, to protest the plans. This judgement of unsafe, although irrational, ended the Barendrecht CO_2 storage project.

There have been researches that find no difference between individual and group decisions, both individuals and groups make decisions violating the expected utility theory (Bone, 1999).

And there are studies that favour the group decisions over individual decisions. These studies find that group decisions are closer to the rational equilibrium in centipede games (Bornstein, 2004). Bornstein et al recognize group processes leading to the rational decision. Moral constraints to this rational decision become less important because the group gives some anonymity. This can be a constraint for climate mitigation, because moral aspects are

very important for these decisions.
Group decisions are more strategic with regard to signalling games (Cooper, 2005), especially if the decisions get more complex the groups learn to perform strategically much faster. In the game decision design of Cooper et al this means less rounds of negotiation to reach a goal. The impact of climate mitigation is not obvious; in an optimistic view one can say that the groups will follow a more strategic path to climate mitigation.
Group decisions are less influenced by myopic loss aversion (Stutter, 2007). Myopic loss aversion is the combination of frequent evaluation of portfolios by investors and the assumption that they are 'loss averse' (Benartzi, 1995). This leads to a situation where investors cannot oversee the short-term losses to profit from a bigger gain in the long run, while this gain is in their investment horizon. For climate mitigation myopic loss aversion is negative, because profits proceed from investments, thus costs. Thus group decisions suffering less from myopic loss aversion than individuals is a positive aspect for climate legislation, because groups are better at valuating future profits against short term losses.

5.2.4 Collective action and n-prisoner's dilemma

This theory is supported by game theory and collective action decision theory. The collective action problem describes a situation where a group has a common interest, but for none of the members the interest is big enough to initiate action. In this scenario they should start a collective action in which they can share the costs of the action (Dowding, 1996). Current climate legislation and the situation after the Kyoto protocol is a good example that this is a sound theoretical approach, but with large shortcomings in describing actual behaviour.
The game theory of the n-prisoner's dilemma (Hardin, 1978 and Hardin, 1982) describes the collective action problem. The climate problem can be seen as a prisoner's dilemma with one round, we just have one change to spoil the climate, or with multiple rounds, for instance the climate conferences can be regarded as negotiation rounds. The Nash Equilibrium is the same for both games, because expectations are that the last game will lead to default of climate action by the players, because there is no change to retaliate. Therefore working together in the second last round is useless, it imposes costs without benefit, except for another round of negotiation. This principle holds for the round before the second-last round and all the rounds before. But if this theory would be right there would be no incentive to cooperate in the first place, because the end state is the same as not cooperating at the start. This does not describe the current state of climate legislation and the efforts made to reduce GHG emissions.

5.2.5 Game theory and climate change

Apparently stakeholders are willing to take actions, which are judged irrational by game theory. People, and apparantly also nations in this case, do not take decisions only in consensus with economic principles, but rather base their decision on an appropriateness framework (Weber, 2004). This approach of Weber et al. pays more emphasis to the group factors, which influence our decisions. In recent research Kopelman found that important factors in decision-making are: identity, rules, recognition and group (Kopelman, 2009). The identity is both formed by the actual identity and the desired identity. The rules are both legal and group rules, which actors also influence. This influence is based on their identity. Recognition is based on the situation, for instance in GHG mitigation decisions Germany might act different based whether mitigation involves nuclear or solar power. Group refers to culture and peer pressure, what are expectations of the different actors to each other.

In a pessimistic approach one can say climate mitigation is due to peer pressure in the group. The other members of the group force a player to cooperate with the group. In this scenario the free-rider theory states that the actors will try to the minimum effort allowed by the group. The more optimistic approach is to recognize that the theory of Kopelman will create incentives to do much more than just the minimum effort allowed by the group, forcing the group as a whole to raise their efforts.

Most climate mitigation programs can be seen as an effort to form groups to create increased climate mitigation incentives. The Kyoto protocol and the CCI are excellent examples of schemes creating (international) groups; in these groups the processes described by Kopelman are reflected. Perhaps the main attribution of the Kyoto protocol and CCI are that they form a group identity. This leads to a framework where identities can be displayed and rules formed. Without these groups it would be even harder to pressurize countries or cities to adapt climate mitigation. The groups give countries that identify themselves as climate mitigation forerunners tools to create peer-pressure and use the identity, rules, recognition and group factors to stimulate climate mitigation.

In this aspect the RCI does not really benefits from the decision-making factors identified by Kopelman, because the crucial group formation is underrepresented. If companies get more changes in the RCI to identify themselves as climate mitigation forerunners, or climate friendly companies, the group processes might also start on a company level within the RCI.

5.3 The global costs of CO_2 emissions

The economic benefits of CCS are found in the avoidance of costs attributed to climate change. There is little debate in literature about whether CO_2 emissions influence the climate, however the consequences of man-caused CO_2 are far from clear and there is little consensus in literature about the impact (Mahlman, 1997). On top of this, climate impact may differ between regions, and also within them. Climate change assessments can be found in literature, explaining the impact of CO_2 emissions to the world. However a comprehensive study of aggregate climate impacts based on regional analyses is not available.

It is a challenge to express the results of climate change in monetary terms; this requires value judgements (Azar, 1999) and therefore results become arguable. After this process, which can be done to economic accepted standards; policy makers will be able to use the provided framework. It is their final comparison and aggregation that will lead to a choice in the trade-off, between avoided impacts of CO_2 emission and costs of emission reduction. In this paragraph the economic principles and problems behind this choice presented. A very important, often undervalued, aspect of climate change is the interest rate. Via the discount rate this is crucial for the estimation of the net present value of climate change. Both academic literature and policy makers paid more emphasis to the estimation of future climate costs, paying too little emphasis for the impact of the estimation of the discount rate.

5.3.1 The discount rate

The discount rate (β_t) is a well-recognised economic principle to calculate the present value of future costs and benefits. The present value of something is the amount of money you would pay today for an amount in the future (Katz, 1998). It can be seen as the opposite of the interest rate (r). For instance 100 euro today is worth 100 x 1.04=104 next year at an interest rate of 4 per cent. Or the other way around, 104 euro next year has a net present value of 100 euro. The discount rate can be calculated using the following formula:

$$\beta_t = 1 / (1+r)^t$$

This leads to the following calculation for our one period discount rate: $\beta_t = 1/(1+0.04)^1 = 0.96$. Thus an amount next year is worth today that amount x0.96. A 100 euro next year will be worth 96 euro today. This formula is often used for calculations in economics The problem is that climate change has an economic impact lasting longer than a couple of years, thus interest rates are likely to change.

If the interest rate changes over time the formula will change, because there are multiple r's. The interest rate in a period becomes r_t, leading to the following formula:

$$\beta_t = 1/(1+r_1) \times 1/(1+r_2) \times (\ldots) \times 1/(1+r_t)$$

This formula allows for changing interest rates, but is based on the assumption that we know all future interest rates. Research shows that this adjustment to discount rates rises the predicted costs of climate change with 80 per cent (Newell, 2003). If we assume that the future is less predictable we should allow scenarios into the formula, which we can multiply with the change (P_x) of realization of the scenario. The following formula can be used with stable interest rate scenarios:

$$\beta_t = P_a/(1+r_a)^t + P_b/(1+r_b)^t + (\ldots) + P_x/(1+r_x)$$

The reason why this formula is because there is no consensus in the future interest rates and, thus the future discount rates. This is important to calculate the impact of climate change, because the timespan of hundreds of years. In literature the plausible range for future interest rates extends from two to seven per cent (Homer, 1998), giving the following discount rates:
$\beta_{100} = P_a /(1+0.02)^{100}=0.138\ldots$ and $\beta_{100} = P_b /(1+0.07)^{100}=0.001\ldots$
A 1,000 euro climate change cost over 100 year has a present value of 138.03 euro with a two per cent interest and a 1.15 euro with a seven per cent interest. The present value with 2 per cent interest is 120 times bigger than with seven per cent interest, far more than the difference in climate impact cost assessment. Note that this is a conservative estimation of GHG impact time and interest rates; let's calculate with a per cent more and less interest.
$\beta_{100} = 1/(1+0.01)^{100}=0.369\ldots$ and $\beta_{100} = 1/(1+0.08)^{100}=0.000\ldots$
The same scenario as before now leads to present values of 0,45 euro and 369.71 euro, the present value of the one per cent scenario more than 821 times the eight per cent scenario. Even the difference between the one and two per cent interest rates is a factor 2.7. In terms of monetary value the lower estimate is an important factor. The scenarios with higher interest rates converge to 0, the lower bound interest rates therefore have a bigger impact on the present value of future climate change costs (Newell, 2003).

An important question is the estimation of future interest rates, especially in the current economic crisis. Continuous economic growth as a scenario is unlikely for the long run, especially at rates of two to seven per cent. If we use the lower bound of two per cent interest rate, a gift of 1 US dollar to Jesus Christ at his birth would now be worth over 200,000,000 trillion US dollar, 2,874,972 times the 2011 world GDP or almost 29 million dollar for each single world citizen (Worldbank, 2012). This presentation might seem over dramatic, but shows that discounting in the way done in most studies on climate change does not describe the real world very well (Rabl, 1995).
For long term estimates the interest rates of government bonds is often used, because they are regarded as the longest term and lowest risk investments (Lind, 1990, Lyon, 1990 and

Hartman, 1990). This is imperfect. Government bonds have a maximum term of 30 years, which is shorter than GHG emissions and climate change effects (Homer, 1998). Another issue is that the current economic crisis made clear that there are risks to government bonds, reflected in the different interest rates. Although the use of government bonds is limited the current interest rate on Swiss government bonds with a term of 30 years gives an indication that, even if the theory was sound interest rates cannot be limited to two per cent. The interest rates of 30-year Swiss government bonds in 2012 clearly show that long-term interest rates get below 2 per cent. These Swiss government bonds have the lowest interest rate with an average interest of 1.085 and lowest of rate of 0.874 (Forexpros, 2012). This is before income taxes, so the effective interest rate may even be lower (Newell, 2004).

