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Editorial

Overview and analysis of the Dutch CCS program as a knowledge network

1. Introduction

In 2007 the Intergovernmental Panel on Climate Change (IPCC) indicated in its fourth Assessment Report that a further rise in CO_2 emissions could lead to a temperature increase in the range of 4–7 °C, with major impacts on the environment and human activity (IPCC, 2007). It was widely recognized that setting CO_2 reduction goals would be required to mitigate the anticipated climate effects and that carbon capture and storage (CCS) should be considered a necessary measure to meet these reduction goals. Also in the Global Energy Assessment of 2012, CCS is considered an important measure to reach climate targets (GEA, 2012). The International Energy Agency foresees an important role for CCS in climate change mitigation (IEA, 2011 and IEA, 2012).

As a necessary step towards full deployment of CCS, the European Union proposed in 2007 to implement a range of large-scale demonstration projects within a 10–15 years period (EC, 2007). The Dutch government stated the ambition to realise one or two of these large scale demonstration projects in the Netherlands by 2015 and to become a CCS frontrunner in Europe (TK, 2009). To this end a "National Taskforce CCS" was established in 2008 as a public/private initiative. At that time it was further concluded that continuation of the Dutch CCS R&D programme CATO[1] (2004–2009) would be essential in providing the necessary knowledge and technical support for the Dutch demonstration projects.

In 2009 the CATO-2 programme was established with a mission to facilitate the integrated development of CCS demo sites in the Netherlands, to work on innovation for new CCS generations, and to build a strong knowledge network around CCS. CATO-2 aims to integrate the full CCS chain, including – in addition to capture, transport and storage – public perception and legislation. The programme covers both fundamental and applied research on all these topics.

The aim of this special issue is to provide an overview of the work done in the CATO-2 programme. This overview can by no means be regarded as complete; the CATO-2 programme plan states some 500 formal deliverables and it is expected that around the same number of journal papers and presentations (both oral and poster) will become available.

In this editorial we discuss three topics. First we give a short overview of the full programme and show how the articles of this issue fit into the programme. Secondly we analyse the contribution of CATO-2 to the global CCS scientific knowledge base. Does the integrated focus of the CATO programs lead to a different type of knowledge output than mono-disciplinary programs? We will go into some detail on the integrated nature of the CATO programmes and explain which structures and procedures were used to realise this. Furthermore, a quantitative analysis of the scientific output of the CATO programme in relation to the total CCS field is used to create insight in the contribution of CATO-2 to the global CCS knowledge base. Finally we analyse the contribution of CATO-2 to Dutch society.

2. CCS research in the Netherlands

The Netherlands have seen a long tradition in CCS research. First papers date back to the end of the 1980s. Since then, Dutch universities and research institutes have participated actively in both national and international research programmes. Plans to set-up a national R&D programme on CCS date back to 2000, resulting – after four years of preparation - in the kick-off of the first CATO programme in 2004. CATO-2 as the successor of the first CATO programme was launched in 2009 – after preparations had started in 2008 - and is expected to last until 2014.

The preparation time for the CATO-1 and CATO-2 programmes can be seen as an indication of the political interest in CCS in the Netherlands. Whereas in 2000 CCS did not play a significant role in Dutch politics (despite the launch of the K12B storage pilot), the "clean and efficient programme", which included an announcement of the Dutch government to participate in the European demonstration programme, apparently changed the political landscape and allowed for a swift launch of the CATO-2 programme. And whereas in 2004 only some 15 partners were attracted to participate in CATO, in 2009 nearly 40 parties (including the power sector) were prepared to join the CATO-2 programme.

For various reasons (among which its geographical location near the North Sea and relatively large domestic natural gas resources) power supply in the Netherlands is largely based on coal-fired and gas-fired power plants. A situation that – in view of the number of newly built fossil-fired plants – is expected to remain unchanged for a significant amount of time. In particular for the Netherlands, CCS can be a valuable means in the transition to a sustainable society.

The conditions to set-up CATO-2 were quite favourable. The first CATO programme established a CCS network and developed part of the skills and knowledge base necessary to implement CCS in the Netherlands. In the meantime, the interest from the Dutch government in CCS increased. External experts therefore regarded CATO-1

[1] CATO is the Dutch acronym for carbon capture, transport and storage. Appendix A presents some figures on the programme.

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http://dx.doi.org/10.1016/j.ijggc.2012.11.004

Table 1
Number of registrations for the bi-annual Dutch CCS conferences.

Ocassion	Date	# of Subscribers
1st Dutch CCS conference	November-2005	196
2nd Dutch CCS conference	December-2006	304
3rd Dutch CCS conference	April-2008	440
4th Dutch CCS conference	April-2009	353
5th Dutch CCS conference	June-2010	213
6th Dutch CCS conference	May-2012	147

as a welcome gift to the government as CCS became an important part of the new Dutch climate change policy (Thambimuthu, 2007).

At the time CATO-2 plans materialised, major industrial parties in the Netherlands were engaged (or preparing to engage) in a number of small scale CCS pilots as well as two integrated large scale demos. In this respect the technology demand from industry was clear and present. This is also reflected in the attendance records of the Dutch CCS conference (see Table 1). The first conference was held in November 2005 with almost 200 participants; attendance increased to 440 in 2008. The conference in 2008 coincided with the deployment of the CATO CO_2 catcher at the E.ON coal-fired power plant on the Maasvlakte in the Rotterdam harbour area. After 2008, the number of participants has gradually declined. One of the reasons for this decline is the delay and cancellation of some of the CCS pilot- and demonstration projects in the Netherlands.

