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Carbon management: Transcending the bioeconomy

This chapter describes how carbon management strategies transcend the bioeconomy by including recycling of carbon and the renewable energy needed to drive carbon conversion and upgrading. Hence, carbon management should be seen as the integration of the bioeconomy, carbon recycling and renewable energy.

The overall challenge goes way beyond the energy sector

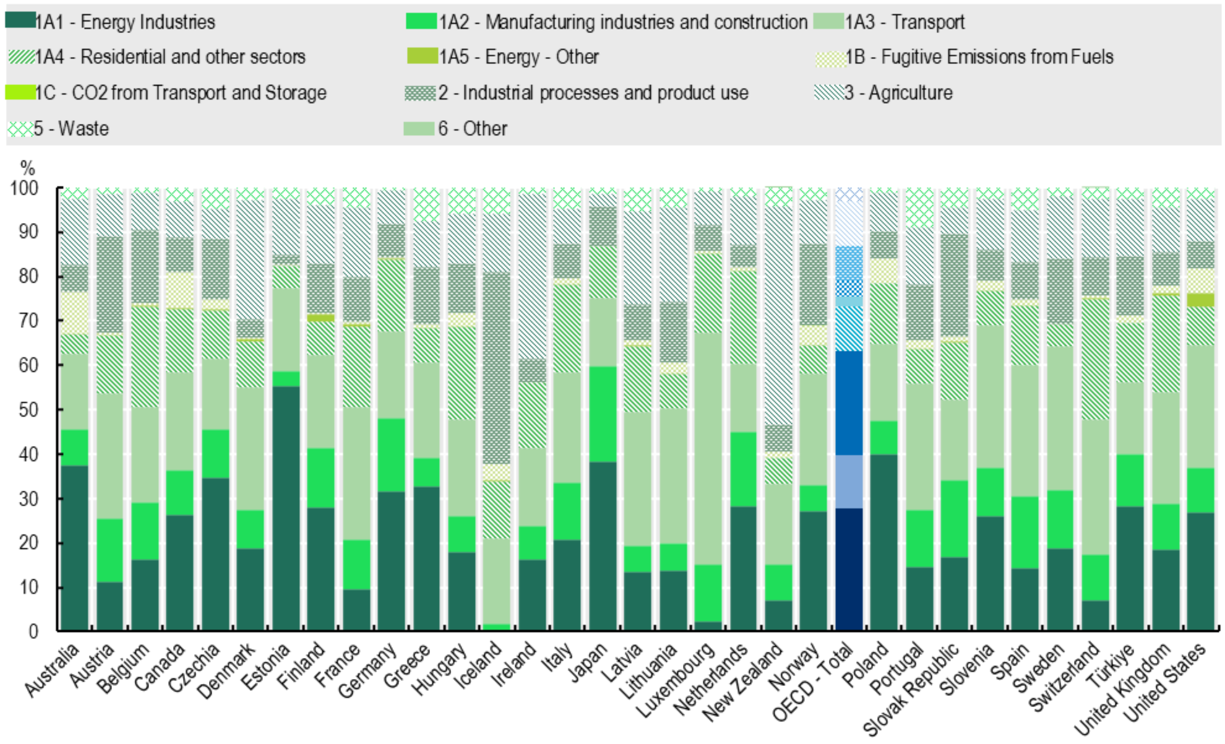
> *"The energy transition is our lifeline. It will enable innovative business models and forms of organisation, transform value chains, redistribute economic power and shape governance in new, more people-centred ways. With the right investments in technology, renewables are the only energy sources offering every country in the world a chance for greater energy autonomy and security".*
>
> *Teresa Ribera Rodríguez, Minister for the Ecological Transition and the Demographic Challenge, Spain*

OECD countries still rely on fossil fuels for about 80% of their energy supply, and while the quote above is certainly true, it gives an incomplete picture of the complexity of the green transition. A strong message is this report is that the transition has to go way beyond energy, where most of the policy is currently focussed. All sectors in all countries need to be involved, particularly those which by necessity involve carbon.

