A Critical Assessment of the IEA's Net Zero Scenario, ESG, and the Cessation of Investment in New Oil and Gas Fields

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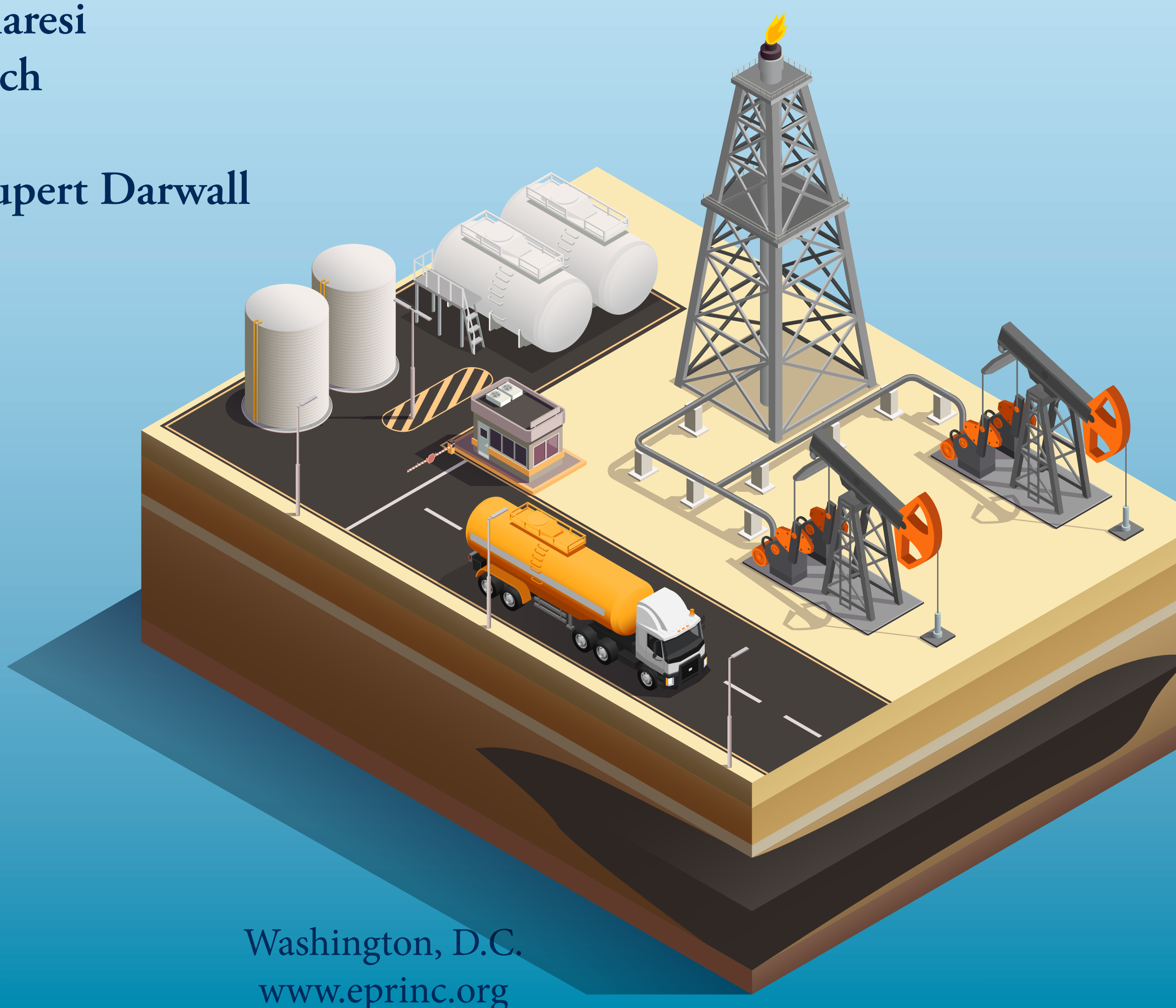

Energy Policy Research Foundation

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About the Energy Policy Research Foundation

The Energy Policy Research Foundation was founded in 1944 and is a not-for-profit organization that studies energy economics and policy issues with special emphasis on energy security, including the role of oil, natural gas, and petroleum products in the national economy. It is known internationally for providing objective and technical analysis on a wide range of energy issues. It is funded by a variety of donors including foundations, the private sector, and the U.S. government. The institute's publications on developments in U.S. and international petroleum are made available on our website: www.eprinc.org.

The Energy Policy Research Foundation's research is routinely presented at conferences and forums, including educational institutions. The institute has been a source of expertise for numerous government studies and its chairman and president have served on virtually every National Petroleum Council study of oil and gas issues. The Energy Policy Research Foundation routinely testifies before Congress and is now engaged in a long-term assessment of costs, benefits, timing, and energy security implications of alternative pathways to a lower carbon energy system for the national economy. Part of this work includes a systematic assessment of the economic and strategic assessment of the role of legacy fuels and U.S. potential to develop supply chains for critical minerals and materials to support the energy transition.

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Foreword

Rupert Darwall
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Efforts by climate activists and Environmental, Social, and Governance (ESG) investors to block investment in oil and gas production by Western companies appeared to have received a seal of approval from no less an authority than the International Energy Agency (IEA), when it published its *Net Zero by 2050: A Roadmap for the Global Energy Sector* in May 2021. As a result, attempts to achieve net zero carbon emissions (NZE) by 2050 have become central to the "E" in ESG, and the net zero roadmap has come to define the NZE baseline for energy companies.

For this reason, the RealClearFoundation asked the Energy Policy Research Foundation to:

- conduct a forensic analysis of the IEA's major reports on achieving net zero emissions by 2050—in particular, *Net Zero by 2050* and the *World Energy Outlook 2022* (October 2022); and
- assess the likely economic impact of a cessation of investment in new oil and gas fields on the production and prices of oil and natural gas.

The Energy Policy Research Foundation's analysis conclusively demonstrates that the IEA's assumptions are unrealistic, internally inconsistent, and often support the case for increased hydrocarbon fuel production. The whole of the IEA net zero roadmap pivots on the assumption that the plunging cost of wind and solar will destroy demand for oil and gas. If that does not hold, the whole roadmap goes up in smoke. But as this report shows, ***the IEA's own analysis contradicts its assumption on the economic superiority of renewable energy.***

In reality, the IEA's "net zero roadmap" is a green mirage that will dramatically increase energy costs, devastate Western economies, and increase human suffering. As such, investment managers and banks that use other people's money to advance this anti-investment agenda are violating their fiduciary obligation to maximize returns for retirees, investors, and shareholders.

Part of the problem stems from net zero advocates doubly misconstruing the IEA's position that there is no ***need*** for investment in ***new*** oil and gas fields as ***requiring*** no new oil and gas investment ***whatsoever***—resulting in calls for the imposition of investment bans to progressively throttle the supply of oil and gas, drive prices up to restrict consumption through demand destruction, and thereby bring about NZE. That is not what the IEA proposed and has categorically warned against.

The IEA's net zero roadmap projects low and falling oil and gas prices due to renewable energy displacing demand for hydrocarbons rather than, as many ESG investors and climate activists claim, on high prices due to limited supply destroying demand. The fundamental assumption underlying the IEA's net zero roadmap is that the superiority of alternatives to hydrocarbons—principally wind and solar (nuclear barely gets a look in)—will cause demand for coal, oil, and natural gas to wither away.

Nonetheless, progressive extremist groups aggressively seized the IEA's reports to justify—indeed, to require—a ban on investment in new oil and gas projects. Climate Action 100+, a group of 700 investors with over $68 trillion in assets under management, hailed the report as a "watershed moment" and highlighted the call from "relatively conservative IEA" for an immediate end to new investment in fossil fuel extraction. Similarly, As You Sow, a not-for-profit climate activist investor, described the IEA NZE report as groundbreaking. Considered as the foremost global energy expert, the IEA now recognized that on a net zero pathway, "there can be no investment in new fossil fuel supply," the activist group said.

NZE advocates have translated these misrepresentations into action. For the 2023 proxy season, As You Sow filed shareholder resolutions at five of the largest U.S. banks, pressing them to align their financing activities with achieving net zero by 2050. Those resolutions all failed, but last year, a resolution filed at the ExxonMobil annual meeting by Ceres, another activist investor and a founding partner of Climate Action 100+, cited the IEA net zero report and requested the company's board to produce an audited report on the impact of applying the IEA's net zero assumptions on the company's financial statements. The resolution received the support of 51.0% of voting shareholders.

Last year, the Environmental Audit Committee of Britain's House of Commons asked 40 leading signatories of the Glasgow Financial Alliance for Net Zero whether they supported the IEA's net zero roadmap. The committee's request elicited a wide range of responses: from BlackRock's straight "no" and Fidelity International's recognition of reality—"The current energy landscape is considerably different from the environment contemplated in the IEA's net zero scenario" to Franklin Templeton's more neutral view—"we respect the findings of the IEA's report" through Morgan Stanley's adoption of the IEA scenario—"we used the absolute IEA NZE emissions scenario to define our energy sector's 2030 interim target" to the net zero activism of Legal & General, Britain's largest asset manager and also a filer of an ExxonMobil shareholder resolution similar to Ceres's—"our research supports that there could be a pathway to net zero … in line with the IEA scenario" and the Church of England Pensions Board—"The Board advocated for and engaged directly alongside other investors with the IEA to provide a public 1.5-degree scenario."

Investment managers and advocacy groups would do well to read the fine print of the

IEA's reports. As the Energy Policy Research Foundation points out, the IEA itself highlighted the destructive consequences of unilateral action designed to suppress supply. "Reducing fossil fuel investment in advance of, or instead of, policy action and clean energy demand would not lead to the same outcomes as in the NZE Scenario," the IEA warned in its *World Energy Outlook 2022*. "If supply were to transition faster than demand, with a drop in fossil fuel investment preceding surge in clean technologies, this would lead to much higher prices—possibly for a prolonged period."

Those words benefited from being written after Russia's invasion of Ukraine. One need only consider the impact of that war on the supply and demand for hydrocarbon fuels to appreciate what a devastating impact a "no investment period" policy would have on people's ability to light and heat their homes and go about their daily business and—given the crucial importance of oil and especially natural gas on food production—on global suffering.

But the impact of IEA's actual proposal—"no new investment in oil and gas production" as demand allegedly withers away with the rise of wind and solar power—would also have a devastating global economic impact when it comes up against adamantine reality. The IEA's supposition is analogous to the claim made by Friedrich Engels that in the transition to socialism, the state would wither away. Of course, it never does.

Based on its assumption of demand obsolescence, the IEA foresees low and falling hydrocarbon prices: $35 a barrel for oil in 2030 (around half its current level); and, for natural gas, $2.1 per million Btu (MMBtu) in the U.S. and $2.0 in the EU in 2030 (p. 51 of the IEA net zero roadmap).

History tells us that these assumptions are fanciful. In the 318 months since January 1997, there were only 26 months when the price of natural gas in the U.S. was less than $2.10—and seven of those were in 2020, when demand was suppressed due to the Covid pandemic. The IEA's forecast for EU natural gas prices is even more improbable. Except for brief periods during the pandemic, European prices for natural gas are a multiple of those in the U.S., as they are structurally higher because of the absence of fracking and, since Russia's invasion of Ukraine, having to compete with Asian markets for limited LNG capacity.

Rather than being a plausible description of the future, the IEA's supposition that hydrocarbon fuel prices will dramatically decline as demand withers away is, at best, an expression of a political or an ideological aspiration, as opposed to an objective assessment of the future. The failure to invest in increased supply is far more likely to result in upwardly spiraling prices as demand increasingly exceeds supply, as the Biden administration understood when it used the Strategic Petroleum Reserve for the nonstrategic purpose of tamping down gasoline prices.

To realistically scope the scale of price increases that would flow from implementing the IEA's no investment in new oil and gas fields, the Energy Policy Research Foundation compares the net zero supply deficit with the IEA's Stated Policies Scenario (STEPS). Based on historical price elasticities of demand, the 35% supply differential for both oil and gas could see prices more than tripling on the net zero pathway. Whether price increases of this magnitude cause a recession or a depression, they will have a significant negative impact on global growth.

The other side of this coin is, of course, the relative cost of wind and solar energy. "Ever-cheaper renewable energy technologies," the IEA claims, "give electricity the edge in the race to zero." Yet the IEA's own numbers demonstrate the inferiority of its post–fossil fuel energy future as it will require vast increases in capital, labor, and land to produce less energy.

By 2030, the IEA says that its net zero pathway requires investment in the energy sector to have risen by $3 trillion annually from its current level of just over $2 trillion a year to almost $5 trillion a year (p. 81). A smooth ramp up, so that each year sees $300bn more investment than the previous one, implies that the energy sector uses an additional $16.5 trillion of capital in 2030.

Usually, more investment makes labor more efficient. Not with clean energy. As well as more capital, non-hydrocarbon energy requires nearly 38.5% more labor. According to the IEA, energy employment expands from about 65 million today to almost 90 million in 2030 (*World Energy Outlook 2022*, p. 78).

Despite these colossal additional inputs of capital and labor, this new energy system produces 7% less energy, as total energy supply falls from 591 exajoules (EJ) in 2020 to 550 EJ in 2030 (p. 56 of the net zero roadmap), implying a 33.0% fall in energy output per employee.

If that's not bad enough, the energy transition has a voracious appetite for land. According to the Energy Policy Research Foundation's calculations, solar and wind generation capacity on the IEA's net zero pathway requires an area equivalent to the combined size of California and Texas and bioenergy for electricity production an area the size of France and Mexico combined, given current land requirement metrics before accounting for grid integration considerations.

