Stockholm Environment Institute

Stockholm Sustainable Finance Centre

What does it take to achieve net zero?

Opportunities and barriers in the steel, cement, agriculture, and oil and gas sectors

SEI report
October 2021

Aaron Maltais
Toby Gardner
Javier Godar
Michael Lazarus
Gökçe Mete
Olle Olsson

Stockholm Environment Institute
Linnégatan 87D 115 23 Stockholm, Sweden
Tel: +46 8 30 80 44 www.sei.org

Author contact: Aaron Maltais
aaron.maltais@sei.org
Editor: Marion Davis
Graphics: Mia Shu
Layout: Richard Clay
Cover photo: Steelworks, UK © Monty Rakusen / Getty

Stockholm Sustainable Finance Centre (SSFC) is a collaboration between the Stockholm Environment Institute (SEI) and the Stockholm School of Economics (SSE). The Centre delivers research, education, and collaboration on how the financial market can support sustainable development in a more powerful way.
www.stockholmsustainablefinance.com

This report has been produced with financial support from Alecta, AMF, Folksam, and Nordea. The views expressed in this report belong to the authors alone and do not reflect the views of their employers or affiliates, or those who have funded the work.

Stockholm Environment Institute is an international non-profit research and policy organization that tackles environment and development challenges.
We connect science and decision-making to develop solutions for a sustainable future for all.
Our approach is highly collaborative: stakeholder involvement is at the heart of our efforts to build capacity, strengthen institutions, and equip partners for the long term.
Our work spans climate, water, air, and land-use issues, and integrates evidence and perspectives on governance, the economy, gender and human health.
Across our eight centres in Europe, Asia, Africa and the Americas, we engage with policy processes, development action and business practice throughout the world.

Suggested citation
Maltais, A., Gardner, T., Godar, J., Lazarus, M., Mete, G., and Olsson, O. (2021). What does it take to achieve net zero? Opportunities and barriers in the steel, cement, agriculture, and oil and gas sectors. SEI Report. Stockholm: Stockholm Environment Institute, Stockholm Sustainable Finance Centre. 38 pp.

DOI: 10.51414/sei2021.023

Contents

Executive summary

If global warming is to be kept below 1.5°C, the Intergovernmental Panel on Climate Change (IPCC) has said, greenhouse gas emissions must reach net zero by mid-century. There is now strong momentum among financial actors to adopt net-zero targets. A recent survey of over 1,000 pension funds and insurers found more than 90% had a net-zero target or planned to adopt one.

However, the IPCC's assessment is at the global scale; it is not meant to be directly translated into targets for specific companies or even countries. In practice, achieving the global target will require completely eliminating emissions from a large share of economic activity, while for some sectors, significant emissions may remain by mid-century. At the same time, from a climate justice perspective, it is widely accepted that for wealthy countries, it is not enough to achieve net zero – they also need to provide significant financial support for low-carbon development in poorer countries.

Interpreting the meaning of net-zero targets for investors represents a special case. For investors, the aim is to reduce the emissions associated with the assets in their portfolios. The emissions intensity of an investment portfolio can be reduced quickly and significantly by just divesting from emissions-intensive sectors and companies and moving investments into lower-emissions assets. However, that may have very little impact on global emissions. If investors want to make a more substantial contribution to the global net-zero target, they need to adopt approaches and practices that advance the decarbonisation of the sectors responsible for the largest share of emissions.

The main ways in which investors can attempt to have an impact on emissions in the real economy is by directly allocating capital towards low-carbon solutions and away from high-carbon activities; encouraging companies in which they have an ownership stake (or that they lend to) to improve their climate performance; or investing in ways that signal to all companies that improved sustainability performance is rewarded and poor sustainability performance is punished – for instance, through higher borrowing costs.

This report focuses on "active engagement", where investors engage with high-emitting sectors, through companies in which they hold ownership stakes and with the actors to whom they provide debt financing, and place expectations on them to adopt new low-emissions technologies, practices and business models. To engage effectively, investors need to understand:

- What high-emitting companies and sectors should be doing to decarbonise production processes or to shift business models;
- The policies and other system conditions necessary for companies to succeed with their decarbonisation strategies; and
- When sectors and companies can adopt credible transition strategies that investors can support, and when other strategies, such as divestment, are likely to be more impactful.

The report provides insights from sustainability experts focused on four high-emitting sectors – steel, cement, agricultural commodities, and oil and gas. In assessments that can be read independently, we highlight what investors need to know about these sectors if they really aim to influence them, including the decarbonisation pathways that appear most promising. Our analysis concludes with a set of broader lessons and questions regarding the role of investors in engaging with climate-intensive sectors. The rest of this executive summary is a synthesis of those overarching insights.

Large opportunities for real-economy impact

One clear conclusion from the analysis in this report is that large, very disruptive changes must start to be implemented in the next decade. None of the sectors we examined has seriously initiated the changes needed to align with the targets of the Paris Agreement. In the oil and gas sector, there is a need for large and consistent annual decreases in production volumes, but production is currently on the rise. In the agricultural commodities sector, emissions are poised to increase significantly. For steel and cement, there are still no commercial-scale sites for zero- or close to zero-emissions production, although the first sites are under development.

Given the nascent state of reform, investors have an enormous opportunity to influence the level of emissions in the real economy. To do so, they need to be willing and able to put coordinated pressure on companies and other actors to plan and start to implement serious decarbonisation transitions. Because it is so early in the process, investor engagement may not always reduce emissions in the near term. Our analysis suggests that what matters most is to get companies to commit to a long-term decarbonisation agenda – to fundamentally change their production systems and business models, and demonstrate that they are implementing these changes.

Long-term transitions require immediate action

Our analysis shows that it will take decades to fully implement new production methods, technologies and business models. This is most clear in the case of heavy industry, due to the long investment cycles of existing assets and the long processes involved in piloting and demonstrating new production technologies and building commercial-scale plants. In the case of oil and gas, drawdowns of production need to coincide with the ramping-up of low-carbon energy sources and electrification over several decades. The complexity of the agricultural commodities sector also means that many of the reforms and behaviour changes needed will take decades to bring about; they need to be handled with extreme care to avoid collateral social impacts. However, the fact that these transitions will take time to implement must not distract from the urgent need to start to implement changes.

The sectors we have reviewed are all critical for avoiding dangerous global warming, and none is close to being aligned with 1.5°C or 2°C targets. This means that investors looking to make an impact on the real economy must set high standards for the implementation planning of companies that want to be seen as frontrunners. Clearly there should also be no new investments in long-lived polluting assets. For heavy industry, current reinvestments and new investments in production technologies and infrastructure should be at least compatible with achieving company-level net-zero targets. In the oil and gas sector, no new investments in expanding aggregate production can be considered compatible with global climate targets. In the agricultural commodities sector, companies must commit to adopting climate-smart approaches at scale, both on- and off-farm, including the elimination of deforestation from supply chains.

Engage with value chains

The analyses of the agricultural commodities and steel and cement sectors highlight the importance of working with value chains. For investment in green steel and green cement to accelerate, there need to be buyers willing to pay the higher cost of green industrial products. If investors view certain industrial products as strategic to achieving real-economy impacts, they can help to create lead markets for green industrial products. That would entail engaging with sectors such as transport and construction to encourage them to choose materials with lower climate impacts and thus help create demand for green industrial products.

Curbing commodity-driven deforestation requires coordinated engagement with a concentrated set of actors that play a central role in the value chains that cause deforestation. Similarly, investors can engage with companies higher up in food value chains to develop business models that can better incorporate the costs of sustainable production. They can also work to support and strengthen policies to help level the playing field and ensure that sustainable practices are competitive.

Sector-wide transitions

Investors should be careful to consider whether the strategies they adopt are incentivising sector-wide alignment with climate targets. It may not be enough to invest in the companies with the lowest emissions in a climate-intensive sector. In the oil and gas sector, we see the problem of companies adopting ambitious climate targets but selling off polluting assets to actors who will not reduce their emissions. Likewise, in the agricultural sector, companies that simply choose to avoid sourcing commodities from emissions-intensive regions may do little to change the unsustainable practices of these regions if producers can secure other buyers. What is needed instead is for large sourcing companies to work to improve the sustainability performance of agriculture in these regions. In the industrial sector, technology transfer of low-carbon solutions will be needed to help avoid a situation where value chains for green steel and cement remain a niche, without broad global adoption.

It is also important to ensure that companies and branch organisations are supporting the policies needed to bring about broad transitions. In general, a key challenge is to find ways to engage on a sector-wide basis and help create broad incentives for sustainable practices and disincentives to "business as usual".

What are the relevant leverage points for investors?

The ability of companies to transition will often depend on a range of policy changes, new infrastructure development, and changes to both upstream and downstream value chains – all happening in parallel with their own efforts. This raises the question of whether there are multiple effective leverage points that investors can use to affect these system conditions. This is an important area for further analysis, both for investor coalitions with net-zero targets, and for researchers. The complexity of the changes needed in the coming decades also means that financial actors have to keep building their own understanding of sustainability transitions, so they are able to engage effectively.

Should investors divest from the oil and gas sector, or engage with it?

The analysis of the oil and gas sector emphasises two important challenges. First, alignment with climate targets requires large and persistent decreases in production volumes. Second, nationally owned oil and gas companies account for more than half of global production and an even greater share of proven reserves. Investor coalitions have had some success in engaging with major oil and gas corporations, particularly with respect to commitments to reduce the carbon intensity of production. They have been less successful, however, in seeking commitments to reduce production levels.

Do investors wishing to make an impact have a better chance of success through engagement, or by divesting from ownership shares in oil and gas and refusing to fund debt? The evidence for cost-of-capital impacts from divesting from publicly traded stocks does not appear to be strong, but can divestment reduce the social licence and blunt the political influence of the industry through stigmatisation? Would limiting access to debt on capital markets, or engaging with banks that provide finance to the sector, be more effective than divestment from equities? Given how far the oil and gas sector still is from alignment with the Paris targets, it appears that both investors and researchers need to do more to understand what the optimal strategy is.

What kinds of sectoral targets can investors effectively aim for?

Portfolio emissions trajectories tend to be the typical way in which investors set targets for themselves. For sectors and companies, targets are usually set in terms of Scope 1 and 2 and sometime Scope 3 emission reductions. One question raised by the sectoral analyses in this report is whether there is also room for targets related to the specific and concrete actions that need to happen to achieve sectoral transitions. For example, can investors set a target for the number of carbon capture and sequestration (CCS) projects initiated by cement companies? For the number of companies with high levels of deforestation exposure that implement new anti-deforestation policies? For the share of oil and gas production fields that move into planned

production decreases? If investors want to accelerate the decarbonisation of these sectors, are there advantages in combining emission reduction targets with expectations of specific steps that companies and other actors must take to implement new business models? This is an area that requires further exploration, to identify potential pitfalls and to determine whether financial actors could potentially work together to lay out concrete actions they expect to see in carbon-intensive sectors.

1. Introduction

Financial actors are increasingly adopting ambitious climate goals in line with the Paris Agreement, and there is now a strong momentum to commit to reach net zero emissions by mid-century. A recent survey of over 1,000 pension funds and insurers found that more than 90% had net-zero targets or planned to adopt one (Levick and Vernoit 2021).

These commitments follow a 2018 report by the Intergovernmental Panel on Climate Change (IPCC) that found that keeping global warming under 1.5°C will require bringing human-caused CO_2 emissions to 45% below 2010 levels by 2030 and net zero by 2050 (IPCC 2018). All greenhouse gas (GHG) emissions will then have to reach net zero by about 2065. Achieving this will require drastic reductions in GHG emissions, combined with carbon removals to offset any remaining emissions. Carbon can be removed by enhancing natural carbon sinks (e.g. through reforestation), or with technologies such as bioenergy with carbon capture and sequestration (BECCS) or through direct air capture.

Net zero is an aggregate level global goal for avoiding a range of destructive climate impacts. However, it may not be appropriate for individual companies or even countries. Indeed, if we are to have any chance of achieving net zero by mid-century, a large share of economic activity will have to fully eliminate its emissions, not just reach net zero. For some sectors, meanwhile, net zero may not be achievable by mid-century. From a climate justice perspective, there is broad agreement that wealthy countries need to go well beyond achieving net-zero and also provide significant financial support for low-carbon development in poorer countries (Holz et al. 2018).

Investors represent a special case in the context of net-zero targets. This is because the core of investors' targets is to reduce the emissions associated with the assets in their portfolios. The emissions intensity of a portfolio can be reduced quickly and significantly by divesting from emissions-intensive sectors and companies and moving investments into lower-emissions sectors and companies; however, that may have little or no impact on the emissions of high-emitting sectors (Heeb and Kölbel 2020).

If investors want to contribute more substantively to achieving net zero at the global level, they need to adopt practices and approaches that help advance decarbonisation in the sectors that are responsible for the largest share of emissions. The main ways in which investors can attempt to have an impact on emissions in the real economy is by directly allocating capital towards low-carbon solutions and away from high-carbon activities; encouraging companies in which they have an ownership stake (or that they lend to) to improve their climate performance; or investing in ways that signal to all companies that improved sustainability performance is rewarded and poor sustainability performance is punished – for instance, through higher borrowing costs (Kölbel et al. 2020).

Members of the United Nations-Convened Net-Zero Asset Owners Alliance have committed to not relying mainly on portfolio reallocation to achieve net zero in their own portfolios. Instead, they aim to have an impact on the real economy by engaging with corporations and industrial sectors as owners and lenders and encouraging them to decarbonise their business models. They are also calling on public authorities to adopt the policies needed to drive the economic transition.[1]

For investors to make an impact through such "active engagement", it is crucial that they understand what high-emitting companies should be doing, over both the short and long term, to decarbonise their production processes or change what they produce. They also need to have a clear understanding of the policies and other system conditions that need to be in place for companies to succeed with their decarbonisation strategies.

1 See https://www.unepfi.org/net-zero-alliance.

This report presents insights from experts working on the decarbonisation of four high-emitting sectors: steel, cement, agricultural commodities, and oil and gas. We highlight what sustainability experts think investors should know about these sectors, including the decarbonisation pathways that seem most promising, if they aim to make an impact on the real economy. Each sector analysis can be read independently.

The intention of this report is not to suggest that investors could bring about sectoral transitions independent of political leadership and the implementation of stronger climate policies. However, broad insights into the potential pathways for carbon-intensive sectors to radically cut their emissions help investors to understand what counts as a credible transition plan for the companies and sectors they want to engage with. A more detailed assessment of sectoral pathways also helps to facilitate an evidence-based discussion among asset owners on what their role should be in helping companies and economies to drastically cut emissions.

The report ends with a set of general lessons and questions on the role of investors in engaging with climate-intensive sectors, drawn from the sectoral analyses. We hope the insights presented here offer a useful point of departure for dialogue among investors on how they can work together to accelerate the transformation of our economies to reach net zero.