Figure 1.1 highlights the need for action on all sectors. However, for some sectors it will be harder to reduce carbon intensity than for others. Sectors frequently described as the hardest to abate are chemistry, steel and cement (e.g., Paltsev et al., 2021), with the highest emissions of all economic sectors (Broeren et al., 2014). Organic chemicals, which per definition are based on carbon, can obviously not be decarbonised. The chemicals/materials sector is the largest industrial energy consumer and the third largest industrial emitter of CO_2 (Levi and Cullen, 2018) accounting for about 5% of global CO_2 emissions (Gabrielli et al., 2023), and importantly consumes around 10% of global natural gas supply and 12% of all oil (Saygin and Gielen, 2021) as carbon feedstock embedded in the final products.

Figure 1.1. Greenhouse gas emissions by source

%, 2021, territory principle



Source: OECD (2023), "Climate change", in Environment at a Glance Indicators, OECD Publishing, Paris, https://doi.org/10.1787/5584ad47-en (accessed on 07 November 2023).based on OECD, "Air and climate: Greenhouse gas emissions by source", OECD Environment Statistics (database), https://doi.org/10.1787/data-00594-en.

The political and policy urgency

At COP21 in 2015 196 parties agreed to limiting global warming to the ‘2 degree level’ compared to pre-industrial levels. During the COVID-19 pandemic, emissions temporarily decreased, but this was followed by a rebound in the second half of 2020 (Tollefson, 2021) to reach the highest level of all time in 2021[1], despite a surge in commitments to reach net-zero carbon during COP26[2]. The IPCC has warned that unless deep GHG emissions cuts occur within the following decades, it will not be possible to limit global warming to well below 2°C or 1.5°C (IPCC, 2021).

Hence, the primary imperative for governments around the world is the need for urgency in policy making. The previous, post-industrial revolution transitions took many decades to implement (Bennett and Pearson, 2009), but they were unencumbered by the threat of climate change. It is possible that the near-term will be the decisive period that determines success or failure for this transition.

There have been many calls for a green recovery from COVID-19 (e.g., Bell et al., 2021), but governments will only achieve their targets if they take systematic, coordinated policy action to close the gap between long-term commitments and near-term actions, both domestically and internationally[3]. Critical to the near-term actions is a drive to systemic change that will contribute to the 55% decarbonisation required by 2030 (GFANZ, 2021).

Decarbonisation may be misleading

Many countries are planning for net-zero carbon by 2050 and expressing these ambitions as a *decarbonisation* of the economy. While ‘zero carbon’, and ‘decarbonisation’ are justified terms in the energy sector as wind and solar are literally zero-carbon technologies, decarbonisation can be a misleading term in other sectors. In many key industries there is no alternative to carbon e.g., food and feed, organic chemicals, fibres, plastics, and cement.

In such sectors the more relevant term would be ‘defossilisation’ (vom Berg et.al., 2022) that implies leaving fossil reserves in the ground and exploiting other sources of carbon. This is the ‘renewable carbon’ concept which “entails all carbon sources that avoid or substitute the use of any additional fossil carbon from the geosphere” (Carus et al., 2020). Renewable carbon circulates between biosphere, atmosphere or technosphere, creating a carbon circular economy. The decline in oil and gas demand in the net-zero emissions scenarios are hopefully sufficiently steep that no new field developments are required.

The term ‘carbon management’ has historically been used and has become controversial in the energy sector, with mixed opinions and motivations (Okereke, 2007). One interpretation of industrial carbon management is the separation and sequestration of fossil carbon from coal or natural gas (Keith, 2001), while still utilising the energy for generating electricity. However, it is widely agreed that to achieve carbon neutrality by mid-century requires all economic sectors and all countries to participate (European Commission, 2021; Stern and Valero, 2021), hence it is argued that carbon management should be given a wider scope to cover all carbon-based value chains.

