FOSSIL FUELS:
ANALYSIS OF TRAJECTORIES COMPATIBLE WITH A 1.5°C SCENARIO

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INTRODUCTION

Financing green and transition activities is essential to help build the low-carbon economy of tomorrow. At the same time, achieving climate objectives also means reducing the use of fossil fuels, which account for 80% of greenhouse gas emissions, according to a trajectory that allows for a gradual alignment towards carbon neutrality, which must combine carbon constraints with technical and economic feasibility.

In addition to the commitments already made on coal and unconventional oil and gas, there is now the matter of financing oil and gas in general. Many players in the Paris marketplace are already developing their own alignment methodologies compatible with the Paris objectives and a 1.5°C scenario. It should be noted that the success of the energy transition requires global action by all players: these commitments must not be limited to players in the Paris financial market if the objective is to reduce investments in fossil fuels at the global level.

The objective of this working group is thus to develop tools for understanding scenarios aligned with 1.5°C to make the use of these scenarios as simple as possible and as suited as possible to the needs of financial players in the development of an investment strategy compatible with the objectives of the Paris Agreement. In a context of strong focus on the strategies of companies and in particular financial institutions regarding fossil fuel financing, **this project aims to build an analysis framework from which these institutions can individually build or develop their strategy.**

The first stage of the work is to identify the main energy-climate scenarios aligned with a 1.5°C objective that are currently used by market players. The International Energy Agency (IEA), the Networking for Greening the Financial System (NGFS, based on scenarios produced by research institutes), the International Renewable Energy Agency (IRENA), BloombergNEF (BNEF) and many others[1,] are all institutions offering scenarios to model possible decarbonisation trajectories. Each of these scenarios has their specific modelling characteristics (scope of analysis, number of variables, optimisation method, etc.) and make different assumptions about the drivers of decarbonisation (maturity and cost of technologies, availability of land, etc.).

Differences in approach between scenarios can sometimes be difficult to grasp. Thus, in autumn 2023, the working group of the Sustainable Finance Institute conducted **a series of hearings with climate experts and scientists**. This work makes it possible to take stock of the science, compare methodologies and identify the main lessons to be learned for investors and financiers.

This analysis aims to align market players with their understanding of investment trajectories compatible with a 1.5°C scenario. Its objective is to identify the main lessons learned from the reference energy-climate scenarios currently available.

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1 Like the One Earth Climate Model (OECM) commissioned by the Net-Zero Asset Owner Alliance and the European Climate Foundation.

SUMMARY OF KEY FINDINGS

The work of the working group is based on six scenarios from leading institutions in the field of climate modelling: the International Energy Agency (IEA), the Networking for Greening the Financial System (NGFS, based on the work of research laboratories), the International Renewable Energy Agency (IRENA) and BloombergNEF (BNEF). Each of the scenarios developed has their specific modelling characteristics (scope of analysis, number of variables, optimisation method, etc.) and make different assumptions on the drivers of decarbonisation (maturity and cost of technologies, availability of land, etc.). Nevertheless, the analysis of these scenarios reveals clear trends in fossil fuel trajectories compatible with warming limited to 1.5°C.

ENERGY TRAJECTORIES: THE 1.5°C SCENARIOS OUTLINE A POSSIBLE BUT NARROW COMMON PATH.

1. To achieve Net Zero by 2050, decarbonisation of the energy sector – both in energy use and in energy production – is a priority.

2. To decarbonise energy usage and production, prioritising solutions based on using electricity for more applications and improving energy efficiency is essential, as these are the most effective and affordable methods for reducing CO2 emissions in most cases (providing carbon reduction at the lowest cost per tonne of CO2 abated).

3. Important solutions for decarbonising energy uses and production are already mature: electric vehicles, heat pumps, substitution of carbon-intensive means of electricity production (especially coal) by low-carbon means of electricity production.

4. By 2050, final energy demand will have to fall (notably by removing fossil fuels from the energy mix), and at the same time electricity demand will have to increase.

5. By 2050, coal and oil consumption will need to have been drastically reduced. The sharp decline in gas demand is also very clear, although more variable depending on the scenarios.

6. Meeting the increase in demand for decarbonised electricity requires a very significant increase in production, via a diversified mix based mainly on strong growth in renewable energies.

7. The anticipated role of hydrogen varies from scenario to scenario because its production cost is still very high, and should be targeted primarily at the sectors most difficult to decarbonise.

8. CC(U)S and negative emission solutions (BECCS, DACCS, afforestation) will probably be necessary to reach the 1.5°C target, but these drivers are constrained, in particular by physical limits.

INVESTMENT TRAJECTORIES: THE 1.5°C SCENARIOS ARE BASED ON RADICALLY INVERTED INVESTMENT RATIOS.

1. In order to meet the trajectories limiting warming to 1.5°, investments in fossil fuels should be halved, or even quartered, by 2050 compared to 2020. According to the IEA, these investments should even be halved by 2030, and should not finance new production projects.

2. Investments in low-carbon energy supply must be increased by 2.5 to 3 times by 2030 compared to 2020 levels.

3. In terms of ratio, investments in the energy transition should be $10 to $1 in fossil fuels by 2030, compared to $1 to $1 just 5 years ago and $1.7 to $1 today.

1. COMPARE BASELINE SCENARIOS TO IDENTIFY CONVERGENCES AND MAJOR TRENDS

HEARINGS CONDUCTED BY THE WORKING GROUP

The first phase of the work aims to identify the key messages of the main existing energy-climate scenarios aligned with a 1.5°C objective. While these scenarios are based on different methodologies and assumptions, the objective is to identify the major trends, despite the diversity of approaches to the scenarios presented. The scenarios are based on a physical analysis of energy systems and CO_2 emissions, but also some propose a projection in terms of the necessary investments. A comparative analysis of the two components is presented here.

It is therefore necessary to identify the determining parameters in the definition of trajectories relating to fossil fuels and to explore the uncertainties linked to these parameters as well as the convergence of their conclusions. The aim of this work is to:

→ Compare the different assumptions of the scenarios: level of final energy demand (sobriety, growth of emerging countries, etc.), growth potential of low-carbon energies, potential in energy efficiency, possibilities for deploying CCS, BECCCS, AFOLU, hydrogen solutions, etc., "overshoot" level, probability of occurrence of scenarios, etc.

→ Analyse the implications of each scenario on demand for fossil fuels (coal, oil, gas, etc.) and low carbon (wind, photovoltaic, nuclear, etc.)

→ Develop a diagnosis of trajectories at the global level but also, as far as possible, at the sectoral and regional level;

→ Establish a common understanding regarding investment trajectories in the energy sector.

The working group conducted a series of hearings with the scientific teams of several reference institutions:

→ **The Institute for Sustainable Development and International Relations** with Henri Waisman who leads the Deep Decarbonization Pathways programme.

→ **The International Energy Agency** with Tanguy de Bienassis and Jérôme Hilaire who are working on the World Energy Outlook scenarios.

→ **The Banque de France and the Network for Greening the Financial System (NGFS)** with Clément Payerols and Paul Champey working on the NGFS scenarios.

→ **BloombergNEF** with David Hostert, Global Head of Economics & Modeling.

→ **Ploy Achakulwisut**, **member of the IPCC and the Stockholm Environment Institute**, and author of an article on fossil fuel reduction strategies in the fight against global warming, “Global fossil fuel reduction pathways under different climate mitigation strategies and ambitions” with Peter Erickson, Céline Guivarch, Roberto Schaeffer, Elina Brutschin, and Steve Pye, published in the journal *Nature.*

→ A new exchange with the staff of **the International Energy Agency,** Tanguy de Bienassis and Jérôme Hilaire, to present the new World Energy Outlook 2023 and the differences with the previous version.

Discussions with the main French energy companies were organised to better understand how they use these scenarios in their strategic work:

→ **Total Energies** with Thomas-Olivier Leauthier, Chief Economist of Total Energies, and Jean-Pascal Clémençon, Senior Vice President Strategy & Markets,

→ **Electricité de France** with Charles Weymuller, Chief Economist.

Finally, for the Sustainable Finance Institute, **Carbone 4** carried out a quantitative analysis comparing energy-climate scenarios.

STUDIED SCENARIOS

The work of the working group is based on six reference scenarios from reference institutions in the field of climate modelling. Each of these scenarios has their specific modelling characteristics (scope of analysis, number of variables, optimisation method, etc.) and make different assumptions about the drivers of decarbonisation (maturity and cost of technologies, availability of land, etc.). These specificities should be taken into account when understanding the models.

IEA Global Energy and Climate Model - Net Zero Energy 2050

IEA World Energy Outlook 2023;

The International Energy Agency's (IEA) energy-climate scenarios are derived from a "bottom-up" partial optimisation model that simulates demand, supply, prices and the transformation of the energy system.

The Net Zero Energy 2050 scenario sets a trajectory for the global energy sector to achieve net zero CO_2 emissions by 2050. It does not rely on emission reductions from outside the overall energy sector to achieve its objectives. The energy sector within the meaning of the IEA must be understood as in the overall sense of the term as all energy consumed in the construction, transport, industry and energy production sectors as such. In the model, universal access to electricity is achieved by 2030. It is based on an assumption of strong growth in clean energy with low use of carbon capture and storage technologies. The IEA understands clean energy as any energy with a low carbon footprint, which includes not only renewable energy (solar, wind, geothermal, biomass, etc.) but also nuclear, hydrogen and fossil fuels with carbon capture.

IRENA - 1.5°C Scenario

World Energy Transitions Outlook: 1.5°C Pathway;

The International Renewable Energy Agency (IRENA) provides modelling of the energy system transition with a focus on renewable energy.

The 1.5 Scenario is an orderly transition to limit global warming to 1.5°C by the end of the century, with a focus on renewable energy. In it, net zero emissions are achieved by 2050. The model is based on energy statistics with a link to a macro-economic model for socio-economic analysis. It is based on an assumption of general growth in energy demand and therefore on both strong growth in low-carbon energies and significant use of gas as a transition energy. This assumption therefore implies the significant use of carbon capture and storage technology. The land use sector is not covered.

NGFS GCAM - Net Zero 2050

NGFS Scenario Explorer

Based on scenarios produced by research institutes, the Network for Greening the Financial System (NGFS) provides transition modelling to develop climate risk management in the financial sector. Developed by a consortium of laboratories, the GCAM model is a partial equilibrium model for the energy and land sector, which assumes consumers and producers make decisions with the information they have at the given time (t).

This NGFS scenario predicts that global CO_2 emissions will reach net zero by 2050. In addition, countries with a clear commitment to a specific policy target of net zero by the end of 2020 are expected to achieve this target. The scenario assumes a more gradual exit from fossil fuels (compared to other scenarios studied) based in particular on techno-optimistic assumptions regarding carbon capture and storage possibilities.