3. The CATO-2 programme

CATO covers the entire CCS chain – including legislation, risk and public perception. The CATO-1 programme was more focussed on fundamental research, whereas CATO-2 addresses the full innovation loop from fundamental (discovery type of) activities to development and deployment activities. One of the objectives of the programme is to integrate activities, both in relation to the research themes (Fig. 1, vertical axis) and with the technology readiness level (Fig. 1, horizontal axis). In Fig. 1 the activities in CATO are illustrated on both axes. The number of activities decreases when the technologies mature. For example several fundamental research projects on new generation capture technologies are included in the programme, whereas in the application only a few technologies are deployed. When the technology is in the deployment phase the activities are linked to a concrete project on a location. The red lines suggest knowledge accumulation.

The programme is structured to facilitate this approach and is based around a matrix with the research themes as the rows and the locations of projects as columns see Table 2. In addition to the actual CCS sites where capture, storage and integrated technology is deployed on Location 1, 2, 3, 4 et cetera, columns have been added to the matrix for projects that have a general applied nature and for projects that should be regarded as strictly fundamental. Location

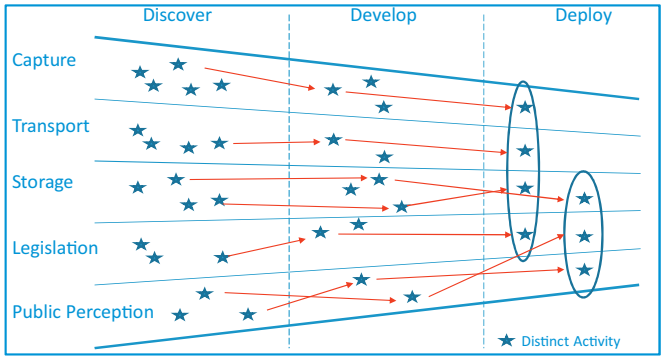

Fig. 1. Activities in CATO programme.

Table 2
Organisation structure of the CATO-2 programme as a programme matrix.

Sub-programs	Fundamental	General applied	Location specific			
			L1	L2	L3	L4
Capture	x	x	x		x	
Transport	x	x		x	x	x
Storage	x	x	x	x		
Legislation	x	x	x			x
Public perception	x	x	x		x	

*L = location of a demonstration project

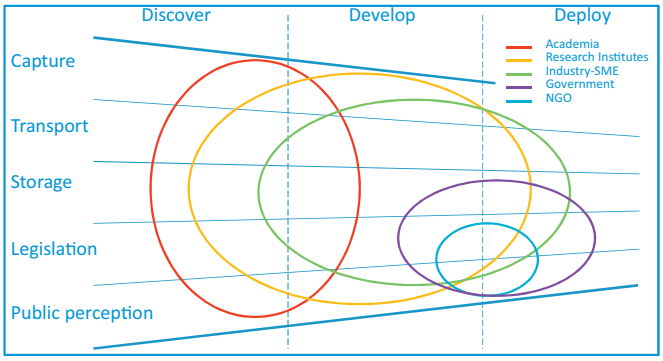

Fig. 2. Involvement of the different organisations in the CATO-2 programme.

specific activities, in particular those locations connected to integrated demo projects, steer R&D activities in all research themes. More importantly they also steer the interaction between these research themes (see Table 2). In Section 6 we will analyse whether this integration is realised in practice.

Some 40 partners and around 400 persons participate in the CATO-2 programme. The participants can be divided into 5 clusters: Academia, Research Institutes[2], Industry (+SME), NGO, and Government. Fig. 2 gives an impression of the participation of the partners in the various research themes and the technology development phase. Whereas industry is involved in the full CCS chain, Government and NGOs participate in a limited number of themes only. In CATO-2 R&D activities in the fields of legislation, risk, and public perception are of specific interest to NGOs and government. The research themes are divided into separate work packages that can be classified as discover, develop, or deploy. A group of stakeholders has been assigned to each work package. Based on the classification of these work packages and the stakeholders involved in each of them, a global idea can be obtained of stakeholder involvement as a function of research theme and technology readiness (Fig. 2).

The total budget of the programme is 60 M€, with equal private and public contributions. From a budget point of view the research focus of the programme lies on capture and storage (around 35% and 20% respectively). The remaining budget is split between transport, legislation and risk, and public perception. Programme management and dissemination activities both take some 5% of the budget. With respect to Technology Readiness levels the emphasis is on development (>50%). Fundamental activities take some 25% of the budget. Deployment activities are to a large extent carried out in parallel to the programme by the industrial parties.

All parties were invited to participate in an iterative earmarking process which allowed them to assign budget to the Work Packages defined in the programme matrix. For those Work Packages (WPs) that showed sufficient stakeholder support (and hence attracted

[2] The Netherlands has several Research Institutes, like TNO and ECN. They are partly government funded. Their focus is on applied research and technology development rather than on fundamental research.

Table 3
An overview of the locations that were included in the original programme plan.

Location	Responsible party	Description
CO2 Catcher Maasvlakte	E.ON	Capture pilot, post-combustion, small-scale
Barendrecht	Shell	Storage/transportation/legislation pilot, depleted gasfield, onshore
Delft Aard-warmte Project	TU Delft	Injection/production pilot, (geo-thermal) aquifer, onshore
K12-B	Gaz de France	Injection/production pilot, producing gasfield, offshore
Q8-A	Wintershall	Storage pilot, depleted gasfield, offshore
Maasvlakte and P15/P18	ROAD (EON, GDF, TAQA)	Integrated demo, post-combustion capture, storage in depleted gasfield, offshore
Eemshaven	RWE	Integrated demo, post-combustion,capture, storage in depleted gasfield, onshore
Eemshaven	NUON	Integrated demo, post-combustion, capture, storage in depleted gasfield, onshore
CO2 Catch-up Buggenum	NUON	Capture pilot, pre-combustion, small-scale
Chemelot	DSM Agro	Storage pilot, aquifer, onshore

sufficient budget) a detailed WP description was drafted taking into account input from those parties that explicitly earmarked these WPs. WPs that did not attract sufficient support were discarded and the assigned budget was re-allocated by the stakeholders.