So, based on the IEA's own data—more inputs of land, labor, and capital result in less energy. There is no theory in growth economics that says that this is a formula for sustained economic growth. Quite the opposite. The IEA's net zero pathway reverses a process that has been under way since the dawn of the Industrial Revolution of society obtaining more outputs for fewer inputs. In short, it would reverse decades of productivity growth, increasing wages, and rising living standards—all of which have improved the human condition and transformed our lives for the better.

Innovation is the secret sauce of the free-market growth machine. Net zero government directives are soaking up and misdirecting scarce innovation resources that the market could better and more effectively allocate to generating higher economic growth. Around half of all emissions reductions on the IEA's net zero roadmap come from technologies that are at an early stage of development. Of 503 clean energy technologies identified by the IEA, 326 are at demonstration or earlier stages and a further 116 require improvements to become competitive.

Bottom line: The IEA's own numbers destroy the economic case for renewable energy. Replacing an energy system overwhelmingly based on hydrocarbons with one centered predominantly on wind and solar would make the world unambiguously poorer and have a negative impact on the lives of billions of people in the world's poorest nations. And this is before considering renewable energy's own negative environmental impacts. Recognizing that widespread deployment of renewables destroys value and destroys nature, it leaves decarbonization as the sole potential benefit from deploying wind and solar. If there is an economic case for net zero, neither the Intergovernmental Panel on Climate Change nor the governments that adopted net zero targets have yet to conduct a proper cost-benefit analysis to prove it.

This leaves ESG-focused investment managers in a tight spot. In its *World Energy Outlook 2022*, the IEA implicitly conceded that ESG investment managers exerting pressure on oil and gas companies to align their investment programs with net zero are contributing to the current macroeconomic malaise of high inflation and weak growth. These investment managers have fiduciary obligations to current and future retirees, savers, and shareholders to maximize their returns. They do not have a mandate to use other people's money in an effort to avert what they believe could possibly be a planetary catastrophe by destroying corporate value and throwing the free-market growth machine into reverse. In particular, their emphasis on hydrocarbon fuel supply reduction conflicts with the IEA's focus on hydrocarbon demand reduction and is antithetical to the interests of investors in oil and gas companies. The clear implication is that climate activism and being a faithful investment fiduciary do not mix.

Finally, there is a geopolitical dimension to NZE that ESG investors and their climate activist allies ignore. According to the IEA, its net zero roadmap sees OPEC's share of the global oil market rise from 37% to 52% in 2050, "a level," the IEA says, "higher than at any point in the history of oil markets." The Energy Policy Research Foundation notes that, if in the likely event that oil demand is much higher than projected in the IEA's net zero roadmap, where non-OPEC producers—pressured by ESG investors—follow the net zero profile of steeply declining oil production while OPEC producers maintain production in line with the IEA's Stated Policies Scenario, OPEC's share would rise to an astounding 82% by 2050. Wittingly or otherwise, ESG investors are undermining the security interests of the West during a period of rising geopolitical tensions.

As we approach the 50th anniversary of Henry Kissinger's December 12, 1973, Pilgrim Speech, which led to the creation of the IEA to counteract OPEC market power, the West is having to relearn a painful lesson on the strategic importance of energy security. In that speech, Kissinger defined the goal of the new energy group as "the assurance of required energy supplies at reasonable cost"—a definition of energy security that is as good as any. Surely no one at the time envisioned the IEA adopting policies that would lead to OPEC's share of the world's oil market growing to somewhere between 52% and 82%, giving it de facto control of both energy supplies and costs.

The IEA could have chosen to remain faithful to its original mandate, but as the Energy Policy Research Foundation report shows, in seeking to become a cheerleader for net zero, the

IEA has allowed itself to be used as a tool for climate extremism, has misled policymakers, and has endangered the world's economy and Western security, all while forsaking the purpose for which it was created.

Executive Summary

The International Energy Agency (IEA) was established in 1974, in the aftermath of the first oil price shock, to act as a buyers' group of Western nations in an attempt to counteract OPEC market power. Latterly, its mission has shifted to become a center of expertise on and advocate for the energy transition. In May 2021, it published *Net Zero by 2050: A Roadmap for the Global Energy Sector* (*Net Zero by 2050*), which the IEA describes as "a normative IEA scenario that shows a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050."[1]

The word "normative" is an important concession to reality, as NZE is a highly implausible scenario. It defies the laws of physics (turning dilute into dense energy) and economics (simultaneously cutting the supply and prices of hydrocarbons), creating a multitude of risks and challenges. The fundamental assumption underlying NZE is that the superiority of alternatives to hydrocarbons as an energy source will cause demand for coal, oil, and natural gas to wither away. It is for this reason that IEA stated that under the NZE, there would be no need for investment in new oil and gas fields, apart from those already approved in 2021. Rather than being a plausible description of the future, demand for hydrocarbons withering away is best thought of as an expression of a political or an ideological aspiration, as opposed to an objective assessment of the future.

Assumptions and Milestones

The IEA has made many questionable assumptions and milestones for NZE about government policies, energy and carbon prices, behavioral changes, economic growth, and technology maturity, among others. Some of the assumptions and milestones of NZE:

- All countries must cooperate toward net zero emissions from 2021. (China alone built two coal plants per week in 2022.)
- The historical average rate of annual energy-intensity improvements must nearly triple throughout the next decade.
- Primary energy supply equal to the size of the current OECD demand must be removed through efficiency and electrification by 2050.
- Global final energy consumption supplied by a single form of energy—electricity—

rises from less than 20% in 2021 to about 50% in 2050.

- The share of all hydrocarbons (oil, gas, coal) in global primary supply decreases from about four-fifths in 2021 to less than one-fifth in 2050. Hydrocarbon supply drops by 30% between 2021 and 2030; this decrease was 5% in 2019–20 (during the pandemic).
- GDP growth is an assumed input, not modeled output. The same growth rates are applied to all IEA scenarios.
- Decreasing oil and gas prices are assumed, despite falling production.
- High CO_2 prices are assumed for all regions, including the poorest regions.
- Decreasing costs of renewables and low-carbon technologies are assumed. The capital cost of technologies such as hydrogen electrolyzers reduces by nearly 80% in less than a decade.
- Massive technological breakthroughs are required. "About half of the emissions reductions in 2050 come from technologies at prototype or demonstration stages today." Of the 503 technologies that are important for net zero, 326 (almost 65%) are currently at the "demonstration" or lower stages.
- Countries must adopt mandated behavioral changes such as reducing motorway speed limits, setting room temperatures within a narrow range, and limiting long-haul flights.

Consequences and Implications

Oil and gas play irreplaceable roles in modern civilization that are not reproducible with low-carbon alternatives. The attempt to substitute them with inferior, less efficient, energy sources will have enormous micro- and macroeconomic consequences and profound geopolitical implications.

- **Higher, more volatile, oil and gas prices.** Under NZE, by 2050, global oil and gas supply decreases 78% and 72%, respectively. Historical price elasticities of demand for oil and gas suggest that such a rapid reduction in supply without concomitant shifts in demand will multiply energy prices. By 2030, in NZE, the crude oil price in the U.S. will likely be more than US$200 (in today's dollars), and gas prices may increase two- to fourfold. The additional economic loss from the supply decline may be between US$12.2 trillion and US$52.6 trillion in the first 10 years of NZE. This range is equivalent to about 1%–4.1% of the world GDP during the same period.
- **Huge increase in capital investment for less output.** Total capital investment in energy must increase from 2.5% of GDP in 2016–20 to 4.5% of GDP by 2030, even after ceasing investment in new oil and gas fields. The annual average investment of US$2.3 trillion (2019 dollars) in 2016–20 must reach US$5 trillion in 2030 and remain at that level through 2050. This annual investment amount is comparable with the GDP of Japan, the world's third-largest economy.

- Despite vastly more capital, labor productivity of the energy sector falls; the IEA projects that **even with an additional 25 million workers in 2030, the energy sector produces 7% less energy.**
- **NZE also requires a larger land-take devoted to energy production, with negative knock-on effects on food security and biodiversity.** A simplistic Energy Policy Research Foundation analysis suggests that total solar PV and onshore wind capacity may require an area almost equivalent to the size of California (159,000 square miles) and Texas (268,000 square miles), respectively, and incremental bioenergy for electricity production an area the size of Mexico (753,000 square miles), given current land requirement metrics before accounting for grid integration considerations.
- Declining labor productivity, combined with investors' need to recover the capital invested in the sector and earn an adequate return on it, would see average electricity supply costs rise by 26%, from US$71 per MWh in 2020 to US$90 per MWh in 2030. As a result, **retail electricity prices will increase by 50%, on average, by 2050, according to the IEA.**
- Far from reducing inflation, as implied by the Inflation Reduction Act, NZE's formula of restricting the supply of hydrocarbons and the switch to an electricity-centered energy system powered by intermittent wind and solar would see **a structural increase in the global price level, risking a further surge in inflation.**
- Whereas higher electricity prices under NZE reflect less efficient use of inputs of capital, labor, and land, **higher oil and gas prices are a consequence of artificially constraining supply and higher economic rents for producers.**
- The IEA concedes that the NZE would see OPEC's share of global oil supply rise from its current 35% to an unprecedented 52% in 2050. A more plausible scenario of non-OPEC + producers following the NZE scenario but OPEC following the more realistic IEA STEPS scenario, **would see OPEC + share rise to 82%, an outcome that would represent an existential threat to the prosperity and security of the West.**
- **The most probable outcome of NZE is an incomplete, two- or multi-speed transition, in which most developing countries do not fully follow through with NZE targets.** To illustrate this point: under NZE, the world would cease the approval of new unabated coal power plants in 2021 (*Net Zero by 2050*, p. 152). This, of course, has yet to materialize. Last year, China alone permitted the construction of two new coal plants every week.[2]

Purpose of Report

The purpose of this report is to assess the likely economic impact of environmental, social, and governance (ESG) with respect to the production and prices of oil and natural gas. This report takes the IEA's major reports—in particular, *Net Zero by 2050: A Roadmap for the Global Energy Sector* (May 2021) and *World Energy Outlook 2022* (*WEO-2022*; October 2022)—on achieving net zero emissions by 2050.

These reports stated:

> ***"No fossil fuel exploration is required in the [Net Zero Scenario] as no new oil and natural gas fields are required beyond those that have already been approved for development."*** (IEA, *Net Zero by 2050*, p. 160)

> ***"In NZE Scenario, declining fossil fuel demand can be met without the need for the development of new oil fields but with continued investment in existing assets."*** (IEA, *World Energy Outlook 2022*, p. 326)

These statements have been interpreted by many financial institutions and banks and the media more generally as prohibiting any investment in new oil and gas fields if the net zero target is to be reached. As the world's economy is heavily dependent on oil and gas supplies and there are no alternatives economically and technologically, rapid and prolonged decline in the production of oil and gas resulting from a lack of investment will have overwhelmingly negative impacts on GDP, national security, and development.

This report examines the feasibility of the IEA's assumptions behind its *Net Zero by 2050* (NZE) scenario and its implications for oil and gas production, energy prices, and the global economy and development. In addition to the aforementioned reports, we reviewed other products by the IEA: "Energy Technology Perspectives," "Global Energy and Climate Model," and "The Role of Critical Minerals in Clean Energy Transitions."

This report consists of four chapters:

Chapter 1 explains how NZE differs from the IEA's baseline Stated Policies (STEPS) scenario and investigates NZE's excessively aspirational assumptions in oil and gas prices, energy intensity, behavioral changes, and investments, among others.

Chapter 2 delves into the multifaceted negative consequences of halting investment in new oil and gas fields on the basis that renewable energy sources do not possess the miracle properties ascribed to them by the IEA as being seamless substitutes for oil and gas. Our analysis estimates the possible oil and gas prices under NZE scenario, using the IEA's global energy production projections and various demand price elasticities.

Chapter 3 evaluates the important role that oil and gas play in various sectors of the economy, with an emphasis on their contribution to the power sector and transportation. The chapter refutes NZE's assertion that hydrocarbons are substitutable at scale and almost fully replaceable by 2050.

