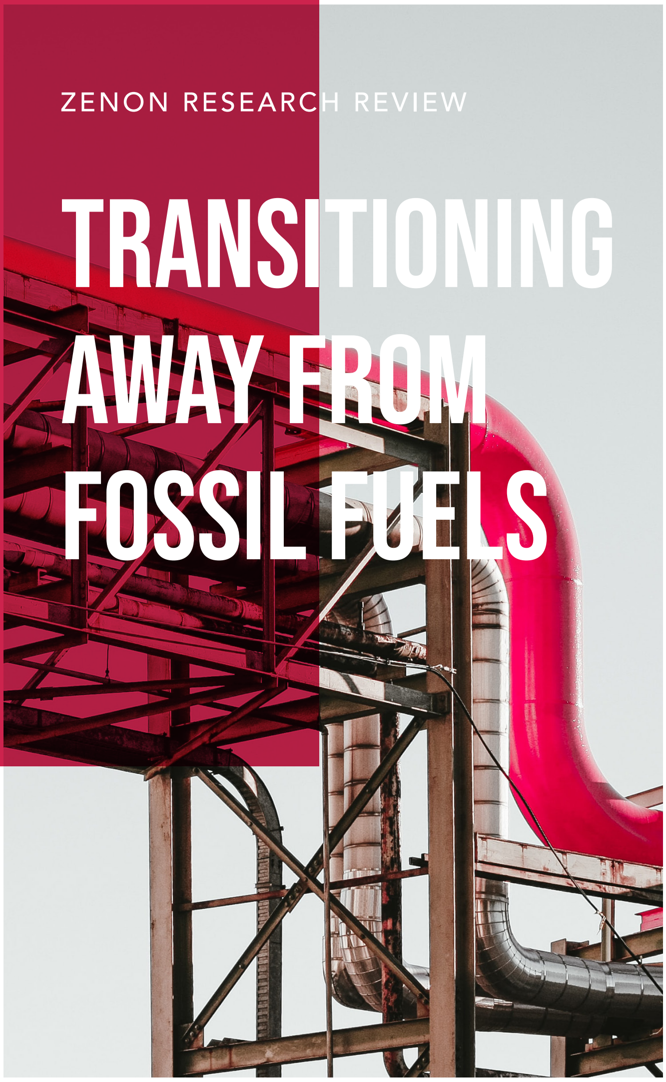
ZENON RESEARCH REVIEW

TRANSITIONING AWAY FROM FOSSIL FUELS



Emissions and global warming

Fossil fuels are a gift from the past, formed by the natural decomposition of buried dead organisms million years ago. They have provided our modern civilization with abundant, cheap, high-density energy that made the 'Great Acceleration' — the considerable take-off of nearly all human activities since the 1950s — possible.

The share of fossil fuels, i.e., coal, oil and gas, in the global energy mix has increased continuously over the last two centuries, from close to zero in the early 1800s to around 80% nowadays (Fig. 1). Around 15 billion tonnes of fossil fuels are now extracted each year and, in 2018, the global oil production symbolically reached 100 million barrels per day (mb/d) for the first time. It represents about 30% of the world's primary energy, while gas and coal are both around 25%.

The problem is that the massive use of fossil fuels has released considerable amounts of carbon dioxide (CO_2) in the atmosphere, amounting to about 78% of all greenhouse gas emissions. CO_2 concentrations are now higher than any time in the past 2 million years, which is the main factor of the ongoing climate change. As famously stated by Revelle and Suess in 1957, we 'human beings are carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future'.

Globally, the total emissions due to fossil fuels amount to about 33 billion tonnes of CO_2 ($GtCO_2$) released to the atmosphere every year. Coal is the largest source of emissions and, by far, the largest emitter per unit of energy produced. Indeed, to generate 1 exajoule (EJ) of energy — roughly the primary energy use of France in one month, the combustion of coal currently (2019) releases around 90 million tonnes of CO_2 ($MtCO_2$). This is almost twice as much as natural gas (~50 $MtCO_2$) and also significantly higher than oil (~70 $MtCO_2$).