1.1 Ambitious decarbonisation pathways

The decarbonisation pathways we are concerned with in this report are step changes that would take sectors as close to net zero, zero or net-negative emissions as is technically and socially feasible over the foreseeable future. We focus here on the larger changes sectors and companies need to make because we are concerned with providing a basis to evaluate how the long-term strategies of companies may fit into a net-zero economy. However, it is important to recognise that incremental improvements remain extremely important for transitions that run over several decades.

Some economic activities cannot be fully decarbonised and residual emissions will need to be compensated for with negative emissions. Also, the rates at which sectors can reasonably be expected to decarbonise may differ between regions. However, for the purpose of our analysis we are largely focused on the most ambitious emissions cuts for the sectors we address given that there is a clear need for large portions of these sectors to adopt the most ambitious pathways possible. A recent UN assessment found that we are currently on track for 3°C of global warming this century, well beyond that Paris targets of well below 2°C and aiming for 1.5°C (UNEP 2020). We consider emissions directly associated with production processes, with purchased energy, and with upstream supply chains and downstream use of products (Scope 1, 2 and 3 emissions, respectively), but often focus on where the sector's emissions impacts are the largest.

It is important to be aware that these transitions will have consequences that must be addressed, such as non-climate-related sustainability impacts and effects on economic development and livelihoods. For the purposes of this report, we focus on sectoral decarbonisation pathways. However, recognising how these transitions fit into broader environmental, economic and social changes is key for successfully implementing net-zero targets.

2. Steel and cement

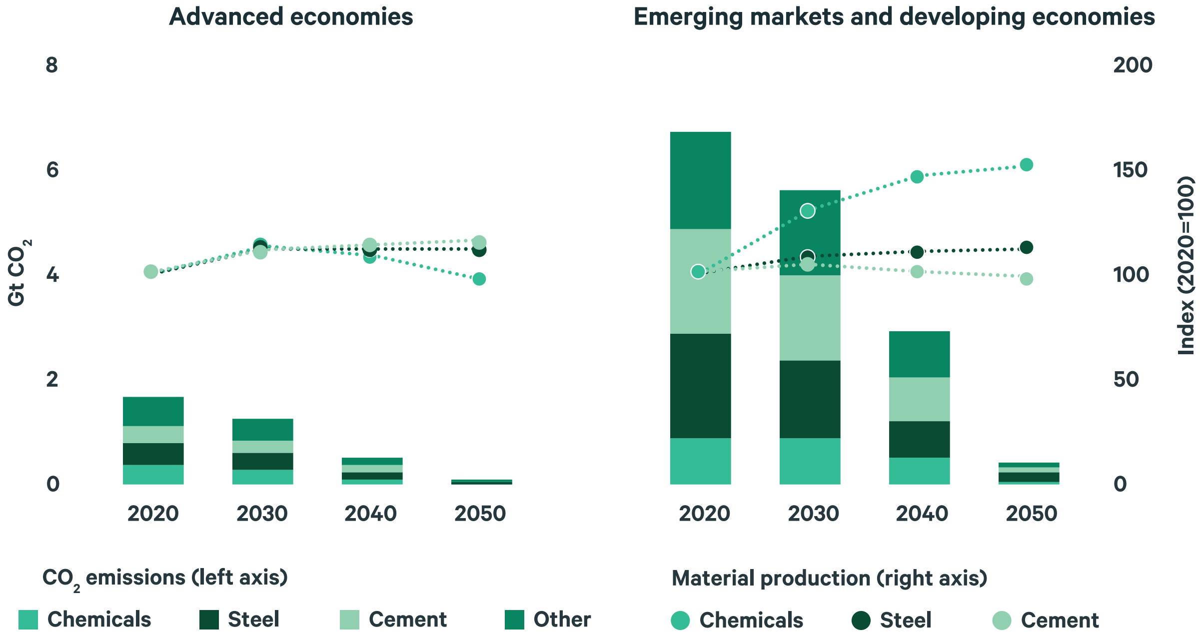
The steel and cement sectors are literally the building blocks of modern infrastructure and will remain so for the foreseeable future. Although material substitution will play a large role in cutting emissions from these sectors, massive amounts of steel and cement will be needed to produce the buildings, infrastructure and equipment needed to provide currently underserved global populations with decent housing, clean water and sanitation, and modern energy services. However, the two sectors have a massive carbon footprint, accounting for a combined 15% of global CO_2 emissions (Bataille 2020).

There are technological solutions within reach that would allow for close to zero-emissions production of both materials. However, verifying that these technological solutions can be reliable for continuous use over many years, and deploying these solutions globally between now and 2050, will be very challenging.

2.1 Alignment with a 1.5°C trajectory

According to the International Energy Agency's net-zero scenarios, global emissions from steel and cement production will have to decrease by more than 90% between 2019 and 2050 in order to be compatible with a 50% probability of limiting global warming to 1.5°C, without a temperature overshoot (IEA 2021). As shown in Figure 1, already by 2030, emissions need to decrease by 25% for steel and by 20% for cement.

Figure 1. Emission reductions necessary in 2020–2050 for industry sectors to be compatible with a 50% likelihood of limiting global warming to 1.5°C above pre-industrial levels.



Data source: IEA (2021).

2.2 Zero-emission pathways

Discussions on how to decarbonise the cement and steel sectors typically revolve around four interrelated solutions: clean energy, increased energy efficiency, reduced process emissions, and material circularity (Energy Transitions Commission 2018). Energy efficiency solutions, such as better insulation and using waste heat, can reduce energy demand, meaning less energy to decarbonise (McKinsey & Company 2017). Material circularity can help reduce demand for new industrial products in the first place, and thus reduce the total process emissions that need to be

mitigated (Allwood et al. 2010; European Commission 2019). A recent study found that circular economy approaches could reduce CO_2 emissions from four major industry sectors (plastics, steel, aluminium and cement) by 40% globally by 2050, and by 56% in developed economies (Material Economics 2018).

However, for both cement and primary steel production (i.e., ore-based as opposed to secondary steel production based on scrap), the key challenge lies is reducing emissions from internal processes (Scope 1). Not only do they produce the largest share of total emissions – around 50% for steel and above 75% for cement[2] – but a large share of these emissions are from processes that are at the very heart of the respective industries. They cannot readily be addressed by switching to clean energy, for instance. For cement, the calcination process, whereby clinker is produced by essentially removing CO_2 from limestone, then releasing that CO_2 into the atmosphere, accounts for more than 60% of process emissions (Bataille 2020). For steel, more than 70% of total sectoral emissions originate from iron ore reduction in blast furnaces, wherein coke is used to remove oxygen from iron ore to produce pig iron, which is then further processed into steel (Toktarova et al. 2020).

These processes have a very long history of being adjusted and refined, with the result that in state-of-the-art facilities, operational efficiencies are approaching the limits of what is practically achievable. This means that while there are certainly gains to be made in implementing the best available technologies in less advanced plants, eliminating remaining emissions will require massive investments in the development and deployment of new low-carbon innovations for existing industrial systems. While some of the technological and process innovations that form part of these solutions are commercially viable or in pilot stages (Bataille et al. 2018), others still require considerable research and development (Skoczkowski et al. 2020). Below we review technological options to achieve deep decarbonisation in the steel and cement sectors.

2.2.1 Steel

In simplified terms, the global steel industry is typically divided into two segments: the *primary* route, based on iron ore, and the *secondary* route, based on recycling of steel scrap. By far the dominant production pathway in the primary route is the so-called blast furnace-basic oxygen furnace (BF-BOF) process, where coke – produced from coking coal – is used in a blast furnace to reduce – i.e., remove the oxygen from – iron ore to produce pig iron. The pig iron is further refined in a basic oxygen furnace, where the carbon content in the pig iron is lowered to produce steel. For each tonne of steel produced this way, 1.5–2.5 tonnes of CO_2 are released into the atmosphere (Hasanbeigi and Springer 2019). In addition to the BF-BOF process, there is also the direct reduction (DR) process, where iron ore is reduced – typically using natural gas[3] – in solid state to sponge iron.

The secondary route is based on the remelting of steel scrap in electric arc furnaces (EAFs).[4] Largely because of problems resulting from copper contamination in steel scrap, this route was traditionally used mainly to make steel for products with lower quality requirements (Daehn et al. 2017). However, in recent decades, process improvements and increased blending of primary iron, predominantly DR-based, has enabled EAF producers to move into higher-quality market segments as well (Giarratani et al. 2006).

Increasing the share of steel that is recycled is the most obvious way to reduce emissions, as steel is highly recyclable. In 2019, about 22% of global steel production was based on EAFs. However, there is much greater potential, as recycling in many places is hampered by poor sorting and contamination issues. Innovations are underway to overcome these barriers. In its net-zero scenario for the steel industry, the IEA projects that the share of recycled steel in total metallic

2 See Wang et al (2021) for data on steel emissions divided by scopes, and Mazars (2021) and Holcim (2021), e.g., for cement.
3 Note though that in India, large DR volumes are used with coal as the reducing agent (Hall et al. 2020).
4 Scrap can be used in the BF-BOF route to a certain extent as well, added either to the blast furnace or the basic oxygen furnace.

raw materials will increase to 46% by 2050, from 32% in 2019, largely as result of increasing amounts of scrap becoming available in emerging economies (IEA 2021). This means, however, that a majority of global steel production would still be based on iron ore in 2050. Achieving the massive emission reductions that are actually needed requires a shift away from current production methods and towards new methods. There is very little room for any unmitigated BF-BOF plants in a global net-zero scenario.

While several alternative iron ore-based steel production technologies have been proposed in recent decades, there has been little progress in terms of commercialisation. The scale and technological maturity of the BF-BOF process has constituted a formidable barrier to entry. The only real exception has been natural gas-based DRI production, which has become competitive in locations with very inexpensive natural gas resources (see Section 4 for further discussion of the problems with gas). In the past five years, however, there has been a remarkable acceleration in the pace of innovation in low-emissions primary steel production.

The technology options that can enable primary steel production with close-to-zero GHG emissions can broadly be divided into three categories:

1. Continued use of fossil carbon as the main reducing agent, but with carbon capture and utilisation or storage (CCUS);

2. Hydrogen-based solutions; and

3. Direct electrolysis of iron ore, essentially using electrons as the reducing agent (ETC and Material Economics 2021).

Having said this, it is important to note that the third option is an early-stage technology that has yet to be demonstrated beyond the lab scale. In its Iron and Steel Technology Roadmap, the IEA (2020a) sees deep decarbonisation of primary steel production by 2050 made possible through a fairly equal division among three technologies: hydrogen-based direct reduction, BF-BOF equipped with CCUS, and smelting reduction combined with CCUS.

Hydrogen-based direct reduction builds on the same iron ore reduction technologies that are currently operated commercially using natural gas, with the subsequent steel production done in an electric arc furnace. As it happens, in the natural gas-based DR process, the actual reduction is already partly done with hydrogen. Doing this with 100% H2 is technologically feasible and has been proven in pilot plants, but so far not commercially. For this pathway to reach close-to-zero emissions, the hydrogen production needs to be low-carbon. This can be means either using "blue" hydrogen – made from natural gas – coupled with CCS, or using "green" hydrogen, made via electrolysis powered by low-carbon electricity.

Smelting reduction technology has advantages relative to BF-BOF in that it uses coal – i.e., not coke – as the reducing agent. Iron ore can be added as fines, not as pellets or sinter. Not only does this reduce the operational cost of the process, but a large portion of CO_2 emissions are then concentrated in one point source, which facilitates CCUS (ETC and Material Economics 2021). This is in contrast to BF-BOF mills, where emissions are distributed across many point sources, making it very expensive to reach high CO_2 capture rates (Toktarova et al. 2020). For this reason, in order for BF-BOF mills to reach zero-emissions, CCS needs to be complemented with measures that substitute biomass for some portions of the coal and coke (Mandova et al. 2019; Tanzer et al. 2020).

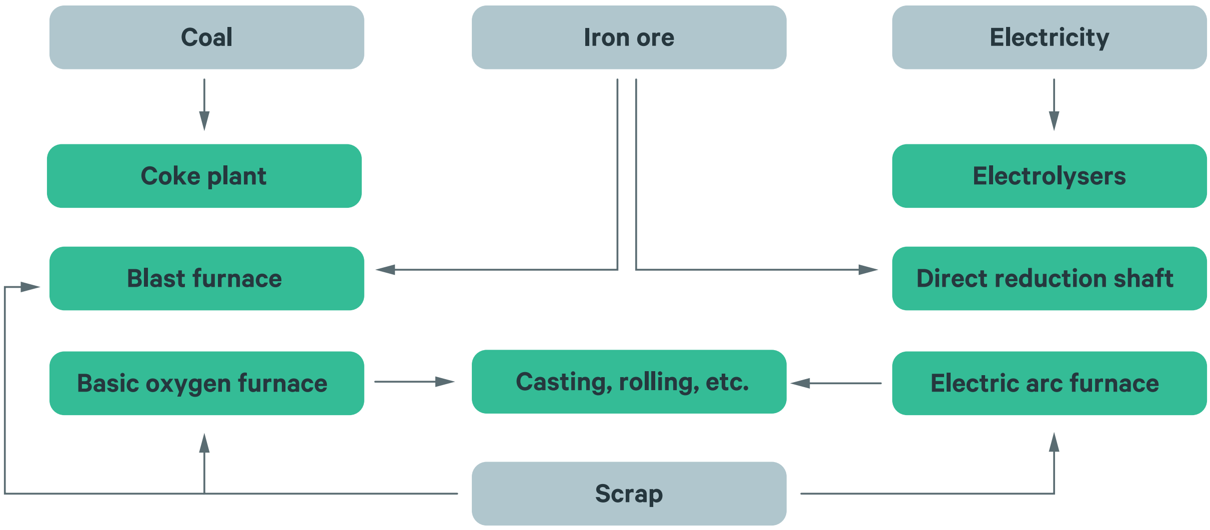
While the specifics of what these value chains will look like when in operation are still unclear, a few observations can be made. Equipping an existing BF-BOF with CCS and biomass might seem relatively straightforward, but it would still be a highly demanding project. Implementing carbon capture when there are many different point sources is complicated, and a transport and storage

supply chain must be in place to ensure that the captured CO_2 stays out of the atmosphere. Moreover, there may also be challenges in ensuring that biomass can be sourced sustainably and in sufficient volumes. That said, this option is based on the same set of key assets (coke oven, sinter plant, blast furnace, basic oxygen furnace) at the core of current BF-BOF steelmaking, which means there would be no fundamental change to the existing supply chain structure.

Smelting reduction, for its part, has been commercially implemented in a small number of locations, but converting BF-BOF mills to smelting reduction essentially entails a thorough redesign of the site. The smelting reduction process removes the need for a blast furnace and uses coal powder and iron ore fines, which means that no coke plant or sinter or pellet plant are needed either.