The sources of renewable carbon are limited

Future carbon demand will be significantly reduced by decarbonisation of the energy sector. However, even with a major reconstruction of the energy sector, there is justified concern that there is still not enough biomass available to substitute the remaining fossil carbon system without damaging consequences (Kircher, 2022). As an example, aviation fuel consumption in the EU was 62.8 million tonnes in 2018. Using sunflower oil as an aviation biofuel would require almost 60% of EU arable land[4]. (In the United States, however, it has been estimated that 100% of 2050 aviation fuel demand can be met using approximately 70% of biomass that could additionally be produced while maintaining food and feed production).

Organic polymers (plastics) in Europe have about the same volume (64 million tonnes in 2019). Globally, plastics demand is forecast to continue growing to about 1 billion tonnes by 2050 (McKinsey, 2018b). Therefore, even if 60% recycling (mechanical and chemical) was attainable, this implies a fossil replacement of about 400 million tonnes.

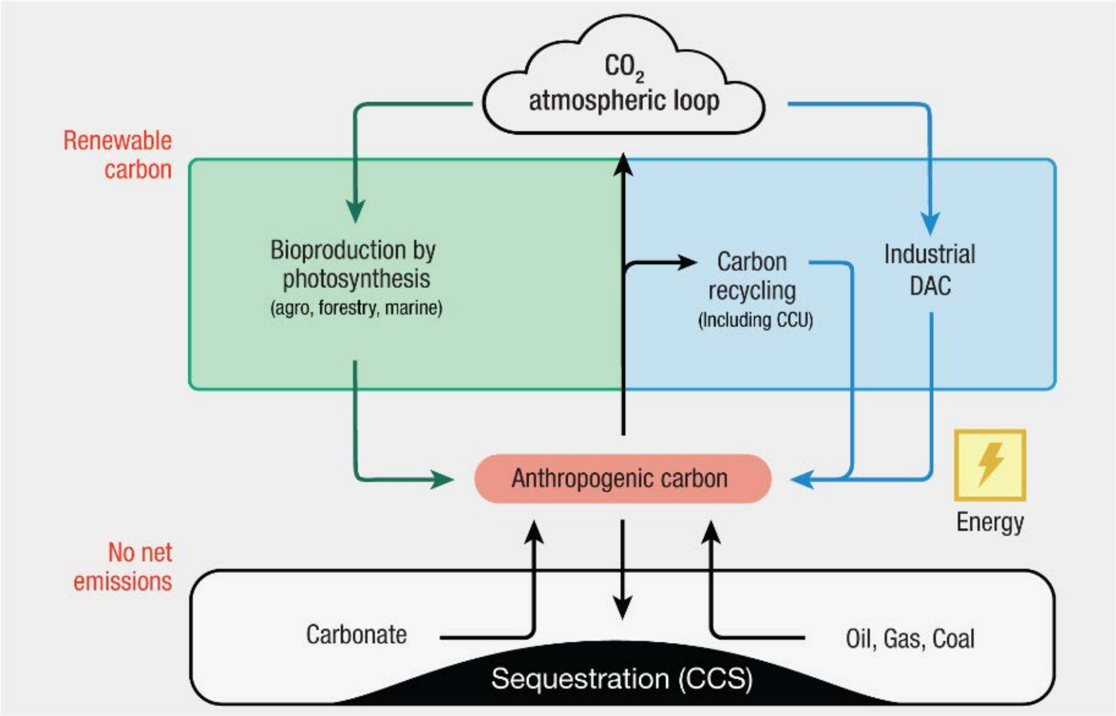
Intensified use of bioresources may lead to increased demand for land, leading to deforestation and biodiversity loss. Planting monoculture crops to support future demand for carbon-based products could have devastating consequences for biodiversity. Prioritising crops for energy, chemicals or materials could in some geographies and contexts negatively affect food prices. In some geographies and contexts, exploitation of agricultural residues is a large potential source of biomass for fuels and chemicals, but such use may also compete with soil management and animal feeds. Efforts to maximise one benefit of land nearly always reduce other benefits (Meyfroidt et al., 2022). Here is enshrined the issue of trade-offs that faces policy makers. The international energy and food price crises of 2022 put these trade-offs in sharp relief.

