Zero emissions platform

Role of CCUS in a below 2 degrees scenario

July 2018

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Executive Summary

- The world's economy is built on energy, 80% of which still came from fossil fuels in 2016 (Shell, 2017). The growth in use of fossil fuels worldwide is still far higher in absolute terms than the growth of non-CO_2 emitting energies, so far employed. In Europe, the EU Commission's 2016 reference scenario for primary energy consumption showed similar levels of demand for natural gas and oil in 2050 as in 2010[1]. Meanwhile, the Paris Agreement commits the world to net-zero emissions in the second half of the century, balancing remaining sources with sinks to achieve neutrality. In a European context, the recently agreed Regulation on Governance of the Energy Union commits the EU to meeting net-zero "as soon as possible". The EU's Long-term strategy for greenhouse gas emissions reduction, to be presented at COP 24 in November, will assess how to reach net-zero by 2050.

- Although a major source for global GHG emissions, the industry sector has largely been shielded from contemporary climate action, postponing relevant measures into the far future. Cash and investment constrained European industry will not make changes to reduce CO_2 emissions without a strong positive business case, which so far is lacking. Within a 32 year timeframe Europe cannot rely on potential breakthrough technologies and fundamental changes in consumer behaviour, but needs to deploy real solutions that are available today to reduce industry emissions. Carbon Capture and Storage, along with utilisation of CO_2 where appropriate (CCUS), is available, scalable, cost effective and suitable to deeply reduce emissions from industrial processes and heat.

- In meeting EU climate ambition, there is a need to retain and ultimately grow jobs and production activity, rather than risk displacing emissions to other countries where global climate impacts may outweigh any economic gain. This report argues that establishing a shared CCUS infrastructure for Europe's industry will protect jobs, and create new economic prosperity for Europe.

- Achieving deep reductions in CO_2 emissions in the most affordable and economically sustainable way will require a mixed portfolio of technologies and solutions. It is estimated that a portfolio of solutions which includes CCS, biomethane and hydrogen as part of a balanced energy mix, delivers a saving of over €1,150bn compared to a pathway without CCS (Pöyry, 2018). This compares to €1,000bn modelled in the ZEP (2017a) 5th Market Economics report. While the EU is on track to reach its renewable energy target for 2020 and has made great progress on energy efficiency, solutions for heat and industry remain underdeveloped:

    - ❖ Carbon Capture and Storage (CCS) is available today, constitutes an essential part of the lowest cost solution, and is particularly necessary for reducing emissions from 'hard to mitigate' sectors such as industrial processes and distributed heating.
    - ❖ A greater proportion of carbon negative solutions will become increasingly important to achieve a balance of sources and sinks in the second century

[1] https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

(IPCC, Rogelj et al. 2015). CCS combined with sustainable biomass for power, heat or fuel production is likely to be a key technology solution that can enable negative emissions within a timeframe to 2050 (IEA, 2017).

- ❖ Clean Hydrogen can be used as a fuel for heating, transport and industry (including as a reducing agent in the latter). Produced through electrolysis and renewable electricity, or steam methane reformation (SMR) with CCS, hydrogen has been shown to be a cost effective and practical solution with a broad range of application in heating, transport and as a method of energy storage. It would have close to zero CO_2 emissions, while the cost of change to inner city infrastructure is assessed as no higher than current maintenance cost (Leeds City Gate, 2017).
- ❖ Carbon Capture and Utilisation (CCU) has the potential to strengthen business models for industrial emissions reduction and can contribute to emissions reduction; however the market for CO_2 use is minimal compared to the amount which will need to be permanently stored. Additionally, while some forms of CCU permanently avoid CO_2 reaching the atmosphere, other forms may only constitute a postponement of emission – any incentive policies driven by climate must hence rely on full Life Cycle Analyses including energy input (IPCC, 2005 and Olfe-Kräutlein et al., 2016). Noting that industrial projects are likely to contain elements of use alongside storage, the term CCUS is used throughout this report.

- Without CCUS, Europe's industrial regions risk rising investment uncertainty as climate pressures mount, resulting in stranded assets, an eventual exodus of process industries, and in the loss of millions of jobs also further down the value chain. In Germany alone, over 50 million tonnes of residual process CO_2 emissions would remain unabated without CCUS, risking about 3.5 million steel-related jobs alone, and several hundred thousand more in the chemicals and cement sectors (BDI, 2018; Destatis - Statistisches Bundesamt, 2018).

- As part of the lowest cost pathway, CCUS enables a 'just transition'. This is one that is perceived as not unduly costly to people locally and globally. A just transition can sustain the economic contribution of the sectors in which we have already invested. It can create new jobs and preserve existing ones, and thereby generate economic growth. Therefore, it is crucial to shift the direction and focus of discussion on CCUS. This study develops an economic narrative based on transparent evidence-based metrics.

- Countries in the EU with most to gain from CCUS include Germany, Netherlands, Norway, France, Belgium, the UK and Poland. Highly industrialised regions such as North-Rhine Westphalia (NRW) in Germany could reduce emissions by 95% in 2050 if connected to CO_2 transport and storage resources, such as offshore Netherlands or Norway, and retain existing assets and jobs. Also regions without a major industrial base, but with significant storage potential could benefit from a CCUS infrastructure through associated job gains.

- National and regional governments should investigate the respective CCUS potential as a strategic option for GHG mitigation. This will involve stimulating cooperation across countries, supporting development and provision of infrastructure, and reducing the level of risk for companies that need to act to reduce emissions where they actually occur.

- The Rotterdam PORTHOS feasibility study shows that the type of infrastructure required can be developed and promoted as a regional or even a local initiative if set in a national and cross-border (e.g. Netherlands-Germany-Belgium) context. Studies show that regions of Europe such as Norway, which are major suppliers of primary energy to the rest of Europe, could use CCS to convert carbon containing fuels such as natural gas to fuel hydrogen. Størset et al. (2018) demonstrate that by becoming a low CO_2 emitting heating fuel supplier, Norway could generate both environmental and socio-economic benefits.

- This report highlights the need to recognise the essential place of CCUS in delivering a societal good, to reduce CO_2 emissions across various sectors of the regional and national economies of Europe. We can compare the development of CCUS to water systems; the collection, treatment, storage, distribution and drainage. Similarly to road transport, both of systems are common public goods. Water system infrastructure was public investment when undertaken in the 19th century in Europe. It is a common public resource we now take for granted. The EU still misses positive incentives for active participants in the real economy to reduce CO_2 emissions. Incentives can be created for CCUS at national level with EU support. This will enable a transition that is regarded as just by the citizens of individual countries and Europe as a whole. Kick-starting pioneering projects now allows Europe to follow the lowest cost pathway to meet our collective commitments.

- EC and individual Member State action is urgently needed to attract private investment for low CO_2 emitting solutions like CCUS. Policy certainty is required to enable private sector actors to invest in CCUS projects. It is necessary to build confidence that appropriate risk allocation will be implemented between governments and industry. Governments can underwrite risks that private companies simply cannot take. Governments should put in place the appropriate mechanisms and platforms to address this.

This report makes two core recommendations. First, Paris targets need to be taken seriously, ensuring all available and cost-effective measures are implemented to allow net-zero emissions to be achieved by mid-century. CCUS is central in this regard, particularly for industrial processes and heat generation. Second, it is necessary to ensure a transition that is 'just'; locally and globally. This requires that sustainability and climate targets are achieved without damaging welfare, jobs, and livelihoods, with cost efficient outcomes making use of existing assets. These core recommendations incorporate the need for:

(i) Clear definition of the role of CCUS and complementary solutions such as hydrogen in the Commission's long-term strategy backed by macro-economic assessment;

(ii) Quantification of economic narratives on CCUS through economy-wide modelling and evaluation that aligns treasury budget holders and a wider set of policy stakeholders;

(iii) European governments, supported by the EC, to collaborate in the development and implementation of plans for CCUS infrastructure with particular focus on the so far largely unaddressed emissions;

(iv) Immediate action by governments and the private sector to cooperate in establishing the needed financial instruments, regulatory bodies and/or capacity to enable a central coordinating body. A market maker could support the planning and implementation of infrastructure between industry clusters, transport hubs and storage locations.