Another reason to set discount rates lower is that part of the discount rates represents the time preference of consumption, while it is treated as the creation of wealth. This time preference is irrelevant to future generations. They only benefit from a growth of the economy (Rabl, 1995). Rabl argues that therefore the intergenerational discount rate should reflect the growth rate of GDP, around one to two per cent. This rate is based on post-industrial GDP growth and net economic welfare figures. When the growth figures for costs and benefits are implement Rabl finds a discounting rate of zero, because of the evolution or escalation rate of costs (Fisher, 1975).

5.3.2 Equity weighing

Equity weighing is needed in climate change costs because an one euro loss to a rich person has a different impact than an one euro loss to a poor person. The costs of climate change are likely to have a larger impact on the developing world than on the developed world for this reason. In current climate change literature there is consensus that equity weighing is important, unfortunately there is no consensus on how (Pearce, 2003).

The effect of equity weighing is largely dependent on the chosen region, population growth and GDP growth (Anton, 2009). The GDP growth is also influenced by the discount rate. The problem of equity weighing is an important factor for climate legislation effectiveness. Also on the side of reducing CO_2 this welfare allocation aspect plays a role.

5.3.3 Marginal costs

The framework to assess the marginal damage costs of CO_2 emissions has been studied by Tol in 2004; he gathered 28 published studies and reviewed and compared the 103 estimates of the marginal costs of CO_2 emission costs. He found interesting results but makes some swift conclusions in the resulting paper. I don't agree with the equity weighing and the discount rate, especially since the chosen way of presenting minimizes costs for CO_2 emissions, at the expense of third would countries and future generations. This is mainly because the influence of climate adaptation is over estimated. The example of the dumb farmer is often used in this context (Pearce, 2003). If a farmer has a bad series of harvests because the temperature rose and the crops cannot withstand this higher temperature he would be stupid not to change the crops he is growing. In climate change effect studies this adaptation is included in the analyses, especially since 1996. But changing the crops is a luxury not in the reach of every farmer, especially in developing countries.

The discount rate also is under pressure; in the current economical crisis calculating with ever increasing growth gives a wrong projection of the problem. Azar and Sterner also did the analyses regarding equity weighing and discount rates for CO_2 emission costs and choose the path maximizing CO_2 emission costs, emphasising to the impact in third world countries and the unlikeliness of ever increasing economic growth (Azar, 1996). The conclusion of Tol gives a good insight in the minimum costs agreed upon in literature, leading to CO_2 emission costs greater than 16 US$/ton CO_2, a more likely scenario of costs exceeding 51 US$/ton without equity weighing, which is theoretically sound (Frankhauser, 1997 and Frankhauser 1998) and morally and economically desirable to display welfare losses (Azar, 1999). The work of Anton, Hepburn and Tol of 2009 give an excellent insight in the different scenarios, both in terms of discount rates and equity weighing (Anton, 2009). It shows that when lower discount rates are chosen (zero or one per cent), which desirable, the costs of climate change are much higher than in literature is presented.

5.4 The local costs of CO_2 emissions

As is described in the introduction of paragraph 5.3 there is little consensus about the impact of climate change on a local scale. An important note once again is that CO_2 has a global impact. The local reduction of CO_2 emissions hardly influences local CO_2 emission costs because it is a fraction of global emissions. Local CO_2 emission costs instead are determined by the global CO_2 emissions. This principle is also explained in paragraph 5.2 more extensively.

Climate change effects described by the RCI for the Rotterdam area are increasing heat stress for people, heavier rain showers, rising sea levels and exceptionally high or low river levels or flows (RCI, 2012).

Further research about the relation between CO_2, climate change and the local impact on the Rotterdam area is beyond the scope of this thesis.

5.5 The costs of CO_2 reduction

This paragraph focuses on the costs of CO_2 reduction via CCS.

5.4.1 Costs of CCS in literature and policy documents

There are different ways to reduce CO_2 emissions, as is also displayed in paragraph 5.1. Each comes with a different cost structure, which might regionally differentiate according to climate and surroundings. Some CO_2 reduction plans might even decrease costs after initial investments, leading to a reduced overall cost pattern.

The assessment of CO_2 reduction schemes is beyond the scope of this thesis, therefor just a short literature review of the costs of CCS is displayed below. Sims et al have done a more detailed survey of carbon emission mitigation costs, leading to the conclusion that CCS is a relevant option in the form of decarbonisation of fuels and flue gases, especially if the technology matures (Sims, 2003). This will be enough to evaluate the role of CCS in CO_2 reduction policies.

Estimates of a price level for the market development of CCS to become economically interesting by the IEA, are 50 US$/ton by 2020 in OECD countries and 2035 in non-OECD countries rising to 100 US$/ton by 2035 in OECD countries and 2040 in non-OECD countries (IEA, 2008). These estimations are higher then in most literature; for instance Martinsen et al. find a price of 30 euro/ton CO_2 (Martinsen, 2006) and 25-40 euro/ton CO_2 in 2020 is found by Odenberger et al. (Odenberger, 2008), this is in line with the price that Linde gas found for the Barendrecht storage project and the OCAP network. Linde gas is a global actor in gases and engineering, for capturing CO_2 and making it ready for transport they believe in a cost function up to 25 euro/ton CO_2 (interview with De Wit, 2012).

5.4.7 Price components of CCS

Three main factors influence the price of CCS. The investments made in hardware have to be redeemed over their lifecycle. Making an energy plant ready for CO_2 capturing involves extra equipment. Also transport requires expensive infrastructure like pipelines. These costs are likely to become lower over time if CCS becomes a developed technology and more implemented process because of economies of scale. Even after the fossil fuel era the investments in technology and hardware can be used in the biomass energy sector.

To filter the CO_2 out of the fuel or flue gases extra industrial products are required and extra steps are added to the energy production process, leading to higher processing costs. These costs are returning as process costs and can be implemented in the energy prices.

An often-overlooked cost factor in literature is the efficiency penalty in energy production because of CO_2 capturing techniques. The process of CO_2 capturing gives an efficiency penalty of at least 15% (House, 2009). This energy penalty results in higher costs for consumable energy, since part of the energy which is generated is consumed for CO_2 capturing.

The following table gives an oversight of the prices for CCS found in chapter 3.

	Capturing	Transport	Storage	Total
Low	20 euro/ton	8	0 (EOR)	23[11]
Most likely	25 euro/ton	10	8	43
High	81 euro/ton	48	20	149
	Euro/ton	Euro/ton 1,000km	Euro/ton	Euro/ton

Figure 13 Cost structure CCS

5.6 The trade-off for CO_2 reduction programs

As is indicated by Tol the real trade-off for CCS should be made by policy makers, since many value judgements are needed to estimate costs and benefits of CO_2 emissions (Tol, 2004). From literature the conclusion can be drawn that even if the value judgements are made in a way that CO_2 emissions costs are at the low end of literature findings, CCS can be implemented economically. Policy makers should develop a framework to internalize the costs of CO_2 emissions to the processes that cause CO_2 emissions. This way the marginal costs of CO_2 emissions for the society and CO_2 emitters become equal. Even if done at minimal cost levels this would make CCS economically interesting, also for 'non-value added' CCS.

For the general interest it would be better to implement CCS to reduce the total costs of human generated CO_2. The interests of industries emitting CO_2 are to produce at the lowest price, which is currently by emitting CO_2 rather than storing it. This is largely so because the costs of emitting CO_2 are not well reflected in the costs bore by the CO_2 emitting industry. In an optimal economical situation this costs would be implemented into pricing systems all over the world, creating a level playing field where the polluter pays. Competition encourages CO_2 prices to be set below costs for CO_2 emissions to stimulate the local industry. Policy makers have failed and are still failing to develop schemes to change this, leading to a sub-optimal result of the world bearing the costs of CO_2 emission, rather then

[11] In this scenario the transportation distance is estimated on 375 km, which is enough to reach the EOR fields closest to Rotterdam, without EOR storage costs will rise but transportation costs will go down, leading to an estimate of 29 euro/ton for CCS.

the lower costs of CO_2 reduction. Industries are expected to invest in CO_2 reduction when the costs are lower then emitting CO_2. Therefore creating a policy to implement CO_2 emissions in prices will increase the welfare in the world because of lower general costs and optimal allocation of assets. In an optimal situation the costs incurred by the companies are the same as the costs for society. This way the market will diminish CO_2 emissions by cost-benefit analyses based on marginal costs and benefits, displayed in figure 14. The ETS scheme of the European Union is very well suited for this objective. Rather than forcing industries to adopt certain CO_2 mitigation options firms can chose to allocate means in the most efficient way. If the price level of CO_2 emissions is set at the societal costs of CO_2 emissions market forces will create the optimum outcome. The precondition that EU ETS system internalizes societal costs is not met. Figure 15 shows the CO_2 prices, in May 2012 around 7 euro/ton CO_2. This level is below the societal costs of CO_2 emissions.