Finally, though a recent BloombergNEF analysis indicates that the HDR-EAF route has potential for substantial cost reductions – possibly to the point where production costs could eventually be lower than for the traditional BF-BOF route (Li 2021) – shifting from BF-BOF to HDR-EAF will require substantial changes. As shown in Figure 2, going from BF-BOF to HDR/EAF will entail key assets being replaced, in addition to possibly introducing a rather different value chain logic (see Section 2.3).

Figure 2. Comparison between the BF-BOF steel production process (left) and the HDR-EAF steel production processes (right).



Source: Authors' own work.

An indication of the current direction of industry strategies can be seen in the Green Steel Tracker, an online tool hosted by LeadIT (the Leadership Group for Industry Transition) that tracks announcements of deep decarbonisation initiatives in steel production.[5] While it is important to note that the size and characteristics of the projects in the database vary, to date most have built on hydrogen-based solutions. A handful use different CCUS options, and a few are based on direct electrolysis (Vogl, Sanchez, et al. 2021).

2.2.2 Cement

After water, concrete is the most used commodity in the world (by weight): 3 tonnes per year, per person (Gagg 2014). Twice as much concrete is used in construction as all other building materials combined. Indeed, concrete is the most used manmade material on the planet, and demand for cement and concrete continues to grow. While decarbonisation options exist for

5 See https://www.industrytransition.org/green-steel-tracker/.

concrete and cement, progress has been slow, as the need to tackle both heat and process emissions translates into higher decarbonisation costs than in other sectors. Low-carbon or carbon-neutral cement and concrete requires both significant capital expenditure (capex) and high(er) and persistent operating expenditure (opex). Consequently, at this stage, the business case for carbon-neutral cement and concrete is not clear.

For cement, important elements of achieving net-zero emissions include using low-emission energy for process heat – either through electrification or by fuel-switching to biomass and waste, reducing the content of both clinker in cement and cement in concrete, CO_2 capture in the built environment, more efficient use of concrete in buildings and infrastructure, and different circular economy solutions. However, while those measures would bring the sector closer to the net-zero target, actually reaching it will likely be impossible without CCS. There are several potential setups through which CCS could be implemented in cement production with variations not just in the capture technology, but also in how process heat is generated.

Process heat in the cement sector is now mainly generated with fossil fuels, but “alternative fuels” in the form of different waste streams are increasingly being used. For example, HeidelbergCement uses 24% alternative fuels, of which around 40% are biogenic and thus renewable (Mazars 2021). Individual plants may have higher shares still, with Heidelberg Cement’s facility in Slite, Sweden, having a biogenic fuel share around 20–30% (Cementa 2021a). According to HeidelbergCement, maximising the biogenic share of the fuel mix while also implementing CCS could enable zero-emission cement production and possibly even net-negative emissions (Cementa 2021b).

Regardless of how CCS is implemented, it will entail a substantial increase in cement production costs, likely doubling them (Energy Transitions Commission 2018). Technological innovation can enable a reduction in the costs of capture, transport and storage, but this will not eliminate the problem that cement production with CCS will be significantly more expensive.

2.3 Value chains

With both steel and cement, it is important to look at the full value chain when assessing the impact of decarbonisation costs. With cement, for instance, the significantly larger cost of producing cement with CCS would still only translate into about a 1% increase in the cost of building a structure using that cement (Rootzén and Johnsson 2017). This means that as with many industrial products, the cost premium for low-carbon cement production appears to be surmountable. More than technological progress, then, the key to making CCS as natural a component of cement plants as other forms of flue gas cleaning is innovation in policy-making and business models. Cement manufacturers will need to work with policy-makers and other stakeholders to get this message across and help set up regulatory frameworks and business practices to spread the added cost across the full value chain.

Value chain changes are also crucial for the cement sector to take full advantage of circular economy opportunities. In the upstream segment, alternative fuels can be sourced from a variety of waste streams, and the waste can be used to simultaneously recover energy and recycle the mineral content. Downstream, concrete can be recycled as aggregate, and the CO_2 released during the cement production phase can be partially reabsorbed at the end of the value chain through so-called recarbonation. These technical pathways require a new industrial logic to create a business model that enables the reallocation of assets, integrating in ways that allows for more efficient processes, improved process technologies and data availability to follow CO_2 across the value chain, including in the use phase.

A new value chain approach is also crucial for the steel sector. Demand for fossil fuel-free steel is growing substantially, with strong interest from global market leaders in sectors such as passenger and commercial vehicles, white goods and furniture. For instance, Volvo recently

announced a new partnership with SSAB and Hybrit to be fossil fuel-free by 2030. Sectors that purchase large volumes of steel will be under increasing pressure to decarbonise, including by reducing the emissions footprint of the steel they use. As with cement, the cost increases on end products seem manageable. The extra cost of a new car built with green steel could be under €300, and for a washing machine, under €20 (European Commission 2021). This means that several sectors have both a commercial interest in growing the market share of green steel and are in a good position to transfer the cost of low- CO_2 steel to consumers (ETC and Material Economics 2021).

Catalysing demand and creating lead markets for green industrial products plays a crucial role in demonstrating to steel producers and investors the business case for scaling up projects. Pressure to decarbonise and scrutiny from financial actors on sectors purchasing steel (along with policy action) can play an important role in creating the demand signals needed to build confidence and unlock investment.

BOX 1. WHERE WILL GREEN STEEL BE PRODUCED?

The commercial viability of iron reduction based on green hydrogen depends on scaling up manufacturing of electrolysers and reducing their cost – and, more important, on access to large amounts of very low-cost clean electricity. This will affect where different process stages are integrated (Gielen et al. 2020; Kinch 2021). For example, Australia is the world's largest producer and exporter of iron ore and has vast solar and wind power potential. It has several options for getting involved in green steelmaking (Wood et al. 2020):

- Establish integrated green steel production in Australia, which can then be shipped to primarily Asian markets;
- Directly reduce iron ore, which can be exported and used for steel production in receiving countries;
- Continue to export iron ore and add green hydrogen exports.

Which of these options turn out to be most viable depends on a host of factors, including transport costs and political factors. Shifting the iron ore reduction stage to Australia from, say, Japan or Korea also means shifting a large portion of the value addition and job opportunities. This is an aspect that should not be taken lightly, given the long history of political sensitivities around the steel industry.

2.4 Investment cycles and decarbonisation

Given the high capital intensity and long investment cycles of industrial production sites, there is a window of opportunity at times of major reinvestments, where the choices made can be absolutely decisive for decarbonisation (Bataille et al. 2018; Nill 2003). This issue is relevant at a company level as well as globally. Immense volumes of CO_2-emitting industrial capacity came online in China in the 2000s, which means that vast amounts of assets are due for reinvestment in the coming decades (Wang et al. 2019). The question of whether these reinvestments perpetuate GHG intensity or are used as an opportunity for switching to Paris-compatible solutions could determine whether global deep emission reductions can be realised. In order to avoid reinvestment in high-emitting, long-life assets and thereby increase the risk of prolonged operation with associated emissions, it is crucial that low-carbon solutions in heavy industry become ready and accepted as viable options to "business as usual" as soon as possible (Vogl, Nykvist, et al. 2021).

One near-term option is to make larger reinvestments that may not enable zero-emissions production right away, but are compatible with a longer-term solution. One example is converting a BF-BOF steel mill to use an electric arc furnace. This does not solve the entire problem, but electric arc furnace steelmaking based on a mixture of scrap and direct reduced iron looks to be the most promising pathway to enable zero-emission steel production. Similarly, even if H-DRI (iron produced via hydrogen direct reduction) is currently not available at commercial volumes, using DRI based on natural gas still entails a substantial emission reduction relative to BF-BOF – though upstream methane leakage needs to be monitored carefully; see Box 2 in Section 4.1 – and it can then be relatively smooth to switch to DRI produced from green hydrogen as such volumes become available.

2.5 Targets for 2030

Where would steel and cement companies aiming for net-zero emissions by 2050 need to be by 2030? Obviously, the answer here will vary from context to context, but a few key overarching observations can be made:

1. All reinvestments in long-lived equipment or infrastructure that are not net-zero compatible should be out of the question by 2030. In countries that are part of the Organisation for Economic Co-operation and Development (OECD), the deadline should be well before then, in line with the effort-sharing principles of the Paris Agreement.

2. By 2030, net-zero emission value chains need to be ready for deployment. This includes integrated processes, infrastructure, business models and regulatory frameworks.

3. By 2030, improvements in material efficiency need to be in place, and standards and codes need to have been developed to allow for the use of innovative materials and the establishment of up- and downstream partnerships that distribute both the costs and benefits of decarbonisation.

3. Agricultural commodities

A prominent study published this year estimated that food systems are responsible for a third of global GHG emissions, about 18 Gt CO_2e per year, and those emissions are rising annually in absolute terms (Crippa et al. 2021). China is the single largest emitter, but 27% of the total is emitted by industrialised countries. Almost three-quarters of food system emissions, or 24% of all anthropogenic emissions, are due to the combination of land use and land use change (LULUC) and production practices, including emissions from the production and manufacture of inputs, such as fertiliser.

The IPCC's 2019 *Special Report on Climate Change and Land* gave a similar estimate, reporting that 23% of global GHG emissions are associated with land use, making it the second largest source of emissions after the energy sector (IPCC 2019). Of those land use emissions, about half (11% of the total) were attributed to deforestation and the conversion of natural ecosystems – mostly for agriculture – and the rest directly to agricultural production, such as emissions from livestock and from fertiliser use. Tropical deforestation alone contributes an estimated 7% of global GHG emissions, and most of that – 5% of global GHG emissions, or about 2.6 Gt CO_2 per year – is driven by the production of agricultural and forest commodities across the tropics (Pendrill et al. 2019; Richards et al. 2020).

These numbers need to be considered against the backdrop of strong evidence that the land sector (agriculture and forestry) offers one of the largest solutions to climate change, due both to the potential to reduce emissions from land use practices, and to the ability to sequester carbon in trees and soil (Girardin et al. 2021; Griscom et al. 2020).

3.1 Estimating emissions from agricultural commodities

Overall, emissions from the food sector – including production and trade in agricultural commodities emissions – can be divided into four categories (see Figure 3):

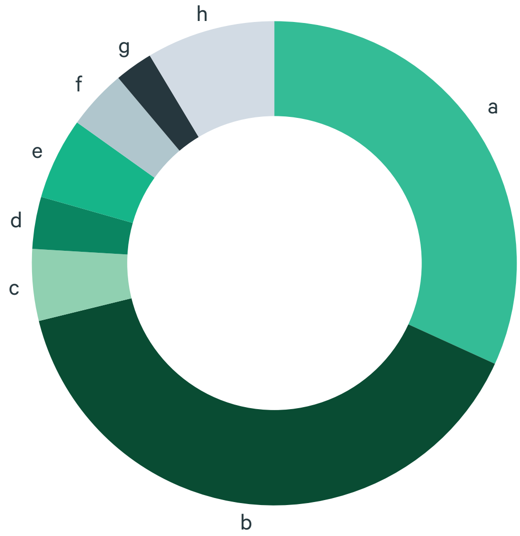
1. Land use change and emissions from the conversion of native ecosystems, including from the removal of both above-ground and below-ground biomass. These represent about half of all land use emissions.

2. Upstream emissions, including from the production of fertilisers, pesticides, seeds and animal feed; maintenance of animal breeding stock; and machinery, not including other aspects, such as the building of infrastructure, including roads, transport hubs, etc. These emissions are considerable, including the fossil fuel-intensive process of producing fertiliser (including mining of raw materials such as potash and phosphorus) and the transport of inputs to the farm gate.

3. On-farm emissions from agricultural practices, which, together with upstream emissions from farming inputs, are slightly larger, globally, than emissions from land use change. They account for some 39% of food system emissions, compared with 38% for land use change (Crippa et al. 2021). On farm emission sources are generally classified as mechanical (from direct farming operations) and non-mechanical (e.g. from enteric fermentation, nitrification, decomposition of organic matter). Agriculture produces the majority of global emissions of methane (CH_4) and nitrous oxide (N_2O), two very powerful greenhouse gases (Smith et al. 2008). The potential for addressing mechanical-source emissions is inherently larger than that for non-mechanical sources, for which some emissions are unavoidable.

4. Downstream emissions, including from food processing, transportation to consumers, packaging, storage, retail, consumption and waste management. Together they correspond to less than 20% of total food system emissions, though the energy intensity of downstream industrial processes has increased over time (Crippa et al. 2021). A major, underappreciated component of downstream emissions is in the transportation of primary agricultural commodities, such as soy, to import markets on the other side of the world (van der Loeff et al. 2018).

Figure 3. GHG emissions from the global food system, by stage, 2015.

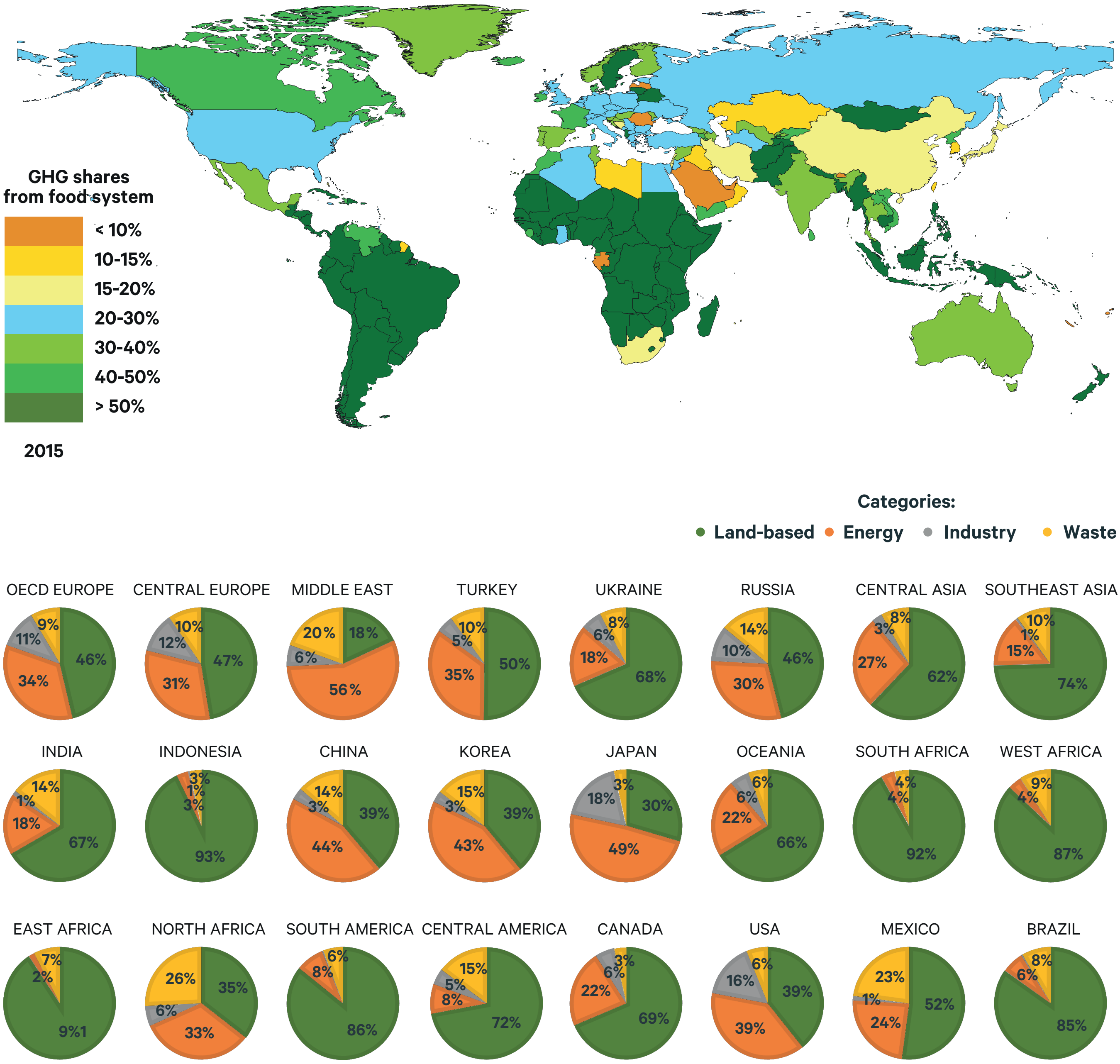


a	Land use & land use change	31.8%
b	Agricultural production (including upstream)	39.4%
c	Transport	4.8%
d	Processing	3.5%
e	Packaging	5.5%
f	Retail	4.0%
g	Consumption	2.5%
h	End of life	8.6%

Source: Redrawn from Crippa et al. (2021), with data from EDGAR-FOOD. https://ec.europa.eu/jrc/en/science-update/edgar-food.