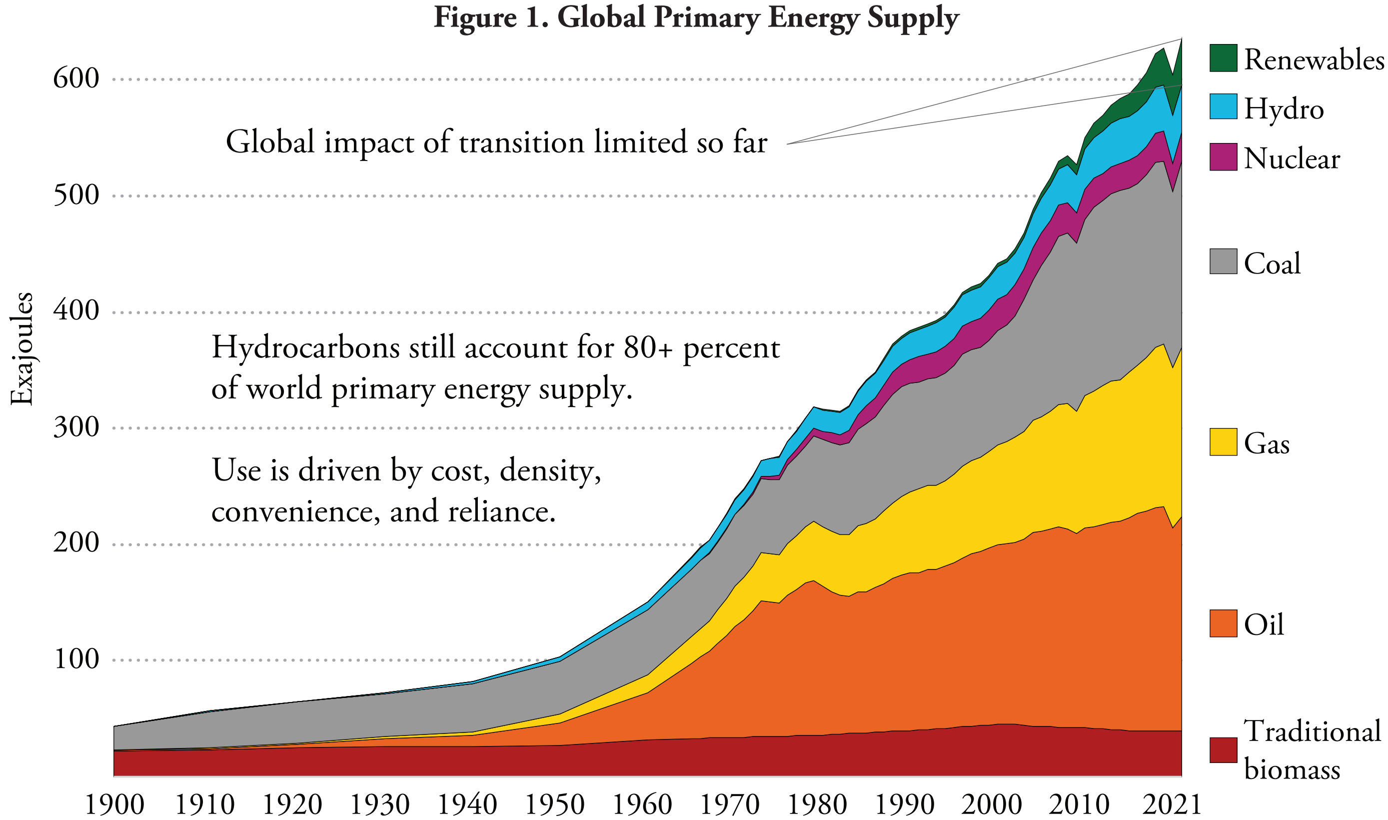
Chapter 4 examines various significant obstacles to achieving a net zero transition, including a lack of technology readiness and the rising costs of renewable energy systems. The chapter concludes by questioning the feasibility of a global net zero transition as advocated by the IEA.

The IEA is an intergovernmental organization consisting of 31 member countries, and it operates within the financial framework of the OECD. The IEA's mission includes implementing measures to address disruptions in oil supplies and undertaking collective measures to ensure the energy security of its members. A central question that this report addresses is whether the call for no investment in new oil and gas fields worldwide will undermine the IEA's central mission to effectively address energy security threats and at the same time impose large and unsustainable economic losses.

Background

The governments of the developed world are undertaking a wide range of programs and regulatory initiatives to reduce human-induced carbon dioxide emissions in order to avert the most damaging impacts of climate change. Much of the recent effort to reduce carbon emissions has focused on developing alternatives to hydrocarbons—oil, natural gas, and coal—to produce electric power. Among the more prosperous economies, the scaling up of renewable and intermittent energy sources, such as wind and solar power, has had substantial progress. However, even with these advances in renewable energy sources, the energy transition remains a formidable task and the world remains largely reliant upon fossil fuels. According to BloombergNEF, over US$6.5 trillion (nominal) has been invested worldwide in the energy transition (excluding investment in power grids) between 2004 and 2022, but the share of non-hydro renewables was just 6.7% of total global primary energy consumption in 2021.[3]

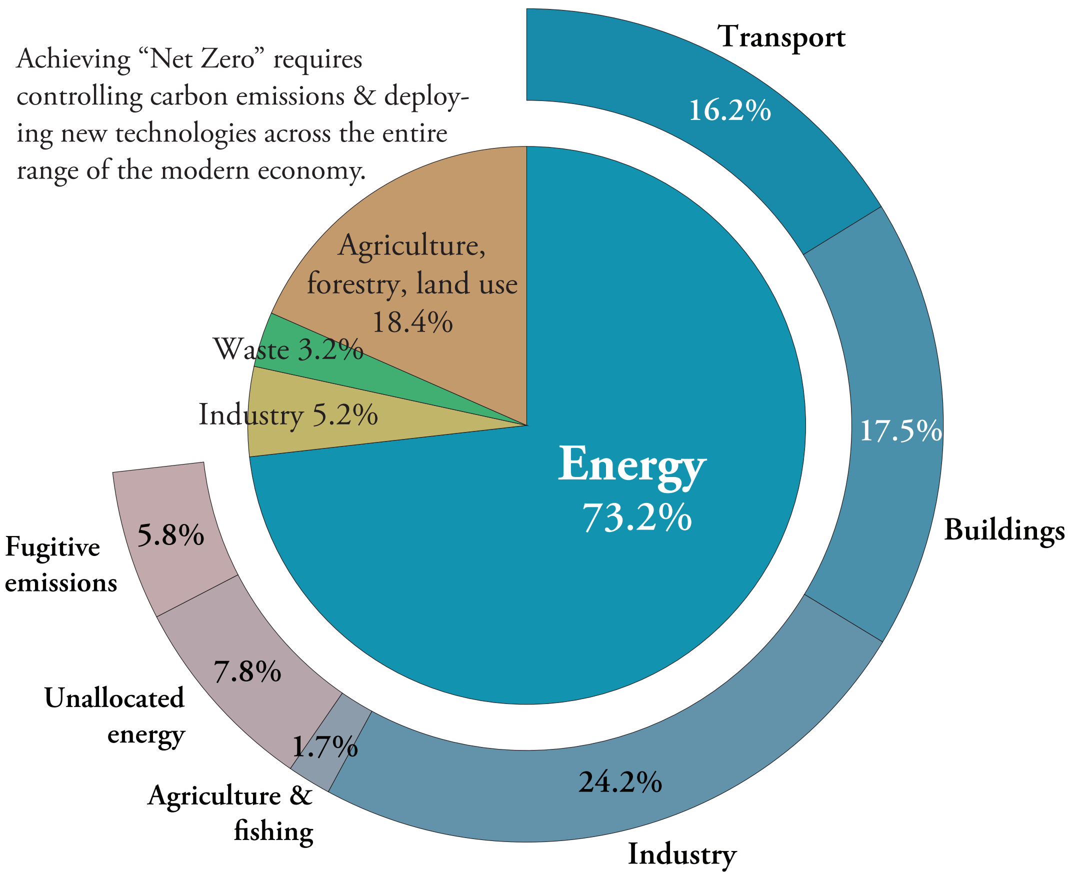
Figure 1. Global Primary Energy Supply



Source: Energy Policy Research, BP, Vaclav Smil

While undertaking a transformation of the power sector is an enormous and difficult task, it pales in comparison to the challenges in deploying substitutes (including large-scale carbon capture) for liquid petroleum fuels. These fuels remain the dominant energy source for transportation as well as the production of plastics, chemicals, fertilizers, and a wide array of essential specialty products. Even with these challenges, concerns about climate change have created public and political pressure to reduce or even eliminate the production of fossil fuels. The U.S. climate envoy John Kerry has publicly stated: "There is 'no need' for any new fossil fuel investments if the world is to meet its climate goals." Pressure on banks and other financial institutions to stop investing in fossil fuels has led some to respond positively, including Blackstone, Inc., which has informed clients that "its private equity arm will no longer invest in the exploration and production of oil and gas."

Figure 2. Carbon Dioxide Emissions by Sector (2019)



Sources: Carbon Watch, WRI via Our World in Data

It is vital for policymakers advocating for aggressive efforts to reduce carbon emissions to quantify the impacts of such a strategy. The most severe recessions in the past century were the direct consequence of the oil crises in 1973 and 1979. Understanding whether an end to petroleum investment would be difficult to devastating, or somewhere in between, is of crucial importance. Moreover, because most non-OECD petroleum provinces will not follow the IEA's advice, continuing demand for hydrocarbons would see a massive transfer of wealth to members of OPEC +, with adverse geopolitical consequences for the West.

Chapter 1

Net Zero Scenario—Assumptions and Milestones

Highlights of Chapter 1

- The Net Zero Scenario by 2050 (NZE) is the International Energy Agency's key normative scenario, with the goal of reaching net zero emissions in the energy sector.
- With the IEA's prestige as a center of expertise, its NZE "no investment in new oil and gas fields" statement validates a position previously adopted by more extreme climate activists, in turn shifting the position of policymakers, financiers, and business CEOs.
- NZE depends on many questionable assumptions about energy and carbon prices, investment, behavioral changes, and energy-intensity improvements, among others.

1.1. What Is the IEA's Net Zero Scenario (NZE)?

> ***"Reaching net-zero emissions globally by 2050 is a critical and formidable goal."*** (Net Zero by 2050 Report: Summary for Policy Makers[4])

The Organization for Economic Co-operation and Development (OECD) member countries established the International Energy Agency (IEA) after the 1973 energy crisis in order to collectively respond to energy-supply disruptions and to address concerns regarding energy security.

In recent years, the IEA has shifted its focus to the energy transition and achieving net zero emissions through its Net Zero Scenario (NZE). This represents a critical departure from the organization's original and long-standing mandate to address the reliability and availability of energy resources.

NZE is a top-down global pathway, so the scenario data provided by the IEA lack regional specificity. Although the IEA has published several reports on country-level net zero or carbon neutrality, they are not fully consistent with NZE. For example, the IEA's report on China, *An Energy Sector Roadmap to Carbon Neutrality in China*, considers only the Announced Policy Scenario—i.e., China's announced target to achieve carbon neutrality by 2060 rather than 2050.

The Global Energy and Climate Model, the model behind NZE, appears to have achieved a high level of sophistication by merging its two main models (World Energy Model and Energy Technology Perspectives Model); but like all models, it relies on the validity of its input assumptions as well as milestones.

Important assumptions of NZE are as follows:[5]

> **"All countries co-operate towards achieving net zero emissions worldwide"** (*Net Zero by 2050*, p. 50). Each country is required to undertake a long list of actions toward net zero, which include establishing "long-term CO2 emissions reduction policy framework[s] by 2025" (p. 130), implementing "comprehensive zero-carbon-ready building codes" by 2030 (p. 144), introducing "[minimum energy performance standards] for all main appliance categories set at the most stringent levels" by 2025 at the latest (p. 149), and transforming the current energy infrastructure to be "based largely on renewable electricity and low-emissions fuels" (p. 180). NZE also asks governments to "signal the end of sales of new internal combustion engine cars" globally by 2035 (*Net Zero by 2050*, p. 139). However, as discussed in Chapter 4, the actual outcome will likely be a two- or multi-speed transition, with many developing countries pursuing different pathways that are largely inconsistent with NZE.
>
> **Unprecedented energy-intensity improvements. In NZE, the global energy demand will be 7% smaller** (nearly equivalent to the entire OECD demand today) by 2050, despite UN's projections that there will be 2 billion more people on the planet and the IEA assuming that the global economy is some 40% larger.[6] The average annual improvement rate of energy intensity (energy requirement per unit of GDP) has averaged 1.2% globally over the past five decades. However, NZE assumes that this rate will increase to 4.2% between now and 2030—about 3.5 times the long-term average (*Net Zero by 2050*, p. 66, table 2.3).
>
> **Extensive reliance on electricity generated from intermittent resources.** In NZE, roughly half of global total final energy consumption comes from electricity in 2050, compared with less than 20% in 2021 (*WEO-2022*, p. 446, table A.2c). This represents a major shift from the current liquid, solid, and gas-based system to an electricity-dominated system, which will have enormous capacity requirements for generating electricity from intermittent resources and converting electricity to different forms of energy. Additionally, there will be an immense need to store massive volumes of energy from these intermittent resources for long hours and sometimes days. This system overhaul presents additional risks to the reliability and resilience of the world electric systems, as well as national security concerns.

End of the hydrocarbon age in under 30 years. The share of oil, natural gas, and coal in global primary energy demand drops from almost four-fifths (79.2%) in 2021 to 61.5% in 2030 to less than one-fifth (18.2%) in 2050 under NZE (*WEO-2022*, p. 445, table A.1c). In 2050, two-thirds of the remaining natural gas and almost nine-tenths of the remaining coal must use Carbon Capture Utilization and Storage (CCUS) technology to capture and store carbon emissions despite the unproven nature of the technology at scale and the certainty of higher costs; the share of the non-energy use of oil (feedstock for petrochemicals, etc.) in total oil consumption will go up from 17% in 2021 to 72.5% in 2050, although the absolute volume of oil consumption for non-energy uses declines by 6.5%. This indicates that oil consumption for energy use must be reduced by almost 14 times in less than three decades.[7]

GDP is an input, not an output: average GDP growth rates are constant across scenarios. The IEA's model applies uniform economic growth rates to all its scenarios. Although the STEPS and NZE scenarios envision vastly different worlds, world GDP remains constant (*WEO-2022*, pp. 107–8). Thus, GDP growth is an assumed input, not modeled output, which therefore risks misleading people as to the impact of net zero on economic growth.[8]

Low oil and gas prices and high carbon taxes. Despite the highly inelastic demand for oil and gas across economic sectors, NZE oil and gas price assumptions are based on the premise that demand for oil and gas decreases at a faster pace than supply reductions (*WEO-2022*, pp.110–13). Our analysis suggests that, given their historical inelastic demand schedules, oil and gas will experience extraordinary price spikes in the short term, which closely tracks the evolution of prices as economic activity bounced back following the pandemic lockdowns and in response to the supply shocks caused by Russian aggression in Ukraine. NZE assumes a high CO_2 price range, between US$180 and US$250 (in 2021 dollars) for all regions (*WEO-2022*, pp. 465–66). However, even the IEA admits that carbon prices must be "introduced carefully, with a view to the likely consequences and distributional impacts" (*WEO-2022*, p. 115).