The earmarking process was also used to assign stakeholder groups to individual work-packages. These stakeholder groups still serve as sounding boards for the individual WP leaders (e.g., when changes to the WP scope are considered) and are involved by the management in the review and approval of all deliverables prepared by the WP. Special attention was given to the integration of PhD students- and post-doc projects in the programme. Over 40 of such projects are executed and it was ensured that for each of these projects a user group was formed that included stakeholders from the deployment clusters (Industry, Government, NGOs).

As indicated, CATO-2 is built around CCS Locations and CCS Research Themes. Some of these locations address single themes in the CCS chain, others address multiple themes, or are fully integrated. Some of the fundamental work is not directly related to specific locations, whereas some of the more general applied work may relate to multiple locations. An overview of CATO-2 locations is given in Table 3. It should be noted that for several of the locations activities have been discontinued. For example the Barendrecht project where CO_2 storage was foreseen by Shell, with CO_2 from a refinery, was cancelled by the national government mainly due to local resistance. Later the national government banned all onshore storage, which resulted in the postponement of CCS at power plants in the Northern Netherlands (Eemshaven RWE and Eemshaven NUON).

Table 4
Subprogramme lines in CATO.

Number of SP*	Full name of subprogramme
SP0	Coordination & dissemination
SP1	Capture
SP2	Transport & chain integration
SP3	Storage & monitoring
SP4	Regulation & safety
SP5	Public perception

* SP = Subprogramme.

As presented in Table 4, the programme has five Subprogramme lines (SPs) around respective Research Themes. A separate SP 0 on coordination and dissemination has been defined.

4. Articles in special issue

This special issue contains 13 articles, covering the whole CCS chain and respective technology development phases. Two articles are directly related to demonstration projects (Arts et al., 2012; De Miguel Mercader et al., 2012). The other papers range from fundamental to applied research.

Arts et al. (2012) describe some of the storage issues related to the ROAD demonstration project, with particular attention to pressure issues during injection of CO_2 in the almost fully depleted P18 gas field. The inability to properly describe the behaviour of the CO_2 near the well under specific P18 conditions using existing well/reservoir models led to the fundamental research described in the paper by ZiabakhshGanji and Kooi (2012) and is an example of how issues in the deployment phase can influence fundamental research.

Draganov et al. (2012) describe a new method of monitoring stored CO_2. Their work is fundamental but could be applied in the near future. Other more fundamental work on the storage is presented by Salimi et al. (2012): they contribute towards a better understanding of the reservoir modelling. Raoof et al. (2012) propose a new model to predict the degradation of the wellbore cement. As the leakage via the well is seen as one of the most important potential risks their fundamental work may easily find its way towards application. Another contribution to a better understanding of risks is the work of Samuelson and Spiers (2012). They modelled seismic activities in the subsurface due to CO_2 injection for a North Sea reservoir. The last paper on storage deals with the interaction between water and coal (Shojai Kaveh et al., 2012). This so- called wetting behaviour of the coal influences the CO_2 storage capacity in coal layers.

In the field of capture, De Miguel Mercader et al. (2012) present a case study on post combustion capture at a coal fired power plant (similar to the Eon plant in the ROAD project). They describe an integral evaluation of the energy needed for the capture plant in order to reduce the energy penalty. In the applied paper of Sanchez Fernandez et al. (2012) a techno-economic evaluation is made of the post-combustion process. Within the CATO programme pre-combustion capture is examined as well. An example is the more fundamental work of Boon et al. (2012) on the use of palladium membranes to separate hydrogen.

As described before, the CATO programme not only deals with technology related research but also with social issues like public perceptions. Ter Mors et al. (2012) give an overview on compensation options for local communities. A survey on the general public was held by De Best-Waldhober et al. (2012a,b). They measured the knowledge and perception of CCS and analysed to what extent misconceptions influence the perception of CCS. Van Egmond and Hekkert (2012) give an overview over the arguments pro and con CCS and discuss their validity for the different CCS chains.

As indicated the selection of papers published in this special issue by no means provides a full overview of the work done in the CATO programme. Other high-quality papers have been recently published – or will be published in future – regular issues of this journal (and other journals).

5. Scientific impact of CATO

In this section we analyse the scientific output of CATO. The research done in CATO is reported in deliverables (e.g., reports, PhD thesis, conference papers, computer models). An overview of the results of CATO-1 is given in De Visser et al., 2009. It is expected that in CATO-2 over 500 deliverables will be produced. Since the type and size of the deliverables vary considerably, it is almost impossible to use these numbers as an indication for the qualitative and/or quantitative output of CATO. As an alternative we propose three methods to get an indication of the output. The first is CATO's contribution to international literature, the second is the expert opinion about the programme's output. As a final indicator we use the participation of CATO partners in other (international) research projects.