About half (56±8%) of all these carbon dioxide emissions are taken up by natural sinks such as vegetation, soils and oceans, and the rest accumulates in the atmosphere. Since 1850, it is estimated that about 2400 $GtCO_2$ have been emitted, of which 960 $GtCO_2$ remains in the atmosphere today. This translates into a global warming whose magnitude is roughly proportional to the total amount of CO_2 released in the atmosphere (Fig. 2). More precisely, each 1000 $GtCO_2$ emitted causes a global surface temperature change assessed to be around +0.45°C (likely range: +0.27°C to +0.63°C).

This relationship implies that **limiting cumulative emissions is necessary to limit global warming to a specific level.** This requires annual emissions to reach net zero, i.e., to be fully balanced by deliberate removals from the atmosphere in addition to natural sinks. Since 78% of all CO_2 emissions from human activities are from fossil fuels, stopping burning them is now crucial to limit the negative consequences of climate change on both the Earth system and human societies.

Considering past emissions and the likelihood of limiting global warming to a given temperature, there is an amount of CO_2 that can still be released into the atmosphere. This is the concept of remaining carbon budget. For instance, **to keep global warming to 1.5°C relative to preindustrial levels with a 67% chance, 400 $GtCO_2$ could still be emitted as of January 1, 2020**. This corresponds to 10 years of emissions at the current level, but the sooner significant emission reductions start, the longer the budget will last. It also implies that developed countries should make greater mitigation efforts so that emerging countries can develop within the remaining budget.

Reserves

As fossil fuels are finite resources, there have long been concerns about their eventual depletion. Regardless of socio-economic consequences, if oil, coal or gas were to become exhausted soon, it would likely result in efficient, though unwitting, climate change mitigation.

However, according to the last World Energy Outlook from the International Energy Agency, **all fuels are at a level comfortably sufficient to meet demand at least until 2050.** The Agency estimates that remaining proven technically recoverable reserves amount to 1753 billion barrels of oil, 221 trillion cubic metres of natural gas and 1076 billion tonnes of coal. Indeed, at the current level of demand, oil and gas needs would be met for about 50 years, and for more than a hundred years for coal.

A simple calculation based on average CO_2 emission factors shows that a 2.9 ± 1.1°C