"Ever cheaper" renewables in electricity generation (*Net Zero by 2050*, p. 14). From 2020 to 2050, the capital costs ($/kW) of coal-fired power plant and gas combined cycle gas turbine (CCGT) stay at 2020 levels in the four regions (U.S., EU, China, and India) for which the IEA provided estimates, with gas CCGT's "fuel, CO_2 controls, and O&M" costs ($/MWh) doubling in the U.S. and EU during the same period. In contrast, the IEA expects capital costs of solar PV and offshore wind to decrease by 42%–47% in these regions between 2020 and 2030 (*Net Zero by 2050*, p. 201).

Decreasing costs of low-carbon technologies. The IEA's Stated Policies Scenario (discussed in the next subchapter) presents aggressive cost estimates for technologies essential for the transition. For example, according to this scenario, the capital costs of battery electric cars (BEVs, $/vehicle) and fuel cells ($/kW) decrease by 26% and 40%, respectively, and that of hydrogen electrolyzers falls almost two thirds (–62%) between 2021 and 2030. NZE goes even further, by reducing the 2030 cost inputs compared with 2021 levels: cost inputs for BEVs fall by 31% (making it capital-cost-competitive against hybrid vehicles), fuel cells by 55%, and hydrogen electrolyzers by 79% (IEA's *Global Energy and Climate Model* documentation, p. 24). Despite the detailed menu of future technologies in the IEA's databases, it is important to note that these cost inputs greatly underestimate the potential impact of key barriers such as high critical mineral prices and limited land availability (further analyzed in Chap. 2, pp. 38-39).

At scale, mandated behavioral changes. NZE requires rapid and significant behavioral changes that go beyond switching to EVs (*Net Zero by 2050*, pp. 67–70,). These include cutting motorway speeds, setting room temperatures within a specific range, and imposing flight premiums to cap long-haul flights, among other behavioral changes and restrictions, which will significantly constrain modern lifestyles and are likely to encounter public resistance. (These are further analyzed on pp. 14–16).

These assumptions lead to the following key **projected outputs** in the model:

"There is no need for investment in new fossil fuel supply in our net zero pathway": No new oil and gas fields beyond those already approved for development (*Net Zero by 2050*, pp. 21, 101–2, 175). NZE projects oil and gas supply to plunge from 329 EJ in 2021 to 256 EJ in 2030 and 81 EJ in 2050 (*WEO-2022*, table A.1c). Contrary to the IEA's low price estimates, a supply decrease of such magnitude could see oil and gas prices break record highs within a short period. Such a scenario will likely lead to deeply negative effects for most countries' economic well-being, development, national security, and energy security.

Massive deployment of alternative energy resources. The global solar PV capacity multiplies 5.7 times from 892 GW in 2021 to 5,052 GW in 2030 and by 17.3 times to 15,468 GW in 2050. Wind capacity growth is still gigantic: from 832 GW in 2021 to 3,072 GW (a 3.7x increase) in 2030 and 7,795 GW (9.4x) in 2050 (*WEO-2022*, p. 448). The solar capacity growth rate of 470% in less than a decade is an extremely tall order, even in the absence of challenges such as land-permitting requirements and critical mineral supply constraints and clashes with the IEA's assumption of falling wind and solar costs. Moreover, generating sufficient energy from these intermittent resources to replace hydrocarbons reliably and economically is assumed, not demonstrated.

Massive scale-up in investment in alternative energy, grid networks, and battery-charging infrastructure. Annual average capital investment in energy increases from 2.5% of global GDP in 2016–20 (about US$2.3 trillion) to 4.5% in 2030 (about US$5 trillion in real dollars). Annual investment in transmission and distribution more than triples, from US$260 million to US$820 million by the end of this decade;

public charging points will require annual investment of about US$90 million by 2030. CO_2 and hydrogen-enabling infrastructure also require an annual investment of US$40 billion in 2030, up from US$1 billion today (*Net Zero by 2050*, pp. 21, 81–82). To put the sheer scale into perspective, the additional annual capital investment of up to US$2.7 trillion is close to France's GDP in 2021 (US$2.9 trillion).

Enormous requirements for critical minerals. "[D]emand for lithium for use in batteries grows 30-fold to 2030 and is more than 100 times higher in 2050 than in 2020" (*Net Zero by 2050*, p. 70). When combined with the required growth of 12 other categories of metals and minerals assessed in the IEA's 2021 critical mineral report, the magnitude of this growth surpasses any previous surge in materials supply, giving rise to substantial economic and environmental risks globally.

The sharp post-pandemic rise in oil prices and the vertiginous rise in natural gas prices in Europe (up nearly 10-fold between January 2021 and August 2022) required the IEA to make some concessions to reality. In its *World Energy Outlook 2022*, which was released after the start of the Russia–Ukraine War, the IEA had to explain away these price surges in view of its NZE assumption of persistently low oil and gas prices: if reductions in hydrocarbon investment occurred at a faster rate than declines in demand, the outcome would be not desirable and, hence, investment in existing fields must continue.[9] In other words, NZE's key assumption hinges on a very rapid rate of decline in fossil fuel demand globally. The IEA goes on to stipulate that reducing investment in oil and gas without sufficient policy action and investment in alternative energy would result in much higher energy prices:

> ***"Reducing fossil fuel investment in advance of, or instead of, policy action and clean energy investment to reduce energy demand would not lead to the same outcomes as in NZE Scenario. If supply were to transition faster than demand, with a drop in fossil fuel investment preceding a surge in clean energy technologies, this would lead to much higher prices—possibly for a prolonged period—even if the world moves towards net zero emissions. The scope for reductions in fossil fuel expenditure is closely linked to the scale and speed of increases in clean energy expenditure, and to the success of efforts to reduce energy demand: it does not make sense to look at any one of these factors in isolation from the others."*** (IEA, *WEO–2022*, p. 134)

This paragraph is a crucial admission by the IEA, as it vitiates any justification by ESG investors and banks seeking to block investment by Western oil and gas companies in new oil and gas fields absent governmental actions to curtail demand. And if such government policies have been adopted and do cut demand, it won't need ESG investors to tell oil and gas companies how to deploy their capital—the capital markets will provide a strong signal in the form of declining stock prices.

1.2. Normative vs. Exploratory Scenarios

In this section, we examine the assumptions underlying NZE, which became its main normative scenario starting in 2021 and is now included in the IEA's flagship *World Energy Outlook* (*WEO*), and compare them to the IEA's other main scenario, Stated Policies (STEPS).[10] Unlike NZE, STEPS defines a set of starting conditions and tries to answer "What can happen?" rather than "What should happen?"[11] STEPS is certainly not a failsafe tool, considering the IEA's poor track record of forecasting; however, it is a reasonable baseline scenario to test the assumptions of NZE. Table 1 summarizes the definitions and objectives of the two scenarios.

Table 1. Definitions and Objectives of NZE and STEPS[12]

	Net Zero Emissions by 2050 Scenario	Stated Policies Scenario
Type	Normative	Exploratory (descriptive)
Definitions	▪ A pathway for the global energy sector to achieve net zero CO_2 emissions ▪ Does not rely on emissions reductions from outside the energy sector ▪ Universal access to electricity and clean cooking by 2030	▪ Reflects current policy settings based on an assessment of the specific policies that are in place and those that have been announced by governments around the world
Objectives	▪ What is needed across the main sectors by various actors and by when to achieve net zero energy-related and industrial process CO_2 emissions ▪ Meet other energy-related sustainable development goals	▪ Provides a benchmark to assess potential achievements and limitations of recent developments in energy and climate policy

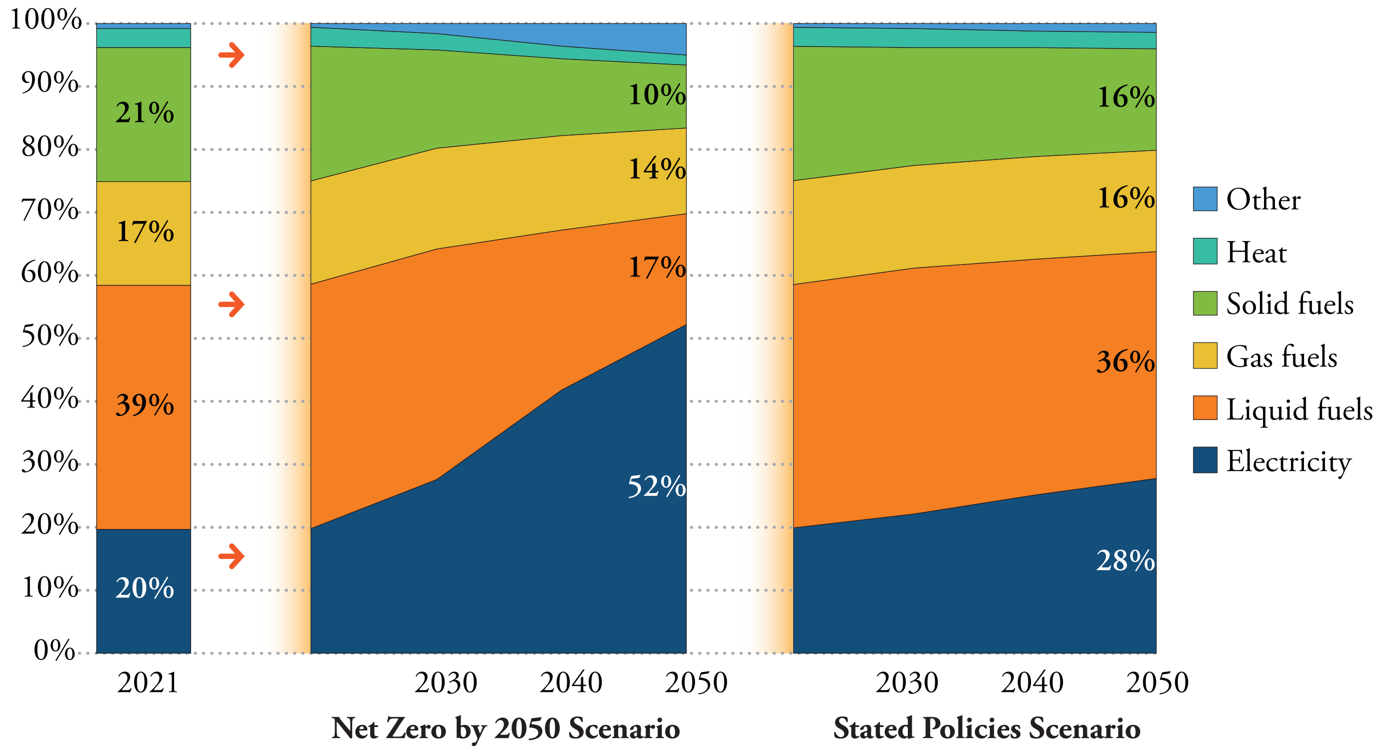
Although STEPS contains some aspirational elements, e.g., by incorporating announced but unimplemented policies, we still consider it a reasonable baseline scenario that better captures real-world trends. As shown in Figure 3, the final energy mix of NZE looks completely different from both today's and the STEPS energy mix, with more than half the energy supplied in the form of electricity.

1.3. Low Oil and Gas Price Expectations

Oil prices are notoriously difficult to forecast, as the IEA should know (see discussion in Chapter 4). As noted above, the NZE scenario's projections for oil and gas prices, coupled with high CO_2 prices, assume that the pace of oil and gas demand reductions exceeds that of supply destruction. In NZE, a quarter of the annual oil demand is wiped out, compared with STEPS by 2030, and the largest drop comes from road transport, which forfeits 35% of the annual global oil demand in favor of electric vehicles (EVs) in 2030. By 2050, oil demand is nearly eradicated in all sectors of the economy, except as a petrochemical feedstock.

The IEA crude oil price, a weighted average import price among the IEA members, moves in opposite directions under STEPS and NZE. In STEPS, the global oil price remains elevated at US$95 (in 2019 dollars) in 2050.[13] In contrast, the NZE scenario's price in 2030 essentially falls back to the 2020 pandemic level and further drops to US$24 by 2050.[14] As discussed in Chapter 2, however, BEVs and other alternative vehicles (FCEVs, etc.) are still far from replacing internal combustion engine (ICE) vehicles at a large scale, let alone displacing a third of the oil supply in road transport by 2030, as suggested by NZE.