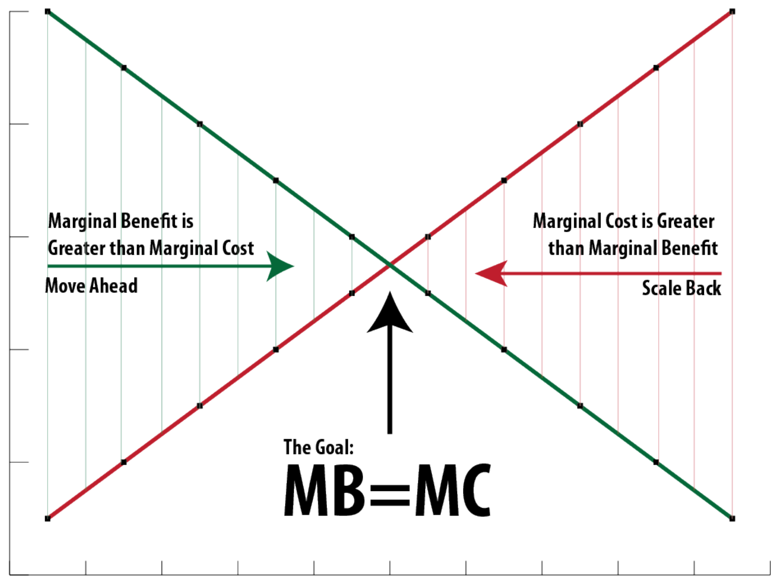


Figure 14 Marginal costs and benefits equilibrium (James, 2012)

Figure 15 EU ETS CO2 price in Euro/tonne (Hone, 2012)

Extra benefits of the development of CCS are that CO_2 capturing techniques will become broader available. In literature and in the working field consensus is that developing countries will increase fossil fuel, especially coal consumption for energy use (Shackley, 2009). In a developing state of their economy these countries will not develop CCS at high costs. If the industrialized countries take action now and develop CCS they can share it with rising economies and put pressure on them to implement CCS right away. It is not unthinkable that this is financed by trading programs or by financial aid, after all CO_2 emissions from the developing economies are not a local problem.

In the future energy production with negative calculated CO_2 emissions will become possible. If CCS is combined with biomass gasification this becomes possible. Biomass production has a CO_2 emission factor of 0, because it is a CO_2 chain where no extra CO_2 is added. By capturing CO_2 and storing it the calculated CO_2 emission becomes negative. This makes it possible that the energy sector becomes a compensating industry for other polluting industries or transport modes.

5.7 The trade-off for the RCI

The trade-off for the RCI is influenced by the ETS prices, because the cost structure of CO_2 emissions reduction changes if the ETS price changes. CO_2 emission reduction can be seen as a substitute for ETS emission permits, which has the value of the ETS price because companies don't need to buy these permits if they reduce their CO_2 emissions, or can sell them if they have ETS permits over.

5.7.1 Abandon RCI goals with low ETS prices

When the ETS prices for CO_2 emissions remain low there is no opportunity for companies to redeem the extra costs of CO_2 reduction. The current market situation already visualises that companies are reluctant to make investments in CO_2 reduction, including CCS. A good example is the ROAD project, which was only started after the government subsidized it (interview with Schoenmakers, 2012). In this scenario an abandonment of the RCI goals will most likely stop CO_2 reduction programs in the Rotterdam area. There is no further influence on the business climate and competitive position of the Rotterdam area.

5.7.2 Enforce RCI goals with low ETS prices

The low ETS prices don't allow for the earning back of the CO_2 emission reduction costs for companies. If the government forces industry to adopt the RCI goals they will face higher costs. These will deteriorate the business climate and competitive position of the Rotterdam area. In this scenario it is likely that the companies try to shift their investments to other areas or at least reduce their investments in the Rotterdam area.

5.7.3 Abandon RCI goals with high ETS prices

This is an unlikely scenario and the outcome is hard to predict. Because of the information gathered by the RCI companies might recognize that the cheapest way to produce is with CCS, rather than buying ETS CO_2 allowances. A large asset of the RCI was that they coordinated industry interest to overcome collective action problems in the Rotterdam area regarding CCS. This might prove a crucial factor for CCS in Rotterdam, if companies don't find another way of organizing CCS.

Although there are no business climate or competitive position effects of the RCI in this scenario anymore, the RCI might have improved the business climate and competitive position of the Rotterdam area in this scenario.

5.7.4 Enforce RCI goals with high ETS prices

The impact of the RCI with high ETS prices is likely to be positive. The Rotterdam based companies will reap the benefits of the developed CCS infrastructure, giving them an opportunity to avoid buying expensive CO_2 allowances on the ETS market. The ambition of Rotterdam is to become a CO_2 hub, so part of these benefits will spill over to companies located outside the Rotterdam area. The Rotterdam located companies will have a lower cost function for CO_2 transport, because the distances towards the CO_2 are lower and, most likely, there are better facilities. In this scenario the RCI is a competitive advantage improving the business climate.

5.8 Summary

There are numerous options to reduce CO_2 emissions all with specific characteristics and cost structures. It is impossible to find a solution in a single way of CO_2 reduction. Because of the worlds addiction to fossil fuels the CO_2 emissions of this energy source have to be reduced to make efficient environmental policies.

CCS will need to play an important role in consuming fossil fuel reserves; renewable energy sources are too expensive to play a leading role in CO_2 mitigation. On top of this the developed technology and infrastructure can be used in the generation of energy with biomass, which expands the lifespan of CCS beyond the fossil fuel era.

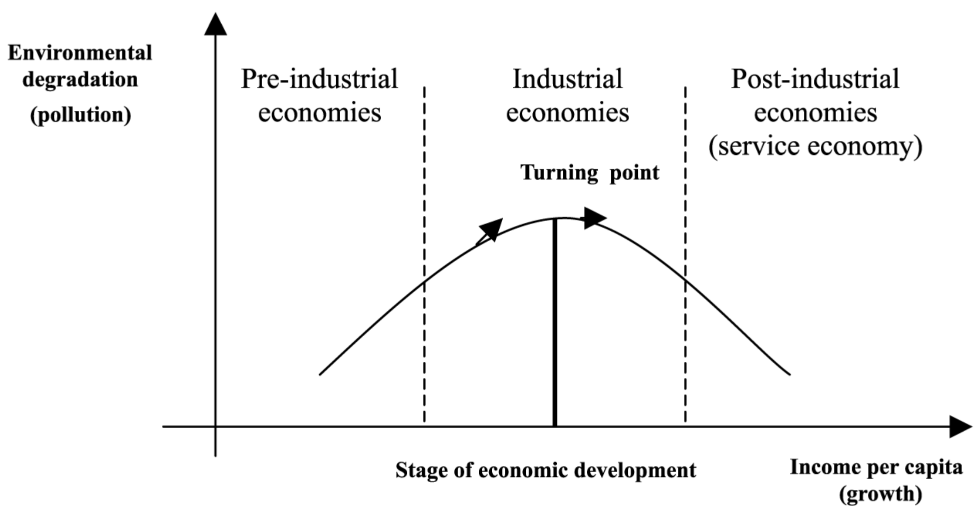
Literature finds no consensus on the discount rate and equity weighing standard for climate change costs. However even at the low end of climate change costs CO_2 mitigation is cheaper. If the interest rate is lower the present value of CO_2 mitigation becomes much higher, due to economic uncertainties and the social desirability an interest rate around zero seems optimal. This makes the discount rate one, leading to huge benefits of CO_2 mitigation. The real challenge to fuel CO_2 reduction programs is to internalize external costs of CO_2 emissions and start collective action on CO_2 emission reduction.

6. Environmental policy and competition

The definitions used for and functions attributed to seaports widely vary among literature and location (Bichou, 2005). For the economic impact of the RCI a wider definition is more appropriate and useful than a narrow definition, because otherwise industrial zones and energy supply zones are out of scope. This is in line with the definition used in Japan, emphasising on the regional influence of a seaport (Uematsu, 1999). In this chapter the different roles of the Port of Rotterdam and competition are displayed and conclusions are drawn whether it is likely that environmental policy influences these decisive factors for the port roles.

6.1 Welfare and the environmental Kuznets curve

Pollution is in economics described as a 'bad', the opposite of a good. Where more income leads to an increased consumption of goods, more income leads to less 'consumption' of 'bads' (Mishan, 1969). Or when income goes up there is more money available to reduce negative effects. For CO_2 emissions this means that if the incumbents of a country increase their income they will try to maximize their welfare, partly by reducing CO_2 emissions. This is intuitively logical; if basic needs of people are fulfilled they will start to fulfil secondary needs like a good and clean living environment.



Source: Panayotou (1993)

Figure 16 The environmental Kruznets curve

6.2 The pollution haven hypothesis

The pollution haven hypothesis is the hypothesis; that polluting industries will concentrate in areas with the lowest costs for pollution. In a paper Matthew Cole pays attention to the fact that if the environmental Kuznets curve is explained by the fact that polluting industry relocates to lower income countries, often third world countries, there is no societal benefit. Especially in terms of CO_2 emissions, which are a global problem, there is no benefit in relocating industries (Cole, 2004). In fact there is a risk that more stringent pollution legislation in developed countries leads to a relocation and abandonment of industry standards regarding pollution.