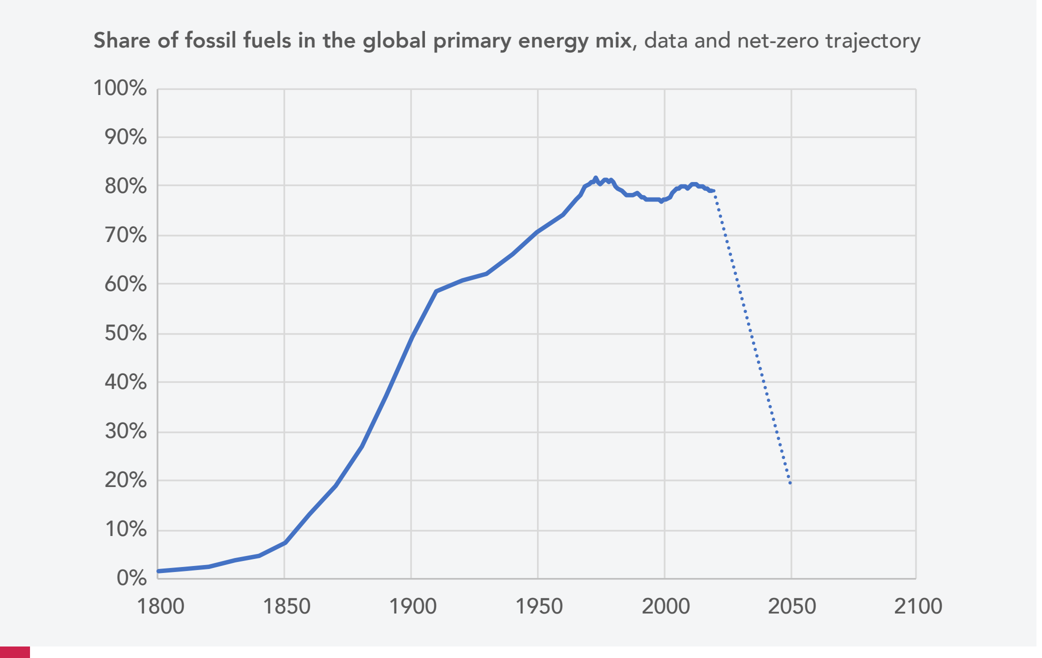
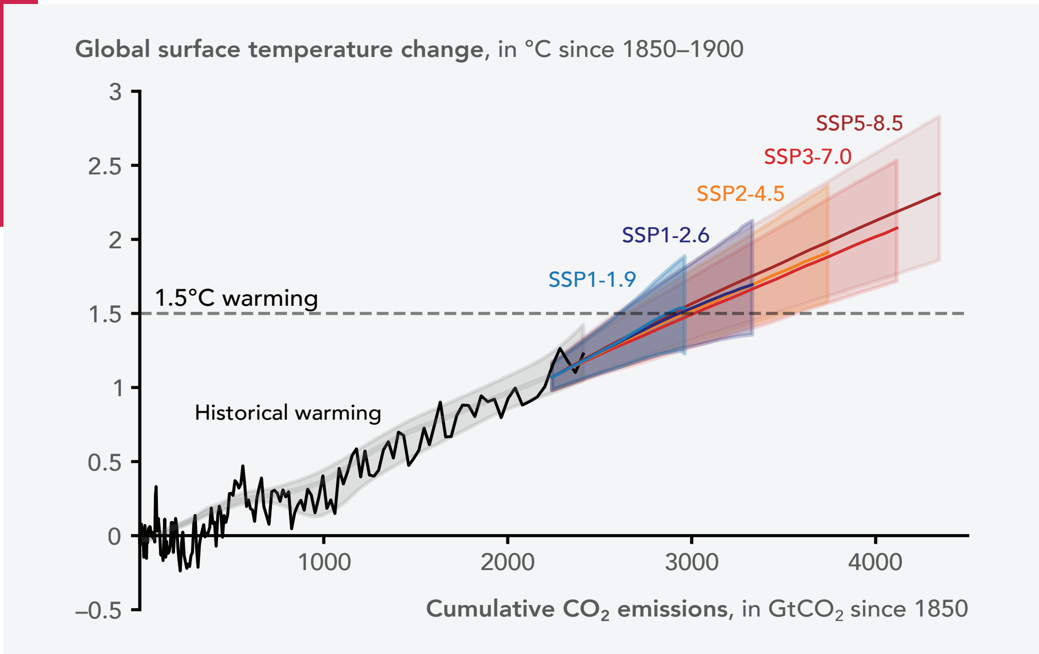


Figure 1: Share of fossil fuels in the global primary energy mix (solid) and the IEA's 'net-zero by 2050' trajectory (dotted, linear interpolation). Historical data from Smil (2017) & BP Statistical Review.

Figure 2: The global temperature change is nearly proportional to the cumulative amount of carbon dioxide released in the atmosphere. Figure adapted from IPCC (2021).



global temperature change would occur if all those proven reserves were burnt, which would have severe impacts on both the Earth system and human societies (e.g., on the economy). Consequently, **to stay within the remaining carbon budget, it is not possible to simply wait for the depletion of fossil fuels.** This is especially true as even more fossil fuels than estimated above may be available, not only because new resources are still to be discovered but also because known *resources* can turn into economically recoverable *reserves* thanks to changes in the so-called 'modifying factors', i.e. technical, economic and societal factors that have an impact on the feasibility of the extraction.

As a consequence, to keep climate change under acceptable levels, **a significant part of the world's fossil fuel reserves must be left in the ground.** This is what is known as 'unburnable carbon'. In 2015, McGlade and Ekins estimated the relative amounts of the three types of fossil fuel – coal, oil and gas – that can be burned and stay within the carbon budget. They found that 88% of the global reserves of coal must remain unextracted, as well as 35% of the reserves of oil and 52% of the reserves of gas, to have a 50% chance of meeting the 2°C warming limit. More stringent mitigation criteria (higher probability and/or lower temperature limit) imply to let even more fossil fuels in the ground. Indeed, the work of McGlade and Ekins has recently been updated with a 1.5°C target. According to this new estimate, around 60% of oil and gas and 90% of coal should be left unburned. This confirms that reserves are far too abundant compared to the pressing need to mitigate climate change.