Figure 3. Share of Global Final Energy Consumption by Fuel Form

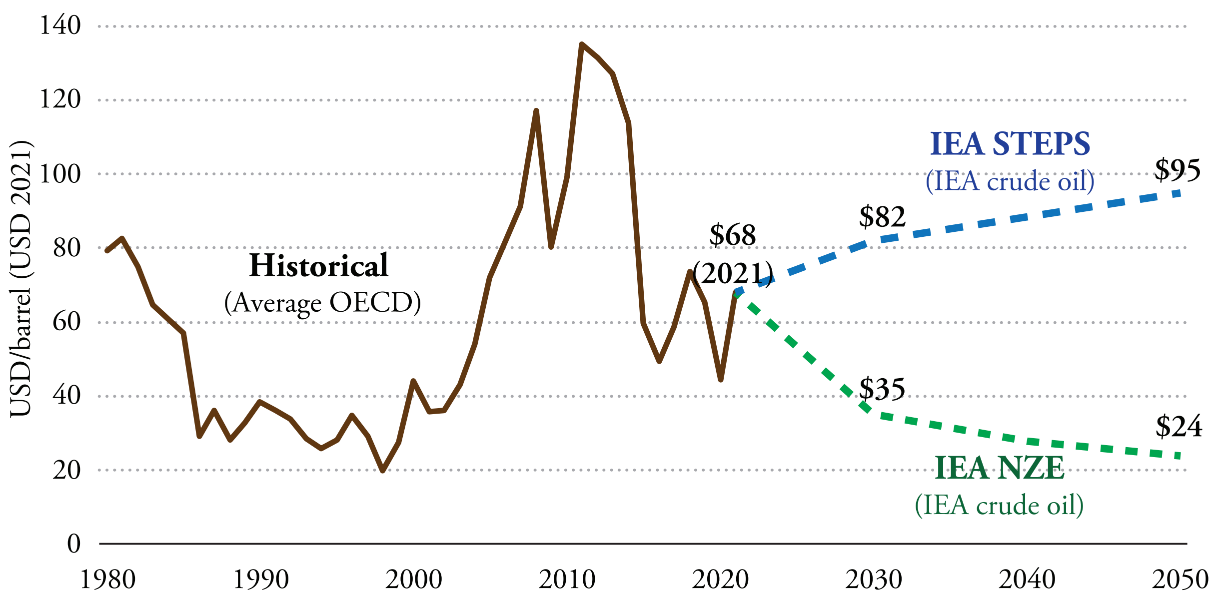


Source: Energy Policy Research, IEA World Energy Outlook 2022

The NZE scenario requires highly restrictive and punitive policies to destroy demand to depress oil and gas prices. According to the GEC model, to prevent a rebound in oil demand from lower oil prices, "an increase of fuel duty on top of CO_2 price is applied whenever is necessary for ensuring that end-user prices are kept at least at the same level as in [STEPS]."[15] Increasing fuel duty and any such additional cost to end users is hard to implement successfully in democratic societies, where such uneconomic, impractical decisions are penalized at the ballot box, something that the Biden administration recognized with its use of the Strategic Petroleum Reserve to bring down gasoline prices.

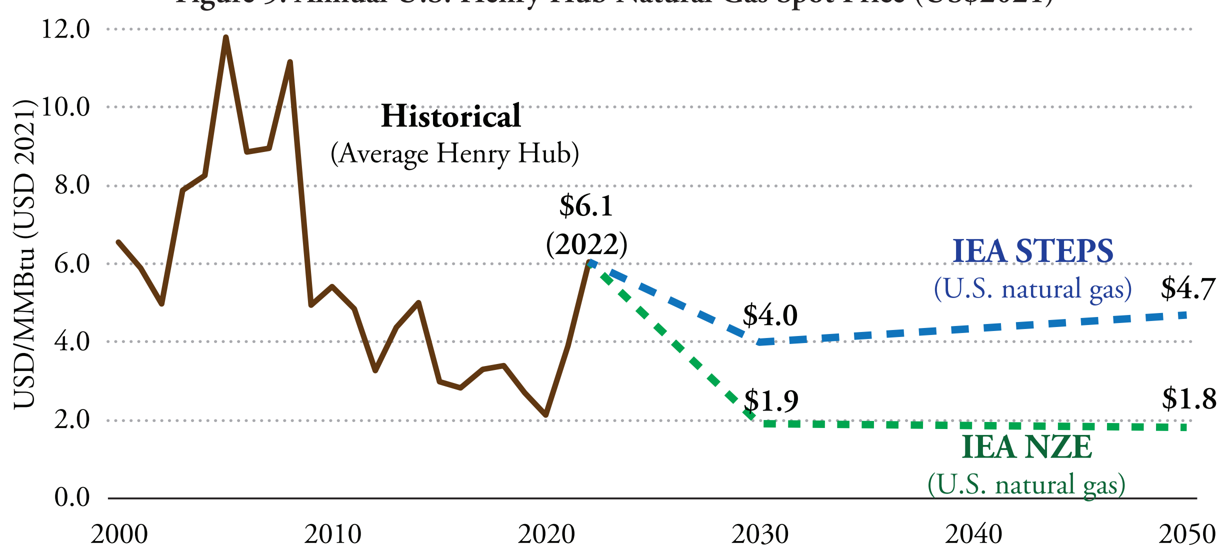
Natural gas prices are expected to remain high in importing regions in STEPS as their reliance on Russian gas decreases. In the NZE scenario, however, natural gas demand is reduced rapidly, leading to a fast decline in gas prices and, by 2030, dropping to about US$5/MMBtu, which, according to the IEA, is "a floor set by the short-run marginal cost of delivering gas from existing export projects." This is a similar situation to oil demand reductions in NZE; the role of natural gas as a key dispatchable fuel in electricity generation and gas-fired turbines' ability to ramp up quickly make it difficult to replace natural gas with intermittent resources. The IEA's executive director Fatih Birol stated in January 2022: "Gas is expected to retain a major role as a source of flexibility and backup for many years to come, especially in economies—such as Europe—that have large seasonal variations in demand."[16]

Figure 4. Annual IEA/OECD Crude Import Price (US$2021)



Source: Energy Policy Research, IEA *WEO-2022*, IEA Statistics, and World Bank
Historical data is calculated by weighted averaging crude oil import prices in OECD. World Bank's GDP deflator is used to calculate real US$ values through 2021. Data points are interpolated.

Figure 5. Annual U.S. Henry Hub Natural Gas Spot Price (US$2021)



Sources: Energy Policy Research, U.S. EIA, IEA *WEO-2022*, World Bank, and U.S. BLS
World Bank's GDP deflator is used to calculate real US$ values through 2021. U.S. CPI is used to convert 2022 data to 2021 dollars. Data points are interpolated.

Because of their numerous advantages over alternative technologies, the probability of oil and gas demand collapsing in this decade is low. As such, any large-scale supply-side destruction will result in large increases in oil and gas prices and reduced national wealth (discussed in more detail in Chapter 2).

1.4. High Carbon Prices Worldwide

Carbon pricing—either through taxes or trading systems—is regarded as a key instrument to achieve the price parity point between hydrocarbons and alternative energy sources. In order to achieve net zero, proponents argue that very high carbon prices need to be imposed on carbon-emitting fuels. An argument for or against carbon pricing is beyond the scope of this report, but we note three problems with the IEA's carbon price assumptions (Tables 2–4):

> **Extremely high carbon prices are assumed for all regions—most notably, in the poorest regions of the world.** The 2022 edition of *WEO* assumes an average price of US$180/tonne of CO_2 (constant 2021 price) by 2050 for non-OECD countries (excluding China, India, and some others), which is 72% of the price assumed for OECD countries. If the long-term average inflation in developing countries stays at 4.8%, which was the historical rate between 2011 and 2020,[17] the nominal price in 2050 would be nearly US$670, assuming a constant exchange rate. However, the nominal rate could be vastly different, depending on actual exchange rates. As most of the energy demand and CO_2 emissions through 2050 are expected from the non-OECD world, utilities, consumers, and businesses in developing countries will have to pay more for their absolute emissions quantities, compared with their counterparts in richer countries.[18]

> **The CO_2 price assumptions for developing countries in the *WEO-2022* increased up to 3.3 times over the *WEO-2021* and the *Net Zero by 2050* report (2021).** The carbon price assumption for "Other emerging market and developing economies" for 2050 was US$55 (constant 2019 price) in *WEO-2021* and *Net Zero by 2050*; but in the *WEO-2022,* the number hiked to US$180 (constant 2021 price). This large change in assumed carbon prices in just one year makes it challenging to take NZE seriously.

> **There are small but important inconsistencies in the dollar values and sectoral coverage across the reports.** *Net Zero by 2050* uses constant 2019 dollars,[19] *WEO-2021* uses constant 2020 dollars, and the *WEO-2022* uses constant 2021 dollars, but the numbers (except for developing countries and one 2030 value for advanced economies) are the same for all three reports. Adjusting for U.S. inflation between 2019 and 2021, the correct numbers in the *WEO-2022* would be 6% higher than in the *Net Zero by 2050* report.[20] Another inconsistency is in the sectoral coverage. While the title of the tables indicates that the coverage is limited to electricity, industry, and energy production, the description says that STEPS prices also cover "end-use sectors, e.g., aviation, road transport and buildings, where applicable." Clarity about sectoral coverage is important, particularly in the context of the EU, where national ETSs exist because the EU ETS doesn't include road transport, heat generation, and other sectors.

Table 2. NZE Report: CO_2 Prices for Electricity, Industry, and Energy Production in NZE

US$ (2019) per tonne of CO_2	2030	2040	2050
Advanced economies	130	205	250
Select emerging market & developing economies (China, Russia, Brazil, & South Africa)	90	160	200
Other emerging-market and developing economies	15	35	55

Table 3. *WEO-2021*: CO_2 Prices for Electricity, Industry and Energy Production in NZE

US$ (2020) per tonne of CO_2	2030	2040	2050
Advanced economies	130	205	250
Major emerging economies (China, Russia, Brazil, & South Africa)	90	160	200
Other emerging-market and developing economies	15	35	55

Table 4. *WEO-2022*: CO_2 Prices for Electricity, Industry and Energy Production in NZE

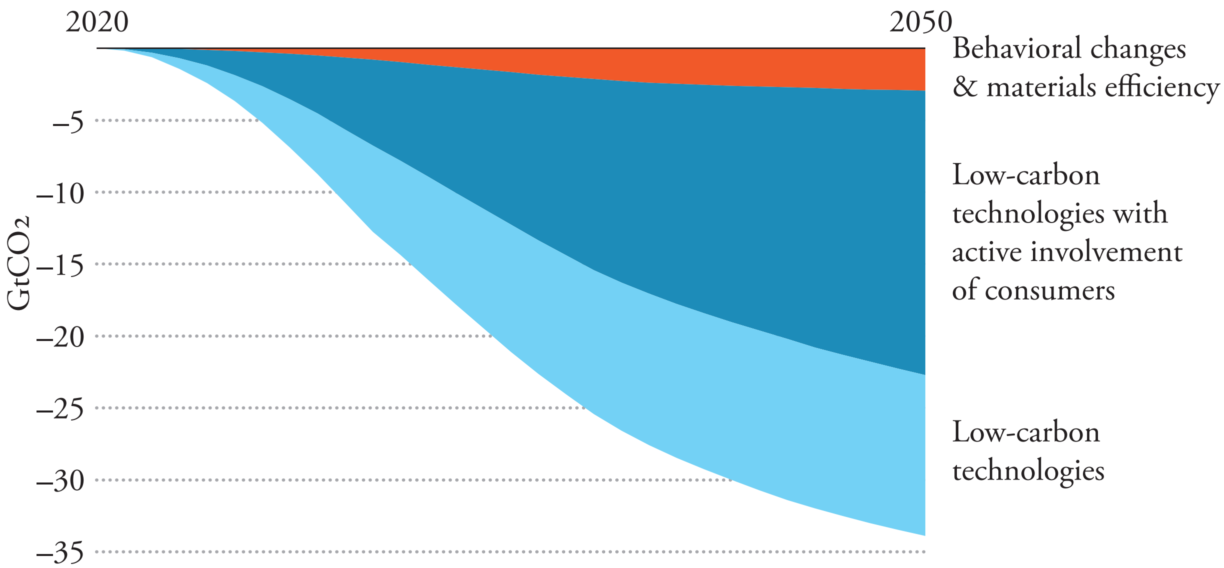
US$ (2021) per tonne of CO_2	2030	2040	2050
Advanced economies with net zero emissions pledges (excl. Mexico)	140	205	250
Emerging market and developing economies with net zero emissions pledges (China, India, Indonesia, Brazil, & South Africa)	90	160	200
Other emerging-market and developing economies	25	85	180

1.5. Rapid, Large-Scale Behavioral Changes

Behavioral change is different from one-off or temporary adjustments in that it is a longer-term change in people's daily activities. The *Net Zero by 2050* report, published during the pandemic in 2021, appears to have overestimated the potential of behavioral changes in the long run. Many changes during the Covid-19 pandemic, such as teleworking, were hailed as permanent shifts in work and life but have now increasingly proved to be temporary adjustments.

The IEA states: "The assumption that people's lifestyles and patterns of consumption will continue unaltered in a scenario of net zero emissions by 2050 is arguably unrealistic, and risks ignoring the potential for individuals, via their choices and habits, to help steer the energy system onto a sustainable path."[21] Although there is some truth to that statement, it is important not to overlook the stickiness of existing behaviors and the potential negative effects of forced behavioral changes on human health, well-being, and prosperity.