Given its limited availability, bioresources based on photosynthesis must be complemented by recycling of carbon waste streams, either industry flue gases or solid waste from households or industry. If the technical and economic challenges around industrial fixation of atmospheric CO_2 (DAC) can be resolved (Shayegh et al., 2021), it may become an important future part of the solution.

Any further use of fossil resources must be balanced by permanent sequestration of the emitted carbon, hence creating emission-free resources. This is for instance important in cement production where the use of carbonate minerals is unavoidable or in the use of so-called blue hydrogen in a transition phase. It is important however, to recognise that such compensatory measures may slow implementation of permanent low emission measures.

In this report, carbon management is used to describe policies addressing the complete system of renewable carbon as well as the compensatory activities for hard-to-abate sectors as outlined in Figure 1.2.

Figure 1.2. Carbon management and renewable carbon



Source: (Marvik, 2021).

Recycling as an alternative to bioproduction

An overarching objective of the circular economy is to close material loops to keep carbon circulating in the economy for as long as possible (OECD/G20, 2021). This would break the pattern of ‘take-make-dispose’ that has characterised the fossil era. By 2019, the first circular economy action plan of the European Union had been completed[5], and a growing number of EU countries, regions, and even cities have been formulating their circular economy strategies and action plans. The circular economy is enshrined in the US National Recycling Strategy[6]. In March 2021, Japan announced their Partnership on Circular Economy in conjunction with the World Economic Forum, and Korea launched the Framework Act on Resource Circulation (FARC) in 2018 (Lee and Cha, 2021).

While the role of carbon capture and utilisation of CO_2 (CCU) in climate change mitigation is debatable, CCU has a clear role in reducing the pressure on bioresources. The many initiatives for carbon capture and geological storage (CCS) create an infrastructure for the supply of concentrated, pure CO_2 as an industry feedstock, pointing to the interplay between CCS and CCU.

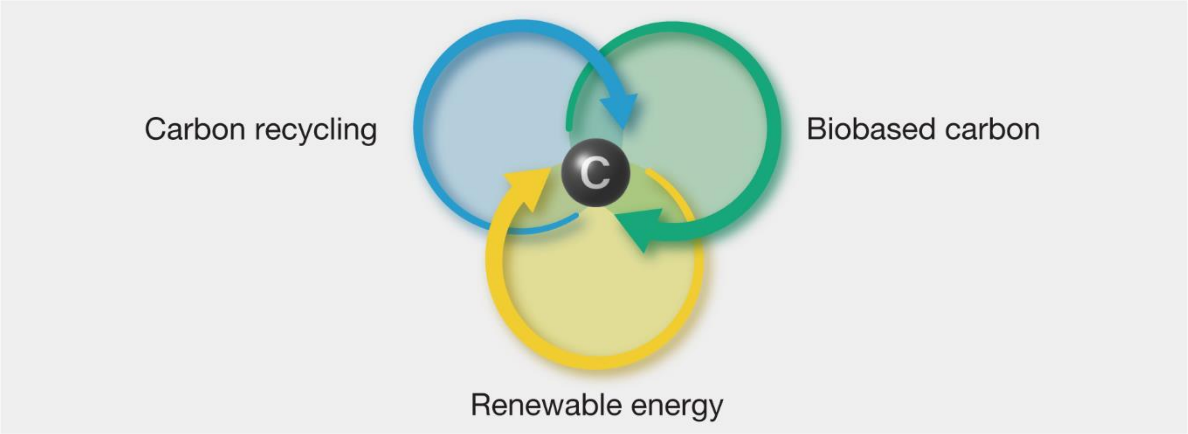
There are potentially many technologies involved in CCU, including biology, chemistry or nanotechnology, and almost all CCU routes use hydrogen as reactant and energy source. Importantly, chemical recycling of solid waste will in many cases involve converting the waste into synthesis gas, comprised of carbon gases and hydrogen, which then may use the same downstream manufacturing processes as for CCU. Eventually, atmospheric CO_2 could also be fed into the same pathway, hence this represents a general industrial platform for renewable carbon.