Supply

However, ***abundant reserves* do not necessarily translate into *abundant supply***, as shown by the ongoing energy crisis. Indeed, the level of supply is driven by demand and depends on a wide range of parameters, such as existing facilities, spare capacity management, stock levels, unplanned outages and geopolitical or weather events. Production capacities only weakly respond to demand changes since they are fixed in the near term by past upstream investments and discoveries. To make it even more complicated, all three fossil fuels are interdependent, notably because price changes can encourage consumers to switch from one fuel to another. Indeed, current tight gas markets result in higher demand for oil and coal, and thus higher oil and coal prices. Conversely, high prices can also stimulate supply growth.

The main lesson that can be learned from the ongoing energy crisis is that, even if most reserves must stay unburnt in the ground, **reducing upstream investment faster than demand leads to** supply tensions. Indeed, the decline rate of existing oil fields is between 3% and 9.5% per year. As long as demand is not reduced accordingly or no alternative energy sources are available, banning future exploration and investment would be premature since new projects are continuously needed just to maintain existing levels of production (Fig. 3). **The challenge is therefore to reduce both fossil fuel demand and supply at compatible rates, in order to transition fast to a net-zero energy system but with as few supply tensions and** rebound effects **as possible.** As stated by the IEA, 'today's investment spending on fuels appears caught between two worlds: neither strong enough to satisfy current fossil fuel consumption trends nor diversified enough to meet tomorrow's clean energy goals'.

Demand

To achieve net-zero emissions in 2050, existing scenarios show that **coal must be** almost entirely eliminated **by then and that oil demand should start to decline immediately.** However, the actual evolution of fossil fuel demand is marred by a high degree of uncertainty and will mainly depend on our collective ability to bridge both ambition and implementation gaps to make climate pledges appropriately ambitious and turn them into actions.

In the short term, demand has notably been affected by the Covid-19 pandemics and the ongoing energy crisis. With lockdowns and related restrictive measures, the year 2020

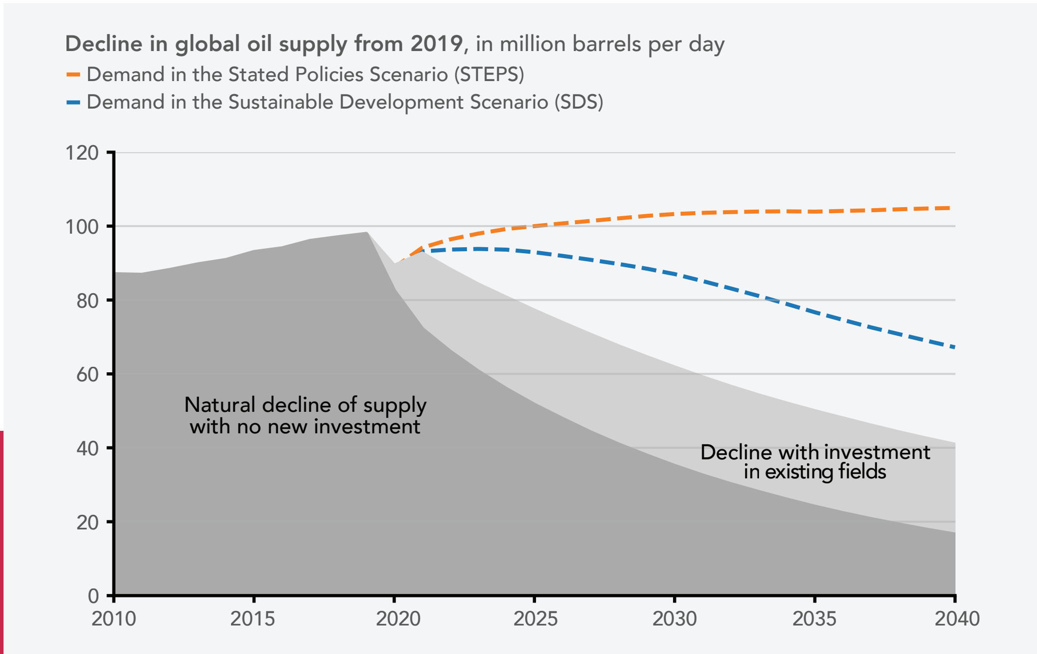


Figure 3: With no new investment, oil supply decreases exponentially well below future demand. Figure adapted from IEA (2020).