6.2.1 Industrial output in a developing economy

Output of industries is often displayed in share of gross domestic product (GDP). In developing economies the share of industrial output will often go down. This falling share of industrial production in total GDP is due to the rise of GDP rather than an absolute decline in industrial production. In other words the piece of the cake of GDP by industrial production doesn't become smaller; the total cake gets bigger, reducing the share of industrial production (Cole, 2000). This is graphically displayed for the USA, UK, France and Germany for the period 1980-1998. Figure 17 clearly indicates a rise in industrial production in this timeframe. Note that industrial production is still rising while pollution is going down; this is in conflict with the pollution haven hypothesis.

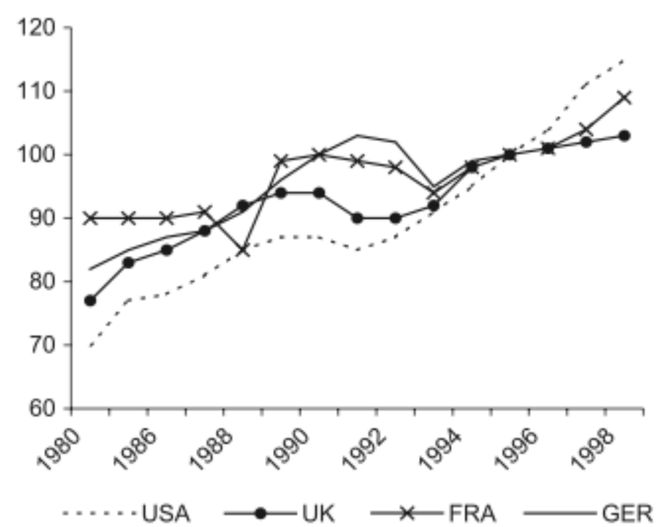


Figure 17 Industrial output in developing economies (Cole, 2000)

6.2.2 Cost factor of legislation

An important aspect of the pollution haven hypothesis is that firms can increase their margin or profit by relocating their business. Dean assessed the literature regarding trade and the environment, to survey whether environmental policy is an important factor in trade flows (Dean, 1991). In this survey there were no clear indications found for the formation of pollution havens. All empirical studies that tried to show reduced competitiveness because of more stringent regulations or pollution havens found no evidence (Dean, 1991). One aspect that is important is that environmental compliance costs are a small portion of total costs for a firm, often even less than two per cent (Cole, 2004).

6.2.3 Pressure from civil society

The last decades a lot of emphasis has been paid to pressure from legislators on industries and firms to accept levels of environmental performance. The bottom-up pressure from society for environmental performance also increased on firms. More and more firms are pushed beyond the statutory minimum to accept behaviour and standards dictated by civil society (Grolin, 1998). A good example of this in Europe was the public pressure on Shell in 1995 to dismantle the oil platform Brent Spar instead of dumping it the Atlantic Ocean (Greenpeace, 2011). Greenpeace rose against the dumping of the platform and succeeded in mobilising society in Europe. In Germany some Shell stations reported a 50% reduction in sales and some countries even reported a reduction of 70% of Shell sales (Guardian, 2002). Although Shell obtained the legal permissions to dump the Brent Spar platform of the United Kingdom the pressure of the Greenpeace action convinced them to scrap the platform and use the scrap materials for recycling.

Pressure from civil society makes it harder to shift polluting activities to developing countries for companies. Companies understand that advertising campaigns are of little value if pressure groups present an image of the company benefitting from other people's misery; the link between multinational companies exploiting the earth and people in poverty is a disaster in marketing terms (Miles, 2000). A problem for a lot of port activities is that they don't serve the general public directly. The lack of a direct link gives consumers hardly any possibilities to pressurize companies.

6.3 The different roles of the Port of Rotterdam

Any seaport has multiple roles. This is also recognised by the PoR and displayed in 'Havenvisie 2030'. The two main focus points of the PoR for 2030 are the role of Rotterdam as a global hub and as Europe's industrial cluster (PoR, 2012). The RCI extracts the energy supply function out of the port out of the industrial cluster in its presentation. The RCI presentation is followed in this paragraph, leading to the three subparagraphs below.

6.3.1Rotterdam as a transportation hub

Seaports are not homogeneous, but perform the same task (Tongzon, 1995). If they have the same hinterland they become competitors for serving this hinterland. There are numerous studies regarding seaport competition. Different factors are reviewed; price; hinterland connections, legislation and policy are key factors in most competitiveness studies. These studies focus on the role of a seaport as a transportation hub. A decisive factor in competitiveness is the throughput capacity (Meersman, 2007). Price is a decisive factor, but energy costs are just a small portion of costs and therefore of less importance (Kreukels, 1998). If CO_2 reduction plays a role this will be mostly in terms of hinterland transport. Although the RCI deals with transportation this mainly focuses on public transport and electric vehicles, which are of minor interest on the role of Rotterdam as a transportation hub.

6.3.2 Rotterdam as an energy supply zone

CCS is mainly focused on the energy sector, so CO_2 emission reduction and the RCI influence this role of Rotterdam to great extent. The RCI and E.ON formed a joint venture and Electrabel is developing a new coal-fired power plant. Both companies invest heavily in infrastructure suitable for CCS. There are risks if investments cannot be redeemed, but the partnering with E.ON, the world's largest investor-owned electric utility service provider, in a 1.2 billion euro project gives good prospects for the feasibility of economical successful operation.

On top of this renewable energy sources are implemented in the Maasvlakte 2 development and renewable energy is promoted in the form of co-firing of biomass, promoting research to biomass energy as an energy source together with the Delft University.

6.3.3 Rotterdam as an industrial zone

There is little information about the influence of legislation on industry in literature. Common economic literature says that commercial activity will seek the place with lowest costs. CO_2 emission reduction will most probably impose costs on different industries in the Rotterdam area. If the cost increase is high enough to relocate industry this might happen. On the other hand CO_2 reduction scheme benefits and knowledge availability might outweigh the costs imposed by the CO_2 reduction. If climate legislation is passed on a European or global scale the forerunner position of Rotterdam can become a strong asset, the possibility of legislation might even bring value to soon to be developed CO_2 infrastructure.

6.4 The different associations

In literature there are different perspectives for the relationship between corporate social performance and financial performance of firms identified, environmental policy can be viewed in this respect as corporate social performance (Graves, 1997).

6.4.1 Negative association

According to economic theory a firm's goal is to maximize its economic profit. This economic profit is the total revenue minus the total economic costs (Katz, 1998). Minimizing total economic costs becomes one of the goals of economic firms. Since regulation and legislation impose an economic cost on industries and thus firms, avoiding legislation and regulation becomes interesting for firms (Posner, 1974). If the total economic costs increase in an area because of more stringent climate legislation it might become interesting to relocate for the firms located in the area. Even if there is no flight of firms to other area's the incumbent firms can perform worse than without more stringent environmental legislation. In both scenarios the region is better off without the more stringent environmental legislation. The RCI can be seen as an added cost for industry, the CCS will add costs for Rotterdam as an energy supply zone and industrial zone. For Rotterdam as a transportation hub there are no additional costs.

The investments in CO_2 emission reduction between 2011 and 2025 are estimated at 11.3 billion Euro, of which 3.5 billion Euro is economically viable with the energy prices and CO_2 emission prices of 2011 (Boston Consulting Group, 2011). Most of these investments have to be done by companies in cooperation with the national government and the EU. On the base of these 2011 figures the industry has to take a loss on their CO_2 reduction investments of 7.5 billion euro between 2011 and 2025.

The total private investments related to the seaport, this includes the electricity generation, where in 2009 1.55 billion euro, of which 0.63 billion euro was invested by industry (Nijdam, 2010). Since CO_2 reduction in the RCI largely depends on the industry (paragraph 2.7) this would mean that almost the entire current investments of the industry sector in the coming 14 years (2011-2025) is needed to meet the CO_2 reduction goals.

The current economically non-viable investments are 7.8 billion Euro in 14 years, or 0.56 billion each year for the coming 14 years. The average direct added value of the seaport of Rotterdam was 10.8 billion euro for the last nine years. This means that more than an entire year added value needs to be invested in CO_2 in the coming 14 years, based

6.4.2 Neutral association

In this scenario there is no link between corporate social performance and financial performance. This can mean two things. There can be a situation where the economic benefits are equal to the economic costs of social performance policy. In the case of pollution the costs and benefits of cleaner production are than the same. Or the costs of environmental policy are too small to make a difference in the financial performance of a company. In the latter case one can argue that there is in fact a negative association, but because of the small impact on the cost aspect this is not obvious in the financial

performance of a firm.
If the costs and benefits of environmental policy are even there is no incentive for a company to implement environmental measures, but government and/or society should be able to persuade companies to implement environmental policy because there are no losses if environmental policy is implemented. On top of this the spin-of from a more environmental friendly image is likely to be positive rather than negative. It is not uncommon that in this scenario companies are reluctant to initiate measures because they find it out of their core business. Here the (local) government can play a leading role according to councillor Van Huffelen (interview with Van Huffelen, 2012).

6.4.3 Positive association
Regarding the positive association there are two models, which are rather positive regarding (local) environmental regulation. The first one is based on the formation of clusters, the second recognises competitiveness as a dynamic process instead of a steady situation. Both are discussed below.