Looking beyond the global estimates, it is important to understand the large differences in the breakdown of food system emission sources across countries, with strong implications for mitigation opportunities and climate change accountability. In industrialised countries, the majority of emissions come from energy use downstream in the supply chain (53%), while in developing countries, land use change and on-farm practices account for over 70% of total emissions from the food sector (Crippa et al. 2021; see also Figure 4).

Figure 4. GHG emissions from the food system, by category and as a share of total emissions, 2015.



Source: Redrawn and adapted from Crippa et al. (2021).

Note: The pie charts show the share of food system emissions in each country that comes from land-based activities, energy use, industry and waste. The colours on the map indicate the share of each country's total GHG emissions coming from food systems. Total GHG emissions (including CO_2, CH_4, N_2O and F-gases) are expressed as CO_2e, calculated using the 100-year global warming potential values (GWP-100) used in the IPCC's Fifth Assessment Report (Myhre et al. 2013); the value for CH_4 is 28, and for N_2O, 265.

3.2 Trends in supply and demand: implications for emissions reductions

Understanding how the farming sector can transition to a lower emissions footing requires an understanding of recent trends and projections of future supply and demand for major agricultural commodities.

Demand for agricultural commodities has grown rapidly in the past two decades. Globally, the consumption of food and agriculture products rose by about 48% between 2001 and 2018, growing twice as fast as the human population. Demand varies significantly across regions, with a marked shift towards Asia, which was responsible for 60% of the increase (World Economic Forum 2021).[6] This additional growth in demand is largely tied to the expansion in the global middle class, which has more than doubled since 2000. Demand for key agricultural commodities is projected to keep growing, driven by underlying trends in economic growth, per capita consumption and ongoing rise in global middle class, and population growth. Even if future rates of demand growth are likely to be slower than the past decades for most agricultural commodities, the absolute demand will be larger.

For the global agricultural system as a whole, including the majority of staple crops, the latest OECD/FAO Agricultural Outlook projects that production will grow by about 1.4% per year, and 87% of that projected growth will come from yield improvements (OECD and FAO 2021). Another 7% is projected to come from multiple cropping (another form of intensification) and only 6% from an increase in cropland. However, absent a major shift in production practices, this level of intensification cannot be achieved without a commensurate increase in emissions, including from the use of fossil fuels (upstream, on-farm and downstream). There is limited substitution potential for alternatives, such as organic fertilisers or non-fossil-fuelled heavy farming machinery, in much of the world (see Section 4.2).

While total crop area for most commodities has largely stabilised across much of the world, the same is not true for a small number of still-rapidly expanding commodities in the tropics – especially soy and oil palm, two of the world´s most important oil-producing crops. Much of that expansion is occurring directly or indirectly at the expense of native vegetation.

3.3 Opportunities for reducing emissions

Given the enormous challenges in eliminating GHG emissions all across the economy within the next three decades, most mitigation scenarios envision a significant role for carbon removal as well (IPCC 2018). Here the agricultural sector has a particularly critical role to play. A recent study estimated that, in broad terms, nature-based solutions have the potential to save some 10 Gt of CO_2e per year, roughly half by avoiding emissions from land conversion, and half through enhanced carbon sinks (Girardin et al. 2021). The latter would be achieved by restoring degraded land and improving land management practices.

Considering both nature and industry-based solutions, there are four broad areas in which agricultural emissions can be reduced:

1. **Conservation of forests and other natural ecosystems:** With emissions from land conversion amounting to about 11% of global GHG emissions (IPCC 2019), efforts to curb deforestation and the loss of other native ecosystems are critical components of any attempt to keep global warming below 1.5°C or 2°C. Trase Earth demonstrates that from the perspective of an individual commodity buyer, major opportunities for emissions reductions can be achieved through changes in sourcing practices.[7] As shown in Figure 5, patterns of deforestation are

6 See also FAO statistics: http://www.fao.org/statistics/en/.
7 See Trase Insights (July 2020), "Carbon emissions vary widely between producer regions": https://insights.trase.earth/insights/ghg-emissions/.

highly concentrated, with the carbon footprints of commodities such as soy, beef and palm oil sourced from the highest-deforestation regions being many times higher than the average levels for those commodities within individual countries. However, market bifurcation and leakage dynamics mean that changes to the sourcing practices and avoidance of high-risk regions by individual actors will not reduce overall emissions on the ground. Instead, what is needed is biome- and sector-wide action that also encourages committed actors (e.g. agro-industrial companies) to invest in high-risk regions and play an active role in curbing global levels of deforestation and conversion.

2. **Restoration of degraded land:** The Bonn Challenge estimates that there are about 350 million hectares of degraded land that are well suited for restoration by 2030, with carbon sequestration potential of 1.7 Gt of CO_2e per year.[8] Adopting a systematic approach to selecting priority areas for restoration can ensure the delivery of substantial co-benefits for biodiversity conservation and job creation, while also minimising implementation costs (Strassburg et al. 2020).

3. **On-farm practices:** Technological developments in agriculture can increase efficiency and yields and help avoid or limit expansion of agriculture to new areas, while also improving the resilience of crops and livestock to climate change. This includes changes in the management of farm inputs, such as reducing fertiliser and chemical use through precision agriculture; nitrification inhibitors; and the reduction of water, waste and energy use in farming practices – all of which are commonly labelled as climate-smart agriculture (Zaman et al. 2021). A range of nature-based solutions for farms are also available, including agro-ecological practices such as low/zero tillage agriculture to improve the conservation of soil organic matter, changes to crop rotation to minimise soil disturbance; the use of cover crops, mulch and biochar to conserve and increase soil organic matter; and the adoption of agroforestry.

4. **More efficient supply chains:** Scope 3 emissions – emissions associated with the value chain of a given organisation – typically represent well over 50% of the total emissions for companies operating in the food sector and buying agricultural commodities (Hertwich and Wood 2018). Emission reductions downstream of agricultural production, including through transportation, processing and waste management, offer one of the most promising targets for action, as they are not affected by many of the same systemic social and governance challenges associated with agricultural production. By contrast, more well-established innovations in emission reductions, including in transport and energy sectors, are already being adopted in the downstream end of the food system, with potential to rapidly scale.

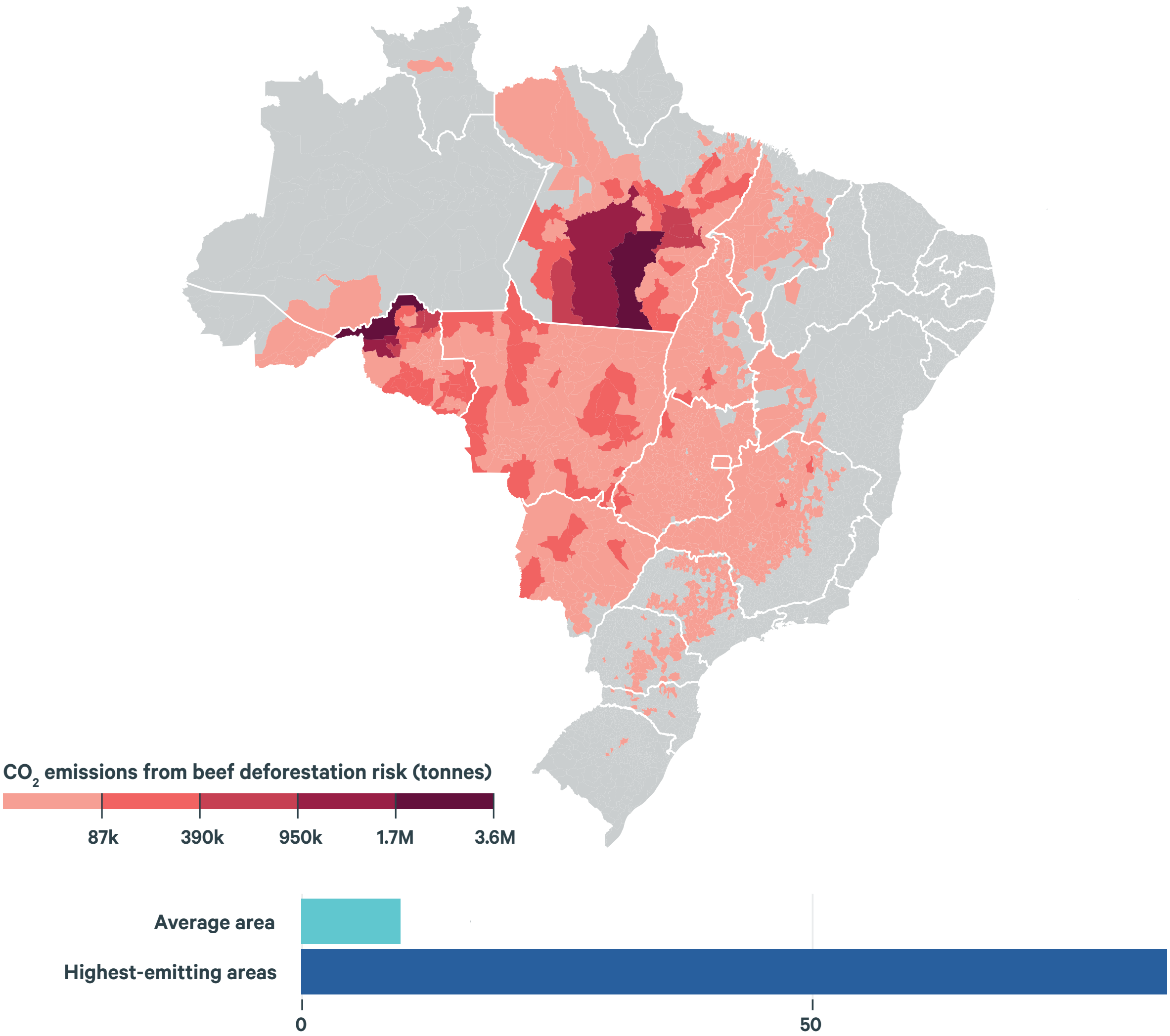
Over time, and contingent on the development of the carbon market and emissions trading schemes, there are opportunities, in theory, for ecosystem service provision, including carbon storage, to become part of the business models of companies in the agricultural sector. This, in turn, could further influence the pricing of more sustainably produced commodities, with the potential to shift consumption patterns. However, even putting aside the still-unresolved debates over Article 6 of the Paris Agreement that are important for scaling up carbon finance, there are equity considerations as well. Carbon finance carries significant risks of exacerbating existing inequalities and excluding many small-scale and vulnerable farmers at the base of many agricultural supply chains, who are comparatively ill-equipped to access such finance.

3.4 Barriers to reducing emissions

Reducing emissions from food systems is profoundly challenging, given the fundamental importance of agriculture to human well-being and socio-cultural values, the rising demand due to population growth and increasing per capita consumption, and the emissions intensity of increased yields, national security and geostrategic interests, and the impacts of climate change itself on agriculture.

8 See https://bonnchallenge.org.

Figure 5. Greenhouse gas emissions from beef-producing regions in Brazil, 2017



Source: Trase (2020): https://insights.trase.earth/insights/ghg-emissions/.

Clearly, avoiding the conversion of forests and other natural ecosystems and changing on-farm practices will be critical parts of any global strategy to achieve net zero. Yet efforts to change land use practices arguably face more systemic social and economic challenges than interventions in other segments of the food system – or, indeed, in other high-emitting sectors. For instance, even if land-clearing can be reduced by limiting access to new agricultural land, productivity and harvest intensity (e.g. through double-cropping) need to increase to meet rising demand – indeed, as noted earlier, the OECD and FAO (2021) project that only 6% of the projected increase in agricultural output for 2021–2030 will come from an expansion of cropland. For many staple crops, such as wheat, maize and rice, there has been limited expansion – or even a decline – in total cropland since the 2000s.[9] Yields have continued to grow for most key crops, and significant yield gaps remain, offering opportunities for further productivity gains, at least in theory (Folberth et al. 2020).

Still, there are three significant caveats. First, although our understanding of the relationship between yield and environmental externalities in different farming systems remains poor (Balmford et al. 2018), in practice, further increases in agricultural productivity will, in many – but not all – cases, come with increasing environmental impacts. This includes higher GHG emissions, driven in particular by increased fertiliser use – as with nitrogen fertilisation of wheat, maize and rice

9 See https://ourworldindata.org/grapher/cropland-extent-over-the-long-run.

production in China (Zhang et al. 2020). That, in turn, would require increased mineral extraction of diminishing phosphorus reserves – a critical limiting factor in agricultural intensification globally (Roy et al. 2016). Those reserves are also being rapidly depleted through soil erosion in many regions (Alewell et al. 2020). Another factor to consider is farmers' continued dependence on fossil fuels for mechanical operations, given existing investment lock-ins and lack of renewable and electricity infrastructure in many rural areas.