Terms and Abbreviations

CCUS	Carbon Capture Utilisation and Storage
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
EC	European Commission
MS	Member States
NRW	North-Rhine Westphalia
Market Makers	As defined in the ZEP Executable Plan[2]
PCI	Project of Common Interest
ETS	Emissions Trading Scheme
FEED	Front End Engineering and Design

[2] ZEP Executable Plan for CCS in Europe (Zero Emissions Platform, 2015)

1. Scoping the challenge

At the Paris COP21, an agreement was made to limit global temperature rise caused by anthropogenic emissions to well below 2 °c with an aspirational 1.5°c target. This will require balancing remaining CO_2 emissions with “sinks”. The European Commission has announced its intention to develop a long-term strategy to achieve net-zero emissions “as soon as possible”, including an assessment of net-zero emissions by 2050.

As Figure 1 shows, on a global scale, while there has been a slowing of the growth in use of coal fuels over the last 15 years, the growth in the use of fossil fuels overall far out strips, in absolute terms, the growth in currently low CO_2 emitting energy sources such as hydro, wind, and solar. In Europe, many industries on which our prosperity is based use processes that consume fossil fuels and also produce CO_2 as part of the industrial process. These include chemicals, steel and cement. There is a very real risk of both carbon and employment/value leakage if policy action simply forces the relocation of CO_2 emitting industrial activity away from European countries. It would be unjust to export the responsibility for emissions reduction to others less well positioned to act to meet 2c targets. This does not need to be the case, but action is required to enable these industries to reduce emissions alongside the rest of the economy.

Figure 2 demonstrates the reductions needed to achieve COP 21 agreement in the coming decades. To achieve 2°c will be extremely difficult, well below 2°c staggeringly so. Given that poorest countries will be hit hardest by the negative impacts of climate change (Geophysical Research Letters 2018), the 2°c target is one generally associated with an acceptance of the need for the most prosperous countries to lead actions to address climate. Thus a just transition is required, where European nations find a pragmatic way to tackle real emissions as they are, without damaging investment, jobs and GDP at home. That is, without risk of simply displacing emissions to less prosperous nations in the world (in the absence of commensurate and balanced gains in the global distribution of sustainable economic wealth).

Additionally, net-zero emissions will require significant investment and urgent actions on all emissions, including the hard to mitigate sectors such as heating of buildings and industries, heavy-duty and maritime transport. Europe therefore needs to deploy all available and most affordable solutions to cut its emissions dramatically. The timeframe to 2050 means that we cannot rely on technological breakthroughs or radical changes in consumption patterns. It is essential to address the emissions we generate with available solutions as fast as possible.

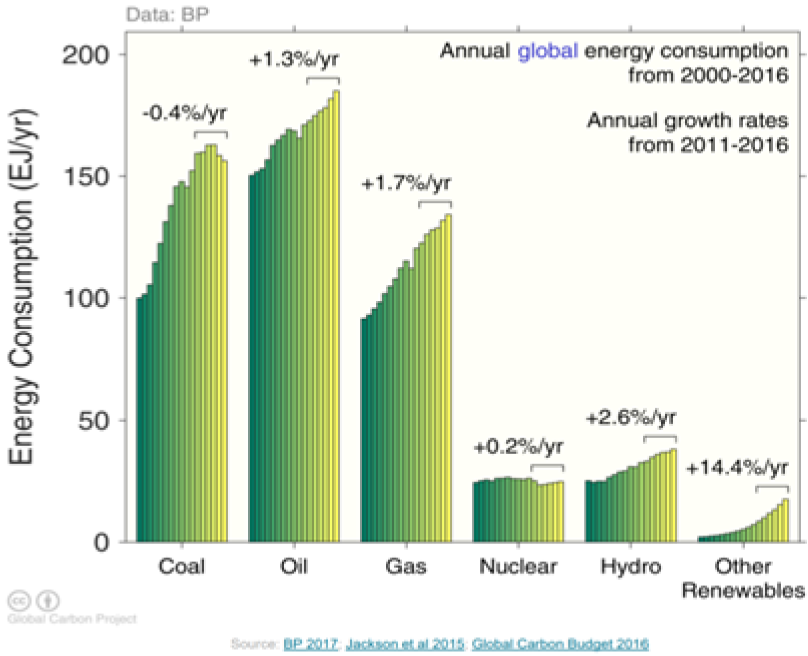

Figure 1. BP Energy Outlook (2017)

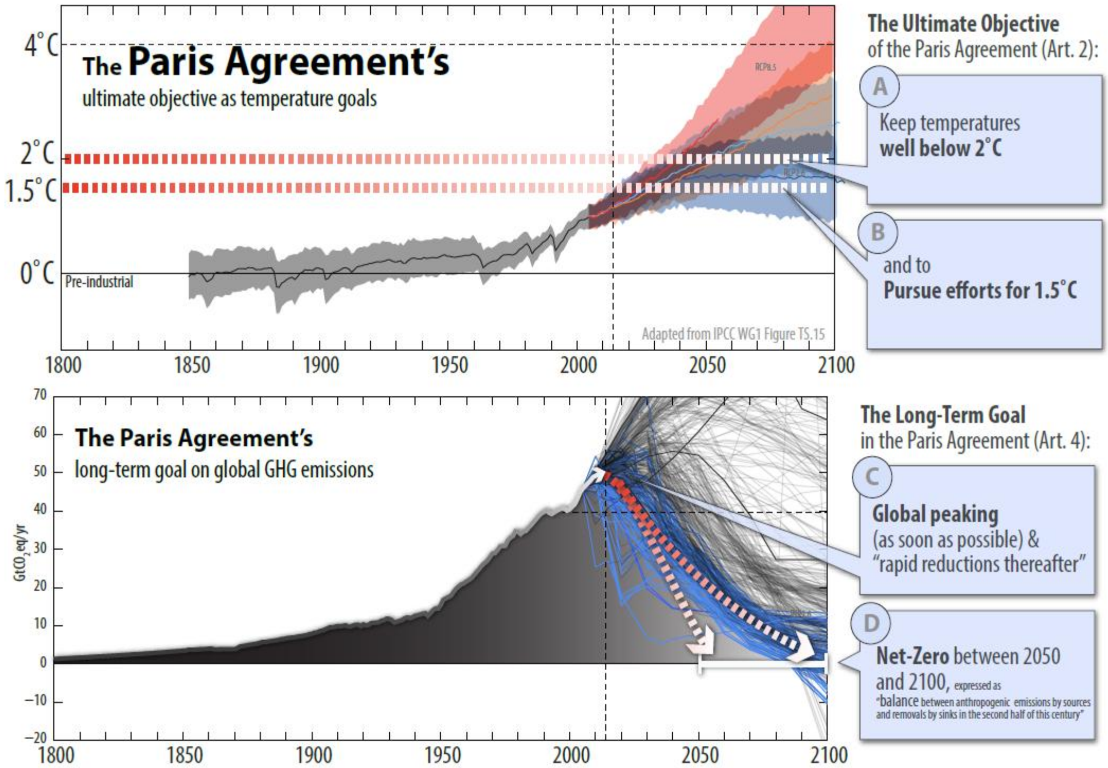

Figure 2: Paris COP21 agreement. Source: M.Meinshausen Nature (2015)

2. Achieving a cost effective climate pathway to 2050

Existing support mechanisms for sustainable energy within the EU have been focused on specific technologies. The significant cost reductions seen in solar PV, wind generation and battery storage, have led to a dominant view that an affordable energy system based on only these technologies is a realistic possibility for the period to 2050. However, there is evidence to show that a regionally optimised combination of a broader set of technologies for reducing CO_2 emissions across heat, transport and industry is significantly less expensive to implement.