NGFS REMIND-MAgPIE - Net Zero 2050

NGFS Scenario Explorer

Developed by the Postdam Institute for Climate Impacts, the REMIND- MagPIE model combines a general equilibrium model on the energy sector and the macroeconomy with a partial equilibrium model on the land sector, assuming, like GCAM, consumers and producers make decisions with the information they have at the given time (t). The REMIND model has a “perfect foresight” approach where agents fully predict future costs until 2050.

This NGFS scenario predicts that global CO2 emissions will reach net zero by 2050. In addition, countries with a clear commitment to a specific policy target of net zero by the end of 2020 are expected to achieve this target. This scenario is based on the assumption of a relative decline in energy consumption by 2050. Thus, it relies comparatively less on the development of renewable energy and CCS before 2050 (the quantity of CCS nevertheless increases after 2050 to compensate for an overshoot of emissions).

NGFS MESSAGEiX-GLOBIOM - Net Zero 2050

NGFS Explorer Scenario

Developed by the International Institute for Applied Systems Analysis and the PBL Netherlands Environmental Assessment Agency, MESSAGEix-GLOBIOM is an integrated assessment model designed to assess the transformation of energy and terrestrial systems to the challenges of climate change and other sustainability issues. The MESSAGE model has a “perfect foresight” approach where agents fully predict future costs until 2050.

This NGFS scenario predicts that global CO_2 emissions will reach net zero by 2050. This scenario represents a middle ground between the assumptions of GCAM and REMIND: it relies on energy sobriety, a transition to gas, and the development of renewable energies. It relies very little on the development of CCS.

BloombergNEF NEO 2022 - Net Zero Scenario

New Energy Outlook 2022

Part of the Bloomberg Group, BloombergNEF (BNEF) is a strategic research provider covering global commodity markets and disruptive technologies driving the transition to a low-carbon economy. The BNEF New Energy Outlook 2022 (NEO 2022) is a long-term scenario analysis from BloombergNEF (BNEF) on the future of the energy economy covering electricity, industry, buildings and transport, as well as the key drivers shaping these sectors through to 2050.

The NEO 2022 NZS scenario describes an evolution of the energy economy to achieve net zero emissions by 2050. Unlike the other scenarios, which target 1.5°C in 2100, it targets 1.77°C in 2050 (without modelling up to 2100): this is a "well below 2°C" scenario and not 1.5°C. This assumption, which is fundamental in modelling, therefore gives it more flexibility in the exit from fossil fuels. As a result of this difference in objective, it relies less on CCS but nevertheless relies on the rapid and significant deployment of renewable energy, nuclear and other low-carbon technologies in the electricity sector. It is also betting on the adoption of cleaner fuels in the final consumption sectors, including hydrogen and bioenergy, which is based on an assumption of significant land use for energy production. If this scenario is used to reach 1.5°C in 2100, it is therefore implicitly based on an overshoot hypothesis and therefore with significant CCS after 2050. Thus, due to its slightly different nature from the other scenarios, the BNEF scenario is kept separate in the comparisons.

“ALL MODELS ARE WRONG, BUT SOME ARE USEFUL”[2]

As with any modelling exercise, these scenarios are useful for looking ahead and anticipating trends based on established assumptions, but are not intended to make accurate predictions of the future. It is useful to recall the limitations inherent in climate scenarios[3]:

→ These scenarios aim to be aligned with the Paris Agreement, which aims to limit global warming to 1.5°C or "well below" 2°C. These targets imply a “translation” of the temperature increase into the global carbon budget. However, due to the complexity of the climate underlyings, there is a certain uncertainty in the exact matches between the carbon budget and the increase in the average temperature on the surface of the global. Thus, by convention, most scenarios give only a certainty of a 50% chance of meeting the stated objectives. In other words, for a given carbon budget, the uncertainties linked to climate phenomena do not make it possible to guarantee, by more than 50%, that the temperature will actually be kept below 1.5°C if it were to occur as planned.

→ As seen below, many climate scenarios only concern CO_2 emitted by the combustion of fossil fuels and therefore do not include certain other emission sectors. For example, emissions from land use, forest management and agriculture are often not taken into account, as are emissions of other greenhouse gases (although they are increasingly taken into account in recent modelling exercises). Thus, the absence of a non-negligible share of emissions in these scenarios creates additional uncertainty regarding compliance with the carbon budget and therefore the achievement of the warming objectives.

→ Growth is an exogenous variable of the scenarios. Scenarios rarely incorporate the effect of major decarbonisation transformations on economic activity. However, such transformations of the energy system would necessarily have impacts on the growth rate.

→ The scenarios are based on many underlying assumptions made by the modeller. Thus, not all assumptions are necessarily documented or justified, which can lead to sometimes questionable results. Decarbonisation trajectories in the different scenarios imply assumptions about the mobilisation of a multitude of decarbonisation drivers (deployment of renewable energy, carbon capture and storage, CO2 elimination technologies, hydrogen, biomass, energy efficiency, fuel economy, etc.). These assumptions can therefore sometimes be ambitious compared to empirical observations or anticipated deployment capacities in the coming decades given technical, physical, economic or social constraints. Although it is useful to increase the number of exercises to "test" different possible carbon transition conditions, it is advisable at the time of decision-making to remain cautious about the weight of the different solutions, given the significant risks associated with not achieving our climate objectives.

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2 This aphorism is attributed to statistician George Box.

3 Here, we draw inspiration from the few points of caution cited by Reclaim Finance in its October 2020 note, “Scénarios climatiques: 5 pièges à éviter pour contenir le réchauffement à 1.5°C"

EACH SCENARIO IS BASED ON A SPECIFIC STORY OF THE FUTURE: UNDERLYING ASSUMPTIONS ARE CENTRAL TO UNDERSTANDING THEM

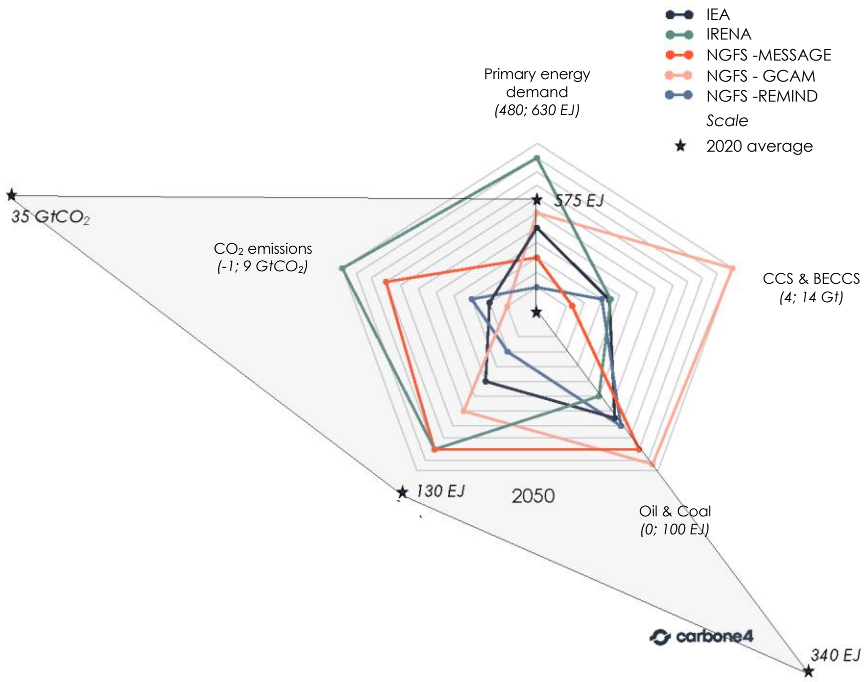


Figure - Stars representing the main energy-climate scenarios in 2050
Source: Carbone 4, IFD, Observatoire de la Finance Durable

Compared to 2020, all scenarios provide for:

→ primary energy consumption that varies little, overall, between 2020 and 2050 (575 EJ in 2020 and between 630 and 480 EJ depending on the scenarios in 2050) but which hides major sectoral and geographical changes.

→ a very sharp reduction in CO_2 emissions related to energy activities due to a very sharp reduction in coal, oil and gas consumption.

These 1.5°C scenarios all reach Net Zero in 2050 but they are based on different assumptions regarding the role of each technology (see the star reflecting the different narratives of the scenarios). They should be considered as inseparable combinations of assumptions.
Looking at the star summarizing the scenarios, different narratives emerge:

→ REMIND is betting on energy efficiency and fuel economy;

→ GCAM and IRENA are more pro-technology scenarios for carbon capture and storage (CCS). IRENA is based on a relatively larger overshoot in 2050 before reaching 1.5°C in 2100;

→ MESSAGE is an intermediate scenario between REMIND and GCAM;

→ The IEA's NZE and Bloomberg's NZS rely little on CO2 capture but rely on ambitious assumptions about the development of decarbonised energy (which appear realistic in light of the increase in renewable energy in recent years[4].

[4] See IEA analyses cited above.

2. PHYSICAL TRAJECTORIES: KEY LESSONS LEARNED FROM ENERGY-CLIMATE SCENARIOS

THE ENERGY TRANSITION IS A TRANSITION FROM FOSSIL FUELS TO LOW-EMISSION SOURCES

In the scenarios, the energy future is driven by low-carbon technologies: solar, wind, geothermal, bioenergy, etc. The aim is to make the best use of all decarbonised sources.

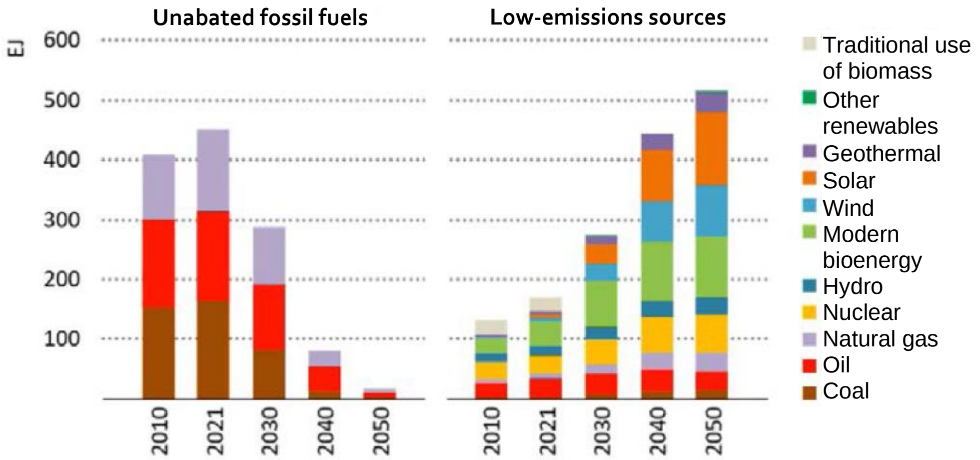


Figure - Evolution of energy production sources in the overall energy system of the IEA NZE scenario

Source: IEA - WEO 2022

In the IEA NZE scenario, as in many others, a significant share of the fossil fuel residual is coupled with CCS technologies.