The second caveat is that even where significant yield gaps may exist in theory, social, economic and political factors can limit the ability of farmers to exploit them in practice, resulting in evidence of slow-down and stagnation of yield growth in some areas (Ray et al. 2012). This contrast between theory and practice is perhaps most pronounced with cattle. Some parts of the sector are undergoing rapid intensification, while large swathes of land remain under very low productivity systems (Latawiec et al. 2017). Some commodities linked to ongoing deforestation are perennials, such as palm oil, coffee and cocoa, for which it is inherently harder to rapidly increase yields, and a large proportion of production is in the hands of smallholders, many of whom face systemic barriers to further reducing yield gaps, such as lack of access to credit and markets. They also risk of being marginalised by actors with more capital.

The third caveat is that there is a growing body of evidence showing that climate change has slowed the potential for agricultural production in some regions, with modelling work suggesting that productivity is lower by as much as one-fifth relative to a counterfactual with no climate change effects in the last 50 years (Ortiz-Bobea et al. 2021). Increased periods of drought have significantly reduced harvests in some places, for instance, especially in regions where agriculture has expanded into more marginal regions.

Put simply, in cases where yield growth is set to continue, these increases will be accompanied by increased emissions, unless there is a major shift in on-farm practices (see Section 4.1) or demand and consumption patterns change. In cases where yield growth remains weak, stagnant or unable to meet rising demand, some of the increased production will inevitably be met through further expansion, partly at the expense of native vegetation, including both forest and non-forest land. This expansion can be through direct land use change, or indirectly, when a crop substitutes another crop or land use, and the latter expands into natural vegetation.

Marked increases in land area are projected for a small but increasingly important subset of mostly tropical commodities, such as soy, palm oil and cocoa – driven in part by exceptionally high and rising levels of demand (beyond what yield improvements alone can provide). In many regions of Latin America and Africa, land also remains abundant and cheap, given complications associated with land tenure. The ability of market and demand-side measures to curb vegetation clearance is limited by the fact that a significant amount of deforestation associated with agriculture across the tropics is not due to the expansion of productive land, but rather to land cleared for speculation, and/or land that is cleared only to be quickly abandoned.

3.5 Unintended consequences of emission reduction efforts

The agricultural "sector" is vastly more complex than the energy, transport or mining sectors, insofar as the production and trade of agricultural commodities are integral to the well-being and economic prosperity of billions of people. Agriculture also underpins the food security of many of the most vulnerable populations on earth, with some 690 million still experiencing persistent hunger (FAO et al. 2020). Agriculture accounts for about 27% of global employment,[10] and in most less-developed countries, over two-thirds of the labour force is in agriculture – the overwhelming majority in subsistence farming.

Actions to reduce emissions will not come without a social and economic cost, at least in the short term. In many cases, smallholder farmers do not have access to the capital and technical support

10 See World Bank data: https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS.

necessary to increase yields and add value to their products. Smallholders also often lose out to a process of consolidation of land ownership into the hands of a small number of individuals and corporations, especially when new financial incentives increase the attractiveness of farming by actors with capital. New regulatory and incentive measures aimed at reducing emissions can trigger unintended consequences for smallholders, who are generally less equipped to engage effectively and adapt to the new situation.

Setting aside potential social consequences, the economic cost of any transition cannot be underestimated, whether due to necessary investments in yield improvements, the opportunity cost of forgoing any further conversion of native vegetation, and the cost of restoring degraded land.

In sum, the social impacts of any transition in the agricultural sector have the potential to be orders of magnitude greater than in other sectors, and extreme caution is needed to ensure that any emission reduction pathway accounts for these trade-offs and includes a package of necessary social and economic mitigation and compensation measures. This further underscores the critical importance of not over-relying agriculture and forests to meet the global net-zero target. It is crucial to reduce emissions as much as possible in other sectors as well.

3.6 How ready is the agricultural sector for decarbonisation?

Overall, the agricultural sector is not moving rapidly to decarbonise, but there are notable exceptions. As outlined in the discussion above, the scale and complexity of the agricultural sector and its fundamental importance for the livelihoods and food security of billions of people makes it immensely challenging to introduce wholesale changes on the ground. Indeed, across many criteria, the needle is pointing in the wrong direction. The status quo (and baseline against which progress needs to be measured) is highly unsustainable – characterised by increasing emissions from high-yielding farming systems, stubbornly high deforestation and conversion rates linked to agricultural expansion of a small number of cash crops across much of the tropics, and ongoing degradation of active and abandoned farmland.

Among large-scale agribusinesses, low margins and low demand for more sustainably produced agricultural commodities mean that there is little incentive, or readily available capital, for sustainable intensification and implementation of nature-based solutions. For many small-scale producers, the upfront costs of the transition are simply too high at the moment. And even in countries with increasingly strong climate policies, including carbon pricing, there is considerable reluctance to apply carbon policies stringently on agriculture (Leahy et al. 2020).

Nevertheless, there are many opportunities for win-win solutions, using available technologies, with benefits for the climate as well as economic and broader environmental outcomes. If implemented more systematically, they have the potential to drive a marked reduction in emissions from agriculture. Foremost among these are climate-smart agriculture techniques (Zaman et al. 2021), such as curbing the massive and widespread over-application of fertilisers (Tian et al. 2020), together with both on- and off-farm nature-based solutions such as zero-tillage agriculture (Mangalassery et al. 2014) and the restoration of soil organic matter and above-ground biomass on degraded land (Strassburg et al. 2020).

Concerted economic investment and political action is needed to provide the necessary enabling conditions, incentives and regulatory frameworks to mobilise the uptake of these and other interventions. There are some encouraging signs across finance, business and government that such a mobilisation is, if not underway, at least within reach. The rising importance of environmental, social and governance (ESG) factors in the investment community provides one indicator, as does the emerging focus on the environmental impacts of trade in free trade agreements (e.g. Mercosur) and due diligence legislation (e.g. in the European Union). Some agribusinesses are also clearly paying more attention, as reflected in the increased number, scope and strength of many corporate sustainability commitments, including around zero-deforestation and emissions reductions. Some are tackling emissions linked to supply chains (Scope 3), driven by increasing transparency and

scientific scrutiny – such as through the Science-Based Targets Initiative.[11] Ultimately, any large-scale transition requires action not only by individual investors and companies who can reduce their own footprint simply by shifting sourcing and investment patterns, but by broad coalitions that can deliver net-positive outcomes on the ground across entire sectors. There is some encouraging movement in this direction, including regarding emissions linked to agriculture and food, such as the Coalitions of Action of the Consumer Goods Forum, as well as more industry-wide engagement by the finance sector (Ceres 2020).

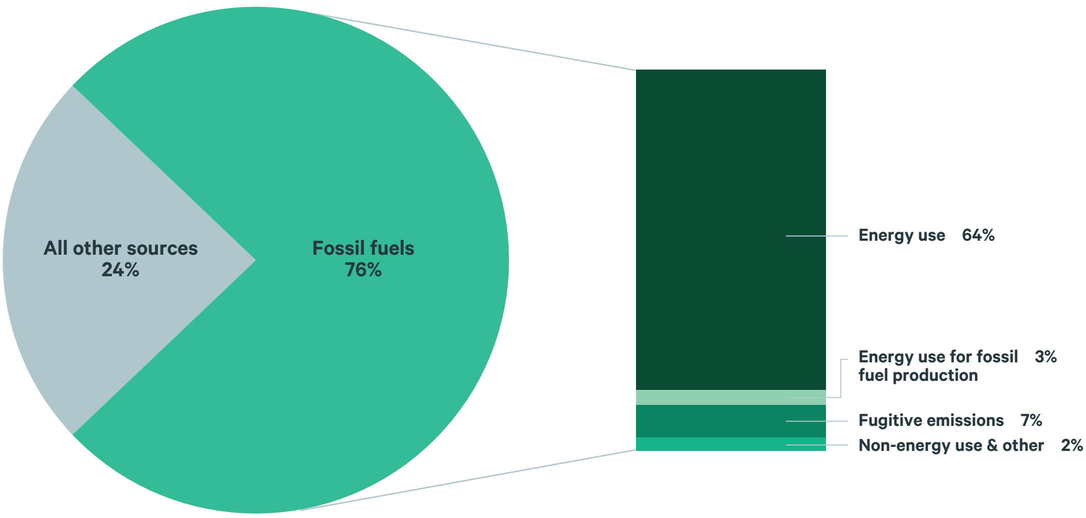
Achieving a major reduction in emissions in the agriculture sector requires a re-envisioning of the role and importance of the sector for overall human prosperity, including with regard to climate mitigation. One implication of this is that we cannot expect food and other farming commodities to remain so cheap (and a diminishing fraction of household expenditure) while also expecting them to be produced more sustainably. Achieving such a shift requires unprecedented levels of engagement by the finance sector, alongside government and business, to redirect incentives away from conventional practices and towards climate-smart and nature-based solutions.

4. Oil and gas

Oil and natural gas account for over half (55%) of total primary energy supply (IEA 2020b). Together with coal, they account for over three-quarters of global GHG emissions – as shown in Figure 6 – and close to 90% of all carbon dioxide emissions. The extraction and transport of oil and gas is also a major source of methane emissions, accounting for roughly 23% of all anthropogenic methane emissions (UNEP and CCAC 2021).

All emissions data were drawn from IEA (2019), except for land use and land use change, which are from the Food and Agriculture Organization of the United Nations (http://www.fao.org/faostat/en/#data). The fraction of emissions attributed to fossil fuels within each source IEA category – fuel combustion, fugitive, industrial processes and product use, and other – were estimated using

Figure 6. Fossil fuels' share of global greenhouse gas emissions, 2015.



Data source: All emissions data were drawn from IEA (2019), except for land use and land use change, which are from the Food and Agriculture Organization of the United Nations (http://www.fao.org/faostat/en/#data).
The fraction of emissions attributed to fossil fuels within each source IEA category – fuel combustion, fugitive, industrial processes and product use, and other – was estimated using data and information from the IEA (2019) and the Emissions Database for Global Atmospheric Research v4.3.2 (Janssens-Maenhout et al. 2019). All non-CO_2 gases were reported using 100-year Global Warming Potentials (GWPs) from the IPCC's Fourth Assessment Report (2007).

11 See https://sciencebasedtargets.org/sectors/forest-land-and-agriculture#about-the-sb-ti-flag-project.

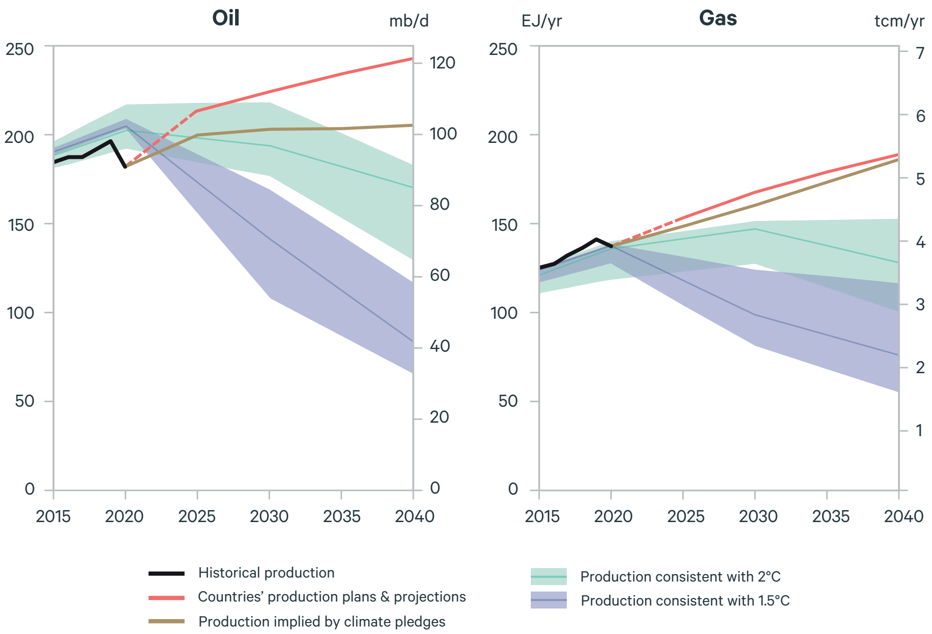
data and information from the IEA (2019) and the Emissions Database for Global Atmospheric Research v4.3.2 (Janssens-Maenhout et al. 2019). All non-CO_2 gases were reported using 100-year Global Warming Potentials (GWPs) from the IPCC's Fourth Assessment Report (2007).

4.1 The need to quickly wind down oil and gas production

Given the oil and gas sector's large share of global GHG emissions, it is clear that achieving net zero will require a rapid wind-down of these fuels' production, coupled with swift action to reduce emissions from any remaining extraction and delivery. Two recent studies provide important insights on how quickly these changes need to occur and the implications for investment in the sector.

The *Production Gap Report*, a collaborative effort of UNEP and leading research institutions and experts, shows a large discrepancy between countries' planned fossil fuel production and the global production levels consistent with limiting global warming to 1.5°C or 2°C (SEI et al. 2020). Figure 7 depicts the gap for oil and gas. Drawing on IPCC scenarios that meet the world's energy needs under a range of socio-economic pathways (Rogelj et al. 2018; IPCC 2018), the analysis finds that to be consistent with a 1.5°C pathway, global oil and gas production would have to decline annually by 4%, and 3%, respectively, from 2020 to 2030. That translates to a 10-year drop of 31% for oil and 28% for gas. By 2040, oil and gas production would need to be about 59% and 45% lower, respectively, than in 2020. (This would also require rapid and far-reaching transitions towards cleaner and more efficient energy use – to reach 70–85% of electricity from renewables – and advances in a range of low-carbon technologies.) In contrast, governments' actual plans and projections for oil and gas production in 2030 – shown by the red lines in the Figure 7 – imply 2% annual growth for each fuel.

Figure 7. Global oil and gas production, 2015–2040, as currently planned, as implied by climate pledges, and consistent with a 1.5°C or 2°C pathway.



Source: Reproduced from SEI et al. (2020).

The 1.5°C and 2°C pathways are based on the mitigation scenarios presented in the IPCC Special Report on Global Warming of 1.5°C (Rogelj et al. 2018). The "2°C-consistent" pathway was calculated as the median of scenarios that have at least a 66% probability of limiting warming to below 2°C, while the "1.5°C-consistent" pathway was calculated as the median of scenarios with at least a 50% likelihood of keeping warming below 1.5°C. Both pathways were further constrained to have limited reliance on carbon dioxide removal (CDR) deployment, given the "multiple feasibility and sustainability constraints" associated with these measures (IPCC 2018, p.19; SEI et al. 2020). For the 1.5°C and 2°C pathways, the median (blue and green lines) and 25th to 75th percentile range (shaded areas) are shown.