Carbon Capture and Storage (CCS) can deliver deep reductions in emissions across the whole energy system (power, heat, transport, industry and negative emissions technologies). Carbon Capture and Utilisation (CCU) can strengthen business models for industrial emissions reduction due to the value attributed to the CO_2. However utilisation must not be considered as an alternative route to permanent storage due to the limited ability to contribute to significant climate mitigation (IPCC, 2005 and Olfe-Kräutlein et al., 2016). Additionally, while some forms of CCU permanently avoid CO_2 reaching the atmosphere, other forms may only constitute a postponement of emission – any incentive policies driven by climate must hence rely on full Life Cycle Analyses including energy input. Recognising that industrial projects are likely to contain elements of use alongside storage, the term CCUS is used throughout this report.

A recently published report from Pyöry (2018) highlights the changes required to energy use to fully reduce CO_2 emissions from Europe's energy system by 2050. The study demonstrates that using a 'zero carbon gas' pathway, which includes CCS, biomethane and hydrogen as part of a balanced energy mix, especially in transforming heat, delivers a saving of over €1,150bn compared to a case without CCS. This compares well to the €1,000bn saving modelled in the ZEP (2017a) 5th Market Economics report.

Similarly, another recent modelling study in the H2020 project SET-Nav Strategic Energy Roadmap (Herbst et al. 2018) considers reducing industrial emissions related to high temperature heat production and process emissions. The study examines two transition scenarios where greenhouse gas (GHG) emissions from 2015 to 2050 are reduced by more than 70% in the European industrial sectors. Whilst one scenario includes CCS as a mitigation option, the other relies on an electricity basis for steel production and using new non-carbon based materials in cement production. The study shows that opting for a pathway that does not include CCS would significantly increase cost in terms of energy expenditures (figure 3). New non-carbon based technologies will not be available at a commercial scale in time to deliver on 2050 climate targets.

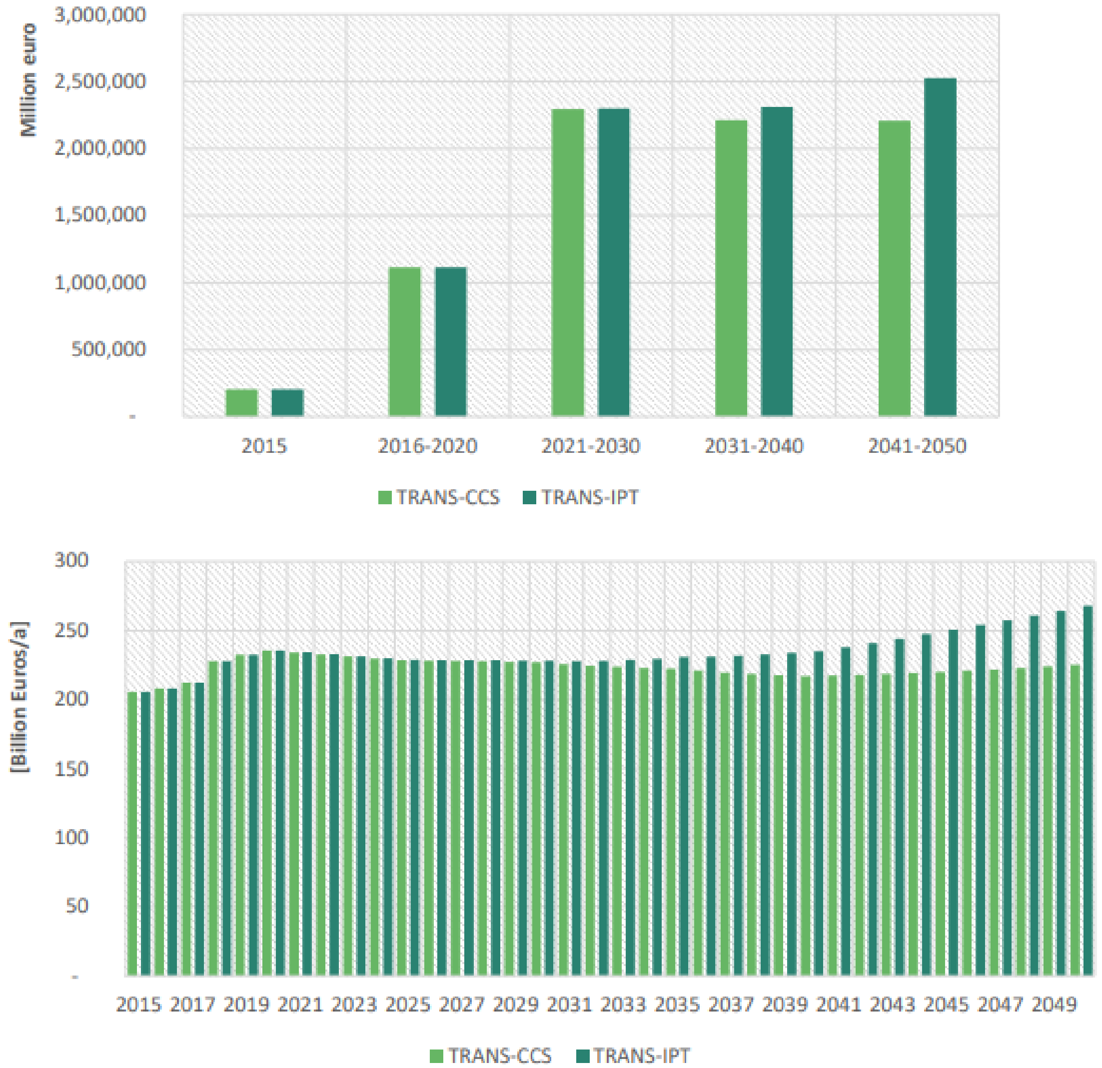

Figure 3: Total industry sector annual energy costs by scenario for EU28 as annual values (bottom) and for selected intervals (top). Source: Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation (2018)

A mixed portfolio of technologies and solutions is required for enabling deep reductions in CO_2 emissions in the EU at an acceptable cost. This portfolio needs to include CCS, which is an essential component in 114 of 120 scenarios with 0.9-2.3c global warming of the IPCC Fifth Assessment Report (2014). Furthermore, the IEA Energy Technology Perspectives 2017 show that CCS becomes more critical the greater the climate ambition. The report uses a reference scenario based on countries' current emissions reduction commitments including Nationally Determined Contributions under the Paris Agreement. Key findings indicate that CCS accounts for 14% of emissions reduction between the reference scenario and the two degrees scenario, and for 32% of further emissions reduction between the two degrees scenario and the below two degrees scenario.

As we move closer to 2050 a greater proportion of carbon negative solutions become increasingly important (IPCC, Rogelj et al. 2015). CCS combined with sustainable biomass for power[3], heat or fuel production is likely to be a key technology solution that can enable negative emissions within a timeframe to 2050 (IEA, 2017). Furthermore, industrial processes (which in some cases represent greater emissions than those related to energy use) will have to be effectively CO_2 emissions free at global level to meet Paris Agreement targets.

Another key driver for concentrated collaborative effort to deployment of CCS at scale is the need to produce low carbon containing fuels. In particular, hydrogen generated through established processes combined with CCS will be important to meet the less than 2c target in an economically viable way. Domestic and industrial heating and transport are key point sources of CO_2 emissions. Thus, hydrogen as a fuel is a common denominator for energy policy. It is not CO_2 emitting, when used as an energy vector and it can be generated from fossil fuels through CCS and also by electrolysis of water using electricity from potentially low CO_2 emitting electricity generation sources.

A key consideration is the sheer volume of hydrogen that would be needed for heating, which is the largest CO_2 emissions source sector in Europe. The Leeds H21 project[4] concluded that Steam Methane Reforming (SMR) with CCS is required to produce hydrogen at the scale required for effectively reducing emissions from the gas grid. In April 2018 the Australian Government announced a collaboration with Japan where the latter's Kawasaki Heavy Industries Ltd will use a power station owned by the Australian electricity producer AGL Energy Ltd for a trial of coal-to-liquid hydrogen conversion. Both are reflective of the conclusion that electrolysis of water will most likely not be capable of producing hydrogen at the scale required for large-scale heating and transport solutions in the period to 2050.