Figure 6. Role of Technology and Behavioral Change in Emissions Reductions in NZE



Source: Recreation of IEA graph. IEA, *Net Zero by 2050* (2021)

As shown in Figure 6, 54% of the cumulative emissions reductions in the NZE pathway come from the adoption of "low-carbon technologies with the active involvement of consumers," such as switching to EVs. However, the effect of behavioral changes coupled with material efficiency gains (i.e., reduced demand for materials through recycling and design improvements) is just 8%,[22] and that of behavioral changes alone is less: "Total CO_2 emission in NZE between 2021–50 are around 4% less than they would be without such behavioural changes" as reducing indoor temperatures and limiting motorway speeds.[23]

Our review of the IEA reports suggests that the historical data used for these behavioral changes are not fully transparent. Although the IEA says that it carried out literature reviews on the energy impact of these assumptions, the starting points for many of these assumptions are not clear enough to be thoroughly examined. Additionally, potential impacts and risks such as cost, social acceptability, and health are not sufficiently addressed by the IEA.

Key behavioral changes from *Net Zero by 2050* are listed in Table 5. Although putative emissions reductions from them are relatively modest, such measures are likely to spark a public backlash, and—other than for select jurisdictions, such as deep-blue cities—politicians might well conclude that they are not worth the expenditure of political capital.

Table 5. NZE Behavioral Changes

	IEA: Policy options
Phase out ICE cars from large cities	▪ Low-emissions zones ▪ Access restrictions ▪ Parking restrictions ▪ Registration caps ▪ Parking pricing ▪ Congestion charges ▪ Investment in cycling lanes and public transportation
Rideshare all urban car trips	
Reduce motorway speeds to less than 100 km/h	▪ Speed limits ▪ Real-time fuel-efficiency displays ▪ Awareness campaigns
Raise air-conditioning temperature in cars by 3°C	
Keep international air travel for business purposes and long-haul flights for leisure at 2019 levels	▪ Awareness campaigns ▪ Price premiums ▪ Corporate targets ▪ Frequent-flier levies
Target average set-point temperatures Space heating: 19–20°C (66.2–68°F) Space cooling: 24–25°C (75.2–77°F)	▪ Awareness campaigns ▪ Consumption feedback ▪ Corporate targets

1.6. Energy Supply Comparable to Entire OECD Must Disappear

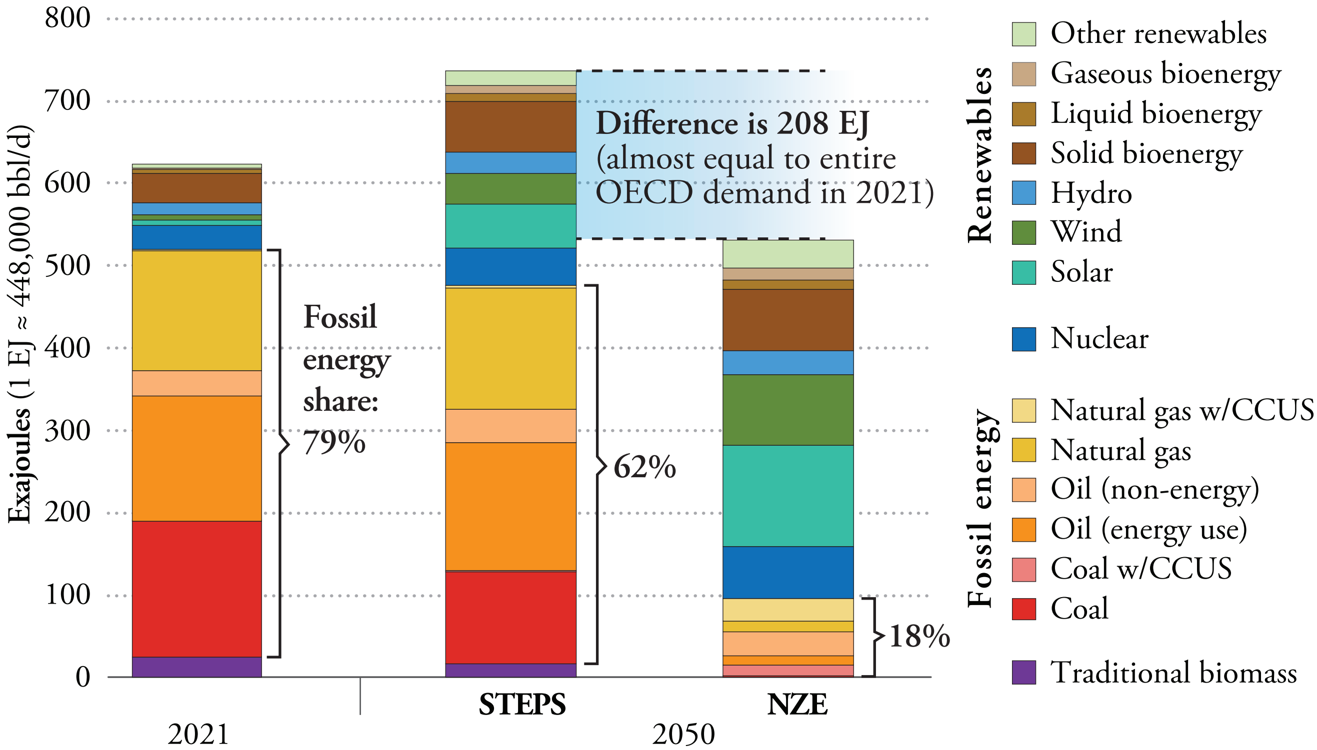
In NZE, the world must undergo a massive transformation in the composition of fuel sources, the volume of energy supply, and the nature of energy sources (electrons vs. molecules) when compared with STEPS. By 2050, the STEPS expects an 18.6% increase in global annual total energy supply over the 2021 level, with fossil energy sources (coal, natural gas, and oil—unabated or abated)[24] providing nearly two-thirds (62%) of the global energy mix. In contrast, NZE sees a 15% reduction in energy supply during the same period, with all types of fossil energy contributing just 18% of the energy mix (Figures 7 and 8).[25] Further, changes in supply through 2040 are much steeper than those between 2040 and 2050, adding to the stringency of these changes. The following points further illustrate the magnitude of the demand reduction under NZE:

- The difference in global energy demand in 2050 between STEPS (740 exajoules [EJ])[26] and NZE (532 EJ) is 208 EJ. This is almost equal to the entire OECD's total energy demand (218 EJ) in 2021. The OECD comprises of the 38 most developed countries, which make up about a third of the global energy demand (IEA's database).[27]

- A demand collapse of similar magnitude occurred in the former Soviet Union (FSU) countries where energy demand plummeted 38% in a span of eight years (1990–98) before somewhat recovering in subsequent years. During this period, almost all FSU countries suffered deep, long economic recessions, and a large portion of their populations became impoverished.[28]

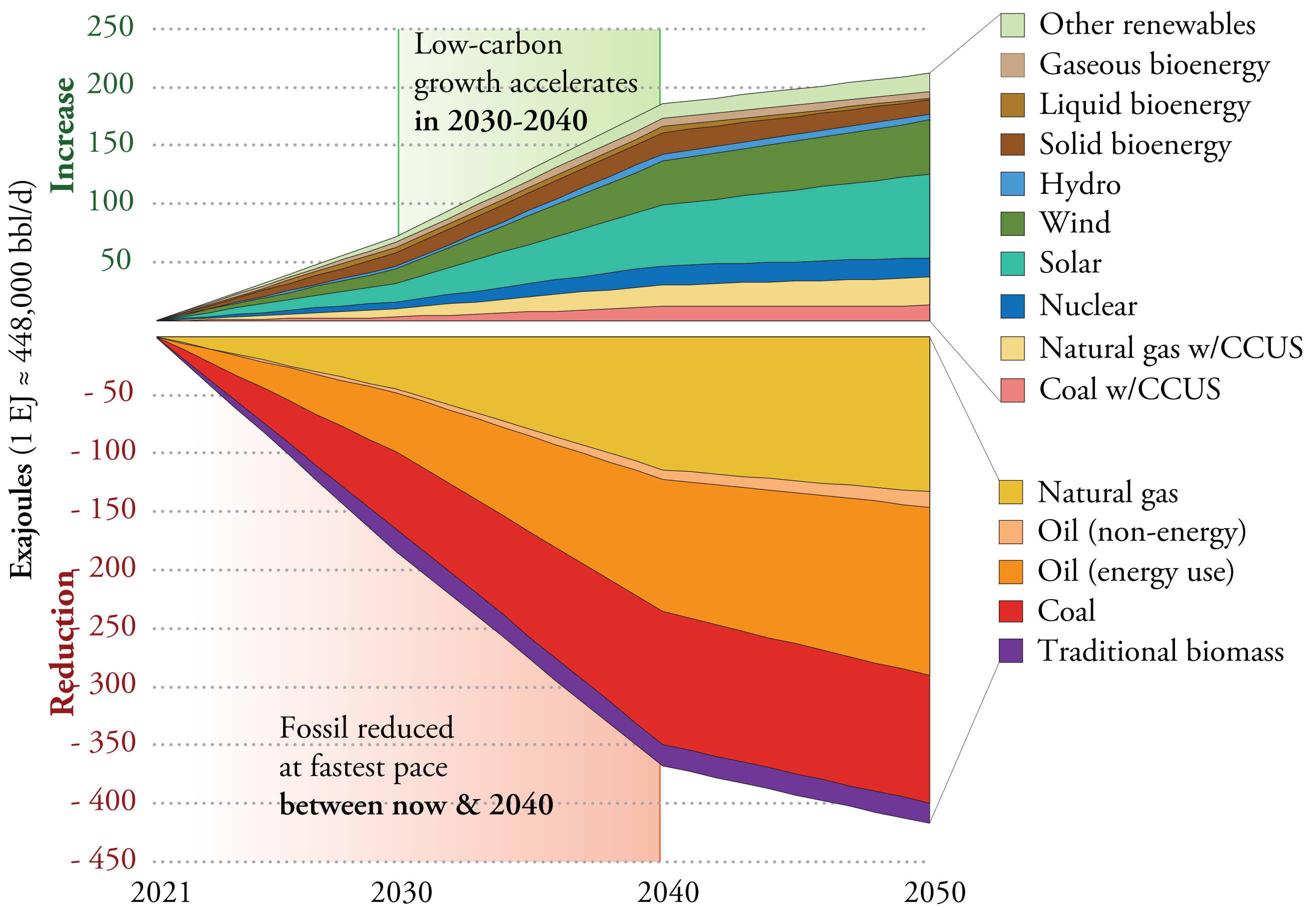
In NZE, the world overly depends on one form of energy—electricity—and forfeits the benefits of other forms of energy that provide flexibility and energy security. By 2050, more than half the modern world's final energy consumption (52%) comes from a single energy form and—for the first time—electrons, not molecules. This contrasts with STEPS, in which liquid fuels provide 36% of final energy consumption while electricity makes up slightly over a quarter (28%) in 2050. This shift from a relatively diverse mix of energy forms to electricity-dominated systems will likely jeopardize the global energy system by exposing it to various grid-related risks and vulnerabilities at a much larger scale, while forsaking reliable and proven energy technologies.

Figure 7. Primary Energy Demand: STEPS vs. NZE in 2050



Source: Energy Policy Research, IEA World Energy Outlook 2022

Figure 8. Assumed Changes in Energy Demand: NZE vs. STEPS



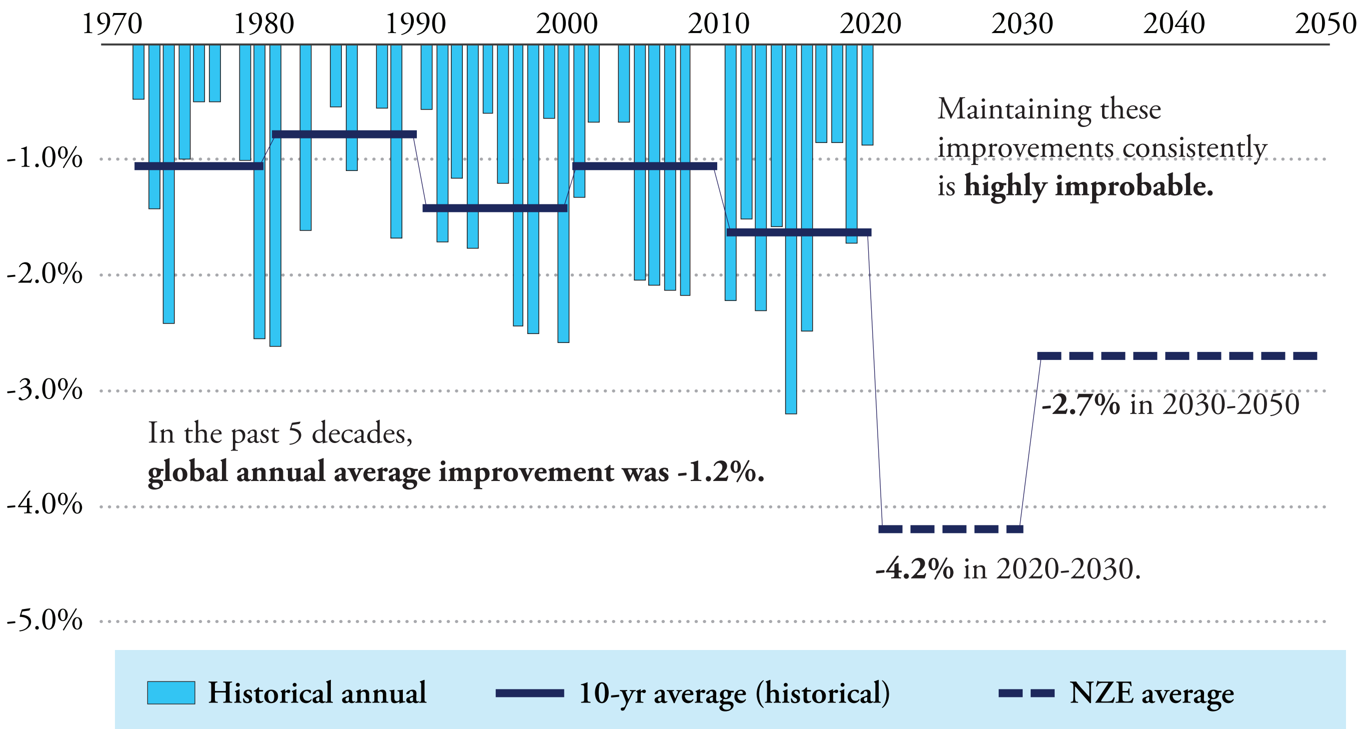
Source: Energy Policy Research, IEA World Energy Outlook 2022

1.7. Unprecedented Energy-Intensity Improvements

NZE assumes a remarkably high level of energy-intensity improvements that have never historically been achieved. To reach the demand-reduction goal, the world must almost triple its average annual energy-intensity improvements throughout the next decade and maintain a very high rate of efficiency improvements between 2030 and 2050 (Figure 9). This assumption alone makes NZE an exceedingly improbable scenario, as it has been proved challenging to sustain a consistently high rate of efficiency improvements for a long time.