Michael Porter's five forces model has been a dominant model in literature regarding economic competition. This theory originates in 1979. In a more recent article for the Harvard Business Review Porter points out the importance of clusters. He argues that input-costs disadvantages are becoming less important and comparative advantage relies more on making more productive use of inputs, requiring constant innovation (Porter, 1998). The aim of the RCI is to become more productive with less CO_2 emissions and to realise this goal partly by becoming more energy efficient.
This led Porter to the theory of economic clusters. This theory is widely adopted in scientific literature (Porter, 1998) and good examples are Silicon-Valley and the German automotive industry. Economic growth of an industry, expressed by an expanding market can lead to a geographical concentration in larger clusters (Bellefamme, 2000). Rotterdam's ambition of becoming a CO_2 cluster might therefore become a driving economic factor.

Industry competitiveness has long been looked at in a static way, assuming that technology, products, processes and consumer needs are static. In such a world cost-minimization is considered to be implemented and increasing environmental demands on production raises costs. Porter was the first to address and question these assumptions in 'The competitive advantage of nations' in 1990 (Porter, 1990). Indeed, a model that accounts for technological, product and process development as well as hanging consumer needs is more likely to deliver output that describes and predicts the real world. In 1995 Porter and Van der Linde published an essay that in this scenario environmental policy is more beneficial. Being a forerunner in environmental policy would make a firm a leader with a comparative advantage over other firms (Porter, 1995). There have been numerous critics around this theory, saying that precision and determinacy are lacking in the paper, but still the theory itself is accepted as relevant (Grant, 1991). Clusters can compete with each other; therefore there is no reason to assume that the comparative advantages that Porter attributes to firms are different for clusters. It is logic that the same way comparative advantages are formed for firms are formed for clusters. Following this reasoning being a forerunner in environmental policy would also be a comparative advantage for clusters. The more stringent environmental policy of the RCI then should be a comparative advantage for the clusters it is covering. The RCI is a comparative advantage for the port and city of Rotterdam then, because the main clusters of Rotterdam benefit from the RCI.

An interesting part of the theory is that Porter explicitly mentions the needed shift in industry thinking away from pollution control towards resource productivity. Decades later and with much higher fuel prices one can argue that Porter was right in this respect and the industry adopted this. On the other hand the development of a steam and CO_2 network shows that there are still huge steps to make in resource productivity. Lowering CO_2 emissions is at first sight a step back to pollution control, but if you think as the environment as a scarce production factor we should also take in aspect how and how much we pollute or use it. In this aspect CCS is a far more efficient way of using the production factor environment than for instance wind energy and solar power (see also paragraph 5.1.2). Another important aspect is that environmental standards are a dynamic process as well. The development of cleaner production processes continues and the legislation follows, the industry often resists new legislation in the beginning, but adopts it along the way. If there are higher environmental standards these get accepted and introduced to a broader area. In retro perspective the evolution to diminish SO_2 started with discussions that are now held for CO_2 (interview with Schoenmakers, 2012). The last decade there has been no discussion in relation to SO_2 emission reduction policies in new developments in any developed country and the perception is that CO_2 reduction will become a standard as well in the future.

6.5 Business establishment and the RCI

An indicator for the impact of the RCI on companies is to look at the business establishment development in the Rotterdam area. Because the impact of the RCI is highest in the industrial sector business establishments in this sector are most important to monitor. Industry development is monitored in the port monitor, which presents data to monitor the development of business establishment. If there is a large impact of the RCI on the business climate the expectation is that the port of Rotterdam business establishment trend breaks after 1997. Figure 18 does not display such a trend break. Figure 19 displays the percentage of business establishments in the Rotterdam seaport compared to the total amount of business establishments in The Netherlands seaport minus business establishments in the Rotterdam seaport. Rotterdam is excluded because the proportion of business establishments in the Rotterdam seaport might influence the total too much. Also in this graph there is no reason to assume a trend break. The choice to compare Rotterdam to other ports was made for three reasons. The first was the availability of uniform data. The second reason is that the RCI is a local ambition, avoiding the RCI is most easy for most companies by (re-) locating just outside the Rotterdam area. The last reason is that other macro economical aspects, which make comparison of ports

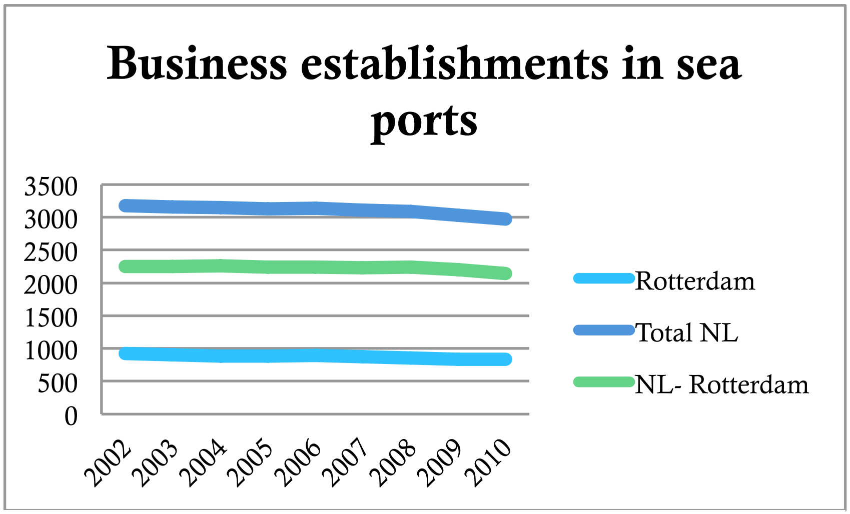


Figure 18 Business establishments in sea ports (Nijdam, 2012)

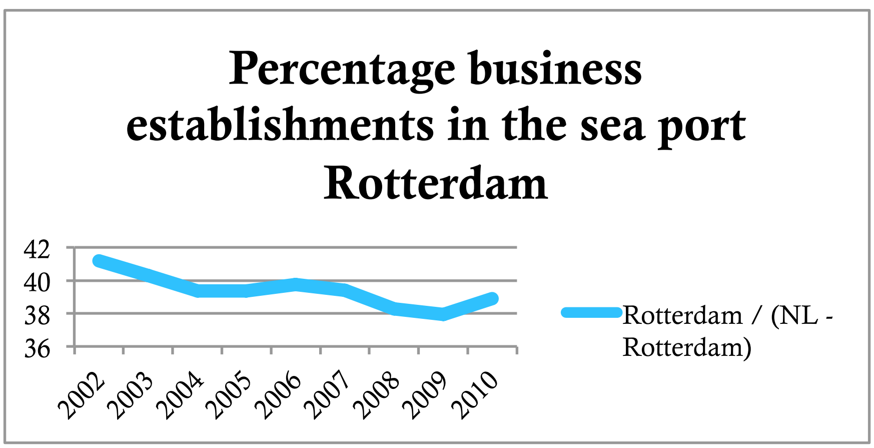


Figure 19 Percentage business establishments in the sea port of Rotterdam (Nijdam, 2012)

located in different countries more complicated, are ruled out in this way. It is important to note that the RCI was presented in 2007 and data is unavailable after 2010. Therefore the data can only be used to try to observe large trend breaks. As is commented before there is no reason to assume a trend break from these figures, future research will need to establish further conclusions about the influence of the RCI on the business climate.

6.6 Summary

From policy documents and literature it is hard to judge how the competitive position of Rotterdam is affected by the RCI. A large impact on Rotterdam as a transportation hub is unlikely because of the small impact on prices, which are just an aspect of competitiveness. The energy sector seems to be attracted to the possibilities, technology and know-how in the Rotterdam area, although climate legislation is under pressure. This might become a burden for the investments in CCS especially. This is also the case for the (petro-chemical) industry. If the costs are higher compared to other ports and climate conferences fail to develop a CO_2 emission market the position of Rotterdam might become under pressure.
An important aspect is that the partners of the RCI are not the companies who have to make the investments. At the moment

Perhaps there will be no big losses in terms of competitiveness, but with a failing CO_2 market it is hard to see how the RCI will ‘ensure and stimulate economic growth’.

7. Conclusions

After the initial rise in climate awareness after ‘An inconvenient truth’ the political and public attention is drawn from the climate subject because of the financial, banking and political crisis. The lack of interest is making it harder to develop the needed climate legislation for a competitive CO_2 emission market.

7.1 The Rotterdam Climate Initiative & CCS

The RCI focuses on the ambition to reduce the CO_2 emissions in the Rotterdam area to 12 Mton in 2025, while ensuring and increasing economic growth. The 12 Mton is based on a 50 per cent reduction of 1990 emissions. To calculate the CO_2 emissions the source or local attribution is chosen.
This ambition is largely dependent on carbon capture and storage. The RCI aims at developing a CCS hub in the Rotterdam port to facilitate their demand for CCS and to serve the market. By serving the market the CCS hub can ensure and increase economic growth for the Rotterdam area.

7.2 Economic impact

Although regulation and legislation are, above other things, a cost factor for firms and industries, the CO_2 or carbon industry is developing in Rotterdam. The industry interest in the RCI is large and attracting companies to the Rotterdam area. The RCI seems an asset, rather than a burden for the Port of Rotterdam.
The pollution haven hypothesis is criticised in literature and in the interviews, there are no signs of Rotterdam based companies or industries relocating to other areas. Environmental cost differences are below the level where relocation becomes interesting, because of other location factors. On top of this the market expectations are that industry and legislation standards will develop to higher standards in other areas as well (Schoenmaker, 2012).
The frontrunner aspect makes it possible for companies to attract extra capital and funding in subsidies, leading to the opportunity to develop CCS as a business asset. For these companies a stable political climate is essential. The cynicism in national politics, which led to the abandonment of Barendrecht can undermine the faith of companies in a good investment climate and damage the interests of CCS and the RCI (Van Heijningen, 2012).