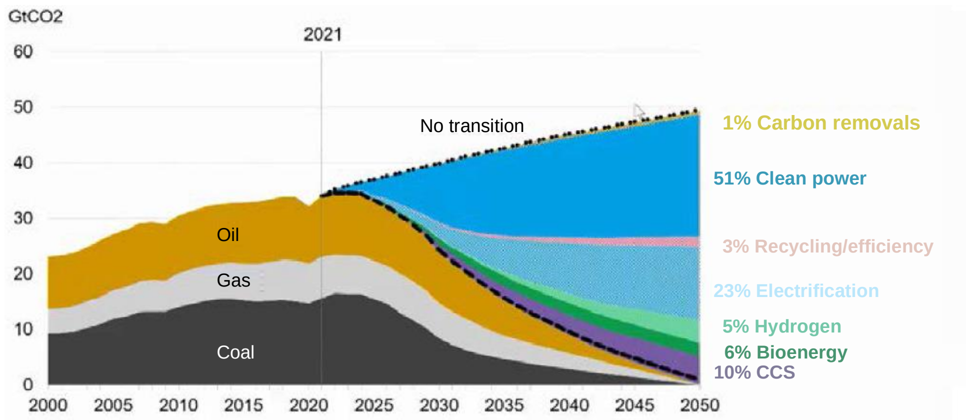


Figure - Reductions in CO_2 emissions from burning fossil fuels, NZS compared to a no-transition scenario, covering the entire energy system

Source: BloombergNEF - NEO2022

The BloombergNEF scenario is consistent with IEA estimates, the vast majority of the decarbonisation effort (more than 75% here) is based on the development of low-carbon electricity generation capacity (51%) combined with the electrification of the energy sector (23%) and an increase in energy efficiency (the latter taking a smaller share in the BNEF scenario than in the IEA scenario). The last quarter concerns technologies that are not yet fully mature (hydrogen, bioenergy outside the electricity sector, carbon capture and storage, direct carbon capture and storage in the air, etc.).

KEY LESSONS FROM GLOBAL ENERGY AND CLIMATE SCENARIOS

1. To achieve Net Zero by 2050, decarbonisation of the energy sector – both in energy use and in energy production – is a priority.

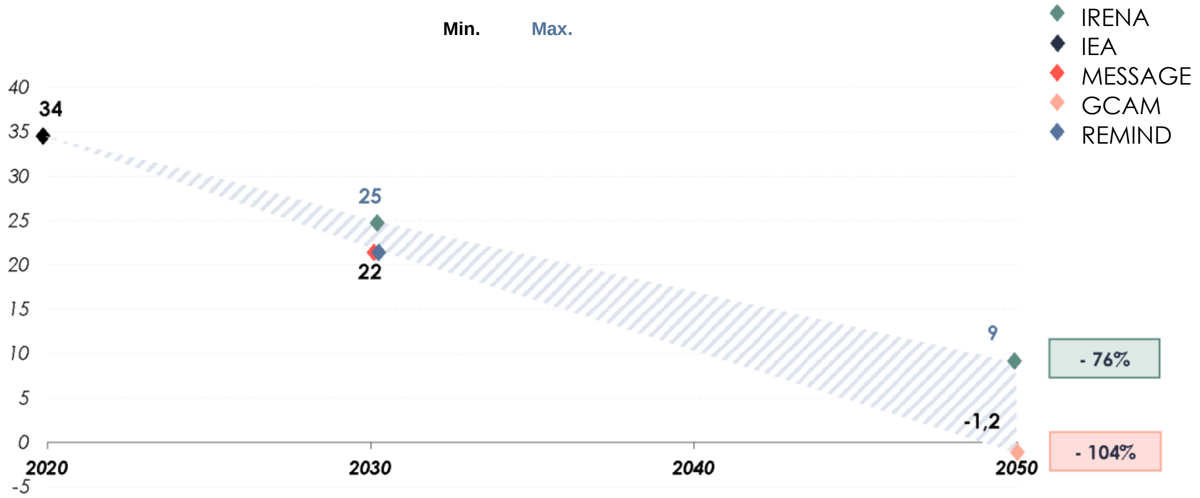


Figure - Range of energy-related CO_2 emissions in the 1.5°C scenarios
Source: Carbone 4, IFD, Observatoire de la Finance Durable

The decarbonisation of human activity mainly involves the decarbonisation of energy, whether in its use (heating, moving, producing, feeding) or in its production. The Global Carbon Budget[5] reports emissions of 34 GtCO2 in 2020 within an uncertainty range of 33-36 GtCO2. The climate models used for the different scenarios under consideration show some variability in the projected evolution of energy-related CO2 emissions. To reach Net Zero by 2050, energy-related CO2 emissions must decrease between 2020 and 2050, from -76% to -104% depending on the scenarios considered.

5 globalcarbonbudget.org/

2. To decarbonise energy usage and production, prioritising solutions based on using electricity for more applications and improving energy efficiency is essential, as these are the most effective and affordable methods for reducing CO2 emissions in most cases (providing carbon reduction at the lowest cost per tonne of CO2 abated).

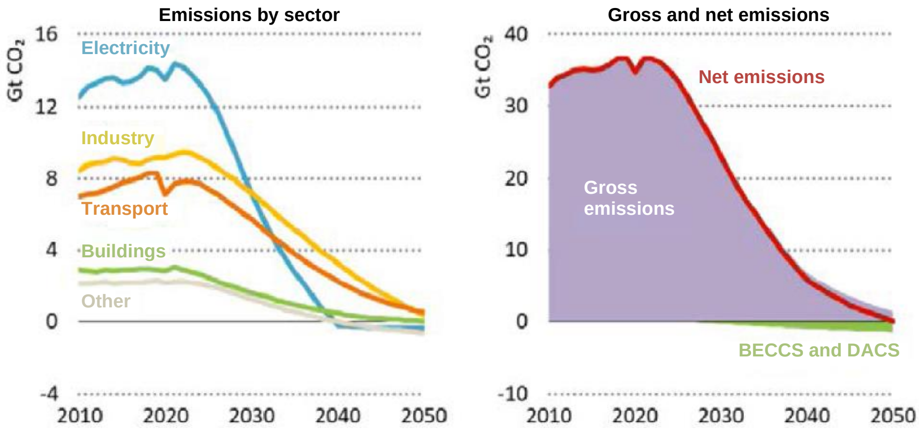


Figure - Decline in CO_2 emissions by sector in the IEA NZE
Source: IEA - WEO 2022

All sectors must contribute to the transition, even if the cost of decarbonisation is not the same for all technologies. One of the key points of the transition is electrification of the energy sector. Moreover, the emission curve of the electricity sector declines much faster than others and even becomes negative thanks to production from biomass combined with carbon capture and storage. Bioenergy with carbon capture and storage (BECCS) is a process of producing energy from biomass, which has absorbed atmospheric carbon during its growth, and capturing and storing carbon during the production of energy, thereby removing it from the atmosphere. Nevertheless, BECCS suffers from limits that allow it to play only a marginal role in reducing CO2 emissions (see below).

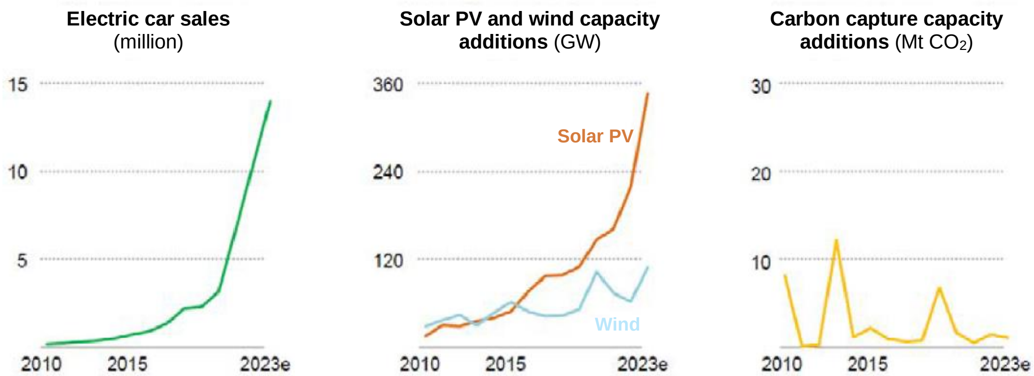


Figure - Growth in decarbonisation drivers over the last 15 years
Source: IEA - WEO 2023

According to the IEA, the recent growth in renewable energy leaves open the possibility of a 1.5°C scenario, but this requires a rapid deployment of other decarbonisation technologies (electric vehicles, CCS, etc.).

3. Major solutions for decarbonising energy uses and production are already mature: electric vehicles, heat pumps, substitution of carbon-intensive means of electricity production (particularly coal) by low-carbon means of electricity production.

Today the decarbonisation of the global energy sector is the most cost-effective: technologies are available and inexpensive. In some sectors, transition costs may be higher and low-carbon technologies do not even exist to replace carbon technologies (e.g. aviation and maritime, agriculture, etc.).

According to the IEA scenario[6], 80% of the solutions needed to achieve the 2030 targets are already available: the targets of tripling renewable energy installations, doubling energy efficiency, and quartering methane leaks in the extraction of fossil fuels, which account for 80% of the effort, are based on already mature technologies.

According to the IEA, 53% of technologies exist for 2050[7]. The remaining half must be developed as soon as possible by investing heavily in R&D.