5.1. Contribution to international literature

5.1.1. Methodology

There is a wealth of data available on knowledge generation as archived by the Web of Science from Thomson Scientific in the form of the Science Citation Index. In our literature search we used keywords "carbon and capture and storage" for the time frame 1990 (when these keywords first appeared) till November 2011. Please note that this search string represents the core of the field, but does not capture the entire field of CCS. However, using other keywords would introduce more ambiguity in the dataset making interpretation more difficult. By taking a smaller sample, it is still possible to compare the Dutch contribution with the rest of the world. All data found from the Web of Science contain institutional addresses, the papers provide keywords, cited references and Journal names. The database thus enables us to specify the number of publications, the locations, cited references and their topics (as indicated by keywords) of all research organizations over a period of time. We assume that most Dutch publications in this field are made by partners of CATO. In our analysis we therefore use the country of the institute from the author(s) to define whether the research is related to CATO. We will verify with the results if this assumption is correct.

The number of published papers is a parameter for the productivity of the programme, but not necessarily for the impact of the papers. We therefore also analyse how often the papers are cited by other scientific papers.

5.1.2. Results

We were able to retrieve 1451 publications from the Web of Science. Publications on CCS have appeared from the early 1990s onwards, but the number rapidly increased in recent years, making the number of papers from 2009 onwards the majority. As can be seen from Table 5, the US contributes more than half to the CCS knowledge base. There were 105 publications with at least one Dutch author. Based on this selection the Netherlands is ranked on the 7th place. The Netherlands contributes to over 7% of the global scientific output in CCS, which is about triple its share in the total global scientific output (UNESCO, 2010). Note that the total number of publications in Table 5 is more than 1451, due to the fact that papers can have authors from more than one country.

Papers by CATO partners versus Dutch knowledge base. Within the Netherlands, Utrecht University (29) and ECN (18) are the main contributors to the field. Utrecht University was the fifth institute worldwide publishing on CCS, after 4 American institutes and one British institute. In type of contributor, universities and knowledge institutes take the lead, both for the Dutch selection as for the total 1451 publications. Shell was the only industrial party in the Dutch selection.

Table 5
Top 10 countries of publications with keywords Carbon and Capture and Storage, where at least one author of that country contributes.

Rank	Country	Number of publications	%
1	USA	791	54.5
2	England	232	16.0
3	Germany	135	9.3
4	France	131	9.0
5	Peoples R China	128	8.8
6	Australia	123	8.5
7	Netherlands	105	7.2
8	Canada	101	7.0
9	Norway	84	5.8
10	Sweden	76	5.2

Of the 105 Dutch publications, 19 were published by institutes that do not directly participate in CATO. Seven of these publications are from the European Union's Joint Research Centre based in Petten, the Netherlands. Being an EU centre, they do not (directly) contribute to the Dutch knowledge base. Another 5 publications are made by Dutch government bodies. They are no official partners of CATO, but they do participate informally in CATO. This leaves 7 publications from Dutch institutes that do not participate in CATO.

5.1.3. Conclusion

Based on the publications, the Netherlands' 7th position puts them among the forerunners of knowledge production on CCS. Since almost all publications are produced by partners of CATO, one could indeed state that CATO is the core of the Dutch CCS knowledge base.

5.2. CATO partners participating in EU programmes

Another indirect indicator of the quality of the research is participation of the partners in international programmes. We assume that partners are able to participate in international research programmes because of their specific expertise and quality. On the other hand participation in international programmes results in a knowledge transfer towards the CATO programme. We used the EU Cordis database[3], which covers the research and development programmes sponsored by the EU, to make an inventory of the CCS related programmes (CORDIS, 2010). The data covered the so-called fifth, sixth and seventh RTD Framework Programme (FP5, FP6 and FP7). This spans the period 2000–2010, when the inventory was made. The programmes varied from very specific CCS research, like NANOGLOWA that focused on nanostructured membranes for CO_2 capture at power plants, to more general CO_2 reduction programmes where CCS was only one of the topics, e.g. ULCOS, which focused on Ultra-Low CO_2 steelmaking.

5.2.1. Results

We identified 48 EU programmes. In 41 of these programmes one or more CATO partners participated, with an average of almost 3 per programme. In 10 cases the CATO partner was the coordinator. TNO participated most in EU programmes (24 times), followed by several industrial partners such as Vattenvall, E.ON, Shell and RWE. Whereas the scientific output of the universities in terms of publications was highest among CATO participants, their participation in the EU programmes is low. Twente University has the largest share (5 times).

[3] Community Research and Development Information Service (CORDIS), is an information space devoted to European research and development (R&D) activities and technology transfer.