The economic impact of the RCI will improve even further when climate change costs from CO_2 emissions are internalized into the CO_2 emission price. There is little consensus of climate change impact and costs in literature. The cost differences are largely attributable to the different discount rates used in the literature, but it is highly unlikely the costs of CO_2 emissions are lower than CCS.

7.3 CO_2 reduction

The reason why goals are not likely to be met is because at the moment it seems unlikely that CO_2 capturing capacity grows to the needed 17.5 MTA in 2025. The financial and political crises shifted interest in society, industry, national and supra-national politics, slowing down decisions and investments. A critical phase will be the decision on the ROAD project later this year, if this project is abandoned the future of CCS will become idle (Schoenmakers, 2012). A failure of ROAD will make companies reluctant or even negative to future investments in CCS in the Rotterdam region (Van Tongeren, 2012).
CINTRA and other business models regarding transport and storage are developed to meet the capacity needed for the RCI CO_2 reduction ambition. Another part of the ambition was to become the CO_2 hub for Northern-Europe (RCI, 2012). The developed CO_2 transport capacity is not enough to meet both goals (CINTRA, 2012). For long-term prospects it might also be better to partner with German or Belgium projects. If the surrounding countries become dedicated to CCS this improves the medium and long term economic prospects for the Port of Rotterdam as an important CO_2 hub and the European support for CCS.

7.4 Conclusion

Although the RCI is likely to fail because of a lack of CO_2 capturing capacity the economic impact is likely to be positive. Rotterdam as a 'hub for CO_2' can attribute to the economic position and future of Rotterdam. The role of the key stakeholders: the municipality, DCMR, Deltalinqs and the PoR was and is very important.
A shortcoming in the choice of these stakeholders is that industry and national politics is under represented. The letters of cooperation, which are signed by some industry partners, left too much space to bailout. The national government also made some choices which where not in the interest of CCS, hurting their own long-term interests as well as the interests of the RCI.

The local dedication to the RCI is a decisive factor for the success of the RCI and CCS in the Rotterdam area.

7.5 Policy recommendations

7.5.1 Create more robust partnerships with companies

The companies emitting CO_2 are crucial for the realization of CCS. The PoR can and should use CCS as a decisive factor in the allocation of land area. The link with CO_2 emitting companies should have a more robust legal base.

7.5.2 Ensure the position of CCS in the national and European policy

Changes in national policy and a lack of support from the EU ETS are problematic for CCS. The Germans set an excellent example with solar power how to boost an industry. This was partly at the expense of CCS via the ETS. The Netherlands should protect their own interests and put pressure on other EU members to keep loyal to the ETS system over other policies. The framework of Kopelman can be useful to address relations and create partnerships to do so.

7.5.3 Better and more coherent presentation of figures and studies

On the website of the RCI and its stakeholders different figures for the same projects are presented. The studies where the figures are based upon are often hard or impossible to find. When studies are presented it is not uncommon that calculations and policy are not in line with the studies.

7.6 Limitations

7.6.1 Political aspects

The scope of this thesis has been economic. The processes in the RCI proved to be very political driven. The role of different political bodies and government layers can be studied more extensively.

7.6.2 Green house gas effects and climate change

The negative effect of GHG emissions is well recognised in literature, the consequences of them are not. The climate processes in general are not well understood and therefore the impact of GHG and climate change are hard to predict. The monetisation of climate change is therefore based on rough estimates.

7.6.3 Running project

Because the RCI is a project, which is still developing involved parties, have incentives not to share all the information they have. In this thesis I was able to find some important turning points, but the best changes to find more conclusions are after the RCI ambition date of 2025.

7.7 Future research

7.7.1 Model for the relationship between GHG and (local) climate change impact

In literature the impact of climate change is often referred to, but a framework to estimate and monetise climate change is not well defined. Although especially local climate change costs are hard to capture in a framework it is desirable that a framework is developed, which at least gives some standard for discounting and equity weighing.

7.7.2 Research cost components of CCS

Most of the figures in the literature are estimates of costs. CCS projects are started in Europe giving the opportunity to monitor the real cost components to create a better understanding of CCS costs.

Bibliography

ACORE, 2012. American Council On Renewable Energy, http://www.acore.org/what-is-renewable-energy/

Argote, L., Devadas, R., Melone, N. (1990). The base-rate fallacy: contrasting processes and outcomes of group and individual judgment. Organiza- tional Behavior and Human Decision Processes 46, 296–310

Aspelund, A., Molnvik, M.J. and De Koeijer, G. "Ship Transport of CO2: Technical Solutions and Analysis of Costs, Energy Utilization, Exergy Efficiency and CO2 Emissions," *Chemical Engineering Research and Design*, Vol. 84, No. 9, 2006, pp. 847-855.

Azar, C., 1999. Weight factors in cost-benefit analysis of climate change. Environmental and Resource Economics 13, 249–268.

Azar, C., Sterner, T., 1996. Discounting and distributional considerations in the context of global warming. Ecological Economics 19, 169–184.

Battjes, J., Beeldman, M., Jansen, J., Kroon, P., Ormel, F., Schaeffer, G. and Sijm, J. (2000), Beleidsopties voor CO2-emissiereductie en de inzet van hernieuwbare energie in een geliberaliseerde energiemarkt, ECN Beleidsstudies, ECN-C--00-048

Belleflamme, P., Picard, P., Thisse, J. (2000), An Economic Theory of Regional Clusters, Journal of Urban Economics 48**,** pp**.** 158–184

Bichou, K. and Gray R. (2005). A critical review of conventional terminology for classifying seaports *Transportation Research Part A: Policy and Practice, 39 (1) (2005), pp. 75–92*

Blinder, A. and Morgan, J. (2005). Are two heads better than one?: monetary policy by committee. Journal of Money, Credit and Banking 37, 798–811.

Bloomberg (2012), http://www.bloomberg.com/news/2012-07-24/eu-co2-plunge-reignites-criticism-about-market-disclosure.html

Bolland, O. (2009), Course EP8103: Thermal power cycles and cogeneration, Norwegian University of Science and Technology

Bone, J., Hey, J., Suckling, J. (1999). Are groups more (or less) consistent than individuals? Journal of Risk and Uncertainty 18, 63–81

Boogers, M. and R. Weterings (2003), De emancipatie van kiezers en politici, in: Beleid en Maatschappij, jrg. 30, 2003, nr. 2, pp. 145-148

Bornstein, G., Kugler, T., and Ziegelmeyer, A. (2004) Individual and group decisions in the centipede game: are groups more 'rational' players? Journal of Experimental Social Psychology, 40, 599–605

Boston Consulting Group, "CO_2 Besparingsmaatregelen in Rotterdam, Economisch en Technisch Potentieel", Amsterdam, 2011

Bradshaw, J., Bach, S., Bonijoly, D., Burruss, R., Holloway, S., Christensen N., Mathaissen O. (2006), "CO2 Storage Estimation: Issues and Development of Standards", in *Proceeding of the 8th International Conference on Greenhouse Gas Technologies,* Trondheim, Norway (June 19-22)

CDC Climat (2011), Closing the door to fraud in the EU ETS, ClimateBrief Focus on the economics of climate change 4, 2-2011 http://www.cdcclimat.com/IMG//pdf/11-02_climate_brief_4_-_closing_the_door_to_fraud_in_the_eu_ets.pdf

Chemical Engineering, Feb 2010, www.che.com

Cole, M. (2000). Air pollution and 'dirty' industries: how and why does the competition of manufactering output change with economic development? *Environmental and resource economics 17 (1), 363-383*

Cole, M. (2004), Trade, the pollution haven hypothesis and the environmental Kuznets curve: examing the linkages, *Ecological Economics 48, 71-81*

Coninck, H., Flach, T., Curnow, P., Richardson, P., Anderson, J., Shackley, S., Sigurthorsson, G. and Reiner, F. (2008), The acceptability of CO_2 capture and storage (CCS) in Europe: An assessment of the key determining factors Part 1. Scientific, technical nd economic dimensions, *International Journal of Greenhouse Gas Control, vol. 3, 2009, pp. 333-343*

Cooper, D.J. and Kagel, J.H. (2005) Are two heads better than one? Team versus individual play in signaling games, American Economic Review, 95, 477–509.

Cox, J.C. and Hayne, S.C. (2006) Barking up the right tree: are small groups rational agents? Experimental Economics, 9, 209–22.

Deltalinqs (2012), www.deltalinqs.nl
http://www.deltalinqs.nl/?mod=members&section=Leden&id=188

Dobbelsteen, V.D, Gommans, L.A. & Roggema, R. Smart Vernacular Planning – sustainable regional design based on local potentials and optimal deployment of the energy chain, Proceedings of the Sustainable Building 08 Conference, Melbourne, 23 Sept 2008

Dowding, K. (1996), *Power*, University of Minnesota Press, pp. 31 *ff*

Ecostars Rotterdam (2012), http://ecostars-rotterdam.nl

Emerald Performance Materials (2012-02-15).
www.emeraldmaterials.com/cms/epm/home.html?p_name=Press%20Releases.

Energieportal.nl (2007-07-28), www.energieportal.nl/Nieuws/Groene-Energie.