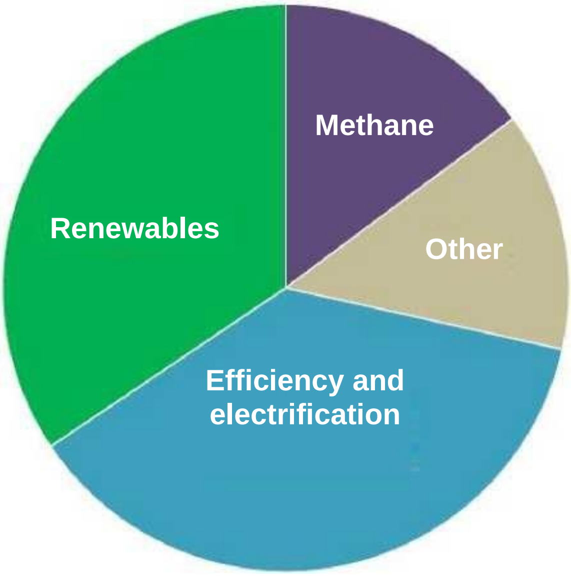


Figure - Emission reductions by measure by 2030 in the IEA NZE scenario Source: IEA - WEO 2023

[6] IEA (2023), World Energy Outlook

[7] IEA (2023), World Energy Outlook

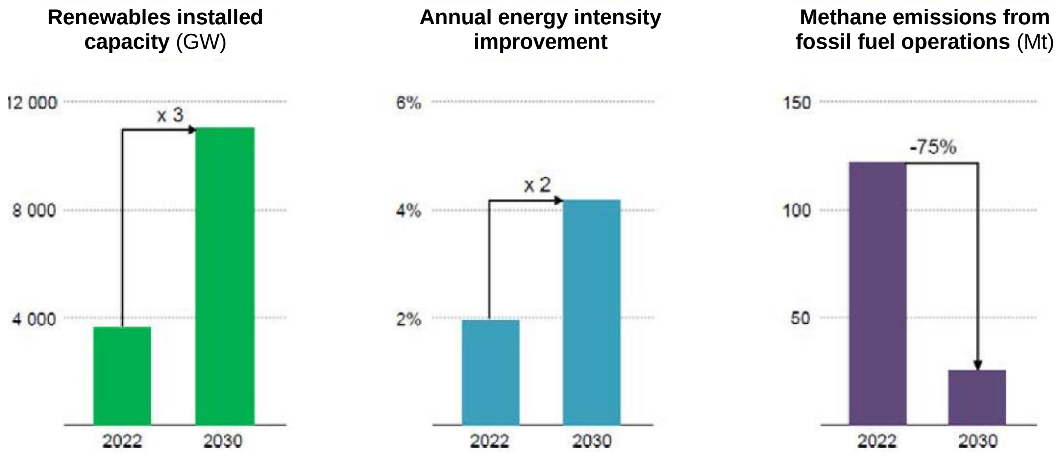


Figure - Changes in the main decarbonisation drivers of the IEA NZE
Source: IEA, WEO 2023

The installation of renewable energy capacity and the electrification of the energy sector are well known measures. On the other hand, the reduction of methane leaks in the extraction of fossil fuels is less so and represents a rapid and significant driver for the decarbonisation of the sector. It allows for an immediate reduction in emissions produced during the oil and gas extraction activity. There is a list of concrete measures to reduce methane emissions from extractive industries by up to -60%[8:] immediate cessation of flaring, electrification of extraction activities and plants to liquefy gas, equipping CCS plants, massification of the use of hydrogen in refineries, etc.

Methane emissions account for about 30% of the warming observed since the industrial revolution[9.] The energy sector is the main emitting sector: oil (49MtCH4/year), gas (29MtCH4/year), coal (40MtCH4/year) and bioenergy (10MtCH4/year). The energy extraction sector accounts for ⅓ of current methane emissions from human activity. 70% of methane emissions from the energy sector are attributed to the ten countries with the highest emissions: First of all, the United States, followed closely by Russia, then China (the largest coal issuer). The amount of methane emitted into the atmosphere by operations linked to the extraction of fossil fuels in 2023 is 170bcm (more than Qatar's annual gas production): for example, Europe's annual gas demand is 320bcm. These leaks are therefore not insignificant in the contribution to climate change: reducing 75% of methane emissions from the energy sector before 2030 is crucial to limiting warming to 1.5°C.

8 Hearing of the International Energy Agency, Sustainable Finance Institute, on Tuesday 12 September 2023.

9 www.iea.org/reports/global-methane-tracker-2024

4. By 2050, final energy demand will have to fall (notably by removing fossil fuels from the energy mix), and at the same time electricity demand will have to increase.

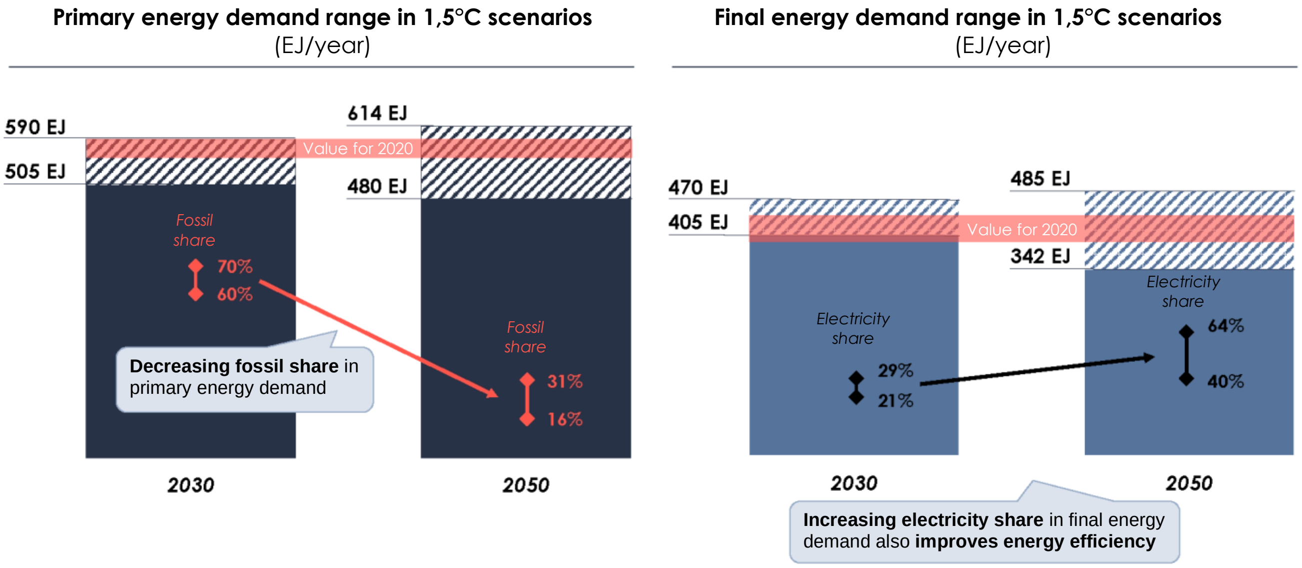


Figure - Change in primary and final energy demand in 1.5°C scenarios
Source: Carbone 4, IFD, Observatoire de la Finance Durable

All the scenarios highlight two simultaneous phenomena leading to a relatively stable overall demand for primary energy between now and 2050 (despite differences between the scenarios):

→ Decrease in the share of fossil fuels in primary energy demand: between 2030 and 2050, depending on the scenarios, the share of fossil fuels is divided by 2 or even 4 in primary energy demand.

→ Increasing the share of electricity in final energy demand also improves energy efficiency: between 2030 and 2050, depending on the scenarios, the share of electricity in final demand is multiplied by at least 2.

5. By 2050, coal and oil consumption will need to have been drastically reduced. The sharp decline in gas demand is also very clear, although more variable depending on the scenarios.

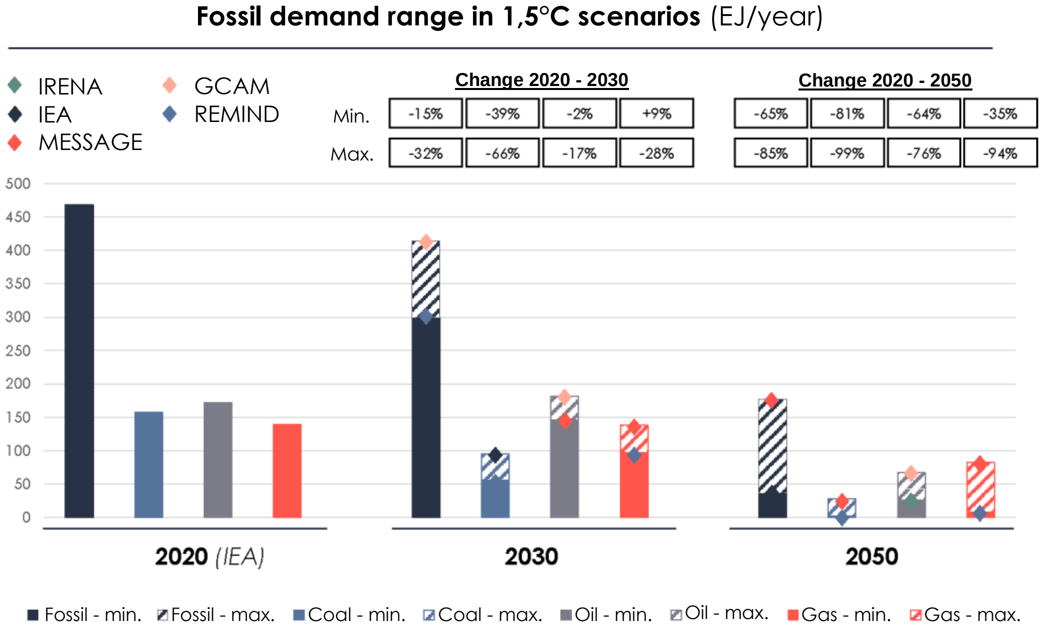


Figure - Ranges for the change in fossil fuel demand in the 1.5°C scenarios
Source: Carbone 4, IFD, Observatoire de la Finance Durable

In each scenario, demand for fossil fuels is divided by at least 3 between 2020 and 2050, and up to 6 in some of them. Demand for coal and oil is drastically reduced in all scenarios to reach residual levels by 2050. The remaining demand will mainly concern the petrochemical uses of oil. The long-term role of gas in the transition is more variable, with demand divided by 1.5 or 20 by 2050 depending on the scenario.

Note that gas-based scenarios rely mainly on gas-fired power plants coupled with CCS, which is a risky bet: "*Higher gas trajectories are made possible by higher CCS and carbon dioxide removal, but they are probably associated with inadequate representation in the models of regional CO_2 storage capacity and technology adoption*"[10]. The conditions for the deployment of this solution will be studied in more detail in the rest of the work of IFD Project 5.

10 Achakulwisut et al., (2023), Global fossil fuel reduction pathways under different climate mitigation strategies and ambitions, Nature Communications

6. Meeting the increase in demand for decarbonised electricity requires a very significant increase in production, via a diversified mix based mainly on strong growth in renewable energies.