Earlier this year, the IEA released a "net zero by 2050" pathway (NZE) for the energy sector (IEA 2021), which it considers consistent with efforts to limit the long- term increase in average global temperatures to 1.5°C. The report suggests similar levels of decline are needed for oil and gas, even assuming significant growth in CCUS applied to gas: production drops 54% for oil and 45% for gas between 2020 and 2040. Notably, under the IEA's net-zero pathway, no new oil and gas fields are developed, beyond those projects already committed as of 2021. "The unwavering policy focus on climate change in the net zero pathway results in a sharp decline in fossil fuel demand, meaning that the focus for oil and gas producers switches entirely to output – and emissions reductions – from the operation of existing assets" (IEA 2021, p.21). Not only does this suggest an end to exploration activities – the IEA net-zero pathway also precludes developing any known, but still-untapped reserves.

Both of these analyses also note the need to quickly reduce Scope 1 and 2 emissions from the sector – that is, the methane and CO_2 emissions associated with extracting and transporting oil and gas extraction.

The implication of these 1.5°C scenario analyses for oil and gas companies is clear:

- Exploration activities should cease, and resources should be redirected to other activities.
- Investment in developing known fields should cease as well.
- Producers should focus on rapidly reducing or sequestering emissions from existing fields and infrastructure and producing existing resources as cleanly as possible.

While companies need to scale up investments in methane capture, flaring reduction, CCS and CDR technologies, among others, as these scenarios show, such investments complement but cannot substitute for the overall winding down of oil and gas production. It is important to note that although the 1.5°C pathways indicate how fast oil and gas production need to decline *globally*, the appropriate wind-down pace for individual companies and regions will vary. It will depend factors such as the cost and carbon-intensity of production as well as equity considerations, such as the dependence of economies and communities on associated jobs and revenues and the financial and economic capacity to transition (Muttitt and Kartha 2020; SEI et al. 2020).

BOX 2. GAS AS TRANSITION FUEL?

Despite increasing recognition that the world's very limited remaining carbon budget leaves little room to expand gas use, some continue to argue that gas is needed as a "bridge" fuel to a low-carbon future (Kusnetz 2020). However, more recent studies call this into question.

Several studies have shown that methane leakage from natural gas systems is much higher than is often indicated in inventories (Alvarez et al. 2018; Höglund-Isaksson 2017; Schwietzke et al. 2016; Brandt et al. 2014). For example, Alvarez et al. (2018) found overall methane leakage rates of 2.3% across the U.S. gas supply chain, 60% greater than official estimates and comparable in warming impact to the CO_2 emissions from gas combustion over a 20-year time horizon.

Lower gas prices and higher availability also stimulate higher overall energy use and emissions (Chen and Xu 2019; McJeon et al. 2014). Moreover, wind, solar, battery and other low-carbon technologies have advanced so fast that using natural gas as a "bridge" fuel is no longer as necessary (Stockman et al. 2019; McGlade et al. 2018). This means that rather than advancing the low-carbon transition, increasing natural gas production and thus lowering gas prices could lead to a net increase in global emissions and potentially delay the introduction of near-zero-emission energy systems (McGlade et al. 2018; Zhang et al. 2016).

4.2 Is there movement towards production declines?

The challenge for oil and gas is fundamentally different than for the other sectors discussed in this report. Abundant supplies of low-carbon steel and cement will still be needed in a net-zero world, and obviously so will sustainably grown agricultural commodities. The same is unlikely to be the case for fossil fuels.

Oil and gas companies will need to reorient their business models to produce as cleanly and efficiently as possible from existing fields and where appropriate, seek new areas of growth that leverage their assets and expertise (e.g. from offshore oil and gas to offshore wind platforms; developing or repurposing infrastructure to transport and store captured carbon; establishing hydrogen networks, etc.). As suggested by a recent Carbon Tracker Initiative report, companies have two strategic options: 1) a "wind-down/harvest model," transferring cash and profits from existing resources to shareholders (e.g. via dividends) or 2) a "transition model", investing in new areas that promise strong returns in a low-carbon world (Coffin 2021).

Observers of the fossil fuel industry have offered a variety of criteria for judging whether an oil and gas company is Paris-aligned. While some touch on 1.5°C alignment, specifically, most criteria were suggested prior to the release of the IEA NZE report, and thus may not reflect its key finding around the need to end the development of new oil and gas fields.

In 2019, DivestInvest issued a report that sets out five criteria for judging whether companies are on a managed decline pathway consistent with the Paris Agreement, building on prior work by the Transition Pathway Initiative (Jensen and Harrison 2019):

1. No lobbying for policies that reduce the probability of the 1.5°C goal;
2. No exploration spending;
3. No approval or acquisition of new fossil fuel infrastructure or projects;
4. A clear plan for wind-down of fossil fuel extraction; and
5. Remuneration policies that support the managed decline of fossil fuel extraction.

At the time of writing, the report authors found no companies had met all five criteria, though two – Orsted and TUI – had transitioned away from fossil fuel extraction or are in the process. Orsted, formerly known as the Danish oil company Dong, is a prime example of a company that has pursued both the wind-down and transition models noted above, ending new development and using its historical oil and gas unit as a cash generator for its growing wind business.

With many oil and gas companies adopting climate and, in some cases, net-zero pledges, Carbon Tracker Initiative and Oil Change International reviewed them against their own set of criteria for Paris (CTI) and 1.5°C (OCI) consistency (Coffin 2021; Tong et al. 2020). OCI found that none of the large oil and gas companies reviewed came close to 1.5°C alignment, noting that all continued to explore and approve new projects, and only Eni had set absolute emissions targets, including Scope 3 emissions and avoiding potential loopholes. OCI's criteria also encompass commitments to end lobbying that obstructs climate solutions – which none of the companies had done. Earlier analysis by the Transition Pathway Initiative had also found that no European oil and gas companies, despite their net-zero ambitions and claims, was aligned with 2°C, let alone 1.5°C (Dietz, Gardiner, et al. 2020).

In July 2021, using the IEA's NZE scenario, the World Benchmarking Alliance, in partnership with ADEME (The French Agency for Ecological Transition) and CDP, assessed 100 oil and gas companies' targets and performance against 1.5°C pathways (World Benchmarking Alliance 2021). Their detailed methodology evaluated investment strategies (extent of emissions locked in by oil

and gas projects, as well as capex in low-carbon and carbon removal technologies), research and development (R&D) expenditures, management capabilities, business model, and supplier, client and policy engagement. Aside from two companies with little direct involvement in oil and gas production (Neste and Engie), no company received a good (better than C) grade. The European majors fared best, but even the commitments of BP, Shell and TotalEnergies – companies that expect declining shares of oil production – were undermined by plans to increase gas production, or in BP's case, plans that to cease new oil and gas exploration only in "new countries". Taken together, these assessments reinforce the conclusion that while some oil and gas companies have taken positive steps, none is yet close to a strategy that could be considered consistent with a 1.5°C, or even 2°C, trajectory.

It is important to recognise that investor-owned companies account for less than half of global oil and gas production, and an even smaller fraction of proven reserves. Investor-owned companies tend to be more nimble than national oil companies, a key asset for transitioning rapidly to new technologies and business models. At the same time, most lowest-cost and lowest-emissions-intensity oil resources are held by national oil companies. This is particularly true of the Middle East. Notably, Saudi Aramco has signalled its intention to be "the last man standing" among producers as oil markets tighten. Therefore, it will be important that financial leverage is exerted on both private and state-owned oil and gas companies.

Legal action presents another threat to producers, particularly those based in Europe and North America. In May 2021, a Dutch court ruled that Royal Dutch Shell PLC must cut its GHG emissions – inclusive of emissions from burning the oil and gas it produces (Scope 3) – by 45% by 2030 from 2019 levels (Joselow 2021). The landmark ruling sent shockwaves through the industry and set a new benchmark for the pace of transition for oil and gas companies.

One consequence of legal action and public pressure has been for companies to "offload" assets, particularly more problematic and high-emitting ones, to smaller, less responsible firms, as BP recently did in Alaska (Adams-Heard 2021). This trend could accelerate if companies elect to use this mechanism to meet court- or self-established emission reduction targets. Offloading assets should not be viewed as a legitimate way for companies to meet targets; indeed, investors should look to leading companies to take both credit and responsibility for cleaning up and decommissioning high-emitting resources, rather than selling them.

BOX 3. WHAT ABOUT CARBON REMOVAL TECHNOLOGIES?

Many industry actors are pinning hopes on CCS and CDR as means to continue or expand production, but there are significant technological, ecological and social barriers. Even if success is rapid, will these technologies and companies be able to compete with clean energy technologies that are increasingly outcompeting even unabated oil and gas in many markets? With that in mind, independent reports tend to caution against oil and gas company plans that rely heavily on yet unproven technologies and dedicating massive land area to CDR (Coffin 2021; Tong et al. 2020; Jensen and Harrison 2019).

Recent research also underscores how overreliance on CDR could weaken incentives for emission reductions and ultimately lead to a greater temperature increase (Grant et al. 2021). That said, some argue that the oil and gas sectors present the best opportunities to commercialise CCS and CDR technologies that will be essential elements of most 1.5°C and net-zero scenarios (Meckling and Biber 2021).

In summary, there are many steps that oil and gas companies should take: from ending exploration, new development and lobbying against climate policy, to establishing ambitious, comprehensive near- and long-term goals for cutting production levels and following through on them. However, such pathways will require dramatic and thorough changes in their business models, culture and management. For the time being, while some companies, particularly European majors such as Eni and BP, have made important advances in their goals and statements, it appears unlikely that any will be able to satisfy the requirements of Paris or 1.5°C consistency. Investors can engage with oil and gas companies to encourage them to accelerate their movement in this direction. It seems clear that investors serious about making a real impact on the production of oil and gas cannot rely only on engagement. This raises the question of whether divestment or other strategies that use investors' financial leverage can be useful in influencing developments in the sector.

5. Investor engagement with carbon-intensive sectors

The analyses presented in Sections 2–4 laid out the central challenges and opportunities for cutting emissions in sectors critical to tackling climate change. The aim was to provide a knowledge base that can support investors and investor coalitions as they develop strategies to help bring about significant emissions reductions. In this final section, we highlight some general lessons drawn from these assessments. We also raise a set of questions on the role of investors in advancing the net-zero agenda that arise from our perspective as experts in sustainability and sustainability transitions.

5.1 Large opportunities for real economy impact

It is clear that very disruptive changes must start to be implemented in this decade to align high-emitting sectors with the Paris targets – but none of the sectors we have examined has begun to make those changes in earnest.

The oil and gas sector needs to quickly ramp down production, but the current trend is of production increases. Only a few oil and gas companies have committed to cutting production levels, and Carbon Tracker finds among the oil majors, that only three have committed to absolute reductions of production volumes, and only one without exceptions (Coffin 2021). In the agricultural commodities sector, meanwhile, current trends also point to significant GHG emission increases, driven by significant demand growth.

In the steel and cement sectors, there are still no commercial-scale sites for zero- or close to zero-emissions production. The first industrial-scale CCS facility at a commercial scale cement plant is now being built by HeidelbergCement in Norway, with government support. It is expected to halve emissions.[12] HeidelbergCement has also proposed to build the world's first carbon-negative cement plant at its Slite site in Sweden, aiming to start operations by 2030, if it can obtain the necessary permits, electricity infrastructure and other financial support.[13] For steel, there are now several carbon-neutral plants under development. Sweden's HYBRIT and H_2 Green Steel projects appear to be farthest ahead, aiming for commercial volumes of green hydrogen-based production by 2026–2030.[14] These are positive signs, but only represent a tiny fraction of each sector. We are clearly only at the very beginning stages of decarbonising cement and steel globally.

There is thus an enormous opportunity for investors to make an impact on the real economy by placing coordinated pressure on companies and other actors to plan for and start to implement

12 See the company's press release from 15 December 2020: https://www.heidelbergcement.com/en/pr-15-12-2020.
13 At the time of writing, HeidelbergCement had failed to secure a permit to continue its operations at the Slite site and was involved in new permitting process.
14 See http://www.hybritdevelopment.se and http://www.h2greensteel.com.

serious transitions of their businesses. Government policy will also play a key role – and of course companies themselves have to make the key leadership decisions. Still, by incentivising and supporting frontrunners, investors can help lay the foundations for sector-wide implementation of net-zero production technologies and methods.

Importantly, the early state of transition also means that investor engagement will not always result in near-term emission reductions. Our analysis suggests that what is most important is to get companies to commit to a longer-term agenda of fundamental change and to demonstrate actions to implement it. On the back of these long-term plans, investors should clearly push for immediate yearly incremental emissions improvements, underpinned by science-based targets and judged against regular milestones.

5.2 Long-term transitions require immediate action

The sectoral analyses shows that fully implementing new production methods, technologies and business models will take decades. This is particularly clear in the case of heavy industry, due to the long investment cycles of existing assets. It also takes a long time to pilot and demonstrate new production technologies and then build commercial-scale plants. In the case of oil and gas, drawdowns of production need to coincide with the ramping-up of low-carbon energy sources and electrification over several decades. The complexity of the agricultural commodities sector also means that many of the reforms and behaviour changes needed will take decades to bring about and need to be handled with extreme care to avoid collateral social impacts. Still, it is clearly urgent to put all four sectors on a course to decarbonisation.

Given how critical these sectors are to achieving net zero, investors looking to make an impact on the real economy must set a high bar for companies that want to be treated as frontrunners. One clear message is that there should be no new investments in long-lived polluting assets. New investments in old technologies risk locking us in to polluting industrial assets through mid-century.

For steel and cement, current reinvestment and new investments in production technologies and infrastructure must at the very least be net-zero-compatible. To meet climate targets, low-carbon production technologies and processes also need to be ready to be scaled up to production levels by the end of this decade. In the oil and gas sector, no new investments in expanding aggregate production can be considered compatible with global climate targets. For an equitable transition, production in wealthy regions may need to decline even faster than global models indicate, to allow for slower transitions in poor regions. In the agricultural commodities sector, companies must commit to adopting climate-smart approaches at scale, both on- and off-farm, including the elimination of deforestation from supply chains.

5.3 Engage with value chains

The analyses of agricultural commodities and steel and cement production highlight the importance of working with value chains. In the area of green industrial products, the logic is quite straightforward: For investment in green steel and green cement to accelerate, there need to be buyers willing to pay the higher cost of sustainably produced materials. Clearly policy should play the main role in internalising the cost of carbon in industrial production and level the playing field between high-emitting and low-emitting producers. However, investors can also help create lead markets for green industrial products by engaging with sectors such as transport and construction. By encouraging these actors to decrease the climate impacts of the materials they use, investors can help create demand for green industrial products (along with improved material efficiency and circularity).