European Commission. European Climate Change Programme, Long Report, June 2001. URL: http://europa.eu.int/comm/environment/climat/eccp_longreport_0106.pdf

European Commission, (2008) Proposal for a Directive of the European Parliament and of the Council on the Geological Storage of Carbon Dioxide and Amending Council Directives 85/337/EEC, 96/61/EC, Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC and Regulation (EC) No 1013/2006. COM(2008)18 Final. [COM(2008)30 Final, SEC(2008)54, SEC(2008)55]. European Commission, Brussels.

Figueroa, J., Fout, T., Plasynski, S., McIlvried, H., Srivastava, R. (2008) "Advances in CO2 capture technology-The U.S. Department of Energy's Carbon Sequestration Program," *International Journal of Greenhouse Gas Control, vol. 2, 2008, pp. 9- 20*

Fisher, A. and Krutilla, J. (1975). Resource conservation, environmental preservation and the rate of discount. *The Quarterly Journal of Economics, 1975, vol. 89, issue 3, pages 358-70*

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Fankhauser, S., Tol, R.S.J., Pearce, D.W., 1997. The aggregation of climate change damages: a welfare theoretic approach. *Environmental and Resource Economics 10, 249–266.*

Fankhauser, S., Tol, R.S.J., Pearce, D.W., (1997). 'The aggregation of climate change damages: A welfare theoretic approach. *Environment and resource economics 10, 249-266*

Fankhauser, S., Tol, R.S.J., Pearce, D.W., (1998). Extensions and alternatives to climate change impact valuation: on the critique of IPCC working group III's impact estimates. *Environment and Development Economics 3, 59–81.*

Feenstra, C., Mikunda, T. and Brunsting, S. (2010), What happened in Barendrecht? Case study on the planned onshore carbon dioxide storage in Barendrecht, the Netherlands, ECN/CEASAR

Forexpros (2012), http://www.forexpros.nl/rates-bonds/switzerland-30-year-bond-yield-historical-data

Fu C., Gundersen, T. (2010), Heat integration of an oxy-combustion process for coal-fired power plants with CO2 capture by pinch analysis, Chemical Engineering Transactions, vol. 21, 2010, pp. 181-186

Fu, C., Gundersen, T. (2012), Carbon Capture and Storage in the Power Industry: Challenges and Opportunities, *Energy Procedia 16 (2012) p. 1806-1812*

Gale, J., Davison J. (2002), "Transmission of CO2-Safety and Economic Considerations", Proceedings of the 6th International Conference on Greenhouse Gas Technologies (GHGT6), Kyoto, Japan.

Gils, M., Huys, M. and De Jong, B. (2009). De Nederlandse mainports onder druk. Houten: Spectrum.

Grant, R. (1991), *PORTER'S 'COMPETITIVE ADVANTAGE OF NATIONS': AN ASSESSMENT,* Strategic Management Journal, Vol. 12, 535-548

Graves, S., Waddock, S. (1997) 'The Corporate Social Performance Financial Performance Link', Strategic Management Journal 18(4), 303-319.

Graves, P.E. (2009), *"A Note on the Valuation of Collective Goods: Overlooked Input Market Free Riding for Non-Individually Incrementable Goods,"* The B.E. Journal of Economic Analysis & Policy 9.1 (2009)

Greenpeace (2011), 1995 - Shell reverses decision to dump the Brent Spar, http://www.greenpeace.org/international/en/about/history/Victories-timeline/Brent-Spar/

Grolin J, 1998, "Corporate legitimacy in risk society: The case of Brent Spar" *Business Strategy and the Environment 7 213-222*

Guardian (2002), Power to the people, http://www.guardian.co.uk/world/2002/dec/20/debtrelief.development

Guardian (2011), http://www.guardian.co.uk/environment/2011/dec/13/canada-pulls-out-kyoto-protocol

Hardin, G. (1968) The Tragedy of the Commons". *Science* **162** (3859): 1243–1248. 1968.

Hardin G., Russell, C. (1982). Collective action *Baltimore: Johns Hopkins University Press.*

Hartman, R.W. 1990. "One Thousand Points of Light Seeking a Number: A Case Study of CBO's Search for a Discount Rate Policy." *Journal of Environmental Economics and Management* 18: S-3-S-7

Heaver, T. (1995). The implications of increased competition among ports for port policy and management, *Maritime Policy & Management: The flagship journal of international shipping and port research Volume 22, Issue 2, 1995*

Holt, T., Lindeberg E.,(2007), "EOR and CO2 Disposal – Economic and Capacity Potential in the North Sea", the 4th Trondheim Conference on CO2 Capture Transport and Storage, Norway (Oct 16-17).

Hoornweg D, Sugar L, Gomez C: Cities and greenhouse gas emissions: moving forward. Environ Urban 2011, 23, in press.

House KZ, Harvey CF, Aziz MJ, Schrag DP. 2009. The energy penalty of post-combustion CO2 capture and storage and its implications for retrofitting the US installed base. Energy Environmental Sciences 2:193–205

Huang, Y., Rezvani, S. McIlveen-Wright, D., Minchener, A., Hewitt N. (2008) "Techno-economic study of CO2 capture and storage in coal fired oxygen fed entrained flow IGCC power plants," Fuel Processing Technology, vol. 89, 2008, pp. 916-925

IEA (2009), Tecnology roadmap: carbon capture and storage

IEA GHG (IEA Greenhouse Gas R&D Programme) (2004), Improvement in Power Generation with Post-Combustion Capture of CO2, Report Number PH 4/33, United Kingdom

IEA GHG (2005), Building the Cost Curves for CO2 Storage: European Sector, Report 2005/02, United Kingdom

IEA (2008b), Energy Technology Perspectives 2008, OECD/IEA, Paris

IEA Greenhouse Gas R&D Programme (2008), "Capturing CO2," 2007, http://www.ieagreen.org.uk/glossies/co2capture.pdf

Ipcc (2005), IPCC special report on carbon dioxide capture and storage

James, 2012, http://www.gospelnomics.net/2011/07/08/marginal-benefit-and-cost/

Jansen,E., J.Overpeck, K. R. Briffa,J.-C.Dup lessy,F. Joos,V.Masson-Delmotte, D. Olago, et al. 2007. "Palaeoclimate." In Climate Change 2007: The Physical Science Basis, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Avery,M. Tignor, and H. L. Miller, 433-98. Cambridge, UK: Cambridge UniversityPress.

Jordal, K., Anheden, M., Yan, J., Strömberg, L. (2004) "Oxyfuel combustion for coal-fired power generation with CO2 capture- opportunities and challenges," in 7th International Conference on Greenhouse Gas Technologies, Vancouver, Canada, 2004.

Kaul, I. and Grunberg, I. (1999), *Global Public Goods: International Cooperation in the 21st Century* OUP, 1999

Kerr, N., Niedermeier, K., Kaplan, M. (1999). Bias in jurors vs bias in juries: new evidence from the SDS perspective. Organizational Behavior and Human Decision Processes 80, 70–86.

Khatib, Z. (2006), "Clean Fossil Fuel Systems: Deployment and Dissemination", The World Energy Council, Cleaner Fossil Fuels for Sustainable Development Workhop, Neptune, Romania (June 13)

Kopelman, S. (2009). The effect of culture and power on cooperation in commons dilemmas: Implications for global resource management. Organization Behavior and Human Decision Processes, 108, 153-163. doi:10.1016/j.obhdp.2008.06.004

Korsten, A. (2011), De thermostaat van Nederland

Kreukels, A.M.J., Weve, E. (1998), North Sea Ports in Transition: Changing Tides, Uitgeverij Van Gorcum, 1998 - 156 pagina's

Kuuskraa, V.A. (2006), "Game-Changer Improvements in Oil Recovery Efficiency using CO2 EOR", First Regional Symposium on Carbon Management, Dhahran, Saudi Arabia (May 22-24)

Laughlin, P. and Ellis, A. (1986). Demonstrability and social combination processes on mathematical intellective tasks. Journal of Experimental Social Psychology 22, 177–189.

Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, (2007) Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 16-17.

Leeuwen, R. van, Krzyzanowski, M. (2000). Air quality guidelines for Europe 2nd edition, *WHO Regional Publications, Europe Series, No. 91.*

Lind, R.C. 1990. "Reassessing the Government's Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility." *Journal of Environmental Economics and Management* 18 (2): S-8-S-28.

Lyon, R.M. 1990. "Federal Discount Rate Policy, the Shadow Price of Capital, and Challenges for Reforms." *Journal of Environmental Economics and Management* 18: S-29-S-50.

Lowex (2012), www.lowex.net

Mahlman, J.D., 1997. Uncertainties in projections of human-caused climate warming. Science 278, 1416–1417.

Mair, P. (2003), Hoe gewoon is gewoon?, in: Beleid en Maatschappij, jrg. 30, 2003, nr. 2, pp. 142-144.

Martinsen, D., Linssen, J,. Markewitz, P., Vogele, S. (2006), CCS: A future CO_2 mitigation option for Germany? - A bottom-up approach, Energy Policy, Volume 35, Issue 4, April 2007, Pages 2110–2120

Marwell, Gerald; Ruth E. Ames (June 1981). "Economists Free Ride, Does Anyone Else? Experiments on the provision of public goods". *Journal of Public Economics* **15** (3): 295-310.

Meersman, Hilde; Pauwels, Tom; Voorde, Van de, Eddy; Vanelslander, Thierry (2007) Havenconcurrentie en hinterlandverbindingen in relatie tot de Ijzeren Rijn en de Betuweroute, *Tijdschrift voor vervoerswetenschap, 43(2007),* p. 35-43.