Global annual energy-intensity improvement rates (defined as the amount of energy used to produce a unit of GDP) exceeding 2% annually have become more frequent over the years. However, since the 1970s, the decadal averages of such improvements have never surpassed 1.6% a year. The most significant efficiency improvements have been observed in China, which, thanks to its strict five-year plans heavily focused on growing its GDP faster than the energy input, achieved a record energy-intensity improvement of 5.6% in 2015.[29] That year, the world witnessed the highest-ever energy-intensity improvement, of about 3%. However, China has been unable to replicate that achievement, as its energy-intensity improvements have slowed significantly since 2015.[30]

Figure 9. Global Energy-Intensity Improvement: Historical vs. NZE



Source: Energy Policy Research, IEA World Energy Balances database
Note: Primary energy / GDP (2019 USD PPP) is used for the calculation.

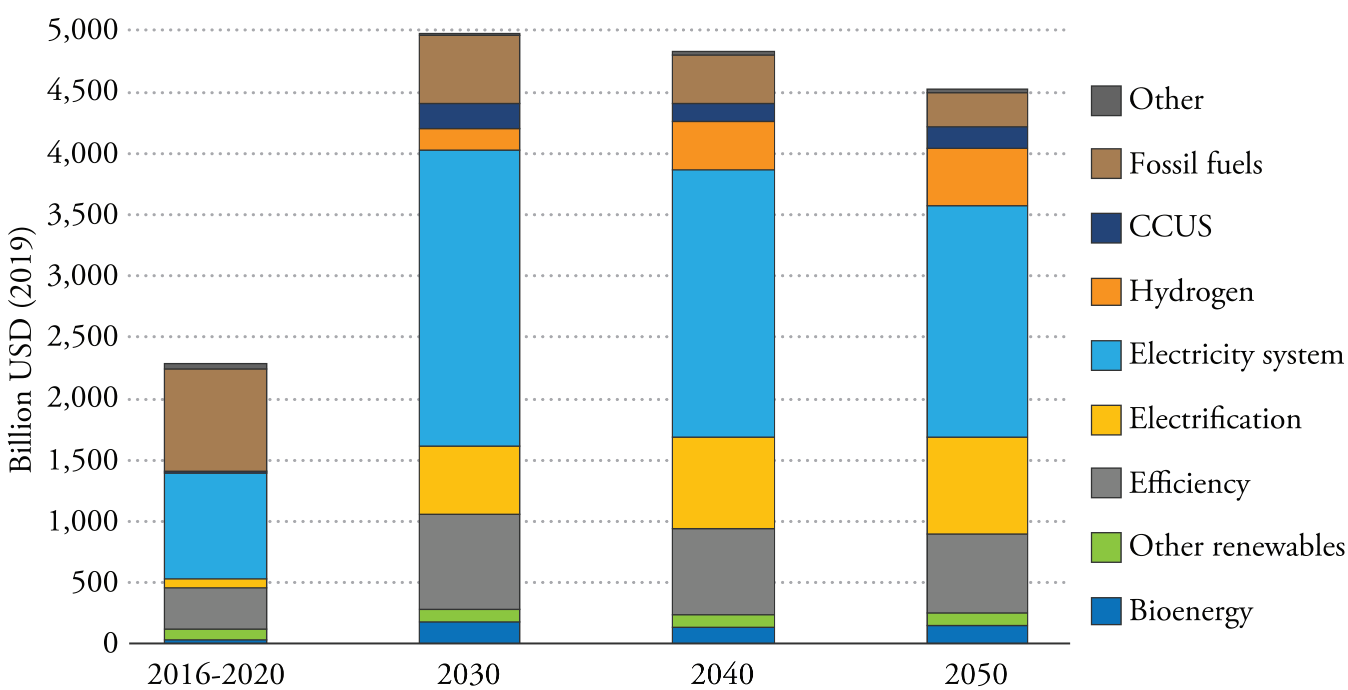
Some of the key milestones to achieve energy-efficiency improvements under NZE are extremely ambitious. For example, the share of zero-carbon-ready buildings[31] in total global stock must increase from less than the current 1% to 25% in 2030 and over 85% by 2050. Just imagine that a quarter of all buildings in the world will either get their electricity and heat only from their home solar (or wind) systems with large enough batteries or be able to get a fully decarbonized energy supply from the grid.

Another NZE milestone is to decrease all new buildings' heating and cooling energy consumption by 50% in 2030 and 80% in 2050 from the 2020 level[32] (it is indeed possible, if we can somehow change human beings' physical and physiological resistance to indoor temperatures twofold in 2030 and fivefold in 2050). These changes are a remarkably tall order, even in the most developed countries. For instance, it will take decades for the EU to convert its buildings, of which 75% are energy-inefficient, into carbon-neutral buildings, as the current rate of yearly deep renovations is just 0.2% and 85–95% of existing EU buildings will still exist by 2050.[33]

1.8. Massive Additional Clean Energy Investments

The *Net Zero by 2050* report estimates that total capital investment in energy must increase from 2.5% of GDP in 2016–20 to 4.5% of GDP by 2030. The annual average investment of US$2.3 trillion (2019 dollars) in 2016–20 must reach US$5 trillion in 2030 and remain high through 2050. To put it into perspective, the total capital investment must exceed the GDP of Japan, the third-largest economy (US$4.9 trillion in 2021, nominal). The difference between the capital investment today and in 2030—US$2.7 trillion—is comparable with France's economy in 2021 (US$2.96 trillion, nominal).[34] In NZE, the annual fossil fuel capital investment drops from US$836 billion to US$559 billion in 2030 and eventually to US$288 billion by 2050. The bulk of the required capital investment must be made in electricity systems (from US$859 billion today to US$2.4 trillion in 2030), electrification (US$77 billion to US$557 billion) and efficiency (US$334 billion to US$777 billion).

Figure 10. Capital Investment in Energy in NZE



Source: IEA, *Net Zero by 2050* (2021)

"Global electricity networks that took over 130 years to build need to more than double in total length by 2040 and increase by another 25% by 2050," the *Net Zero by 2050* report states.[35] To achieve this growth, annual investment in electric grid network infrastructure must more than triple, from US$259 billion (all values in 2019 dollars) in 2020 to US$822 billion in 2030 and almost quadruple to US$1 trillion in 2040 under NZE (Figure 11).

Furthermore, the global electricity supply cost is expected to increase even further due to the higher cost of capital recovery, operations and maintenance, and increased CO_2 prices, among others. This translates to a higher average electricity supply cost per MWh through 2050 (Figure 12), rising from US$70.9 per MWh in 2020 to US$89.5 per MWh in 2030. As a result, NZE expects retail electricity prices to "increase by 50% on average" by 2050.[36] The need for investors to recover their capital costs and scale of these cost increases demonstrates that policies such as the Inflation Reduction Act, which encourages investment in wind and solar, will have the opposite effect by raising inflation and worsening the cost-of-living crisis.

However, these are likely to be substantial underestimates due to the various challenges to the net zero transition, as discussed in subsequent chapters of this report (e.g., increasing renewable system costs, higher material prices, land requirements, technology cost, and readiness levels).

Figure 11. NZE Grid Investment

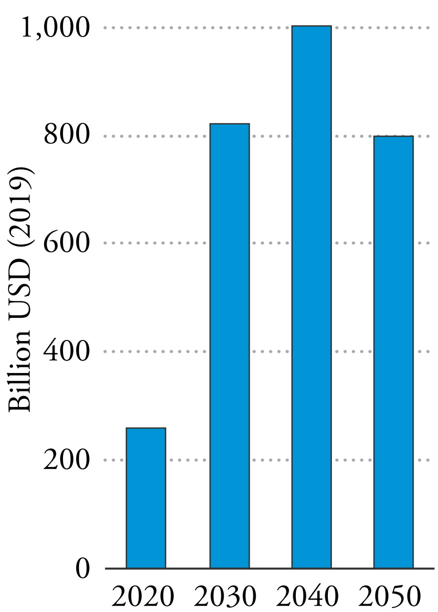
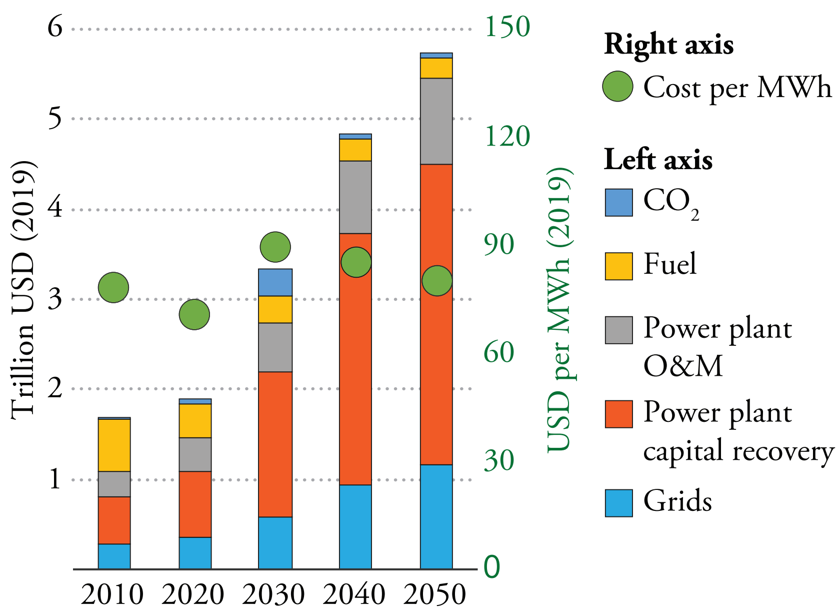


Figure 12: NZE. Global Electricity Supply Costs



Source: IEA, *Net Zero by 2050* (2021)

Table 6. NZE Grid Investment (See Figure 11)

Billion US$ (2019)	2020	2030	2040	2050
Grid investment	259	822	1,003	799

Table 7. NZE: Global Electricity Supply Costs (See Figure 12)

	2010	2020	2030	2040	2050
Trillion US$ (2019)—Left axis					
Grids	0.28	0.37	0.58	0.95	1.17
Power plant capital recovery	0.53	0.73	1.62	2.79	3.33
Power plant operations and maintenance	0.29	0.36	0.53	0.80	0.95
Fuel	0.58	0.37	0.31	0.24	0.23
CO_2 price	0.01	0.07	0.30	0.06	0.05
US$ per MWh (2019)—Right axis					
Average cost (right axis)	78.40	70.90	89.50	85.50	80.30

1.9. GDP Growth Assumptions Constant Across Scenarios

According to the *WEO-2022*, "The assumed rates of economic growth are held constant across the scenarios. This allows for a comparison of the effects of different energy and climate choices against a common macroeconomic backdrop, but it does not capture feedback loops between climate action, climate change and economic growth."[37]

This grossly underestimates the relationship between GDP and the impact of net zero efforts. Some argue that global GDP may increase because of massive spending on alternative technologies and low-carbon infrastructure in NZE. Such high levels of policy-driven capital investment are likely to crowd out more productive uses of capital. Any short-term stimulus will likely dissipate in the medium to long term; and the world, especially OECD countries, will have much less wealth than in STEPS because of its dependence on higher-cost, capital-hungry, inflexible sources of energy.