There are several other projects that support this concept. The Magnum project being undertaken by Equinor and Vattenfall in the Netherlands plans to use CCS to convert methane to hydrogen for use in an existing power station. This would demonstrate the potential to make Norway's energy exports non CO_2 emitting at the point of use. This is a breakthrough. The Leeds 21 HyNet project in the UK studied the conversion of city infrastructure to use distributed hydrogen as heating fuel. Heating has several special factors: the infrastructure is embedded in the city and discontinued use would lead to significant asset stranding. The Leeds 21 project proposed that converting the heating gas supply from methane to hydrogen would enable continued use of existing infrastructure at acceptable conversion cost. The ZEP (2017a) 5th Market Economics study showed that the cost of this route was reasonable compared to alternatives.

[3] Drax Group plc, for instance, announced May 2018 further conversion to sustainable biomass. See: http://biomassmagazine.com/articles/15379/from-neutral-to-negative.

[4] https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf

3. Enabling a just transition to a net zero economy by protecting existing jobs & GDP in a competitive world

CCUS has the potential to protect the societal value of GDP, jobs and the tax revenue present in European energy supply systems and industrial plants. Indeed, it can grow this value through the creation of new industrial and supply chain activities. Similar conclusions can be drawn for hydrogen production, sustaining activity and continuing to leverage previous investments in our gas networks. In the case of CCUS, there is further potential for new markets and value chains to emerge particularly where CO_2 can command a positive price. CO2 utilisation could in this context be a driver to early investment in and deployment of CO_2 capture, transport, and storage systems. Where hydrogen is to be produced via SMR, CCS takes the role of a key 'enabler', in addition to helping sustain existing industries.

One way of making a first assessment of the nature and extent of societal value of existing activities is to make use of national accounting 'input-output' (IO) data produced by most countries under the UN System of National accounts. IO tables report transactions occurring between different sectors of the economy, which translate to interactions and interdependences supporting employment and the generation of value-added (GDP). Thus, we can report 'multiplier' relationships in term of total activity generated throughout the wider economy for every pound spent or person employed in any one sector.

One such study in Turner's (2015) 'Preliminary Study on Developing Economic Multipliers for CO_2-EOR Activity'. This study considers the sustained role of thermal power generation in the UK economy, with and without CCS, where the latter is linked to enhanced oil recovery. The CO_2 price is subject to sensitivity analysis to assess the marginal return to public support via a subsidy mechanism. The key finding is that the wider economic return to supporting continued thermal generation exceeds alternatives in the presence of CCS linked to EOR.

In the case of hydrogen, a recently published preliminary 'economic multiplier' study by Turner et al. (2018a) suggests that, at operational stage, almost three times as many UK supply chain jobs and more than twice as much domestic GDP may be supported by hydrogen vehicles, as is currently the case with petrol and diesel supply chains. The core explanation for such positive multiplier results is the sustained role of existing gas and/or electricity supply networks/sectors and their strong pre-existing domestic supply chains. This may be regarded as sufficient 'return' for public support and collaboration in developing and enabling required infrastructure development. The Turner et al. study is a preliminary work (building on EPSRC Supergen Hydrogen Hub work reported in Smith et al. 2017) and focus on the nature of existing supply chains that may be exploited in hydrogen and/or electric vehicles more generally in the context of low carbon personal transportation. Thus, more work is required investigating the technical and infrastructure requirements of producing hydrogen, transporting it, storing it and making it available to different types of customers for different industry and domestic, heating and transport uses. There are similarities to what may be expected for CCUS, given that enabling large scale network solutions such as hydrogen and/or CCUS will generally require significant upfront investment in infrastructure. That is, the infrastructure development itself, as well as the operational stages that follow (where new supply chain activity is likely to emerge), is likely deliver a fuller range of multiplier gains.

In addition to considering how a range of economic gains may be realised, it is also important to consider the avoidance of unnecessary and counter-productive negative effects. One of these is referred to as “leakage” and extends to international leakage of CO_2 emissions, as well as investment, jobs, GDP and other measures of economic value in the remaining time before 2050. Consequently, any strategy for emissions reductions should ensure the protection of jobs and livelihoods whilst providing European taxpayers with the lowest-cost route to meeting climate targets.

So how do we measure the societal value of sustaining the contribution of energy supplying and using industries? The public, political and policy debates around domestic CO_2 reduction strategies are poorly developed in many countries. There is a real challenge in terms of engaging government departments concerned with wider economic affairs, including for national treasuries, when considering the merits of public support for CCUS-related action. In this context, it is crucial to shift the direction and focus of discussion through developing an economic narrative around how this can underpin what is perceived to be a fair and sustainable just transition at both home and abroad. To this end, a wider stakeholder audience must be involved in the development of and building consensus around such narratives. This requires communication via straightforward and transparent evidence-based metrics.

As in the CO_2-EOR and hydrogen studies, a first step is to consider basic economic ‘multipliers’ based on national accounting IO data as explained above. Ultimately, however, economic narratives need to be quantified using more sophisticated and flexible methods and understand the impact of deploying CCUS in different scenarios and contexts. This may involve, developing the type of multi-sector economy-wide ‘CGE’ model employed by finance ministries, e.g. UK HM Treasury, to consider CCS and hydrogen.

In section 6 we present case studies for the Port of Rotterdam and Norway, which are positive examples of how the economic narrative around CCUS may develop over time. The most compelling narrative in countries like the UK and Germany may be the ‘sustained contribution’ narrative proposed by Turner et al. (2018b). This focuses on the potential role of CCS in sustaining (and ultimately potentially extended) contribution of sectors where we have already invested, from which we currently realise value. In the UK context, this relates directly to themes in the 2017 UK Industrial Strategy.

Two types of industries are particularly relevant to this narrative. The energy-using/emitting industries that may engage in CO_2 capture. The fossil fuel supplying oil and gas industry, where much of the skills, expertise, physical infrastructure and supply chain linkages and assets already exist to enable to CO_2 transport and storage networks and implementation of large scale CCUS projects.

The capital (and risk) intensive nature of activities tends to be a deciding factor governing the impact these types of industries. For example, the economic multiplier analysis presented by Turner et al. (2018b) reports that for the example of the UK, the oil and gas extraction industry supports around 3 direct plus indirect jobs across the wider economy for every £1million of output sold (in replicating this type of analysis for other countries it would be useful to set this in the context of net taxes/subsidies paid/received in producing this output). However, only around 1 in 10 of the total UK jobs supported by the industry are directly located within the industry itself.

A key point is to understand how multiplier analysis of current activity informs the sustained, and potentially growing, contribution of an industry like oil and gas. The underlying national accounting data refer to current brown field, maintenance and operation activity, where the infrastructure is already in existence (having been invested in Europe since the 1960s). However, in CCUS, we are considering the future role of the industry. Thus, the input-output data need to be defined for jobs in developing and operating infrastructure for CCUS (the same would be true in considering shifts in the types of fuel produced and supply – e.g. hydrogen). Some capacity may come from declining oil and gas operations (though this must be set in the context of decommissioning and how the timeframe therein may be impacted). However, it is likely that new additional direct and indirect (supply chain) jobs will be created to operate CCUS and hydrogen infrastructure.

Considering capture, the UK example in Turner et al. (2018b) focussed on the petrochemicals industry. Here, the corresponding figures are around 5 jobs per £1million of output sold (future work is needed to put in the context of net taxes/subsidies). Only around 1 in 5 of total UK jobs supported are directly located within the industry. As with the oil and gas industry above, the direct industry jobs are relatively difficult to create in these industries. This is due to low labour requirements to fulfil production. However, this point serves to emphasise the need for planning ahead. The skills required to build and operate CCUS and hydrogen infrastructure has implications for training and higher education.