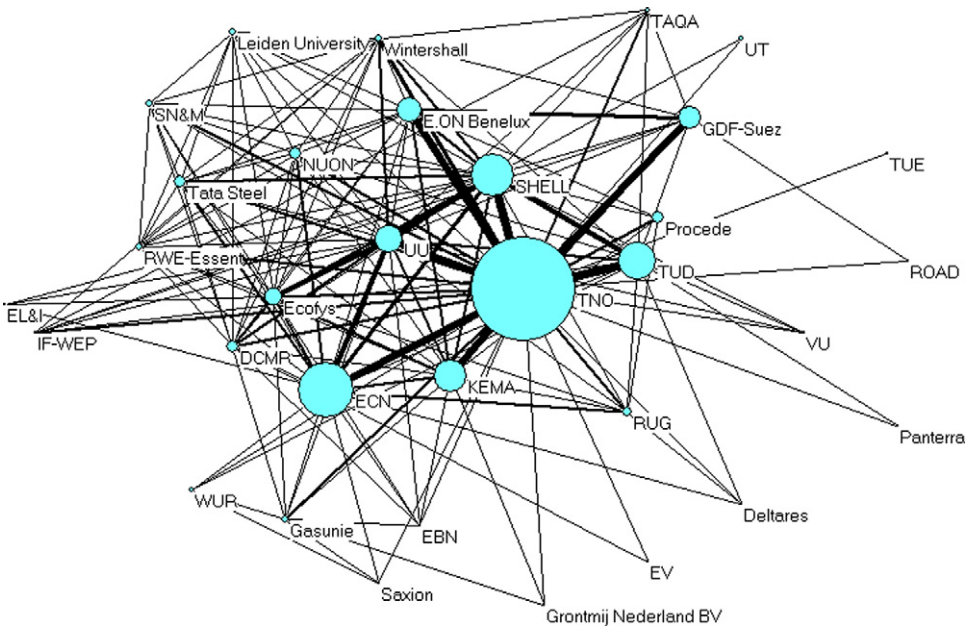

Fig. 3. Network visualisation in work package participation of CATO.

5.2.2. Conclusion

The CATO partners are very well represented in the EU research en development programmes. Therefore, it is likely that CATO knowledge is effectively dissiminated to other European knowledge institutes through cooperation in European Framework programmes.

6. CATO as a knowledge integrating environment

In this section we describe the interaction within CATO, both from the horizontal and the vertical perspective.

6.1. Horizontal interaction (between knowledge clusters)

Within CATO all the work is split into 5 research subprogrammes and these subprogrammes are divided into 53 work packages. We analysed the participation of the almost 40 partners in CATO-2 in the work packages. We defined participation in a specific work package as paid activities that are done or planned. TNO participates in the highest number of work packages (38 out of 53), followed by ECN (19), Delft University (13) and Shell (12). On average a work package consists of almost 6 organisations. This network is graphically presented in Fig. 3. The figure clearly shows the central position of TNO in the programme. The other two knowledge institutes, ECN and KEMA, play an important role as well. The focus of these two organisations is on capture and system integration, whereas TNO covers almost all topics. Shell is an important partner as well; they participate in almost all of the main topics as well.

The size of the dots in Fig. 3 indicates the total number of work packages in which the institute participates. The thickness of the line indicates the number of joint participants in the work packages. When participation of parties in work packages is divided according to type of research (Discover, Develop, Deploy), Fig. 4 can be made.

The numbers outside the triangle in Fig. 4 indicate the number of work packages in which both adjacent clusters participate. Hence there are 11 work packages in which Discover and Deploy organisations participate jointly. The numbers inside the figure give the same number, but only for those work packages without participation of the third cluster. So, there is only 1 work package with joint participation by Discover and Deploy without a contribution of the Develop cluster. This illustrates once again the importance of the Develop cluster as an integrator in the programme. In ten of the work packages all of the three clusters, Discover, Develop and Deploy participate. In 16 of the work packages only one cluster participates. This means that in those work packages knowledge transfer between the different clusters is not integrated in the structure of the programme. This occurs mainly in the Develop cluster. The industry may often be interested in the work, but they do not actively perform research themselves in those work packages. Based on the formal relations in CATO one may conclude that the cooperation between the clusters is good, as in 70% of the work packages two or more clusters participate. Another conclusion is that the Develop cluster is the focal point of the research in the programme.

Beside the formal structure that supports the interaction within CATO, the programme management pays a lot of attention to more informal activities. These activities contribute to a better integration of the programme. A good example is the annual CATO symposium, where the research is presented to CATO community. This gathering is open only to CATO participants. The subscriptions to this day may be seen as an indication for one's interest in the results and progress of the programme.

In Fig. 5 the subscriptions for CATO days are divided according to the type of subscriber organisation. This figure illustrates that

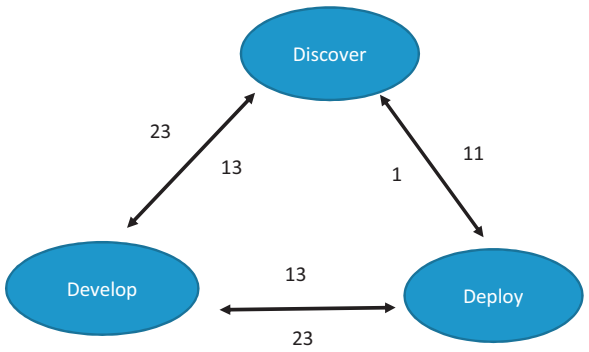

Fig. 4. Participation of different clusters in work packages. Based on paid activities in work packages, total work packages = 53.

Fig. 5. The share of each cluster in the annual CATO meetings The CATO day in 2007 was open for electricity companies. However, these organizations only became official members of CATO-2 in 2009, and they were not invited in 2008. They contributed almost 15% of the subscribers in 2007.

all three clusters (Discover, Develop and Deploy) contribute to the CATO community. At the start of the programme, in the CATO-1 phase, universities (Discover) were the main participants. The share of the Development cluster gradually increased and they became the largest contributor from 2008 onwards. The participation from industry (Deploy) increased as well, however this peaked in 2009, and declined afterwards. The decrease of interest from industry can be explained as most of the CCS demonstration projects were stopped or postponed.

6.1.1. Conclusion

Within CATO the Deploy cluster plays a very important role: it transfers knowledge from the Discovery to the Deployment sector. The interest of the industry is strongly related to the possibilities of demonstration projects; however these opportunities have been strongly reduced in the last year, resulting in a decline of interest of industry.

6.2. Vertical interaction CCS chain

6.2.1. Methodology

In this section we analyse the knowledge integration in CATO-2 between the several disciplines of the CCS chain. For example research on capture originated from disciplines like chemistry and process and separation technology, whereas storage issues are related to geology fields such as reservoir engineering. On the other hand issues related to public acceptation have their roots in the social sciences, at quite some distance from the natural sciences. First we carry out a general analysis of the disciplinary organization of knowledge production in the CCS field.