A recent report from Ceres, a non-profit organisation that works to make the business case for sustainability, found that up to 39% of the GHG emissions from deforestation associated with

agricultural commodities are related to the international trade of commodities (Ceres 2020). Deforestation exposure is often concentrated with traders, meat-packers (beef) and palm oil refiners, Ceres noted. Of the 2,500 entities trading forest-risk commodities from Latin America, for instance, just three dozen accounted for more than half of those exports. The work of the Trase initiative, meanwhile, shows that most of the deforestation and land-based emissions associated with the production and trade of these commodities is concentrated in less than 5% of the localities where they are grown.[15]

Coordinated investor engagement with the actors that play a central role in the value chains causing deforestation is key – both directly, and indirectly through their sources of financing (especially banks). In this context, it is important to note that rather than just encouraging companies to change where they source commodities, investors may often have more impact if they can incentivise companies sourcing commodities from regions with high deforestation to work with suppliers to implement more sustainable practices.

Another fundamental challenge facing any transition in the agriculture sector is how to create a price premium for sustainably produced commodities. Here investors can engage with companies higher up in value chains to develop business models that can better incorporate these costs, while also working to support and strengthen policies to help level the playing field and ensure that sustainable practices are competitive.

5.4 Sector-wide transitions

Investors should be careful to consider whether the strategies they adopt incentivise sector-wide alignment with climate targets. It may not be enough to invest in the companies with the lowest emissions in a climate-intensive sector. The oil and gas analysis, for instance, highlighted the problem of leakage, as companies sell off polluting assets to other actors that are not reducing their emissions. Likewise, in the agricultural sector, companies that simply change where they source commodities may do little to change unsustainable practices in emissions-intensive regions if producers can secure other buyers. In the cement and steel sectors, it will be important to avoid a situation where value chains for green materials remain a niche, without broad movement to change production processes globally.

One important recommendation for investors seeking to advance sector-wide transitions is to push companies to fix problems with their polluting assets or supply chains, rather than off-loading them. Another important element is to ensure that companies and branch organisations support the policies needed to bring about broad transitions. In general, a key challenge is to find ways to engage on a sector-wide basis and help create broad incentives for sustainable practices and broad disincentives to “business as usual”.

5.5 What are the relevant leverage points for investors?

Active engagement is focused on companies where investors hold ownership stakes, and this is clearly the most direct point of leverage. However, the analyses of heavy industry, oil and gas, and agriculture all show that the ability of companies to transition will often depend on policy changes, the development of new infrastructure, and changes to both upstream and downstream value chains, all happening in parallel with their own efforts. Political action will of course be most important in ensuring the right conditions for transforming our economies.

Identifying where investors are best placed to influence these system conditions is an important area for further analysis, both for investor coalitions with net-zero targets and for researchers. The sectoral analyses in this report demonstrate the complexity of many of the changes required. Financial actors will need to invest in building their own capacities and understanding of the issues, so they can engage effectively.

15 See the online Trase Yearbook 2020: https://insights.trase.earth/yearbook/summary/.

5.6 Investor engagement or divestment in the oil and gas sector?

The analysis of the oil and gas sector emphasises two important challenges. First, alignment with climate targets requires large and persistent decreases in production volumes. Second, nationally owned oil and gas companies account for more than half of global production and an even greater share of proven reserves. Investor coalitions have already had some success in engaging with major oil and gas corporations, particularly with respect to commitments to reduce the carbon intensity of oil and gas production itself. However, there has been much less success in securing commitments to reduce production levels (Dietz, Byrne, et al. 2020). This raises questions about whether investor engagement is really a viable way of getting oil and gas companies to commit to winding down the core of their business models and to invest in producing energy from renewable sources.

Investors cannot have the same type of owner influence on nationally owned oil and gas companies as they do on publicly traded companies, but they do play a central role in providing financing to these actors through the banking sector and debt markets. Do investors with ambitions to have real-economy impact have a better chance of success by divesting from oil and gas and refusing debt funding to raise the cost of capital for the oil and gas sector or through engagement? The evidence for cost of capital impacts from divesting from publicly trade stocks (secondary markets) does not appear to be strong (Kölbel et al. 2020), but can divestment reduce the social licence and blunt the political influence of the industry through stigmatisation? Would limiting access to debt on capital markets, or engaging with banks that provide finance to the sector, be more effective than divesting? A clear active ownership approach is for investors to engage with sectors such as transport and petrochemicals to influence demand for oil and gas. However, given how far the oil and gas sector still is from alignment with the Paris targets, it appears that both investors and researchers need to do more to understand what the optimal strategy is.

5.7 What kinds of sectoral targets can investors effectively aim for?

A striking feature of the sectors reviewed in this report is the level of complexity involved in transitioning to net zero. Just a few of the uncertainties include which technologies will be economically viable and socially acceptable, how market conditions will develop and affect the kinds of products that will be viable as we move to net zero, and how quickly policies will be put in place to align our economies with global climate targets. This complexity means that investors aiming to make an impact on emissions in the real economy will face challenges in showing a direct link between their efforts and results, in setting reachable and specific targets for what counts as "real economy" impact, and in communicating to their stakeholders what types of impacts investors can reasonably be expected to achieve and where the limits of their influence lie.

Portfolio emissions trajectories are the typical way in which investors set targets for themselves. For sectors and companies, targets are usually set in terms of Scope 1 and 2 and sometime Scope 3 emissions reductions. One question the sectoral analyses raise is whether there is also room for targets related to the specific and concrete *actions* that need to happen to achieve sectoral transitions. For example, can investors set targets for the number of new CCS projects initiated by cement companies, the number of companies with high levels of deforestation exposure that implement anti-deforestation policies, or the share of oil and gas fields that start to wind down production? Are there advantages to be had in combining emissions targets with expectations of specific steps companies and other actors must take to implement new business models? Where should investors be cautious with this approach, and is it possible for financial actors to coordinate around sets of concrete actions they expect to see in carbon-intensive sectors? These are important questions that warrant further study.

References

Adams-Heard, R. (2021). Selling Its Alaskan Oil Business Was a Green Win for BP—Not the Planet. *Bloomberg Green*, 15 April. https://www.bloomberg.com/graphics/2021-tracking-carbon-emissions-BP-hilcorp/.

Alewell, C., Ringeval, B., Ballabio, C., Robinson, D. A., Panagos, P. and Borrelli, P. (2020). Global phosphorus shortage will be aggravated by soil erosion. *Nature Communications*, 11(1). 4546. https://doi.org/10.1038/s41467-020-18326-7.

Allwood, J. M., Cullen, J. M. and Milford, R. L. (2010). Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050. *Environmental Science & Technology*, 44(6). 1888–94. https://doi.org/10.1021/es902909k.

Alvarez, R. A., Zavala-Araiza, D., Lyon, D. R., Allen, D. T., Barkley, Z. R., et al. (2018). Assessment of methane emissions from the U.S. oil and gas supply chain. *Science*, 361(6398). 186–88. https://doi.org/10.1126/science.aar7204.

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., et al. (2018). The environmental costs and benefits of high-yield farming. *Nature Sustainability*, 1(9). 477–85. https://doi.org/10.1038/s41893-018-0138-5.

Bataille, C. (2020). *Low and Zero Emissions in the Steel and Cement Industries*. 2020–02. OECD. https://doi.org/10.1787/5ccf8e33-en. OECD Green Growth Papers.

Bataille, C., Åhman, M., Neuhoff, K., Nilsson, L. J., Fischedick, M., et al. (2018). A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement. *Journal of Cleaner Production*, 187. 960–73. https://doi.org/10.1016/j.jclepro.2018.03.107.

Brandt, A. R., Heath, G. A., Kort, E. A., O'Sullivan, F., Pétron, G., et al. (2014). Methane leaks from North American natural gas systems. *Science*, 343(6172). 733–35. https://doi.org/10.1126/science.1247045.

Cementa (2021a). *Så Här Kommer Svenskarnas Avfall till Användning*. https://www.cementa.se/sv/sa-har-kommer-svenskarnas-avfall-till-anvandning.

Cementa (2021b). *Sweden First in the World with Carbon-Neutral Cement Plant*. https://www.cementa.se/sv/sweden-first-in-the-world-with-carbon-neutral-cement-plant.

Ceres (2020). *The Investor Guide to Deforestation and Climate Change*. Ceres, San Francisco, CA. https://www.ceres.org/resources/reports/investor-guide-deforestation-and-climate-change.

Chen, Y. and Xu, J. (2019). The shale gas boom in the US: Productivity shocks and price responsiveness. *Journal of Cleaner Production*, 229. 399–411. https://doi.org/10.1016/j.jclepro.2019.04.337.

Coffin, M. (2021). *Absolute Impact 2021: Why Oil and Gas "Net Zero" Ambitions Are Not Enough*. Analyst note. Carbon Tracker Initiative, London. https://carbontracker.org/reports/absolute-impact-2021/.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N. and Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2(3). 198–209. https://doi.org/10.1038/s43016-021-00225-9.

Daehn, K. E., Cabrera Serrenho, A. and Allwood, J. M. (2017). How will copper contamination constrain future global steel recycling? *Environmental Science & Technology*, 51(11). 6599–6606. https://doi.org/10.1021/acs.est.7b00997.

Dietz, S., Byrne, R., Gardiner, D., Gostlow, G., Jahn, V., Nachmany, M. and Sullivan, R. (2020). *TPI State of Transition Report 2020*. Transition Pathway Initiative.

Dietz, S., Gardiner, D., Jahn, V. and Noels, J. (2020). *Carbon Performance of European Integrated Oil and Gas Companies*. Transition Pathway Initiative. https://www.transitionpathwayinitiative.org/publications/58.

Energy Transitions Commission (2018). *Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century*. https://www.energy-transitions.org/publications/mission-possible/.

ETC and Material Economics (2021). *Steeling Demand - Mobilising Buyers to Bring Net-Zero Steel to Market before 2030*. https://www.energy-transitions.org/publications/steeling-demand/#download-form.

European Commission (2019). *Masterplan for a Competitive Transformation of EU Energy-Intensive Industries: Enabling a Climate-Neutral, Circular Economy by 2050*. Report by the High-Level Group on Energy-intensive Industries. Publications Office of the European Union, Luxembourg. https://ec.europa.eu/docsroom/documents/38403.

European Commission (2021). *Towards Competitive and Clean European Steel*. SWD (2021) 353 Final. https://ec.europa.eu/info/sites/default/files/swd-competitive-clean-european-steel_en.pdf.

FAO, IFAD, UNICEF, WFP and WHO (2020). *The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets*. The State of Food Security and Nutrition in the World (SOFI). Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, and World Health Organization, Rome, Italy. https://doi.org/10.4060/ca9692en.

Folberth, C., Khabarov, N., Balkovič, J., Skalskỳ, R., Visconti, P., Ciais, P., Janssens, I. A., Peñuelas, J. and Obersteiner, M. (2020). The global cropland-sparing potential of high-yield farming. *Nature Sustainability*, 3(4). 281–89.

Gagg, C. R. (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Engineering Failure Analysis*, 40. 114–40. https://doi.org/10.1016/j.engfailanal.2014.02.004.

Giarratani, F., Gruver, G. and Jackson, R. (2006). Plant Location and the Advent of Slab Casting by U.S. Steel Minimills: An Observation-Based Analysis. *Economic Geography*, 82(4). 401–19. https://doi.org/https://doi.org/10.1111/j.1944-8287.2006.tb00323.x.

Gielen, D., Saygin, D., Taibi, E. and Birat, J.-P. (2020). Renewables-based decarbonization and relocation of iron and steel making: A case study. Journal of Industrial Ecology, 24(5). 1113–25. https://doi.org/10.1111/jiec.12997.

Girardin, C. A. J., Jenkins, S., Seddon, N., Allen, M., Lewis, S. L., Wheeler, C. E., Griscom, B. W. and Malhi, Y. (2021). Nature-based solutions can help cool the planet — if we act now. *Nature*, 593(7858). 191–94. https://doi.org/10.1038/d41586-021-01241-2.

Grant, N., Hawkes, A., Mittal, S. and Gambhir, A. (2021). Confronting mitigation deterrence in low-carbon scenarios. *Environmental Research Letters*, 16(6). 064099. https://doi.org/10.1088/1748-9326/ac0749.

Griscom, B. W., Busch, J., Cook-Patton, S. C., Ellis, P. W., Funk, J., et al. (2020). National mitigation potential from natural climate solutions in the tropics. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 375(1794). 20190126. https://doi.org/10.1098/rstb.2019.0126.

Hall, W., Spencer, T. and Kumar, S. (2020). *Towards a Low-Carbon Steel Sector - Overview of the Changing Market, Technology, and Policy Context for Indian Steel*. TERI. https://www.teriin.org/sites/default/files/2020-02/Towards%20a%20Low%20Carbon%20Steel%20Sector%20Report_0.pdf.

Hasanbeigi, A. and Springer, C. (2019). *How Clean Is the US Steel Industry? An International Benchmarking of Energy and CO2 Intensities*. Global Efficiency Intelligence. https://www.globalefficiencyintel.com/new-blog/2019/12/3/new-report-how-clean-is-the-us-steel-industry.

Heeb, F. and Kölbel, J. F. (2020). *The Investor's Guide to Impact: Evidence-Based Advice for Investors Who Want to Change the World*. Center for Sustainable Finance & Private Wealth. https://www.csp.uzh.ch/dam/jcr:ab4d648c-92cd-4b6d-8fc8-5bc527b0c4d9/CSP_Investors%20Guide%20to%20Impact_21_10_2020_spreads.pdf.

Hertwich, E. G. and Wood, R. (2018). The growing importance of scope 3 greenhouse gas emissions from industry. *Environmental Research Letters*, 13(10). 104013.

Höglund-Isaksson, L. (2017). Bottom-up simulations of methane and ethane emissions from global oil and gas systems 1980 to 2012. *Environmental Research Letters*, 12(2). 024007.

Holcim (2021). *Our CO2 Footprint*. https://www.holcim.com/our-co2-footprint.

Holz, C., Kartha, S. and Athanasiou, T. (2018). Fairly sharing 1.5: national fair shares of a 1.5 °C-compliant global mitigation effort. *International Environmental Agreements: Politics, Law and Economics*, 18(1). 117–34. https://doi.org/10.1007/s10784-017-9371-z.

IEA (2019). *CO_2 Emissions from Fuel Combustion 2018*. International Energy Agency, Paris. https://doi.org/10.1787/co2_fuel-2018-en.

IEA (2020a). *Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking*. International Energy Agency, Paris. https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf.

IEA (2020b). *World Energy Outlook 2020*. IEA Flagship Report. International Energy Agency, Paris. https://www.iea.org/reports/world-energy-outlook-2020.

IEA (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. International Energy Agency, Paris. https://www.iea.org/reports/net-zero-by-2050.

IPCC (2018). Summary for Policymakers. In *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. V. Mason-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, et al. (eds.). Intergovernmental Panel on Climate Change, Geneva. https://www.ipcc.ch/sr15/.

IPCC (2019). *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. https://www.ipcc.ch/site/assets/uploads/sites/4/2021/07/210714-IPCCJ7230-SRCCL-Complete-BOOK-HRES.pdf.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., et al. (2019). EDGAR v4.3.2 Global Atlas of the three major greenhouse gas emissions for the period 1970–2012. *Earth System Science Data*, 11(3). 959–1002. https://doi.org/10.5194/essd-11-959-2019.