Use of this type of multiplier result also reflects the fact that any loss of domestic industry production (and jobs) is likely to have large negative indirect employment impacts across the economy. For example, if a future higher ETS price causes activity to be relocated in other countries longer term impacts on jobs, economies and energy security as the European oil and gas industry declines may ultimately be more concerning. The shorter term economic leakage arising from things like changes like ETS prices may carry greater weight with publics and politicians. Recognition of this point is central to the concept of a 'just transition' (perceived and actual). In either case, a key policy concern is likely to be the specific location and nature of the jobs involved at different points in the supply chains and the timing of any negative and positive impacts.

The nature of 'multiplier' relationships will differ between jobs and GDP (value-added) where CCUS-relevant industries are capital intensive. This point is illustrated in the German case (where we conducted analysis using input-output accounting data produced by the OECD, 2018). Here, in the absence of a significant oil and gas extraction activity, focus of debate is likely to focus mainly on energy-using process industries (and potentially also on CO_2-using industries in the context of utilisation). Direct GDP impacts are important, for example, in the German chemicals industry. Just under 50% of the GDP that is supported throughout the German economy by demand for chemical industry outputs is located directly in the industry itself. A similar share applies in the case of the industry grouping containing cement manufacturing.

While figures such as these do still imply negative effects on GDP if such activities relocated outside of Germany (a doubling of the direct GDP loss), a key factor may be the impact on domestic GDP from domestic downstream industries. For example, the German construction industry has strong supply chain linkages throughout the domestic economy. This involves a GDP multiplier of around 800,000 euro in GDP generation per 1million in output produced. Around 65% of the construction industry's GDP impact is located directly within the industry. Of this, around 7% of the indirect GDP impact is located in the industry grouping that includes cement manufacture. Future economy-wide modelling and evaluation work (generally and for specific case studies) should focus on the nature and sectoral/geographical location of these indirect effects. The crucial point is that a 'third tier' of particularly service sector industries will almost always underpin most industrial supply chains. This is true of the manufacturing, energy supply and extraction industries associated with 'technical solutions' like CCUS. This point is also emphasised as a key conclusion in the context of hydrogen in the aforementioned Turner et al. (2018a) study. It ultimately pertains to real societal impacts, for example in smaller regional communities that host important industries and may be hugely impacted in indirect ways if plants shut down.

4. Case study: Making Germany's *Industriestandort* climate-ready

As Europe's largest economy and reflecting on the GDP multiplier evidence considered above, Germany stands to lose a lot if industries are not incentivised and provided with measures to enable deep emissions reductions. Germany's three highest emitting industries – chemicals/pharmaceuticals, cement, and steel – release almost 137 million tonnes of CO_2 per year. This is equivalent to more than half of Germany's coal emissions (Öko-Institut, 2017; European Environmental Agency, 2018). All three industries are energy-intensive and produce emissions as part of their processes. As such, even with expected efficiency gains and after implementing other climate mitigation measures, such as electrification, recycling, and upcycling, almost 50 million tonnes of residual CO_2 process emissions would remain unabated if Germany's industry does not have access to a CCUS network in the future - equal to the total CO_2 currently emitted by Portugal (BDI, 2018; Global Carbon Atlas, 2018).

The chemical, cement, and steel industries provide over half a million direct jobs, and a turnover of more than 221 billion Euros (Destatis - Statistisches Bundesamt, 2018). Millions of jobs further along the value chain depend on them. In fact, about 3.5 million jobs in Germany alone are 'steel-intensive' (Destatis - Statistisches Bundesamt, 2018). As suggested in the previous section, the interconnectedness of Germany's industrial and manufacturing sectors means that losing one million euro of GDP or one job in the heavy industry is likely to lead to a compounding of GDP and job losses through the supply chain. This endangers Germany's *Industriestandort* and its economy that crucially depends on its export sector, which currently generates a trade surplus of 244 billion Euros, and is made up to 42% of processed steel and metals that are worth some 506 billion Euros (World Trading Organization, 2017; Destatis - Statistisches Bundesamt, 2018; Nienaber). A potential deindustrialisation due to mounting climate pressures and lack of solutions would also cost the government revenues in wage, corporate, and turnover tax, paired with rising social welfare costs as unemployment rates increase. Together, in 2017, these three tax sources provided about half of total German tax revenues; approximately 330 billion Euros (Bundesfinanzministerium, 2018).

As highlighted in the ZEP (2017a) 5th Market Economics report, Germany is the European nation that could benefit most from CCUS due to the size of its industry, and therefore has an important opportunity. Germany should begin a just transition for its industry to ensure that sustainability and climate targets can be achieved without endangering jobs and livelihoods. The current transition addresses the coal sector with only some twenty-thousand remaining direct jobs (Bundesverband Braunkohle), and targets a commodity that is readily substitutable with renewable electricity. Unlike coal, other industries worth millions of jobs and revenues cannot be replaced and simply phased out. Germany's industrial just transition has to evolve beyond its current shape and form. CCUS represents a crucial building block to facilitate this process, and provides relevant players with the means to deeply reduce emissions. As explained further in the section 5, without the appropriate measures in place, industry sectors as well as labour unions will have little opportunity to engage in European efforts to reduce CO_2 emissions, halting progress and increasing regulatory and investment uncertainty. As climate burdens increase through growing public pressure and potentially rising carbon prices, industries need effective measures in place if a departure of industry sites from Germany and Europe is to be prevented.

Thus, highly industrialised regions, like NRW, have a major interest in developing CCUS systems today that help to achieve ambitious domestic climate targets without endangering jobs and economic power. This is illustrated by Figure 4, showing NRW's contribution to Germany's total emissions. Such regions will be key beneficiaries of a CCUS infrastructure, by allowing new investments, protecting existing assets and reinforcing the attractiveness of their business location.

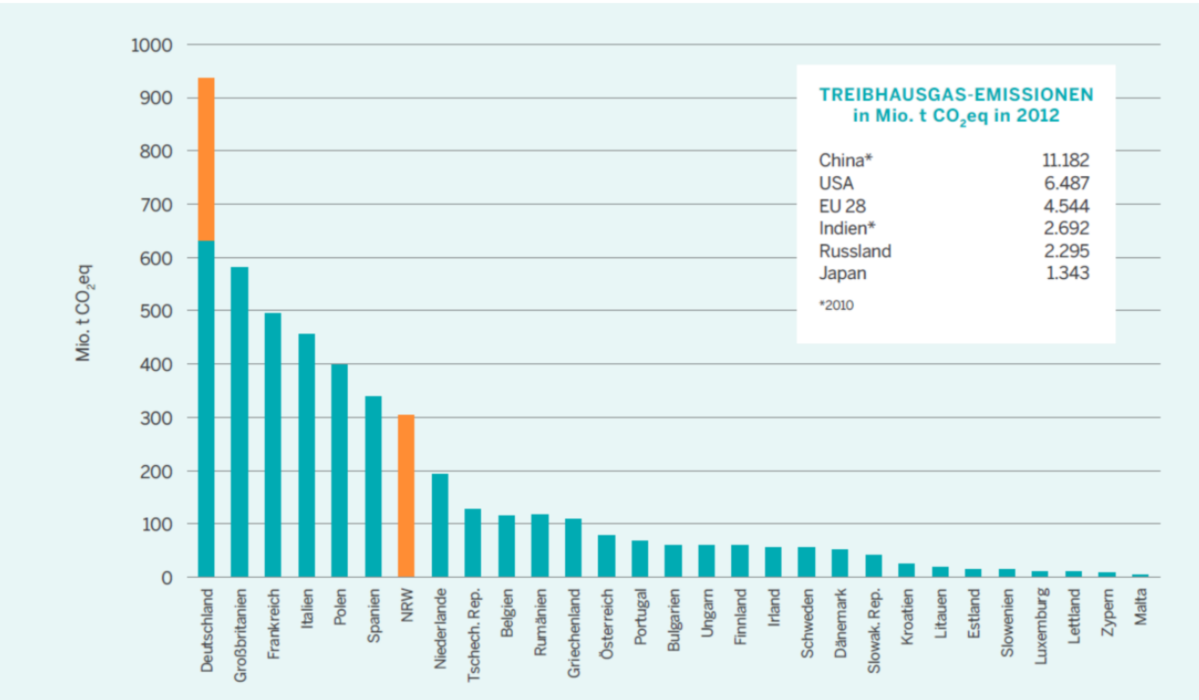

Figure 4: Climate protection in NRW – GHG emissions comparison. Source: Klimaschutzplan NRW (2015)

5. Supporting energy-intensive industries to participate in taking action

At present there is limited opportunity for energy-intensive industries to participate in European efforts to reduce CO_2 emissions. The capital plant that is used in Europe has a long life and the profit margins are narrow. Furthermore, many of these companies operate in global markets that are sensitive to increased costs arising from national or regional policy. Hence the companies concerned are very constrained in new investment. The imposition of carbon costs is already driving many down a route of shutting plants in Europe and moving production to regions where costs (including carbon reduction policy instruments) are lower/less demanding. European steelmakers for instance, are under intense pressure as they compete with companies located in China, India and Russia where significant investment has occurred in recent years (Figure 5).