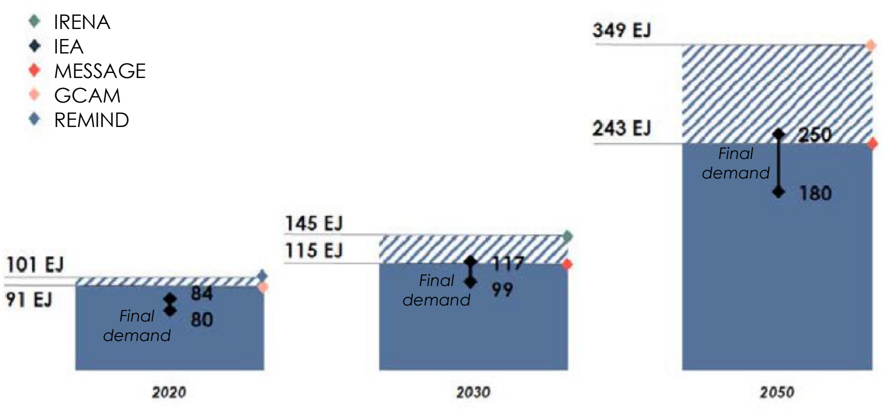


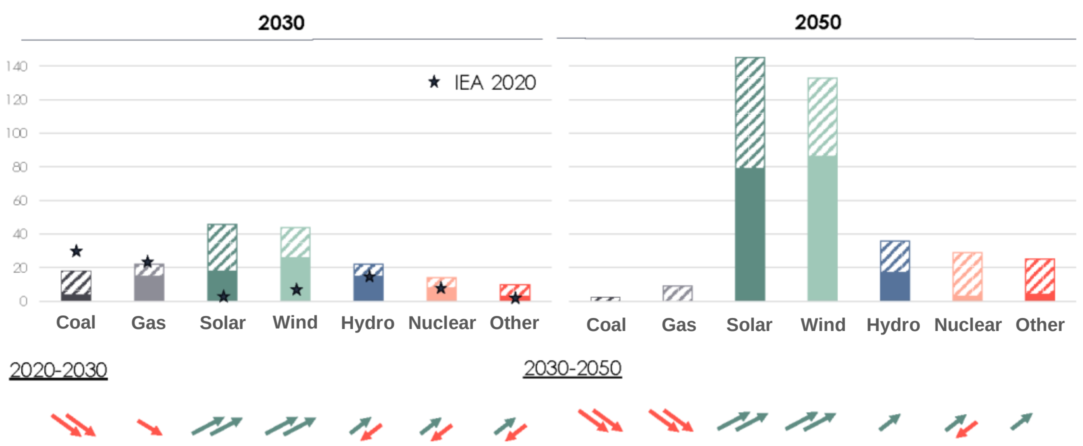
Figure - Electricity generation ranges in scenarios at 1.5°C (EJ/year) Source: Carbone 4, IFD, Observatoire de la Finance Durable

Note: Final demand volumes (ranges in the centre of the histogram bars) are also measured in EJ. These volumes are lower than for generation as part of the electricity is intended for secondary uses

Electricity generation increases in all scenarios: regardless of the scenario, electricity generation must be multiplied by at least 2.5, if not 4, between 2020 and 2050.

The graph also shows the final demand for electricity, which is observed to increase at a slower rate than electricity generation because electricity is used more as a secondary energy vector in the transition, for example for hydrogen production by electrolysis.

The strong growth of renewable energies temporarily requires a carbon electricity production base that can be ordered (making it possible to meet the flexibility needs of the electricity system, generated by intermittent renewables).



	Coal	Gas	Solar	Wind	Hydro	Nuclear	Other
2020-2030	-50%	-5%	+1430%	+630%	+40%	+400%	+150%
	-90%	-35%	+500%	+330%	-5%	-20%	-25%
2030-2050	-90%	-60%	+340%	+230%	+65%	+100%	+150%
	-100%	-100%	+215%	+200%	+15%	-60%	+30%

Figure - Electricity generation ranges by energy type in the scenarios at 1.5°C in 2030 and 2050
Source: Carbone 4, IFD, Observatoire de la Finance Durable

Reading note: The hatched parts represent the range between the minimum and maximum of the six scenarios studied.

Renewable energies are key to massifying electricity production. This is a massive deployment of solar and wind capacity to replace fossil energy production, a trend observed regardless of the scenario. Solar energy production is expected to increase by 40 on average between 2020 and 2050, and by 15 on average for wind energy. The long-term role of hydroelectricity and nuclear power, on the other hand, is more variable and depends heavily on local context and political choices.

7. The anticipated role of hydrogen varies from scenario to scenario because its production cost is still very high, and should be targeted primarily at the sectors most difficult to decarbonise.

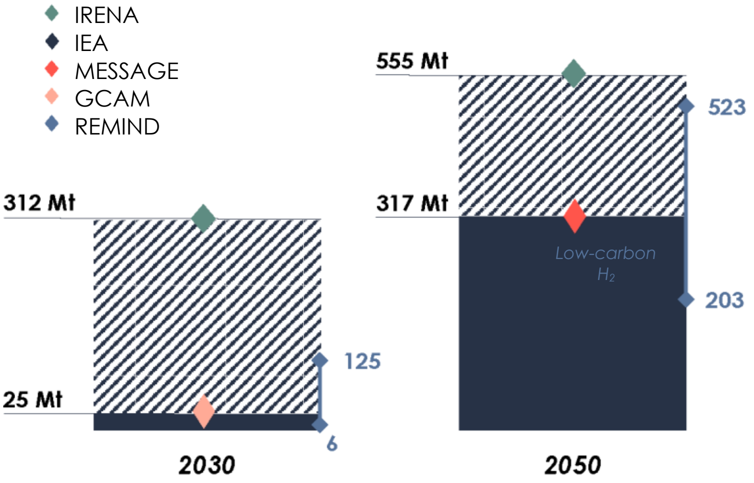


Figure - Ranges for comparing hydrogen production between 2030 and 2050 in the 1.5°C scenarios
Source: Carbone 4, IFD, Observatoire de la Finance Durable

Note: Final low carbon hydrogen production volumes (ranges on the side of the histogram bars) are also measured in EJ. These volumes are lower than for total production insofar as part of the hydrogen produced remains carbon-intensive.

The long-term role of hydrogen in 1.5°C scenarios is highly variable. Hydrogen production is multiplied by 2 to 10 between 2030 and 2050 depending on the scenarios envisaged. Low carbon hydrogen, in all scenarios, accounts for a majority of hydrogen production. Low carbon hydrogen is made from electrolysis either from natural gas with CCS (blue hydrogen) or from renewable energy (green hydrogen).

However, this technology plays a secondary role in climate scenarios because of its high cost. For green hydrogen (produced by electrolysis from renewable energy), the cost remained at best above €75/MWh in 2020[11]. By way of comparison, these costs are systematically higher than the cost of renewable energies, which vary according to technologies (solar, onshore wind, offshore wind, geothermal, etc.) and projects between €23/MWh and €71/MWh on the same date[12]. However, with the fall in the cost of electrolysis, the authors estimate that costs can fall to less than €40/MWh of green hydrogen by 2035[13], which could potentially be a more competitive cost depending on uses.

11 Inès Bouacida, Nicolas Berghmans, "Hydrogène pour la neutralité climat: conditions de déploiement en France et en Europe", January 2022, IDDRI, link

12 ADEME, "Coût des énergies renouvelables et de récupération en France", 2019

13 Inès Bouacida, Nicolas Berghmans, January 2022

The hierarchy of final uses for hydrogen is important to consider when investing in "no-regret" hydrogen production projects:

1. Green hydrogen to replace fossil hydrogen in existing uses (ammonia, methanol, fertilizer, etc.)

2. Green hydrogen for new uses that have few decarbonisation options (maritime transport, steel industry, network flexibility.)

3. Where appropriate, green hydrogen for new uses that have good decarbonisation options (road transport).

Hydrogen, on the other hand, is much less competitive for electricity generation.

8. CC(U)S and negative emission solutions will probably be necessary to achieve the 1.5°C target, but these drivers are constrained, in particular by physical limits.

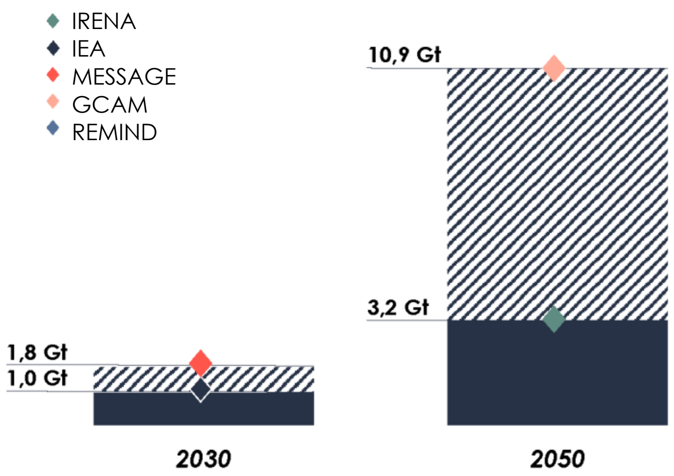


Figure - Ranges for comparing the volume of CCS between 2030 and 2050 in the 1.5°C scenarios

Source: Carbone 4, IFD, Observatoire de la Finance Durable

The long-term role of CC(U)S in 1.5°C scenarios is highly variable. The annual carbon capture and storage capacity is multiplied by 3 to 10 between 2030 and 2050 depending on the scenarios envisaged: it has a very large range in 2050. Even the low range of 3 $GtCO_2e$ is a significantly important value compared to the range of residual emissions modelled for 2050, which is between 9 and -1.2 Gt of CO2. The CC(U)S is thus a strong bet on the scenarios today, but it remains risky given the immaturity of the technology at this stage.

While investments in CC(U)S need to increase, to remain credible in terms of physical constraints, they must remain complementary to investments in reducing gross greenhouse gas emissions, especially as the effectiveness of these technologies remains uncertain on a large scale.

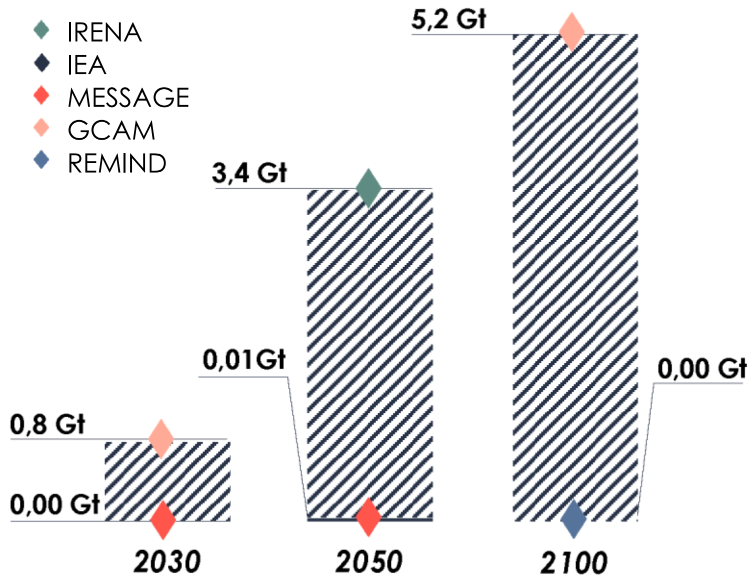


Figure - Ranges for comparing BECCS volume between 2030, 2050 and 2100 in the 1.5°C scenarios

Source: Carbone 4, IFD, Observatoire de la Finance Durable

With regard more specifically to bioenergy carbon capture and storage (BECCS), its role in the 1.5 °C scenarios is also very variable. The IRENA and the NGFS GCAM model give it an important role in their scenario, while the IEA and the NGFS MESSAGE and REMIND models give this solution almost zero weight.