Global CO_2 production is approximately ten times greater than global oil production today, measured in tonnes. On the current trajectory, this may increase to 20 times by 2050 (IEA, 2012a). While most of these CO_2 emissions are of fossil origin today, this will gradually change as more biogenic and recycled carbon are used in the future carbon economy. VTT of Finland has modelled and evaluated new innovative CCU and CCS concepts for the most important sources of global CO_2 emissions. They concluded that[7] “all transport fuels and most of the chemical products could be produced by using recycled CO_2 and clean hydrogen.”

Renewable carbon requires renewable energy

While further research will be required, recycling carbon provides significant opportunities. However, as alluded to above, the carbon cycle is inherently an energy cycle, with energy-poor CO_2 and energy-rich methane (CH_4) as the two extremes. Energy input is therefore needed for most carbon recycling as well as for upgrading of bioresources in many applications. Hence, carbon management should be seen as the integration of the bioeconomy, carbon recycling and the renewable energy required for various carbon pathways (Figure 1.3).

Figure 1.3. Carbon management integrates carbon recycling, the bioeconomy and sustainable energy



Source: (Marvik, 2023).

Energy represents a significant share of manufacturing costs: in the US chemicals industry, for some energy-intensive products, energy accounts for up to 85% of total production costs[8]. Manufacturing with renewable carbon may have at least similar energy needs. This is further illustrated by a study of Kätelhön et al (2019). Here, they show that while CCU has the "technical potential to lead to a carbon-neutral chemical industry and decouple chemical production from fossil resources," this transition would increase the need for low-carbon electricity. They calculated that although CCU in the chemicals industry has the potential for more than 12 gigatonnes CO_2 mitigation potential by 2030, the major caveat it that it would require a clean energy equivalent of 55% of estimated global power production.

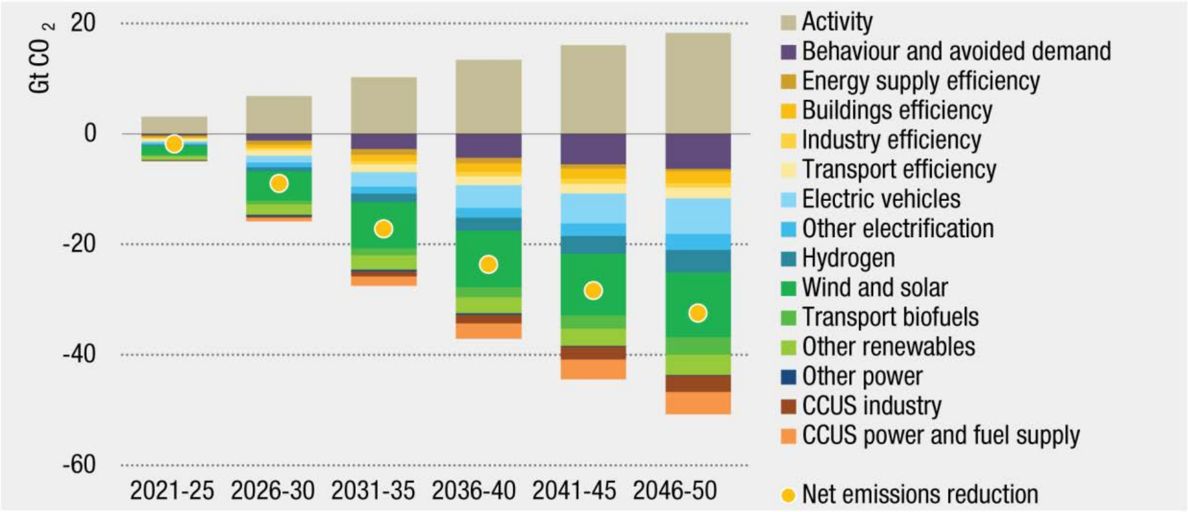
As in many aspects of net-zero carbon scenarios, great uncertainty exists over future energy demand, with most predicting or assuming large increases. Grubler et al. (2018) bucked the trend of ever-rising energy demand, resulting in a lower estimate than comparable scenarios in the mitigation literature. They projected that global final energy demand by 2050 could be around 40% lower than today, despite rises in population, income and activity. They in fact assume that demand for industrial commodities falls by around 15% as a result of dematerialisation and improvements in material efficiency. Obviously, these differences in scenarios pose great challenges for policy makers.