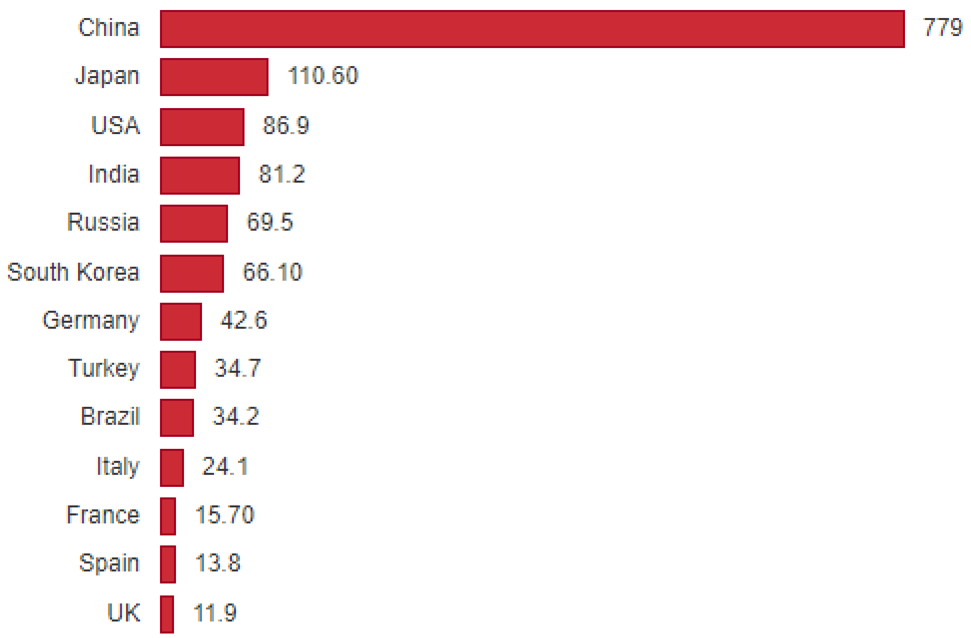

Figure 5: World crude steel production 2013 in millions of tones. Source: EEF (2016)

Even at a low price, the ETS imposes an uncertain cost on operations; it is effectively an incentive to not produce when production is directly linked to continued CO_2 emissions. It is at best a very weak incentive to reduce emissions from production. It is one that drives leakage of CO_2 emissions, investment, jobs, GDP and tax revenue. Provision of an ETS ‘opt-out’ to smaller emitters (to reduce regulatory burdens) only serves to delay but compound the negative incentives. There is an imperative to act quickly to ensure Europe retains the steel, cement and other manufacturing capability it needs to 2050 and beyond. This is not a ‘protectionist’ stance; rather, the key issue is one of leakage. The impacts of climate change will impact globally on economies, populations and migration patterns. Relocation of activity without reduced consumption simply relocates emissions, certainly with increased transport emissions and with implications for the perceived justness of the low carbon transition.

Yet these industries are likely to be ready to participate and act provided they have credible options available to them to reduce emissions. The crucial point is that addressing climate change is for the public good, because these industries deliver societal value through GDP, jobs and tax revenues. Governments must consider how they can both support low CO_2 emission infrastructure and a level of certainty (reduction of risk) on which firms large and small, can act to reduce real emissions while retaining production activity .

European funding opportunities such as the Innovation Fund and the Connecting Europe Facility are available to develop CO_2 capture and transport projects. However, funding availability is likely to be limited before 2020. Therefore, contributions from Member States will be vital in the short-term to limit the damaging climate effects of continued inaction (Industrial Innovation for Competitiveness and Element Energy 2017). The Commission should further support the transition by providing a strong governance framework through its strategy for long-term emissions reduction, enabling Member States to plan effectively for the transition to 2050. The EU Structural Funds are not currently available for developing CCUS infrastructure despite the fact that this will be critical to ensuring a just transition in the industrial regions these funds are intended to support.

The Element Energy report (2017:9) outlines a funding pathway for an industrial CCS cluster in Europe, which could be helpful in designing financial support for CCS infrastructure. The study stresses that enabling the deployment of CCS industrial clusters will require a variety of coordinated funds and subsidies. These will include grants for storage appraisal and construction, loan guarantees to encourage private investment, operational subsidies and operational guarantees and a sharing of storage liability (see figure 6).

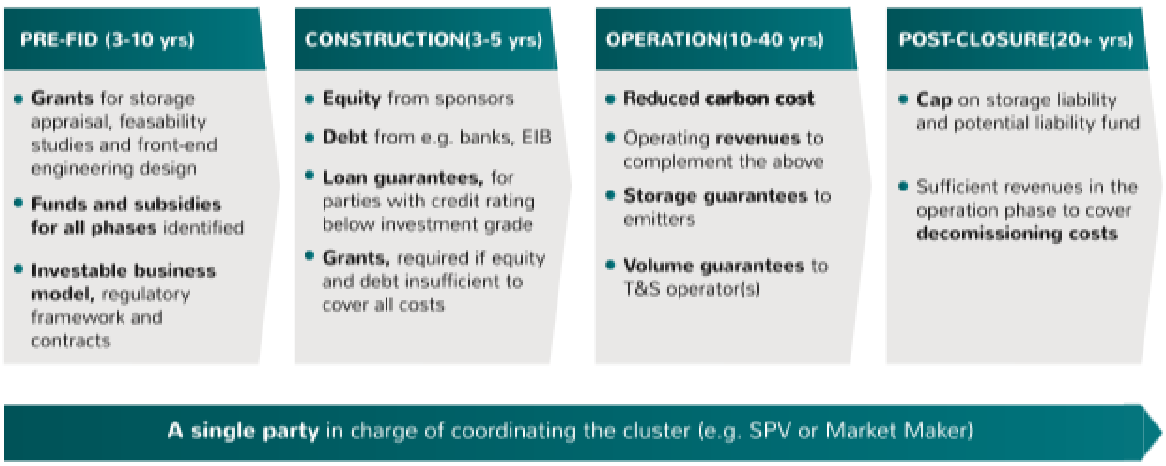

Figure 6: Financing European CCS clusters. Source: Element Energy report (2017).

Achieving a coordinated project across CO_2 capture, transport, and storage is a complex task, which may be simplified via the establishment of a single entity. This entity could be a Special Purpose Vehicle or a 'market maker'. The ZEP (2014) report on business models for commercial CO_2 transport and storage introduces the 'market maker' as a suitable business model for growing storage volumes during an early phase. It consists of a regulated entity, which removes counterparty risk by a) managing the development of primary infrastructure on behalf of the state (trunk pipeline and back-up storage site); and b) having a duty to take all captured CO_2 and ensure corresponding storage is available. A market maker is a proven method of developing emerging markets (e.g. Gasunie in the Netherlands) (Element Energy, 2017). In Norway, the Government has set up Gassnova, an organisation responsible for the development and deployment of technology and industrial full-scale pioneer CCS plants. Gassnova may ultimately be seen as an example that shows how a market maker for CCUS could operate in practice.