Leydesdorff and Rafols (2011) have shown that journal-journal citations can be used as an operational indicator for the disciplinary organization of knowledge production. We have used the method for delineating specialties as described by Cozzens and Leydesdorff (1993). This method is based on a factor analysis of the journal-journal citations matrix of the core journal of a specialty, the 'central tendency journal'. In this case, The International Journal of Greenhouse Gas Control (IJGGC), publised by Elsevier, provides a starting point for the analysis. The International Journal of Greenhouse Gas Control focuses on scientific and engineering developments in greenhouse gas control through capture and storage at large stationary emitters in the power sector and in other major resource, manufacturing and production industries. It comprises both technical and non-technical related literature in one volume.

Table 6
Top 10 of countries publishing in IJGCC (at least one author of that country contributing to a paper in IJGGC).

Rank	Country	Number of publications	%
1	USA	216	22.3
2	Germany	89	9.2
3	Australia	84	8.7
4	Norway	75	7.8
5	England	67	6.9
6	Japan	61	6.3
7	Canada	52	5.4
8	Netherlands	52	5.4
9	Peoples R China	45	4.7
10	France	41	4.2

For every year, we determine the relational citation environment of that journal, using a threshold of 1% in the citing dimension. For the resulting set of journals we can make the journal-journal citation matrix, with the citing behavior as the variables. One can expect strong citation relations within and between journals belonging to a discipline, and (much) weaker relations with other journals.

As the International Journal of Greenhouse Gas Control is now becoming the core publication of the CCS field, we compare the Dutch share in this journal with our sample based on the keywords (See Section 6.1). As we assume that the Dutch knowledge is more oriented around the CCS topic, rather than organised via mono disciplines, we expect that Dutch papers will be overrepresented in the IJGGC, so more than 7%.

6.2.2. Results

Fig. 6 provides the wider journal environment in which IJGGC is positioned. IJGGC is a central node in a very multidisciplinary environment. Several clusters of journals (representing different disciplines) are connected through the journal. Prominent neighbouring disciplines include a cluster of geosciences journals, environmental sciences, engineering journals and energy sciences. The network visualization thus confirms the hypothesis of a very dispersed multidisciplinary knowledge base.

6.2.2.1. Contribution of countries to IJGCC. We found 471 papers in the IJGCC. In Table 6 the top 10 of countries that contribute to this journal is presented (note that almost the same countries as in Table 4 are mentioned here). As in the generic sample on CCS, the US again contributes most to the knowledge base. The Netherlands is ranked on 8th place, one place lower than in the generic sample. Also the relative contribution of Dutch papers is lower, from 7.2% in the generic case to 5.4% in the IJGGC.

Another observation from Table 5 is that the distribution of countries is more flat in the IJGGC than compared with the selection presented in Table 4. For example the contribution of the US, number one on both rankings, more than halved from 55% to 22%. Only Japan (4.7% to 6.3%) and Norway (5.8% to 7.8%) contributed relatively more towards IJGGC.

If publication in IJGGC is seen as a proxy for the multidisciplinary character of a paper it cannot be generally concluded that the Netherlands is more focused on the multi-disciplinary IJGGC than on more mono-disciplinary journals when it comes to CCS.

6.2.2.2. Dutch contribution to IJGGC. When we look at the contributions of the CATO partners to IJGGC, as in the other sample Utrecht University is leading with 13 publications, followed by ECN (10), TNO (6) and Shell (6). All Dutch contributions to IJGGC were made by CATO partners. In the generic sample the Dutch universities scored relatively higher than in the IJGCC. Apparently IJGCC is relatively more attractive for knowledge institutes like ECN and TNO