Like the CCS, the volumes at stake (3GtCO_2eq. for the upper range in 2050) are considerable compared to the range of emissions modelled for 2050. Thus, it remains risky to bet on the success of the massive deployment of these technologies to limit global warming.

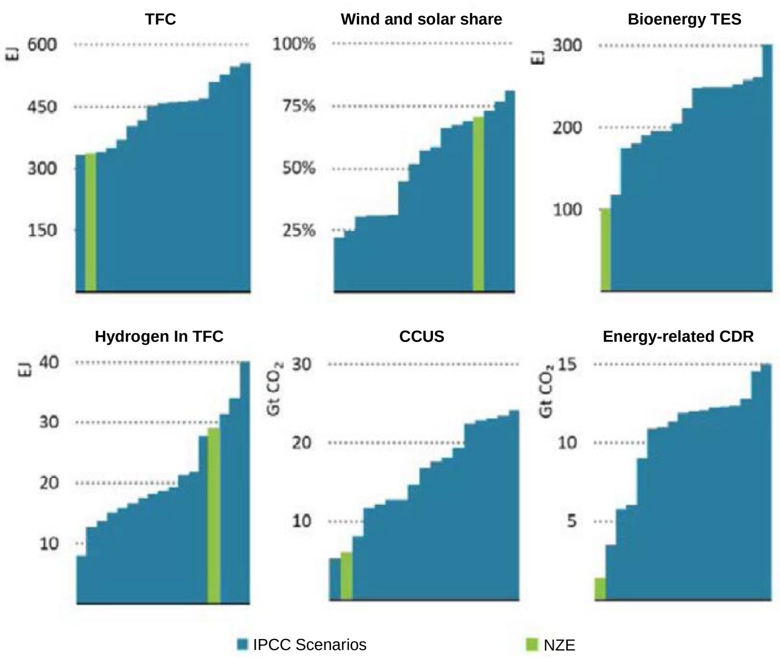


Figure - Comparison of IEA NZE with IPCC database scenarios

Source: IEA - WEO 2022

Reading note: This graph represents the positioning of the IEA NZE against the scenarios in the IPCC database. The NZE scenario is based comparatively more heavily on the deployment of renewable energy and hydrogen than the average of the IPCC scenarios. On the other hand, it relies comparatively less on CCUS, CO_2 removal and biomass technologies.

Focus: uncertainties related to carbon capture and storage (CCS) and atmospheric CO_2 removal technology (CDR)[14]

Two crucial assumptions in climate models concern the availability of methods for removing CO_2 from the atmosphere (CDR for carbon dioxide removal - including direct air carbon capture and storage, bioenergy carbon capture and storage and afforestation technologies) and carbon capture and storage (CCS) technology, both of which have not yet been deployed on a large scale.

According to the IPCC, *"the CDR deployed on a large scale is not proven, and the use of [CDR] is a major risk to the ability to limit warming to 1.5°C"*[15.] However, many models rely on a very large-scale CDR, with elimination achieved either by sequestration of carbon by reforestation and afforestation, or by bioenergy with CCS (BECCS). This dependence is very controversial within the scientific community.

Models aimed at minimising total system costs often favour CDR: subsequent CO2 eliminations offer a way to push costs back decades into the future, resulting in lower discounted costs. However, this distant horizon increases the uncertainty of deployment. In addition, if CDR solutions cannot be deployed as expected, it will be too late for an adjustment to the gross emissions that have already occurred.

Solutions to generate negative emissions are highly constrained. Recent analyses show that very few models remain within the reasonable limits corresponding to the actual capabilities of these solutions. In particular, CO2 storage capacities are limited. Recent analyses estimate that "*The maximum CO2 storage capacity (...) is 8.6 GtCO2 per year around the middle of the century, after taking into account actual regional differences in storage capacity and injection rates"*[16.] Some scenarios would therefore be beyond this limit, as we see with GCAM.

Forests and BECCS both require considerable land area. For example, capturing 11.5 Gt of CO2 per year using BECCS (compared to current annual global emissions of 40 Gt of CO2) would require a land area of 380 to 700 Mha, which is equivalent to 25 to 46% of the world's arable land. Capturing the same amount with forests would require three times as much land as BECCS (IPCC, 2022). This land requirement raises concerns about competition with food production and impacts on biodiversity where wild land is converted. Taking these limitations into account, the researchers estimated what could be considered the maximum sustainable potential of different approaches to CDR (de Coninck et al., 2018; Fuss et al., 2018).

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14 Focus largely from the report "Navigating Energy Transitions: Mapping the road to 1.5°C", International Institute for Sustainable Development, Octobre 2022, www.iisd.org/publications/report/navigating-energy-transitions

15 Rogelj, Shindell et Jiang, 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, p. 96, link

16 Achakulwisut et al., (2023), Global fossil fuel reduction pathways under different climate mitigation strategies and ambitions, Nature Communications

Even at potentially achievable levels, uncertainties remain as to whether and how CDR or CCS can be achieved. The deployment of the CCS to date is constantly lagging behind expectations. After more than 30 years of efforts to commercialize CCS, at the end of 2022 there were only 27 CCS facilities in operation, with a total nominal capacity of 36Mt of CO_2 (0.1% of global emissions). Only five of these facilities aim to ensure the long-term storage of CO_2 (Global Institute for CCS, 2021). Many CCS projects have failed (Robertson and Mousavian, 2022; Wang, Akimoto and Nemet 2021), and costs remain high compared to other low carbon alternatives.

Thus, CCS and negative emission technologies (BECCS, DACCS, afforestation) will probably be necessary to achieve the 1.5°C target, but these drivers are constrained, in particular by physical limits. But beyond the physical limits, one of the limiting factors will also be the costs of these projects. The way in which these technologies and carbon emissions (e.g. through the price of carbon) are regulated will or will not allow their economic viability.

SET SHORT AND MEDIUM TERM MILESTONES TO STAY BELOW 1.5°C

Climate scenarios allow players to set a timetable of actions over time. By way of illustration, the IEA carried out this exercise for its NZE scenario by setting short- and medium-term objectives to be met in order to remain in line with the scenario.

They propose several necessary milestones:

- As of today, no new oil and gas fields approved for development and no new coal mines or mines extensions (CCS[17]): an investor is investing in new projects on new extraction fields could not define themselves as aligned with the NZE scenario.
- From 2025, no more fossil fuel-based boiler sales.
- By 2030, no more CCS-free coal-fired power plants in developed economies[18].
- 100% decarbonised electricity in 2035 in developed countries (and in 2040 worldwide).
- In 2040, half of the existing buildings to have undergone an efficient energy renovation.
- In 2035, 100% of car sales are electric

[17] WEO 2022, IEA

[18] The wording of the IEA is "Phase out of unabated coal in advanced economies", with the following definition: "Advanced economies: OECD regional grouping and Bulgaria, Croatia, Cyprus, Malta and Romania."

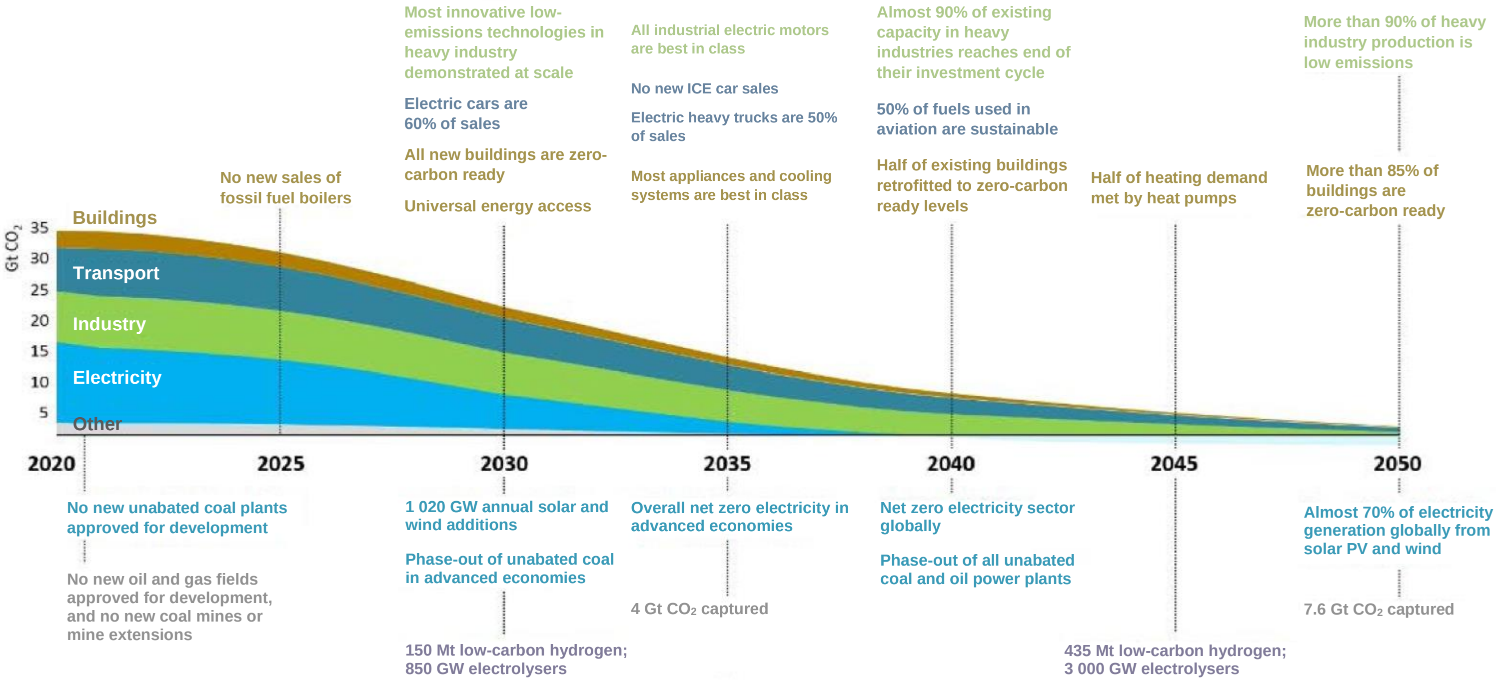

Figure - The main milestones to reach 1.5°C in the IEA NZE
Source: IEA - WEO 2022

HIGHLY VARIABLE TRANSITION SCENARIOS BY COUNTRY AND REGION OF THE WORLD

At the global level, the future of the electricity system will rely on low-carbon energy. Oil, coal and gas are quickly eliminated, while nuclear remains a significant part, alongside bioenergies. Hydrogen remains a small part of the electricity mix as it is the most expensive technology. It is interesting to note that the major global trends mask the regional specificities, which will be very strong.