Climate targets depend on CCS and carbon removal

Stabilising atmospheric CO_2 concentrations at 450 ppm, is considered necessary to avoid exceeding 2°C of global warming. To meet this objective, it will be necessary to store 120-160 gigatonnes of CO_2 via carbon capture and storage (CCS) over the next 30 years. There is a need for technology development to both improve resilience to climate change and to reduce GHG emissions, with technology development necessarily complemented by the need for finance in deployment and capacity building.

To reach the emissions reduction targets of the energy sector by 2050, around half of the technologies required by then are not available now (IEA, 2021b). Even so, less than 1% of all recovery spending is directed towards green R&D[3]. The IEA envisages "major roles" for technologies like CCUS in emissions reductions, which will still be growing in capacity by 2050 (Figure 1.4).

Figure 1.4. Average annual CO_2 reductions from 2020 in the IEA net-zero emissions scenario



Source: IEA (2021b)

This view broadly aligns with those of the IPCC (IPCC, 2022). The European Commission considers that "CCUS can play a key role not only in meeting CO_2 emission reduction targets, such as the ones set by the Paris Agreement, but also in accelerating the energy transition and in accomplishing the industry redeployment"[9]. By mid-century CCUS technologies would be capable of mitigating an estimated 14-20% of CO_2 emissions (Ruttinger et al., 2022).

The need for large-scale investments

> *"Only mainstream private finance can match the scale of climate action needed for the net-zero transition including meeting investment needs in emerging markets and developing countries. We cannot get to net zero through niche efforts; we must green the entire financial system, along with every sector of our economies".*
>
> *Mark Carney, former Governor of the Bank of England, co-chair, GFANZ*[10]

The financing of the transition is proving to be challenging (e.g., Pilat, 2022). Given that this green transition is to feedstocks and energy carriers that are often more expensive and less efficient than the fossil resources in current use, then the market will hardly bear the brunt of the cost, at least not in the near-term. **The most immediate policy objective is to stimulate green private investment in large quantities**.

Only four commodities account for almost 45% of industry's CO_2 emissions: cement, steel, ammonia and ethylene. According to McKinsey, the estimated cost of reaching net zero within these four industries by 2050 is USD 21 trillion and does not include the necessary net-zero electricity capacity required to support these industrial transitions (McKinsey, 2018a). This is equivalent to a yearly cost of about 0.4 to 0.8% of global GDP for the next three decades – just for these four industries.

Attracting sufficient capital would require significant coordination and collaboration across governments and industries alike. Public policies must send strong price signals to ensure that renewable carbon and energy efficiency investments offer a sufficiently attractive risk-adjusted return. The Glasgow Financial Alliance for Net Zero (GFANZ), is a private initiative, which collectively represented over USD 130 trillion in assets in 45 countries as of November 2021 (GFANZ, 2021). It is accelerating the best practice tools and methodologies that are essential for "ensuring that the climate is at the heart of every financial decision."

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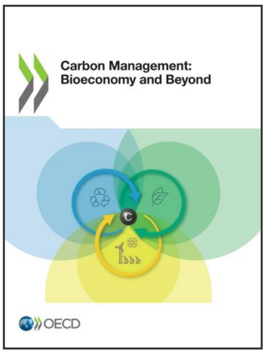

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