In summary, within the current landscape, European energy-intensive industries are key actors but may see little opportunity to participate in reducing CO_2 emissions and meeting 2050 targets. Industries need to be incentivised and be given the tools to be able to act quickly. However, the just transition to a net zero economy also requires cooperation at the European level, as explored in section below.

6. Cooperation is key

As the capture technology for CO_2 is tested and readily available, access to transport and storage infrastructure with guaranteed service provision is currently the biggest hurdle. Yet its development does not have to be, a national solo effort. Establishing CCUS infrastructure requires European cooperation because not all regions have their own large-scale CO_2 storage resources. Europe's largest storage potential lies offshore in former natural gas and oil reservoirs and saline aquifers. Countries such as Norway, the UK and the Netherlands are already taking steps to develop the needed infrastructure and the Port of Rotterdam – host of multiple energy-intensive industries in the country - has begun establishing itself as a CO_2 hub for the region with a backbone CO_2 pipeline servicing the port. These examples, presented below as case studies, illustrate how infrastructure developments can be achieved, and represent positive examples of collaboration between governments and industry. For adjacent countries such as Germany, Belgium and Sweden, it is a low-risk, high-reward opportunity to join these ambitions, and support selected capture projects as a first step to creating an inclusive CO_2 network for the region.

a. Rotterdam, Netherlands

The case study of the Port of Rotterdam provides focus on how a CCUS cluster may enable infrastructure development for a system that initially involves major CO_2 emitters in the Port area. This is well motivated by the fact that around 20% of total CO_2 emissions produced within the Netherlands are generated at the Port of Rotterdam. The Port Authority together with Gasunie and EBN is currently exploring building an open access infrastructure for CO_2 storage. All industries operating in the Port area could connect so that CO_2 would be captured rather than emitted into the atmosphere. The (independent) operator of this "backbone" then takes the captured CO_2 and stores it.

The Port Authority has identified the 15 biggest emitters, which account for 95% of emissions in the Port site. This includes 3 power plants and 12 large industrial emitters. The project excludes the power plants (the coal fired plants have to be closed by 2030) and will probably start with 2 or 3 of the other emitters. The Dutch Government has been supportive and provided an overall frame in their recent coalition agreement, given that 20 mega-tonnes of CCS capacity is required to meet Dutch carbon reduction requirements. The Port of Rotterdam can make a key contribution in meeting this target.

The project is still at the stage of a feasibility study. The aim is for 2 mega-tonne reduction in emissions in the Port site in the first phase, building to 5 mega-tonnes by 2030. Ultimately, the aim is for capture, transport and storage of up to 10 mega-tonnes of CO_2 but this will depend on other technological developments, energy demand etc. There are also ambitions in terms of cross-border CCUS provision via the Port. During the 2nd or 3rd phases, it may be possible to help Antwerp in Belgium or NRW in Germany. Generally, the aim is to start with a local/regional focus but to extend over time.

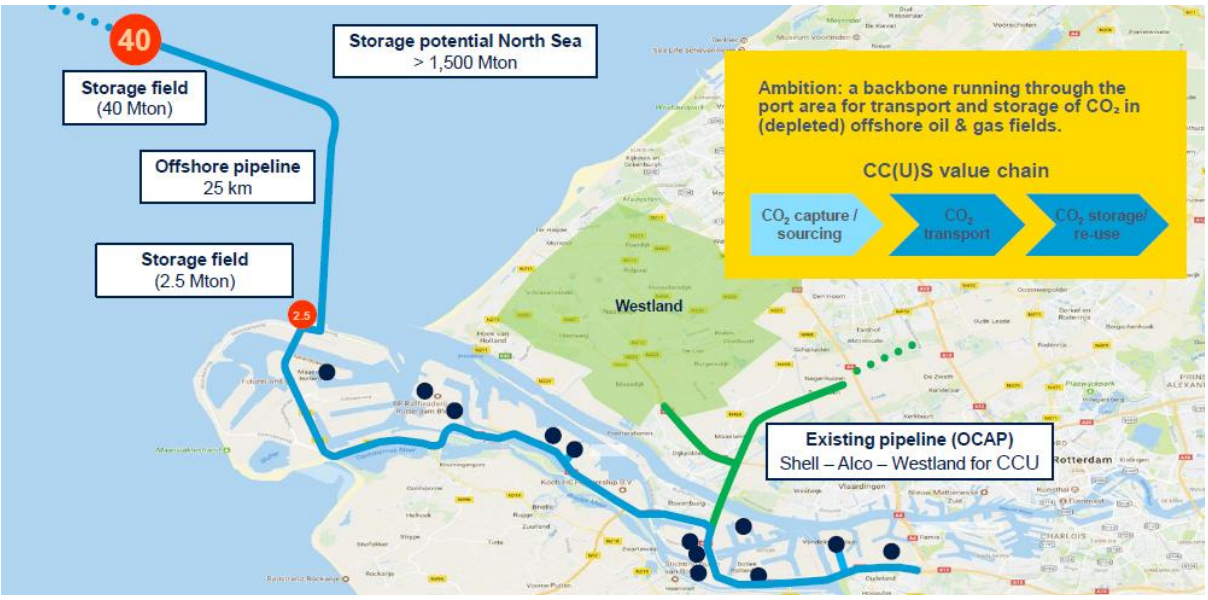

Figure 7: Port of Rotterdam Authority backbone CCUS infrastructure project (2018).

b. Norway

In Norway, plans for the realisation of a full-scale CCS chain by 2022 include: the capture of CO_2 from one or two industrial sources in the Oslo area (the Norcem Heidelberg Cement factory and the Klementsrud [Fortum Oslo Varme AS] Energy Recovery plant); transport of CO_2 by ship to a hub on the western coast of Norway; and from there transport by pipeline to injection in the Smeaheia formation. Each of the capture sites can provide up to 0.5 Mton CO_2/year. In recent months, while the transport and storage part of the project, led by

Equinor in cooperation with Shell and Total has been proceeding to plan, the CO_2 capture projects has been halted, awaiting for a decision regarding the funding of the FEED phase of the projects. On May 15 2018, funding of the FEED phase for CO_2 capture at the Norcem cement factory was announced. The Norwegian full-scale project is also basis for one of four Projects of Common Interests on CCS launched in 2017.

The Størset et al. (2018) report published by SINTEF/NTNU in April 2018 builds on specific examples of key economic opportunities related to the full-scale CCS project in Norway. In the report, the motivation for a full-scale CCS system is set in the dual context of strengthening the competitiveness of Norwegian processing industries, which currently account for around 30,000 jobs in the economy, and the industry aim of achieving zero emissions by 2050 whilst doubling production levels. In an international context, Norway is identified as a 'CCS host nation' where CCS service provision is linked to identification and exploitation of new industrial development.

The study also introduced the emphasis on potential new sources of economic value and jobs generation by linking CCS infrastructure to the production of hydrogen as a low carbon fuel. This is projected to potentially support as many jobs as already exist in Norwegian processing industries. It links the CCS narrative to one of Norway's key existing economic strengths in the extraction of natural gas but with new possibilities for low carbon fossil fuel supply and use, with focus on production and distribution of hydrogen.

More generally, it is estimated that a European CCS industry could support up to 40,000 jobs by 2030 and up to 90,000 by 2050, with Norway identified in the SINTEF work as a key potential beneficiary. By 2050, Norway could have more than 10,000 people directly employed in the CCS industry in the North Sea, with ripple effects throughout the Norwegian economy potentially employing up to another 10,000 people. By 2050, the shipping requirements for CO_2 transport may involve up to 600 vessels and 10,000 jobs, with Norwegian shipyards and shipping companies being well positioned to exploit opportunities. Markets for CCS technology and facilities are also likely to provide important opportunities and up to 40,000 jobs, again with Norwegian companies well positioned to respond.

A solid knowledge base, combined with significant storage resources for CO_2 on the Norwegian shelf and a petroleum industry with infrastructure and expertise directly applicable to CCS, puts Norway in a position to develop new concepts for the capture and storage of CO_2. This is essential for the reduction of greenhouse gas emissions both in Norway and internationally.