Jensen, L. and Harrison, T. (2019). *Managed Decline of Fossil Fuel Businesses*. DivestInvest. https://www.divestinvest.org/managed-decline-fossil-fuel-businesses/.

Joselow, M. (2021). Court Orders Shell to Slash Emissions in Historic Ruling. *Scientific American*, 27 May. https://www.scientificamerican.com/article/court-orders-shell-to-slash-emissions-in-historic-ruling/.

Kinch, D. (2021). Metal, steel production must relocate near renewable energy to decarbonize. *S & P Global Platts*, 22 June. https://www.spglobal.com/platts/en/market-insights/latest-news/metals/062221-metal-steel-production-must-relocate-near-renewable-energy-to-decarbonize-forum.

Kölbel, J. F., Heeb, F., Paetzold, F. and Busch, T. (2020). Can sustainable investing save the world? Reviewing the mechanisms of investor impact. *Organization & Environment*, 33(4). 554–74.

Kusnetz, N. (2020). Is Natural Gas Really Helping the U.S. Cut Emissions? *Inside Climate News*, 30 January. https://insideclimatenews.org/news/30012020/natural-gas-methane-carbon-emissions/.

Latawiec, A. E., Strassburg, B. B., Silva, D., Alves-Pinto, H. N., Feltran-Barbieri, R., et al. (2017). Improving land management in Brazil: A perspective from producers. *Agriculture, Ecosystems & Environment*, 240. 276–86.

Leahy, S., Clark, H. and Reisinger, A. (2020). Challenges and prospects for agricultural greenhouse gas mitigation pathways consistent with the Paris agreement. *Frontiers in Sustainable Food Systems*, 4. 69.

Levick, K. and Vernoit, I. E. (2021). What role for public policy in developing a net-zero financial sector? E3G News, 13 May. https://www.e3g.org/news/what-role-for-public-policy-in-developing-a-net-zero-financial-sector/.

Li, Y. Y. (2021). Green steel? Look to hydrogen as the answer, BNEF says. *BNN Bloomberg*, 25 August. https://www.bnnbloomberg.ca/green-steel-look-to-hydrogen-as-the-answer-bnef-says-1.1643916.

Mandova, H., Patrizio, P., Leduc, S., Kjärstad, J., Wang, C., Wetterlund, E., Kraxner, F. and Gale, W. (2019). Achieving carbon-neutral iron and steelmaking in Europe through the deployment of bioenergy with carbon capture and storage. *Journal of Cleaner Production*, 218. 118–29. https://doi.org/10.1016/j.jclepro.2019.01.247.

Mangalassery, S., Sjögersten, S., Sparkes, D. L., Sturrock, C. J., Craigon, J. and Mooney, S. J. (2014). To what extent can zero tillage lead to a reduction in greenhouse gas emissions from temperate soils? *Scientific Reports*, 4(1). 4586. https://doi.org/10.1038/srep04586.

Material Economics (2018). *The Circular Economy: A Powerful Force for Climate Mitigation*. Stockholm. https://materialeconomics.com/publications/the-circular-economy-a-powerful-force-for-climate-mitigation-1.

Mazars (2021). *Independent Limited Assurance Report on Selected Indicators Regarding Carbon Emissions (Scope 2-3), Water Withdrawal and Quarry Rehabilitation and Biodiversity Management for the Cement Business Line and Selected Carbon Emissions (Scope 3) Indicators for the Ready-Mixed Concrete and Aggregates Business Lines for the Period from 1. January to 31. December 2020*. Prepared for HeidelbergCement AG, Frankfurt. https://www.heidelbergcement.com/en/system/files_force/assets/document/b0/53/nfe_report_hc_ag_mazars_isae3000_sustainability_2020_nr2.pdf.

McGlade, C., Pye, S., Ekins, P., Bradshaw, M. and Watson, J. (2018). The future role of natural gas in the UK: A bridge to nowhere? *Energy Policy*, 113. 454–65. https://doi.org/10.1016/j.enpol.2017.11.022.

McJeon, H., Edmonds, J., Bauer, N., Clarke, L., Fisher, B., et al. (2014). Limited impact on decadal-scale climate change from increased use of natural gas. *Nature*, 514(7523). 482–85.

McKinsey & Company (2017). *Energy Transition: Mission (Im)Possible for Industry? A Dutch Example for Decarbonization*. McKinsey & Company.

Meckling, J. and Biber, E. (2021). A policy roadmap for negative emissions using direct air capture. *Nature Communications*, 12(1). 2051. https://doi.org/10.1038/s41467-021-22347-1.

Muttitt, G. and Kartha, S. (2020). Equity, climate justice and fossil fuel extraction: principles for a managed phase out. *Climate Policy*, 20(8). 1024–42. https://doi.org/10.1080/14693062.2020.1763900.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., et al. (2013). Anthropogenic and natural radiative forcing. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. https://www.ipcc.ch/report/ar5/wg1/.

Nill, J. (2003). *Technological Competition, Time, and Windows of Opportunity – The Case of Iron and Steel Production*. Institute for Ecological Economy Research, Berlin, IÖW Discussion Paper, 58(03).

OECD and FAO (2021). *OECD-FAO Agricultural Outlook 2021–2030*. Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations, Paris and Rome. https://doi.org/10.1787/19428846-en.

Ortiz-Bobea, A., Ault, T. R., Carrillo, C. M., Chambers, R. G. and Lobell, D. B. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11(4). 306–12. https://doi.org/10.1038/s41558-021-01000-1.

Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S. and Wood, R. (2019). Agricultural and forestry trade drives large share of tropical deforestation emissions. *Global Environmental Change*, 56. 1–10. https://doi.org/10.1016/j.gloenvcha.2019.03.002.

Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C. and Foley, J. A. (2012). Recent patterns of crop yield growth and stagnation. *Nature Communications*, 3(1). 1293. https://doi.org/10.1038/ncomms2296.

Richards, D. R., Thompson, B. S. and Wijedasa, L. (2020). Quantifying net loss of global mangrove carbon stocks from 20 years of land cover change. *Nature Communications*, 11(1). 4260. https://doi.org/10.1038/s41467-020-18118-z.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., et al. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development. In *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. V. Mason-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, et al. (eds.). Intergovernmental Panel on Climate Change, Geneva. https://www.ipcc.ch/sr15/.

Rootzén, J. and Johnsson, F. (2017). Managing the costs of CO2 abatement in the cement industry. *Climate Policy*, 17(6). 781–800. https://doi.org/10.1080/14693062.2016.1191007.

Roy, E. D., Richards, P. D., Martinelli, L. A., Coletta, L. D., Lins, S. R. M., et al. (2016). The phosphorus cost of agricultural intensification in the tropics. *Nature Plants*, 2(5). 1–6. https://doi.org/10.1038/nplants.2016.43.

Schwietzke, S., Sherwood, O. A., Bruhwiler, L. M., Miller, J. B., Etiope, G., et al. (2016). Upward revision of global fossil fuel methane emissions based on isotope database. *Nature*, 538(7623). 88–91.

SEI, IISD, ODI, E3G and UNEP (2020). *The Production Gap Report: 2020 Special Report*. Stockholm Environment Institute, International Institute for Sustainable Development, Overseas Development Institute, E3G, and United Nations Environment Programme. https://productiongap.org/2020report/.

Skoczkowski, T., Verdolini, E., Bielecki, S., Kochański, M., Korczak, K. and Węglarz, A. (2020). Technology innovation system analysis of decarbonisation options in the EU steel industry. **Energy**, 212. 118688. https://doi.org/10.1016/j.energy.2020.118688.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., et al. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1492). 789–813. https://doi.org/10.1098/rstb.2007.2184.

Stockman, L., Trout, K. and Blumenthal, B. (2019). *Burning the Gas 'Bridge Fuel' Myth: Why Gas Is Not Clean, Cheap, or Necessary*. Oil Change International, Washington, DC. http://priceofoil.org/2019/05/30/gas-is-not-a-bridge-fuel/.

Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., et al. (2020). Global priority areas for ecosystem restoration. *Nature*, 586(7831). 724–29. https://doi.org/10.1038/s41586-020-2784-9.

Tanzer, S. E., Blok, K. and Ramírez, A. (2020). Can bioenergy with carbon capture and storage result in carbon negative steel? *International Journal of Greenhouse Gas Control*, 100. 103104. https://doi.org/10.1016/j.ijggc.2020.103104.

Tian, H., Xu, R., Canadell, J. G., Thompson, R. L., Winiwarter, W., et al. (2020). A comprehensive quantification of global nitrous oxide sources and sinks. *Nature*, 586(7828). 248–56. https://doi.org/10.1038/s41586-020-2780-0.

Toktarova, A., Karlsson, I., Rootzén, J., Göransson, L., Odenberger, M. and Johnsson, F. (2020). Pathways for Low-Carbon Transition of the Steel Industry—A Swedish Case Study. *Energies*, 13(15). 3840. https://doi.org/10.3390/en13153840.

Tong, D., Trout, K., McKinnon, H. and Stockman, L. (2020). *Big Oil Reality Check — Assessing Oil and Gas Climate Plans*. Discussion paper. Oil Change International, Washington, DC. http://priceofoil.org/2020/09/23/big-oil-reality-check/.

UNEP (2020). *Emissions Gap Report 2020*. United Nations Environment Programme, Nairobi. https://www.unep.org/emissions-gap-report-2020.

UNEP and CCAC (2021). *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*. United Nations Environment Programme and Climate and Clean Air Coalition, Nairobi. https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions.

van der Loeff, W. S., Godar, J. and Prakash, V. (2018). A spatially explicit data-driven approach to calculating commodity-specific shipping emissions per vessel. *Journal of Cleaner Production*, 205. 895–908. https://doi.org/10.1016/j.jclepro.2018.09.053.

Vogl, V., Nykvist, B. and Olsson, O. (2021, in press). Phasing out the blast furnace to meet global climate targets. *Joule*.

Vogl, V., Sanchez, F., Gerres, T., Lettow, F., Bhaskar, A., et al. (2021). *Green Steel Tracker Version 4/2021*. Dataset. https://www.industrytransition.org/green-steel-tracker/.

Wang, J., Rodrigues, J. F. D., Hu, M., Behrens, P. and Tukker, A. (2019). The evolution of Chinese industrial CO_2 emissions 2000–2050: A review and meta-analysis of historical drivers, projections and policy goals. *Renewable and Sustainable Energy Reviews*, 116. 109433. https://doi.org/10.1016/j.rser.2019.109433.

Wang, P., Ryberg, M., Yang, Y., Feng, K., Kara, S., Hauschild, M. and Chen, W.-Q. (2021). Efficiency stagnation in global steel production urges joint supply- and demand-side mitigation efforts. *Nature Communications*, 12(1). 2066. https://doi.org/10.1038/s41467-021-22245-6.

Wood, T., Dundas, G. and Ha, J. (2020). *Start with Steel: A Practical Plan to Support Carbon Workers and Cut Emissions*. Grattan Institute. https://grattan.edu.au/wp-content/uploads/2020/05/2020-06-Start-with-steel.pdf.

World Benchmarking Alliance (2021). *Climate and Energy: Benchmark in Oil and Gas Insights Report*. https://www.worldbenchmarkingalliance.org/research/launching-the-oil-and-gas-benchmark/.

World Economic Forum (2021). *Forests, Food Systems, and Livelihoods: Trends, Forecasts, and Solutions to Reframe Approaches to Protecting Forests*. Report produced by the Tropical Forest Alliance for the WEF, Geneva. https://www.weforum.org/reports/forests-food-systems-and-livelihoods-trends-forecasts-and-solutions-to-reframe-approaches-to-protecting-forests/.

Zaman, M., Kleineidam, K., Bakken, L., Berendt, J., Bracken, C., et al. (2021). Climate-smart agriculture practices for mitigating greenhouse gas emissions. In *Measuring Emission of Agricultural Greenhouse Gases and Developing Mitigation Options using Nuclear and Related Techniques: Applications of Nuclear Techniques for GHGs*. M. Zaman, L. Heng, and C. Müller (eds.). Springer International Publishing, Cham. 303–28. https://doi.org/10.1007/978-3-030-55396-8_8.

Zhang, J., Tian, H., Shi, H., Zhang, J., Wang, X., Pan, S. and Yang, J. (2020). Increased greenhouse gas emissions intensity of major croplands in China: Implications for food security and climate change mitigation. *Global Change Biology*, 26(11). 6116–33. https://doi.org/10.1111/gcb.15290.

Zhang, X., Myhrvold, N. P., Hausfather, Z. and Caldeira, K. (2016). Climate benefits of natural gas as a bridge fuel and potential delay of near-zero energy systems. *Applied Energy*, 167. 317–22. https://doi.org/10.1016/j.apenergy.2015.10.016.

Visit us

SEI Headquarters
Linnégatan 87D Box 24218
104 51 Stockholm Sweden
Tel: +46 8 30 80 44
info@sei.org

Måns Nilsson
Executive Director

SEI Africa
World Agroforestry Centre
United Nations Avenue
Gigiri P.O. Box 30677
Nairobi 00100 Kenya
Tel: +254 20 722 4886
info-Africa@sei.org

Philip Osano
Centre Director

SEI Asia
10th Floor, Kasem Uttayanin Building,
254 Chulalongkorn University,
Henri Dunant Road, Pathumwan, Bangkok,
10330 Thailand
Tel: +66 2 251 4415
info-Asia@sei.org

Niall O'Connor
Centre Director

SEI Tallinn
Arsenal Centre
Erika 14, 10416
Tallinn, Estonia
Tel: +372 6276 100
info-Tallinn@sei.org

Lauri Tammiste
Centre Director

SEI Oxford
Oxford Eco Centre, Roger House,
Osney Mead, Oxford,
OX2 0ES, UK
Tel: +44 1865 42 6316
info-Oxford@sei.org

Ruth Butterfield
Centre Director

SEI US Main Office
11 Curtis Avenue
Somerville MA 02144-1224 USA
Tel: +1 617 627 3786
info-US@sei.org

Michael Lazarus
Centre Director

SEI US Davis Office
400 F Street
Davis CA 95616 USA
Tel: +1 530 753 3035

SEI US Seattle Office
1402 Third Avenue Suite 900
Seattle WA 98101 USA
Tel: +1 206 547 4000

SEI York
University of York
Heslington York
YO10 5DD UK
Tel: +44 1904 32 2897
info-York@sei.org

Sarah West
Centre Director

SEI Latin America
Calle 71 # 11–10
Oficina 801
Bogota Colombia
Tel: +57 1 6355319
info-LatinAmerica@sei.org

David Purkey
Centre Director

SEI Stockholm Environment Institute

sei.org
@SEIresearch @SEIclimate