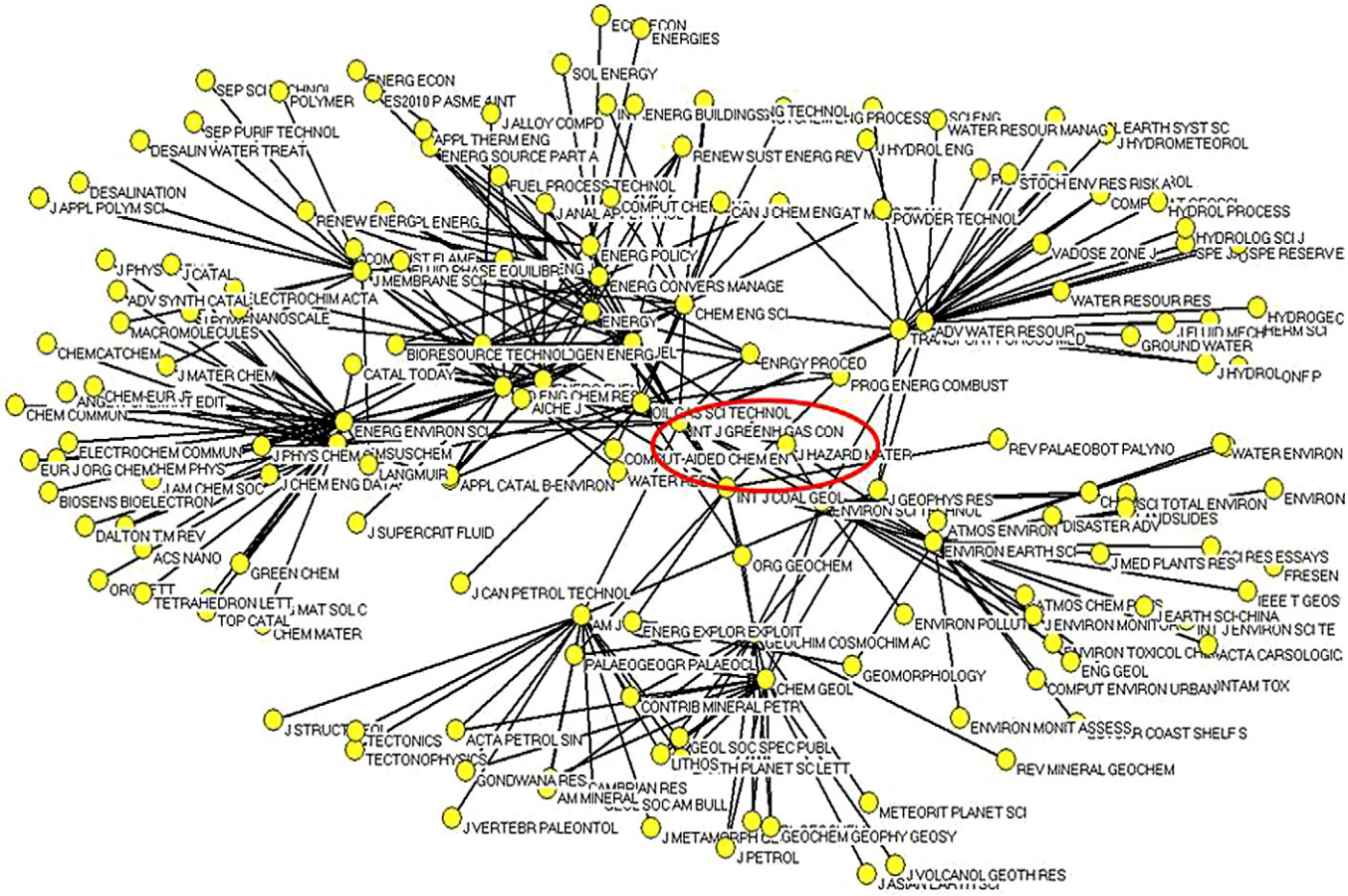

Fig. 6. Network visualization of CCS publications. Each yellow dot is a scientific journal.

and companies, suggesting that this journal is less focused on fundamental research.

6.2.3. Examples of interaction in practice

The analysis above is based on quantitative data of written scientific output. Beside this formal cooperation we also see interaction on a more informal base.

At least twice a year meetings are organised for the whole CATO community. Although part of the programme is reserved for the exchange of in-depth knowledge among kindred spirits, we strongly encourage sessions on general CCS issues and integration of different disciplines. For instance, we invite experts on storage to participate in discussions on public perception and encourage the non-geologists to test and enhance their knowledge on storage issues.

Although these type of activities help to get a better understanding of each other's scientific field, joint projects are essential for true integration. As an example the full impact of CO_2 impurities and flexible volumes of CO_2 captured (for power plants not operating at full load) only became evident when capture, transport, and storage were jointly addressed in the discussion on the ROAD project.

6.3. Conclusion

Although cross-disciplinary interaction is strongly encouraged in CATO, especially around pilot plants and demonstration projects, this is not (yet) reflected in the scientific output. To some extent this may be due to the large number of CATO-1 papers incorporated in the analysis (CATO-1 might be regarded as more fundamental and mono-disciplinary).

7. CATO's contribution to Dutch society

CATO-2 aims to facilitate the integrated development of CCS demonstration sites in the Netherlands, to work on innovation for new CCS generations, and to build a strong knowledge network for CCS. In other words, the research programme has a clear focus on knowledge development. However, a new technology cannot be implemented unless it is accepted by society. The Subprogramme on public acceptance has developed a strong knowledge bases on this issue (e.g Terwel (2008), Ter Mors (2008), Terwel and Daamen (2012)). However, the responsibility of the consortium goes further since it is (partly) financed by the tax payers. There have been many discussions about what CATO-2 can and may do to prepare Dutch society for CCS by other means than research. These opinions have also changed in time. The principle that CATO adheres to is that the programme should disseminate knowledge in a correct, value-free and independent way. Although most scientists within CATO are convinced that CCS is needed to mitigate climate change and can be applied in a safe and acceptable way, they do not want to become CCS advocates. Scientific papers clearly fall outside the scope of advocacy, yet at the same time by their scientific nature are almost inaccessible for Dutch society to influence their opinion on CCS. However, it is important for society in general to have access to proper knowledge in order to make a judgment whether and how CCS can be implemented.

At the start of CATO-1, in 2004, the consortium restricted itself to the realm of universities and knowledge institutes. Outside the academic world, hardly any interest existed for CCS. The communication activities were more or less restricted to the scientific community and aimed at network building within CATO. During the programme the interest of industrial partners, policy makers,

media and local residents on CCS increased, mainly due to the development of CCS demonstration projects, e.g. the Shell Barendrecht project. This resulted in an increase of media coverage and debates in parliament, among other things. As a consequence, the need arose for accessible and independent public information on the pros and cons of CCS. At the same time the national government was very reluctant to communicate on CCS towards the general public. CATO stepped into this void and started being more proactive in public communication by providing the necessary input for an informed debate on CCS. The development of the relationship between CATO and the Dutch media, NGOs, scientists, local and general public is described below.