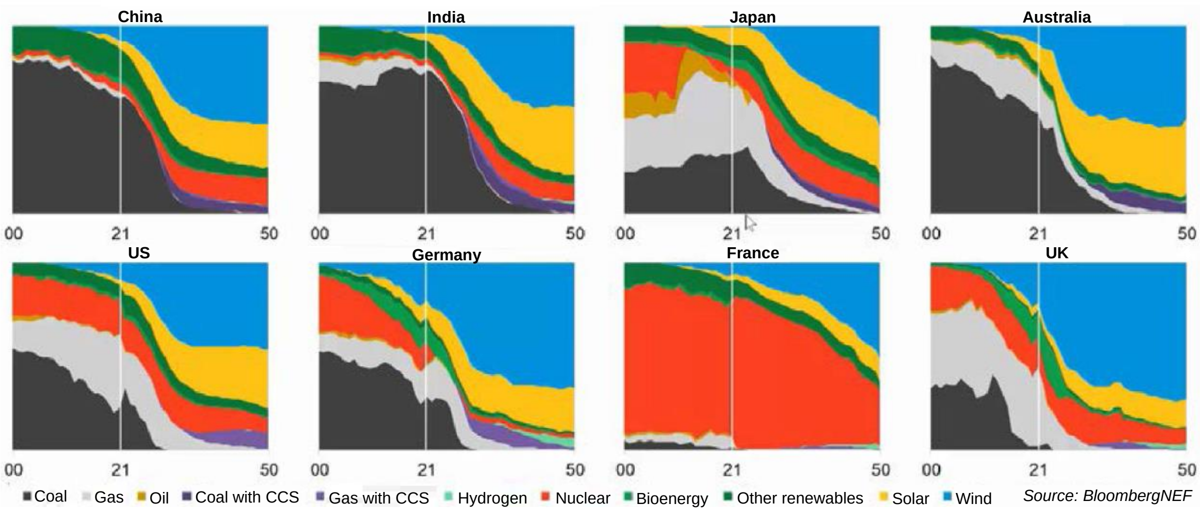

Figure - Electricity generation mix transition scenarios by country
Source: BloombergNEF - NEO 2022

There are a multitude of solutions per country: each country has its own electricity production trajectory according to its own political and economic choices. For example, France already has a low-carbon electricity mix thanks to nuclear energy, while Australia now relies heavily on coal and will rely mainly on wind and solar power in 2050. The UK currently relies heavily on gas: in 2050, given its geographical location, the majority of its electricity will come from wind power.

Focus: the National Low Carbon Strategy 3 - the reference scenario for France

The French Energy and Climate Strategy *is the French Government's roadmap to achieve carbon neutrality by 2050 and to adapt the economy to the impacts of climate change. In the coming months, it will be broken down into a Programming Act and two decrees - the National Low Carbon Strategy (SNBC), the Multiannual Energy Programme (PPE) - and a programmatic document, the National Climate Change Adaptation Plan (NAP).*

SNBC-3's challenge: "Getting out of fossil fuel dependence"

The choice made by France several decades ago of electrical independence and nuclear power allows us to benefit from a lead in terms of decarbonisation and the competitiveness of our electricity. Thus, our production, which is more than 90% decarbonised, covers most of the time our national needs.

However, as in most major industrialised countries, our energy mix is still dominated by fossil fuels, with 37% oil and 21% natural gas in our final energy consumption.

The French strategy for energy and climate in figures:

→ **Energy efficiency:** reduction in final energy consumption corresponding to -25% in 2030, -32% in 2035 and from -40 to -50% in 2050, compared with 2021.

→ **Exit from fossil fuels:** fossil energy consumption divided by 2 between 2021 and 2030, by 3 by 2035, before reaching the total exit from fossil fuels by 2050.

→ **Rebalancing of the French energy mix:** while fossil fuels represent 60% of final energy consumption today (17% for nuclear and 23% for renewable energies), in 2035, fossil fuels will represent only 29% thanks to the ramp-up of nuclear power (33%) and renewable energies (38%).

→ **Increase in decarbonised electricity production:** 21% growth in French production by 2030 and 2035, compared with 2021, 55% between 2021 and 2050. This growth is based on the development of the nuclear programme (+29% of production capacity between 2021 and 2035) and renewable energies.

→ **Considerable investment needs in renewable energies:** With regard to photovoltaics, SNBC-3 forecasts solar production to increase by a factor of 3 by 2030, and by a factor of 5 by 2035. It forecasts a 2-fold increase in onshore wind production by 2035, a 14-fold increase in offshore wind production by 2030, and a 70-fold increase by 2035 (from 2 farms currently installed to 36 by 2035). For renewable energy, not intended for electricity production, the SNBC-3 forecasts growth of 63% in 2030 and a doubling in the production of renewable heat and cold and recovery in 2035. It also forecasts biogas to multiply by 5 in 2030 and by 6 in 2035.

→ **Hydrogen, a marginal bet:** while France intends to develop hydrogen capacity, with its production remaining marginal in the energy mix in 2030 (0.5%) and 2035 (0.9%).

→ **Additional investments in the energy sector** are expected to reach €8 billion per year by 2030, roughly equally divided between nuclear production, renewable energy production and networks (source: Pisani-Ferry-Mahfouz report based on RTE, Rexecode and Ademe estimates).

FOSSIL FUELS: ANALYSIS OF TRAJECTORIES COMPATIBLE WITH A 1.5°C SCENARIO

3. INVESTMENT TRAJECTORIES: INVESTMENT RATIOS MUST BE REVERSED

1. Investments in the supply of fossil fuels must be halved, or even quartered, by 2050 compared to 2020, with a halving by 2030 according to the IEA, and must not finance new production projects.

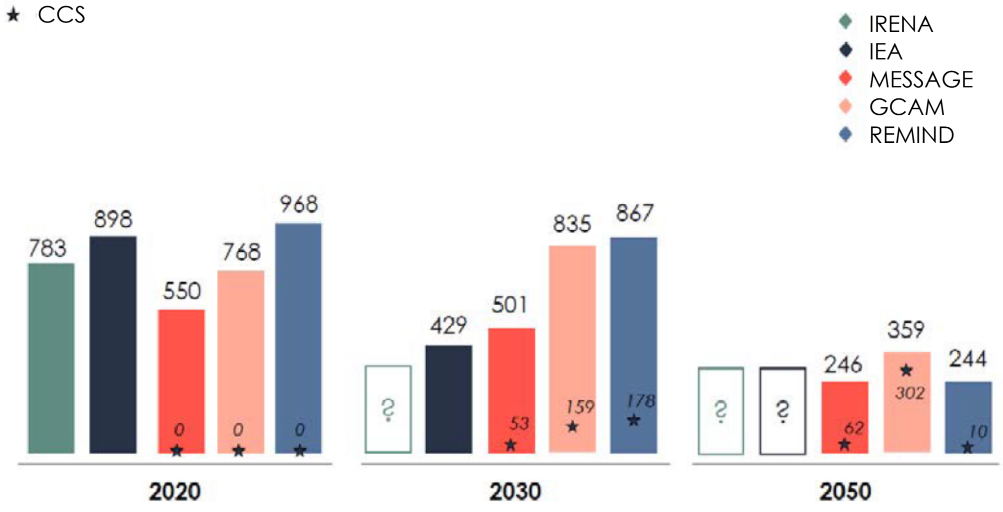

Figure - Investments in fossil fuel supply ($bn/year)

Source: Carbone 4, IFD, Observatoire de la Finance Durable

These figures are based on multiple assumptions revealed by the 2020 range of values, but the dominant trend towards 2050 is a significant reduction in investments in fossil fuel supply. REMIND indicates a quartering of investments in fossil fuel supply between 2020 and 2050. MESSAGE and GCAM indicate that investments in fossil fuel supply will be halved between 2020 and 2050. The IEA indicates a drastic reduction from 2030: the scenario indicates the need for fossil fuel investments to halve between 2020 and 2030[19].

At the same time, we can see that in particular GCAM and REMIND, where the decline in investments in fossil fuel supply is the lowest in 2030, rely more on CCS (investments in CCS in 2030 are respectively $159 billion and $178 billion per year in 2030, i.e. 3 times more than MESSAGE for example).

These investments in fossil fuels may still appear substantial between 2030 and 2050. It should be noted that the nature of investments is changing radically. The remaining investments are not directed towards new extraction projects but towards the optimisation and maintenance of existing infrastructure, such as the reduction of fugitive methane emissions from the fossil fuel industry.

19 www.iea.org/reports/world-energy-outlook-2023

The remaining investments must be analysed in detail (subject of the next stages of the work), in particular in terms of:

→ geographical distribution

→ position in the fossil value chain

→ other assumptions structuring the scenarios (use of CCS, BECCS, etc.). Investments in CCS vary widely depending on the models and clearly demonstrate the diversity of possible decarbonisation scenarios.

2. Investments in low-carbon electricity production must be multiplied by 2.5 to 3 times from 2030 compared to the amounts of 2020.

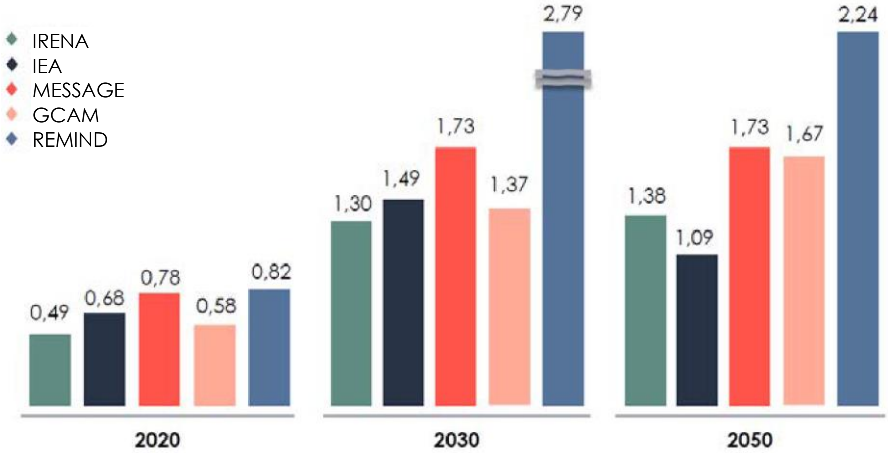

Figure - Investments in low-carbon electricity production ($trillion/year)

Source: Carbone 4, IFD, Observatoire de la Finance Durable

Investment needs in low-carbon electricity generation are rising sharply in all scenarios, before 2030. Regardless of the scenario, investment needs in low-carbon electricity generation are multiplied by 2.5 to 3 times in 2030 compared to the amounts of 2020.