7. Recommendations

(1) **Taking Paris targets seriously**

To keep the warming of surface temperatures below 2 degrees compared to pre-industrial levels, countries will have to become significantly more ambitious in reducing source emissions across all sectors. It is imperative to implement all available and cost-effective measures to enable net-zero emissions by mid-century. CCUS (emissions reduction in industries, incorporating opportunities to use CO_2 as a useful input to production) and hydrogen (for heating and transport) are central to address hard to mitigate emissions, for instance in industrial processes and heat generation.

(2) Ensuring a 'just' transition

A just transition allows for the achievement of sustainability and climate targets without damaging welfare, jobs, and livelihoods. To ensure Europe meets its commitments under Paris without endangering its economic future, climate measures need to be effective in reducing emissions, protect jobs and existing assets, while also being cost-efficient. Without a balanced energy mix, CCUS and sooner or later, hydrogen, industries will struggle to meet the 2050 target. They are then left with increasing costs for emitting CO_2 and rising public pressures as other sectors approach carbon neutrality. They will also face a lack of options to reduce emissions, endangering their continued existence in Europe with fatal consequences for Europe's economy and the climate. Therefore, it is in these industries' interest to develop emissions reduction measures now which enable them to remain competitive in a net-zero economy. At the same time, it is also in the interest of labour unions and governments to ensure a sustainable industrial sector that provides continued employment and wealth generation, preserving and generating domestic/local investments and economic activity.

Recommendations:

- Quantifying economic narratives on CCUS

Engaging with government departments concerned with wider economic affairs, to consider the merits of public support for CCUS action has previously been challenging. Therefore, it is crucial to shift the direction and focus of discussion to developing an economic narrative. In making this a sustainable just transition both locally and globally we can ensure that the value that CCUS can bring to the economy is taken into account alongside cost. Bringing CCUS into the narrative may be helpful to associate the capture of CO_2 with useful production. It may add an intuitive element (for example, in 2018 European media and publics have learned of CO_2 shortages impacting production of favourite beverages). To this end a wider stakeholder audience must be involved to build a consensus around such narratives and evidence-based metrics.

This should be done in a manner that effectively brings treasury budget holders and a wider set of policy stakeholders concerned with economic affairs into the conversation around CCUS. This requires building on the type of ‘economic multiplier’ analysis considered here with more sophisticated economic modelling. Such a development is necessary to enable consideration of the fuller private and public (social) costs and benefits (and, crucially, their distribution) involved in introducing systems around CCUS, hydrogen and other low emissions solutions. Multiple sector, economy-wide modelling and evaluation frameworks are required. These will include the changing roles of energy service suppliers and demanders (e.g. as the traditional oil and gas industry takes on the role of supplying CO_2 transport and storage services, and producing low carbon fuels such as hydrogen). Analysis is required on how different markets and actors respond to different scenarios of economic and policy conditions over different timeframes. Frameworks that may be used do exist, such as multi-sector economy-wide ‘computable general equilibrium’ (CGE) simulation models for policy evaluation. CGE methods are already employed by finance ministries around the world to evaluate the wider impacts of different policy options, industry changes and economic disturbances.

- Infrastructure development

This report urges European governments to collaborate together to develop and implement plans for CCUS infrastructure that allow for accelerated and deep reductions in CO_2 emissions of key and so far largely untouched emitters.

In many ways, we can think of the change we face as like public health and/or national infrastructure provision. Actions to reduce emissions can be compared to actions to improve public water treatment systems in the 19th century or to develop road transport networks over the last century. Government action was needed to ensure investment happened and the infrastructure was built. The public water systems needed water collection, treatment, pipelines and storage solutions. Similarly, the road transport network required connectivity across countries and to link populations to industry hub. Both cases have similarities with what we need for CO_2 emission removal today. To meet the Paris COP21 targets and safeguard the value and prosperity already enjoyed in our economies, we need equivalent solutions to be in place before 2030 so that CO_2 emissions can actually be reduced, and a net-zero economy established by mid-century.

The role of governments in financing CO_2 transport infrastructure will be crucial in the short-term since European funding availability is likely to be limited before 2020. Nonetheless, CO_2 transport and infrastructure projects need to be coordinated at European level given that all countries do not have access to storage sites. The European Commission can support these developments by providing a strong framework through its long-term strategy, enabling Member States to plan effectively and fairly for the transition to a 2050 net zero economy, including for the areas that remain largely untouched. Moreover, the EU Structural Funds should also be made available for developing CCUS infrastructure as this will be critical to ensuring a just transition in the industrial regions these funds are intended to support.

- Regulatory reform to support new institutions for CCUS or to activate new capacity within existing regulatory bodies

Establishing a European CCUS infrastructure benefits all parts of society through sustained domestic industrial production, continued jobs and affordable products, and effective climate mitigation. However, an increasing carbon price alone does not provide the necessary incentives for companies and governments to begin implementing capture technologies, build pipelines, and begin permanently storing CO_2. Nor can the entire CCUS value chain be expected to be developed by and for a single industry site alone. What is needed is a cooperative framework that reduces risks across involved actors (industries capturing CO_2, and companies transporting and storing it), as well as costs by allowing as many industrial CO_2 source points as possible to participate. A central coordinating body or ‘market maker’ can support the planning and implementation of an infrastructure between industry clusters, transport hubs and storage locations, much as Gassnova is doing for Norway’s full-chain CCS project. A market maker could also operate on a trans-regional, European basis. Financial support coming from the private sector, regional and national governments, as well as the EU (for example through the Innovation Fund or PCI framework) can help stem the initial capital investments needed.

It is therefore important for governments and the private sector to cooperate, and establish the needed regulatory bodies. Immediate action is required to ensure a timely implementation of measures is possible.

Conclusion

The climate protection actions required to meet the Paris targets will have many components. The 2c target is one that requires immediate action by countries already enjoying greater prosperity and with better capability to take action. This paper recognises the need for a just transition to extend to the people (and electorates) of those countries. In this context, the paper proposes that among the many other actions on going, CCUS (and ultimately also hydrogen) have a crucial role in reducing real emissions at current source in a manner that does not lead to the transfer of emissions and economic benefits of industry to other regions. This will enable CCUS infrastructure to be developed as both a national and global common public resource, incentivising the type of cooperative public-private action that has been observed in the past, for example in the case of water treatment and storage.

In this regard, we propose that the EU strategy for long-term emissions reductions assesses how CCUS, along with other solutions such as hydrogen will enable a truly just transition toward the 2c target, and to involve a wider stakeholder audience in this discussion. As discussed, this will require that the economic narrative set out here is further developed based on fuller development of the type of transparent evidence-based metrics presented in this study. It will also require a fuller set of the economy-wide modelling methods to generate them. At this stage, our review shows that both CCUS and hydrogen are part of the least cost portfolio for 2050. Without CCUS in 2050 and all along the timeline to 2050, the local, national and global economic and environmental costs of achieving the 2c Paris targets will be much higher. Worse, the likelihood of achieving the targets much reduced. There is a positive business case for CCUS across the EU Member States, if they are to achieve their commitments.

Achieving the required CO_2 emissions reduction will require local solutions at industrial cluster level. It will also require regional infrastructure solutions so that a transport and storage service provided for CO_2 captured. This reflects the need for incentives for CCUS to be established by Member States to provide certainty for investors. This constitutes the key role for government actors. CCUS should be implemented on a country and regional basis to the level and extent of cooperation required across an integrated European economy. In the case of CCS, the key point is making best use of the CO_2 storage resources that will be developed to address the real current emissions where they occur in their currently locations. In the case of hydrogen production involving CCS, the crucial point is bringing fuel production closer to its point of distribution and use. Only by using all available and cost-effective funding and policy mechanisms – which may involve approaches such as developing a 'market maker' – can the EU meet its commitments to the Paris Agreement, including any increase in ambition to reach net-zero emissions within the EU by 2050.

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