7.1. Media

The CATO programme management believes that an open relationship with society, including journalists, is crucial for the acceptance of a new technology like CCS. In some cases, however, the media do not present the relevant information or, even worse, present wrong information. CATO-2 therefore created a team that actively follows the media and refutes misconceptions in the media by giving the facts in a balanced way. An example of this approach is the case around a possible CO_2 leak at the Weyburn project in Canada in January 2011 (PTRC, 2011). CATO responded fast with balanced statements to the journalists. The result: several informative articles in national newspapers e.g. NRC (2011).To build a more structural relation with journalists, CATO also invited science journalists of the main Dutch newspapers to participate in a geological excursion to the Eiffel in Germany where natural CO_2 release occurs. During this excursion scientists shared their insight in geology with the journalists and CO_2 releases from the deep surface were put into perspective. An important result of the trip was that the scientists and journalists got to know each other better. This was necessary since, after some preceding biased media coverage, CATO scientists had become very cautious about talking to journalists. They were afraid that their words would be misinterpreted and misrepresented in the media.

Our impression is that the relationship between CATO and science journalists is reasonable; they know where to find each other when necessary.

7.2. Environmental NGOs

From the start of the programme a lot of effort has been devoted to get organisations involved in CATO with different ideas on CCS. In CATO-1 the environmental NGOs, for instance Greenpeace and WWF, participated in the programme. The mission in CATO-1 was to investigate whether CCS can contribute toward a sustainable Dutch energy system and to build a knowledge network as a basis for the implementation phase of CCS. This is more open than the current mission which focuses on supporting the implementation. Although it is still highly encouraged and possible to participate in the programme regardless of your opinion on CCS, some NGOs, such as Greenpeace and the North Sea Foundation decided to end their participation. It was no longer expedient for them to participate in the programme in an official capacity, co-operating with CCS project developers. As a consequence, opinion on CCS in CATO has become less varied. The balance has moved slightly towards a pro CCS attitude. This has been observed worldwide in the CCS community by one of the CATO participants De Coninck (2010).

In order to counterbalance this development, the CATO programme office has encouraged the exchange of different opinions about CCS. One example is the production of the CCS Argument Map, containing all pros and cons on CCS. Both advocates and critics were consulted when preparing this tool (Van Egmond and Hekkert, 2012). This map was printed in the one of our national newspapers (Volkskrant) with a balanced comment.

Our impression is that the relationship between CATO and NGOs is poor: they each travel their own separate paths.

7.3. Critical external experts

As part of the dialogue CATO also wants to facilitate the debate between critical scientists, within and outside CATO. For example, a workshop was organised on the safety of CO_2 transport at the Barendrecht project. In this workshop experts from within and outside the CATO programme participated together with some concerned inhabitants. Even though their initial ideas on the Barendrecht project were very different, this workshop bridged some of the gaps between the different participants. A number of science journalists participated in this workshop as observers.

7.4. Local residents

In the original CATO-2 programme plan a local dialogue process was foreseen. That should have been a test case of the ideas developed at Leiden University in the CATO-1 programme. Unfortunately, after cancellation of the Barendrecht pilot project – and in view of the on-going public debate – all onshore storage projects in the Netherlands have been postponed by the national government (TK, 2011), making it but impossible to test the approach in reality. The generic work on public perception, however is unaffected.

7.5. The general public

The initial CATO website on CCS was written in English and focused on the scientific community (www.co2-cato.org). Since December 2011 – as it was difficult to find non-scientific information on CCS – CATO hosts a Dutch website with general information on CCS (www.co2-cato.nl). The website attracts about 500 visits per month. This is larger than the current CCS community in the Netherlands, but still only a tiny fraction of the general public.

The CATO programme has carried out several studies regarding the knowledge and beliefs of the Dutch public (e.g De Best-Waldhober et al. (2012a), De Best-Waldhober et al. (2012b). Those studies provide a good insight in the public perception of CCS in the Netherlands. The approach in these studies was one of observation rather than interaction, although a more active – dialogue type – approach was foreseen for some local communities.

7.6. Policymakers

The government have commissioned the CATO programme. Even though they do not participate directly in CATO (the relationship between policymakers and the programme is limited to a sponsor-client relationship), they did influence the topics that were to be researched and they have shown a keen interest in the outcomes. The Ministry of Economic Affairs, Innovation and Agriculture often consults scientists in the programme for answers to their questions. CATO does not have a lobbying strategy aimed at policymakers for CCS implementation. Clearly the (industrial) partners have their own agenda outside CATO and they do approach Members of Parliament and the government.

8. Conclusion

In this article we have described the CATO programme and how this programme contributes towards the Dutch knowledge network on CCS. We have shown that the Dutch knowledge base is formed by the participants of CATO. This knowledge base is among

the frontrunners worldwide. The programme deals with the complete CCS chain for different phases in technology development. The cooperation between different areas of expertise is particularly clear in demonstration projects, which makes demonstration projects crucial for integrated technology development.

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Annex A. Figures on CATO

CATO is the Dutch acronym for Carbon Capture, Transport and Storage.

Table A1.

Table A1
Figures on CATO-1 and CATO-2.

	CATO-1	CATO-2
Number of partners	17 partners	40 partners
Focus	Full CCS chain	Full CCS chain
Type of research	Fundamental research	Fundamental and applied research
Budget	25 Million Euro	60 Million Euro
Period	2004-2009	2009-2014

The CATO programme is a Dutch research programme on CCS. The first CATO programme, referred to as CATO-1 in this paper, lasted from 2004 until 2009.The current CATO-2 programme started in 2009. Although the scope, participants and size of the programme changed, in practice there was an overlap. In some cases it is not possible to attribute something to either of the two programmes specifically: we will then use the generic term CATO. Table 0 gives the figures on both programmes.

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