saw a historic decline in global demand for all three fuels. Oil was hit the hardest and global oil demand is not expected to recover until late 2022 or early 2023. On the contrary, coal demand has already surged above pre-crisis levels. The recovery of natural gas, which was less impacted than oil and coal, was also expected to offset its 2020 decline this year, but it is weakened by tightened markets.

However, in the medium term, gas is anticipated to be the fastest growing fossil fuel. All scenarios from the last 2021 outlooks of the International Energy Agency and BP expect the global gas use to increase over the coming years. Beyond 2025, the trend is less clear, though. Depending on the storyline, natural gas demand may keep growing and exceed 5000 million cubic metres per year in 2050 or reach a maximum as soon as in the mid-2020s, and decrease more or less sharply afterwards. A key determinant of this evolution will be the degree of coal-to-gas switching.

Oil demand projections are uncertain too. The OECD demand peaked in 2005 so that the global demand is now primarily driven by developing economies, especially in Asia. It is expected to verge on 100 million barrels per day (mb/d) in 2022. **For the first time this year, all the scenarios from BP and the IEA foresee an eventual decline in global oil demand, even if there is a lot of uncertainty about its speed and scale.** Current policy settings imply that oil demand will plateau around 105 mb/d until the mid-2030s, and then slowly decrease. If countries actually meet their climate pledges, oil demand may peak sooner, by the mid-2020s at the latest, or may even never return to its pre-pandemics level. Accurately estimating the date of the peak is actually extremely difficult because it is sensitive to small changes in a large set of parameters, such as the geopolitical and economic context. More importantly, the focus on its precise timing is of interest only if the peak is sharp enough to mark a significant subsequent decrease.

As for the global coal demand, it has been thought to have peaked in 2013 and, until very recently, all BP and IEA scenarios agreed that it would never recover to its level back then. However, the latest forecast from the IEA now expects a new all-time high in the next two years, around 8000 million tonnes per year. Indeed, even if the number of new coal plant projects has already decreased sharply since 2015, the strong recovery in 2021 may delay the necessary, urgent decline of coal. In its latest

Fossil fuel	Net-zero trajectory	Near-term forecast
Coal	-98% by 2050 (should decline as soon as possible)	Plateau around 8000 Mt/yr at least until ~2024
Oil	-75% by 2050 (should decline as soon as possible)	Plateau between 100 and 105 mb/d at least until ~2025
Gas	-55% by 2050	Continued growth at least until ~2025

Table 1. Net-zero trajectories are from the IEA's Net Zero by 2050 scenario.

outlook, the IEA underlined that developing countries account for more than 80% of current global demand while they have no net-zero pledges or aim only to reduce emissions after 2030, so that the implementation of announced pledges would only make a 6% difference in 2030 compared to current policies. Since then, new commitments have been taken at the COP26 Climate Change Conference in Glasgow, notably by India.

Summary and conclusion

All three fossil fuels are at a level comfortably sufficient to meet demand at least until 2050. Indeed, compared to the pressing need to keep global warming under acceptable levels, reserves are far too abundant. A recent estimate reports that around 60% of oil and gas and 90% of coal must be left in the ground to stay within a 1.5°C trajectory. This is determined by our remaining carbon budget, which amounts to around 10 years of emissions at the current level. It is therefore urgent to reduce the energy use of fossil fuels to zero as soon as possible. In particular, according to net-zero scenarios, oil demand should be cut as soon as possible and coal must be almost entirely eliminated by 2050.