Miles, M., Covin, J. (2000) Environmental policy and industrial innovation: integrating environment and economy through ecological modernisation, Journal of Business Ethics, 2000 - Springer

MISHANE,.J. "The Relationship between Joint Products, Collective Goods, and External Effects," The Journal of Political Economy, May/June 1969, 77(3), pp. 329-48

Moel, M. (2010-08-30), Biomass in the port of Rotterdam - Position paper, 7.

NER300 (2012), www.NER300.com

Newell, R. and Pizer, A. (2003), Discounting the benefits of climate mitigation. How much do uncertain rates increase valuations? , Journal of Environmental Economics and Management, 46 (2003), pp. 52–71

Newell, R. and Pizer, A. (2004), Uncertain discount rates in climate policy analysis, Energy Policy Volume 32, Issue 4, March 2004, Pages 519–529

Nijdam, M, Lugt, L. and Bakker, B. (2012), Havenmonitor 2010, De economische betekenis van Nederlandse zeehavens

Nordhaus, W (1991) `To Slow or Not To Slow: The Economics of the Greenhouse Effect' Economic Journal, vol 101, no 6, pp. 920–937

OCAP (2012), www.OCAP.nl

Odenberger, M., Unger, T., Johnsson, F. (2008), Pathways for the North European electricity supply, Energy Policy, Volume 37, Issue 5, May 2009, Pages 1660–1677

Ostrom, Elinor (2000). "Collective Action and the Evolution of Social Norms". *Journal of Economic Perspectives* **14** (3): 137-158.

Plomp, A., Hekkenberg, M., Roeterdink, W., Wilde, H. de (2010-5), Verkenning CO_2-emissie Rotterdam HIC 2015/2020/2025, Update en precisering.

PoR, 2010, Jaarverslag 2010, 'Wereldklasse doen', http://www.portofrotterdam.com/nl/Havenbedrijf/financien/Documents/Jaarverslag-2010-HavenbedrijfRotterdam.pdf

Porter, M. E. *The Competitive Advantage of Nations,* Free Press, New York, 1990.

Porter, M. (1998), Clusters and the new economics of competition, *Harvard Business Review, november-December,* pp. 77-90.

Posner, R. A. "Theories Of Economic Regulation," Bell Journal of Economics, 1974, v5(2), 335-358

Praetorius, B., Schumacher, K. (2009), Greenhouse gas mitigation in a carbon constrained world: The role of carbon capture and storage; Energy Policy, Volume 37, Issue 12, December 2009, pages 5081-5093

RCI (2009-6), The new Rotterdam

Rotterdam (2009-6-11), http://www.rotterdam.nl/tekst:the_rotterdam_area

Rotterdam (2011), Investeren in duurzame groei, Programma duurzaam 2010-2014

Samuelson, P. (1954). "The Pure Theory of Public Expenditure". *Review of Economics and Statistics* (The MIT Press) **36** (4): 387–389

Shackley, D. Reiner, P. Upham, H. de Coninck, G. Sigurthorsson, J. Anderson (2009) The acceptability of CO2 capture and storage (CCS) in Europe: an assessment of the key determining factors. Part 2. The social acceptability of CCS and the wider impacts and repercussions of its implementation, *International Journal of Greenhouse Gas Control, 3 (2009), pp. 344–356*

Hone, D. (2012), The bureaucracy in Europe blinks, http://blogs.shell.com/climatechange/2012/07/blinks/

Shoup, D. (2006), Cruising for parking, Elsevier, Transport Policy 13 (2006) 479–486

Sims, R., Rogner, H. and Gregory, K. (2003), Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricty generation, *Energy policy 31, pp. 1315-1326*

Statline, 2012, Emissies van broeikasgassen, berekend volgens IPCC-voorschriften, http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=70946NED&D1=a&D2=0-4,10-15&D3=a&HDR=G2&STB=T,G1&VW=T

Stedin (2012-02-16), www.stedin.net/Informatie_voor/Pers/Persberichten

Steekelenburg, M., Stelpstra, C., Van Zijl, J. (20011), Van Mainport-Greenport naar Growport Samenwerking tussen de Rotterdamse Haven en het Westland/Oostland in 24 voorbeelden, SBN/EAN: 978-90-79307-03-6

Stevens, S., Kuuskraa V., Gale, J. (2000), "Sequestration of CO2 in Depleted Oil and Gas Fields: Global Capacity and Barriers to Overcome", Fifth International Conference on Greenhouse Gas Control Technologies Cairns, Australia (Aug. 13-16)

Sutter, M., Kocher, M. & Strauß, S. (2008). Individuals and teams in auctions. Oxford Economic Papers.

Svensson, R., Odenberger, M., Johnsson, F., Stromberg, L. (2004), Transportation systems for CO_2 - application to carbon capture and storage, *Energy Conversion and Management Vol 45, Issues 15-16 p. 2343-2353*

Taylor, D. (2011-05-20), http://www.globalccsinstitute.com/community/blogs/authors/derektaylor/2011/05/20/mystery-14th-project-insights-progression-europes-ner

Tetteroo, M and Van der Ben, C. (2011-11). Knowledge sharing report 10: CINTRA Business Model

Thaler, Richard H. (1988). "Anomalies: The Winner's Curse". *Journal of Economic Perspectives* **2** (1): 191–202. JSTOR 1942752

Tillie, et al. (2009), REAP : Towards CO2 neutral urban planning, 45th ISOCARP Congress 2009

Tol, R.S.J. (2005), The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties, *Energy Policy 33,* p. 2064-2074

Tongzon, J. (1995): Systematizing international benchmarking for ports. Maritime Policy and Management 2: 171–177

Tranier, J., Dubettier, R., Perrin, N. (2009), Air separation unit for oxy-coal combustion systems, in 1st International Oxyfuel Combustion Conference Cottbus, Germany, 2009.

UCAR (2012), http://www.ucar.edu/learn/1_3_1.htm

Uematsu, H., (1999). Asian shipowners forum and Japanese maritime policy issues. Maritime Policy Seminar, Japanese Shipowners Association and World Maritime University, 16–20 September 1999, Malmo, Sweden.

UNFCCC, 2012, Kyoto Protocol, http://unfccc.int/kyoto_protocol/items/2830.php/

University Corporation for Atmospheric research, http://www.ucar.edu/learn/index.htm

Verhey, L.F. (2007), Nulemeting CO_2 uitstoot, RCI, www.rci.nl

Volkskrant (2011), http://www.volkskrant.nl/vk/nl/2664/Nieuws/article/detail/2871460/2011/08/27/Nederland-probeert-met-dubieuze-kunstgrepen-Kyoto-te-halen.dhtml

Weber, M., Kopelman, S., & Messick, D. (2004). A conceptual Review of Decision Making in Social Dilemmas: Applying the Logic of Appropriateness Personality and Social Psychology Review, 8 (3), 281-307

Wiedmann, T. and Minx, J. (2008). A Definition of 'Carbon Footprint'. In: C. C. Pertsova, Ecological Economics Research Trends: Chapter 1, pp. 1-11, Nova Science Publishers, Hauppauge NY, USA. https://www.novapublishers.com/catalog/product_info.php?products_id=5999.

Worldbank (2012), http://data.worldbank.org/indicator/NY.GDP.MKTP.CD

Zero Emission Resource Organisation (2012), Air Liquide Green Hydrogen Project, http://www.zeroco2.no/projects/air-liquide-green-hydrogen-project

Appendix Interviews

This appendix shows which people were interviewed, what their professional role with regard to the RCI is and the interview questions are displayed.

Mr. F.D. van Heijnigen, former chairman of DCMR
Drs. G.J. van Tongeren, chairman Deltalinqs Energy Forum and boardmember RCI
Drs. A. van Huffelen, alderman Rotterdam and board member RCI
Ir. C.J. Asselbergs, director Deltalinqs and board member RCI
Mr. H. Schoenmakers, project director ROAD
Ir. H. de Wit, former director OCAP

1. How important is climate change in your professional and personal life?
2. Do you think the amount of emphasis paid to climate change and the climate challenge is too much, enough or too little?
3. How do you see the role of the government?
4. Regarding the previous question, what do you think of the structure of the RCI?
5. At which level should these processes be promoted (local, regional, national, supra-national)?
6. What is your opinion about the importance of different strategies to fight climate change in general and greenhouse gasses especially?
7. What are important partners for the PoR to work with regarding the RCI goals?
8. What would be the right ambitions and incentives for these partners and do you feel these are present at the moment and/or future?
9. The RCI depends largely on CCS, what is your opinion about this choice?
10. Will it become possible to store CO2 on a large scale and what will be the amount stored in 2025?
11. Storage capacity can become a constraint for CCS; do you think this will become a problem?

12. If not, where do you think capacity will be realized?

13. CCS is viewed as a transition solution, what are your thoughts about this regarding the period CCS is needed and the involved costs?

14. Do you think industry will develop technologies to capture enough CO_2?

15. How realistic are the ambitions of the RCI in general and for CCS in particular?

16. Rotterdam wants to develop CCS also as a business opportunity; do you believe this market will develop?

17. How would you value the position of Rotterdam in this CO_2 market?

18. Will the RCI become a burden or an asset to the port?

19. Will the RCI be a burden of an asset for your company?

20. Did you miss any questions and/or do you have remarks?