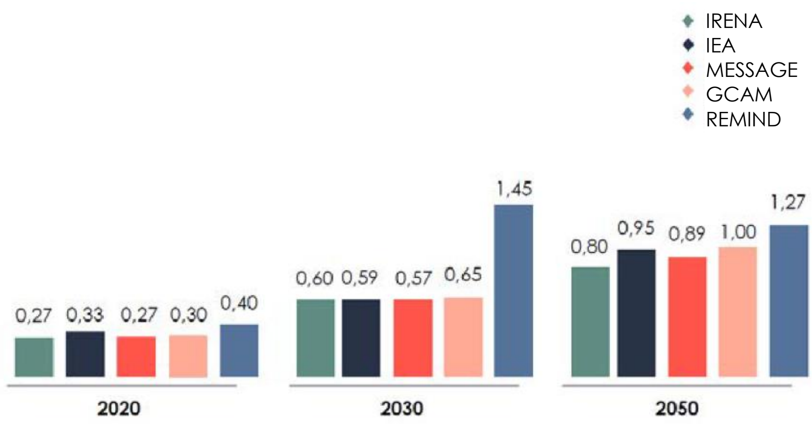

Figure - Investments in the energy network ($trillion/year)

Source: Carbone 4, IFD, Observatoire de la Finance Durable

Regardless of the scenario, investment needs in network, storage and flexibility are multiplied by 4 or 5, doubling from 2030.

3. In terms of ratio, investments in the energy transition should be $10 to $1 in fossil fuels by 2030, compared to $1 to $1 just 5 years ago and $1.7 to $1 today.

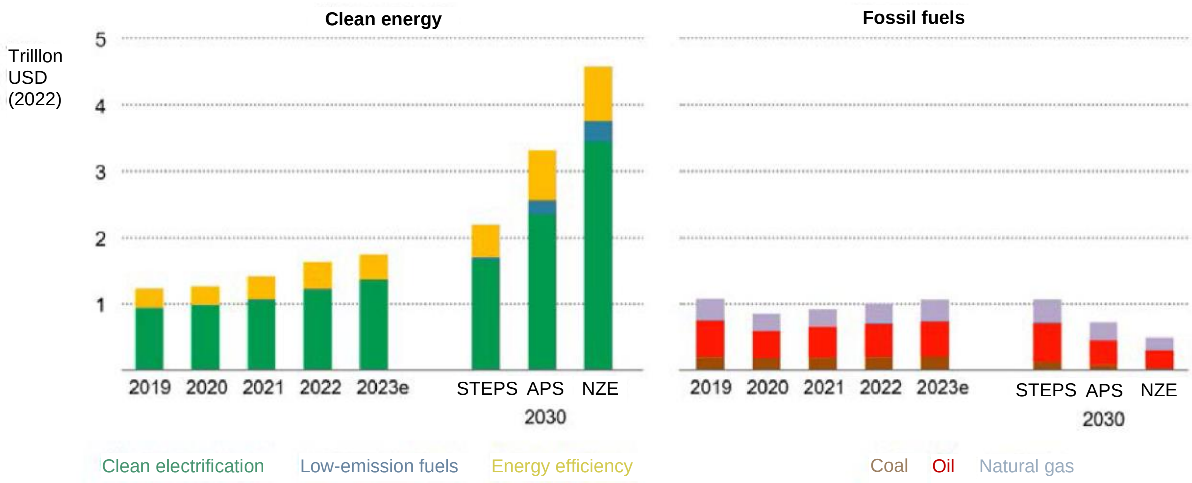

Figure - Comparison of investments in low-carbon and fossil fuels in the IEA scenarios
Source: IEA - WEO 2022

According to the IEA[20], if the ratio was about $1 in low-carbon transition investment to $1 in fossil fuels 5 years ago, today it is 1.7 to 1. But to be on the right track, it would have to be $10 in the transition to $1 in fossil fuels by 2030. Within this $10 for the low-carbon transition, $6 goes for the production of low-carbon energies (including storage, grid, etc.). Investments in decarbonised energy are not currently sufficient to offset the decline in investments in fossil fuels in production projections.

In 2030, there are still residual investments in fossil fuels (for energy efficiency, CCS, non-energy uses, etc.).

20 IEA, WEO 2023

CONCLUSION

This comparison of fossil fuel alignment trajectories highlights that the path is narrow for a transition to a sustainable energy model that limits global warming to 1.5°C. The data presented highlights the need to significantly increase investments in low-carbon energy to drastically reduce investments in fossil fuels over the next 5 years. Investments in low-carbon energies *make it possible* to reduce investments in fossil fuels.

The future prospects for this work involve an in-depth analysis of the policies and technologies needed to achieve these objectives. On the one hand, it will be necessary to continue the geographical and sectoral analysis of these data. On the other hand, these different scenarios are partly based on still uncertain decarbonisation drivers (carbon capture and storage, hydrogen, biomass, etc.). The scenarios studied take little account of the technical, physical and economic constraints of these different technologies. The aim of the Sustainable Finance Institute is to deepen their understanding by developing a physical and socio-economic framework of the various drivers.

It is crucial to continue to develop tools for understanding scenarios aligned with 1.5°C in order to support financial decision makers in their investment strategies. By using scientific expertise and integrating market developments, the Paris financial market can play a key role in the transition to a sustainable and resilient energy future.

APPENDICES

I. LIST OF MEMBERS OF THE WORKING GROUP

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II. GLOSSARY

LOW CARBON VS. RENEWABLE ENERGY

The terms "low carbon energy" and "renewable energy" are often used interchangeably, but the distinction is important in understanding the energy-climate scenarios:

→ **Renewable energy**: Renewable energy, also known as alternative energy, refers to a category of energy produced from natural resources that are constantly being renewed. These resources include the sun, wind, water, biomass and the Earth's internal heat (geothermal). Renewable energies do not run out with their use and are considered sustainable in the long term. They are also characterised by their low environmental impact and their contribution to reducing greenhouse gas emissions.

→ **Low carbon energy**: Energy is said to be low carbon when it produces little or no carbon emissions (or greenhouse gas equivalent). In energy-climate scenarios, low carbon energies encompass all energies with a low carbon footprint (below a certain conventional threshold). To define the degree of decarbonisation of an energy, the entire life cycle is taken into account: construction of equipment, operation, recycling, etc. The carbon footprint is measured in terms of the quantity of CO_2 emitted to produce one kilowatt-hour of electricity. Thus, renewable energy is part of clean energy, but other energies are part of it such as nuclear, green hydrogen (made from renewable electricity), blue hydrogen (made from natural gas with CO_2 capture), biomass and fossil fuels with CO_2 capture.

ENERGY SECTOR VS. OVERALL ENERGY SYSTEM

The distinction between the energy sector and the overall energy system is often used in energy-climate scenarios, in particular by the International Energy Agency.

→ **The energy sector**: it only includes the energy production activity (fossil fuel production, electricity production, etc.).

→ **The overall energy system**: it includes all economic activity based on energy consumption (mainly energy sector, industry, transport and construction).

Thus, the energy sector is a subset of the overall energy system.

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The work was led by Cécile Goubet, Chief Executive Officer of the Sustainable Finance Institute and the staff of the Sustainable Finance Institute.

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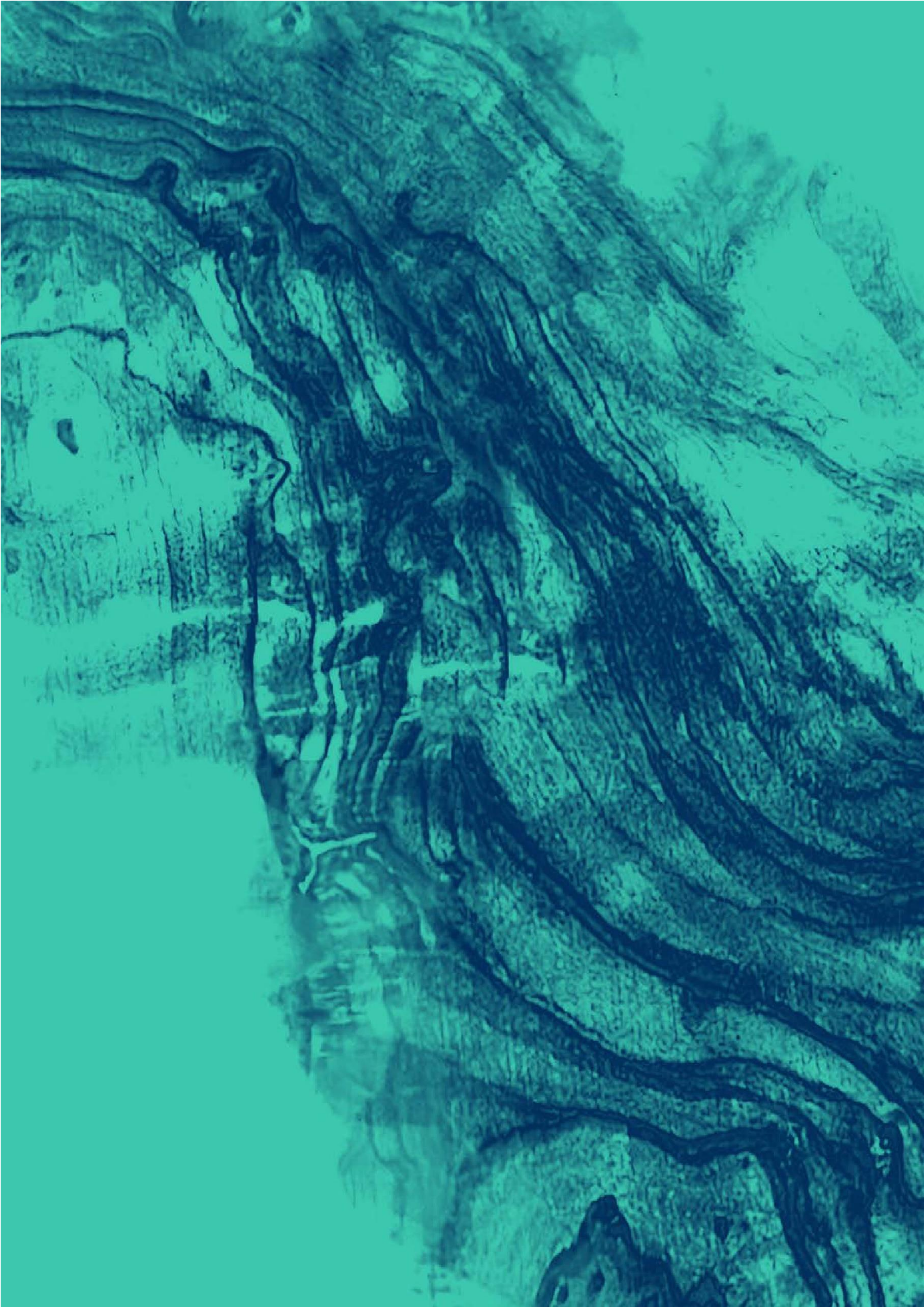

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