However, reducing upstream investment in fossil fuels faster than demand could lead to supply tensions, mainly because of the depletion of existing oil fields. Abundant reserves do not prevent possible supply crunches, especially in the context of historically low drilling activity and investment. The challenge is therefore to reduce both fossil fuel demand and supply simultaneously while limiting supply tensions and take-back effects as much as possible.

Reducing fossil fuel demand requires pursuing strong policies to massively deploy clean energy sources and technologies to fill the gap, as well as reducing the all-fuel energy demand through energy efficiency measures and behavioural changes.

References

Baker, D. R. et al. (Oct. 5, 2021). Global Energy Crisis Is the First of Many in the Clean-Power Era. Bloomberg Green.
Boissier, F. (Nov. 30, 2021). Une France zéro carbone en 2050 : pourquoi le débat sur la sobriété est incontournable. The Conversation France.
BP (2020). Energy Outlook: 2020 edition. BP p.l.c., London, UK.
Brockway, P. E. (2021). Energy efficiency and economy-wide rebound effects: A review of the evidence and its implications. Renewable and Sustainable Energy Reviews, 141.
Chuard, D. et al. (2021). Too Hot to Grow: How global warming can make the world enter into structural economic recession. Zenon Research, Paris, France.
Commissariat général au développement durable (2021). Bilan énergétique de la France pour 2019. Ministère de la Transition écologique, Paris, France.
Friedlingstein, P. et al. (2021). Global Carbon Budget 2021. Earth System Science Data Discussions, 2021, 1–191.
Hacquard, P. et al. (2019). Is the oil industry able to support a world that consumes 105 million barrels of oil per day in 2025? Oil & Gas Science and Technology - Rev. IFP Energies nouvelles, 74(88).

Authors

Dimitri Chuard
Mines Paris PSL, IHEIE
dimitri.chuard@mines-paristech.fr

Greg De Temmerman
Zenon Research
Mines Paris PSL, IHEIE
greg@zenonresearch.org

IEA (2021). Coal 2021. IEA, Paris, France.
IEA (2021), Global coal demand surpassed pre-Covid levels in late 2020, underlining the world's emissions challenge, IEA, Paris, France.
IEA (2021). What is behind soaring energy prices and what happens next? IEA, Paris, France.
IEA (2021). World Energy Investment 2021. IEA, Paris, France.
IEA (2021). World Energy Outlook 2021. IEA, Paris, France.
International Resource Panel (2019). Global Resources Outlook 2019: Natural Resources for the Future We Want. United Nations Environment Programme. Nairobi, Kenya.
IPCC (2014). Climate Change 2014: Mitigation of Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
IPCC (2021). Climate Change 2021: The Physical Science Basis. Cambridge University Press. In Press.
Jackson, P. M. and Smith, L. K. (2014). Exploring the undulating plateau: the future of global oil supply. Phil. Trans. R. Soc. A., 372(20120491).
Maisonnier, G. (Sept. 27, 2021). Situation inédite : le marché gazier impacte le marché pétrolier. Tableau de bord pétrolier. IFP Énergies nouvelles.
Matthews, C. M. et al. (Oct. 17, 2021). Behind the Energy Crisis: Fossil Fuel Investment Drops, and Renewables Aren't Ready. The Wall Street Journal.
McGlade, C., and Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. Nature, 517, 187–190.
Mohan, A. et al. (2021). UNFCCC must confront the political economy of net-negative emissions. One Earth, 4(10), 1348–1351.
Perkins, R. (Aug. 23, 2021). Global oil demand to peak by 2025 under UN pathway. Market Insights, S&P Global Platts Analytics.
Revelle, R. and Suess, H. E. (1957). Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO2 during the Past Decades. Tellus, 9, 18-27.
Roberts, L. and Shearer C. (Sept. 14, 2021). How world's coal-power pipeline has shrunk by three-quarters. Guest Posts, Carbon Brief.
Steffen, W. et al. (2015). The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review, 2(1), 81–98.
Welsby, D. et al. (2021). Unextractable fossil fuels in a 1.5 °C world. Nature, 597, 230–234.

This note should be cited as:
Chuard, D. and De Temmerman, G. (2021).
Transitioning away from fossil fuels. Zenon Research, Paris, France.