Table 8. IEA's GDP Growth Assumptions

	North America	C. & S. America	Europe	Africa	Middle East	Eurasia	Asia Pacific	China	India
2010–21	1.9%	0.9%	1.6%	2.7%	2.0%	2.1%	4.9%	6.8%	5.5%
2021–30	2.0%	2.4%	2.0%	4.1%	3.2%	0.1%	4.7%	4.7%	7.2%
2030–50	2.0%	2.4%	1.4%	4.2%	3.2%	1.4%	3.1%	2.8%	4.4%
2021–50	2.0%	2.4%	1.6%	4.1%	3.2%	1.0%	3.6%	3.4%	5.2%

Chapter 2

Implications of No New Oil and Gas Development

Highlights of Chapter 2

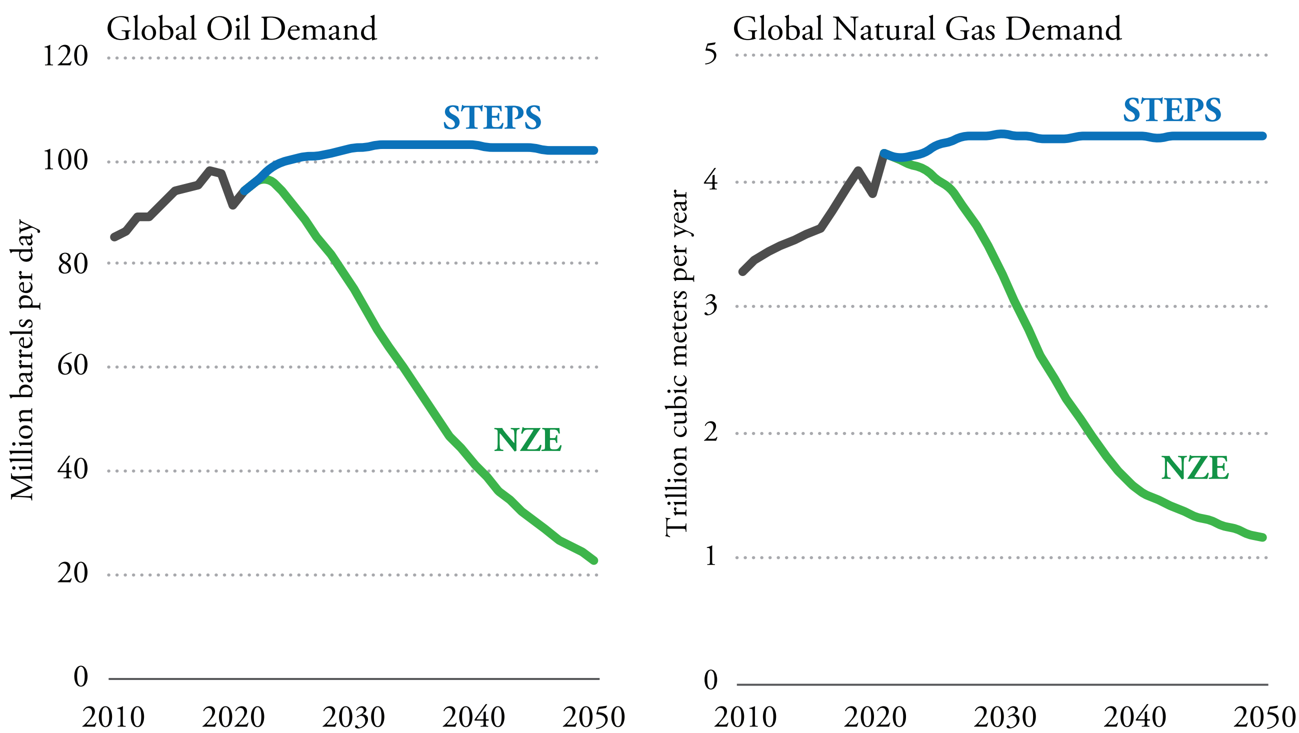
- Under NZE, by 2050, global oil and gas supply is expected to decrease by 78% and 72%, respectively.
- Historical price elasticities of demand for oil and gas suggest that such a rapid reduction in supply without concomitant shifts in demand will multiply energy prices. By 2030, in NZE, the crude oil price will likely be more than US$200, and gas prices may increase two- to fourfold.
- The additional economic loss from the supply decline may be between US$12.2 trillion and US$52.6 trillion in the first 10 years of NZE. This range is equivalent to about 1.0%–4.1% of world GDP during the same period.
- The potential supply shock, coupled with the lack of scalability and substitutability of renewables to replace hydrocarbons, will lead to costs and risks in six main areas: macroeconomy (inflation, GDP), energy security (dependence, reliability, etc.), social issues (wages, communities), development, innovation, and environment & health.

2.1. Oil and Gas Production Without New Oil and Gas Fields

> ***"The trajectory of oil demand in the NZE means that no exploration for new resources is required and, other than fields already approved for development, no new oil fields are necessary. However, continued investment in existing sources of oil production are needed. On average oil demand in the NZE falls by more than 4% per year between 2020 and 2050. If all capital investment in producing oil fields were to cease***

immediately, this would lead to a loss of over 8% of supply each year. If investment were to continue in producing fields but no new fields were developed, then the average annual loss of supply would be around 4.5%. The difference is made up by fields that are already approved for development." (page 101, *Net Zero by 2050*)

Figure 13. Oil and Gas Demand in IEA *WEO-2022*



Source: Data from IEA, *World Energy Outlook* (2022) & Outlooks for gas markets and investment (2023). The data derived and estimated from graphs in the *WEO-2022* and the IEA's gas report for the G7, as the IEA's data tables only show scenario data for 2030 and 2050.

Based on the IEA data, global investment in upstream oil and gas in 2022 was US$417 billion (in 2021 dollars), considerably less than the pre-pandemic annual average of US$533 billion over five years.[38] Under STEPS, this investment will have to increase to an average of US$650 billion by 2030 to meet additional demand.[39] Therefore, cessation of investment in new oil and gas fields beyond those already approved for development in 2021 will dramatically reduce oil and gas supply, both in the short and the long term. The question of how rapidly oil and gas production will decrease under NZE depends on the observed decline rate for oil and gas fields,[40] as well as the size of upstream projects already approved for development. This analysis uses scenario data from the *WEO-2022* (Figure 13); but in Appendix 4, we also consider a more extreme scenario, based on energy economist Michael Lynch's estimates, which exclude approved projects.

In NZE, global oil supply drops from 96.2 million barrels per day in 2022 to 75.3 MMB/D by 2030 and 22.8 MMB/D by 2050, representing a near 80% decrease from pre-pandemic levels. This is a stark contrast to STEPS, which shows continued growth until the mid-2030s, followed by stable demand of more than 100 MMB/D through 2050. NZE also predicts that natural gas supply rapidly declines from over 4 trillion cubic meters (tcm) to 3.3 tcm by 2030 and further drops to 1.2 tcm by 2050.[41] By contrast, STEPS anticipates sustained dependence on natural gas through 2050, with global gas demand peaking at about 4.4 tcm in the late 2020s and staying stable thereafter.

2.2. Price Elasticities of Demand and Oil and Gas Prices

As discussed in Chapter 1, the IEA assumes for the NZE that the pace of the demand destruction will exceed that of the supply shock, leading to continued oil and gas price declines through 2050. According to the IEA, the long-term floor of oil price "is largely determined by the operating costs for fields currently in operation."[42] The assumption of a rapid and prolonged decline in oil and gas demand is highly unlikely, given the growing demand for affordable, reliable, and proven energy sources in the developing world. Further, NZE's assumption that oil and gas prices will decrease through 2050 requires a supersonic decrease in demand that far outpaces the supply shock resulting from the proposed cessation of investment in new oil and gas fields.

This section utilizes simplified price elasticity assumptions to understand the potential of massive price spikes in the short and the long term. Price elasticity of demand measures the responsiveness of the quantity demanded of a good or service to changes in its price. To calculate the price effect resulting from a rapid decrease in supply, we use the formula of price elasticity of demand:

$$\textit{Price Elasticities of Demand} = \frac{\textit{\% Change in Quantity}}{\textit{\% Change in Price}}$$

Estimating the impact on oil and gas prices of a massive decline in production is rather like the challenge facing economists in the early 1970s when oil prices soared far beyond historical experience. At the time, groups like the OECD (1974) relied on assumed price elasticities of demand, specifically –0.3, indicating that for every 10% price increase, demand would drop by 3%.[43] However, a review of more recent literature reveals that this rate is lower; 32 studies collected by Caldara et al. had a median price elasticity of –0.13.[44] The natural gas price elasticity falls between –0.1 and –0.2, according to various studies.[45]

Using the index score of 100 for Year 0 and different short-term price elasticities of demand, Table 9 shows the first 10 years' price levels needed to cope with the *Net Zero by 2050* report's estimated drop in supply compared with the baseline demand projections in the STEPS scenario.[46]

Table 9. Price Response Potentials by Price-Elasticity Level (Real Terms)[47]

First year =US$100	Price Elasticity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Crude Oil	–0.1	122.5	153.6	186.8	219.7	255.9	292.1	329.2	367.2	407.9	445.2
	–0.15	115.0	135.8	157.8	179.8	203.9	228.1	252.8	278.2	305.3	330.1
	–0.2	111.2	126.8	143.4	159.9	178.0	196.1	214.6	233.6	254.0	272.6
	–0.3	107.5	117.9	128.9	139.9	152.0	164.0	176.4	189.1	202.6	215.1
	NZE–STEPS Supply Differential	-2%	-5%	-9%	-12%	-16%	-19%	-23%	-27%	-31%	-35%
Natural Gas	–0.1	112.9	130.9	162.9	189.7	224.5	263.8	303.4	353.3	401.6	451.5
	–0.15	108.6	120.6	141.9	159.8	183.0	209.2	235.6	268.9	301.0	334.3
	–0.2	106.4	115.4	131.5	144.9	162.3	181.9	201.7	226.7	250.8	275.7
	–0.3	104.3	110.3	121.0	129.9	141.5	154.6	167.8	184.4	200.5	217.2
	NZE–STEPS Supply Differential	-1%	-3%	-6%	-9%	-12%	-16%	-20%	-25%	-30%	-35%

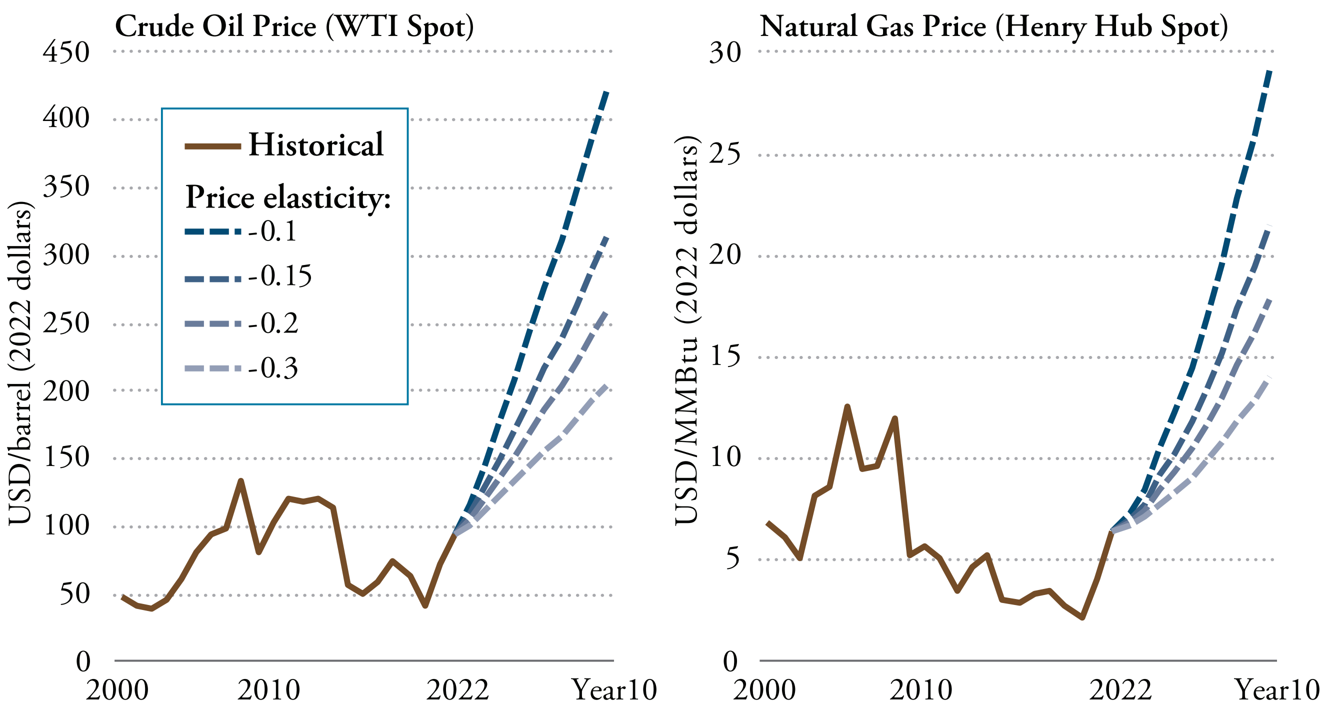
Based on the differentials between the supply estimates under NZE and the STEPS, the oil price elasticities of –0.3 to –0.1 imply an increase of 115% to 345% in the first 10 years, while for natural gas, the range is 117%–352% during the same period. It is unlikely that price increases of this scale for such a prolonged period would not trigger a major recession, and long-term effects would start to come into play in the medium term (more capital equipment replacement and radical behavioral changes that forcefully alter modern lifestyles).

Because NZE allows investment in upstream oil and gas projects already approved for development, these price spikes would be much higher under a complete cessation of all new oil and gas upstream projects (see Appendix 4 for a price analysis of the latter scenario). Over time, demand for oil and gas may become more price-elastic due to substitution effects, but these will severely affect the economic well-being and national security of most of the world.

These price projections depend on the initial year the elasticity is operating from. In the past five years, the price has varied from deeply negative to well over US$100 in nominal terms. The most recent annual crude price was US$94.9 (in 2022). Depending on assumed lag times, equation structure, and so forth, prices would climb sharply each year until longer-term effects had an impact and slowed the price rise. Under NZE, a price of crude oil (WTI) US$ below

180/barrel (2022 dollars) by 2030[48] seems highly unlikely, while a price greater than US$200 seems almost certain. The natural gas price in the U.S. could well double to quadruple under NZE.

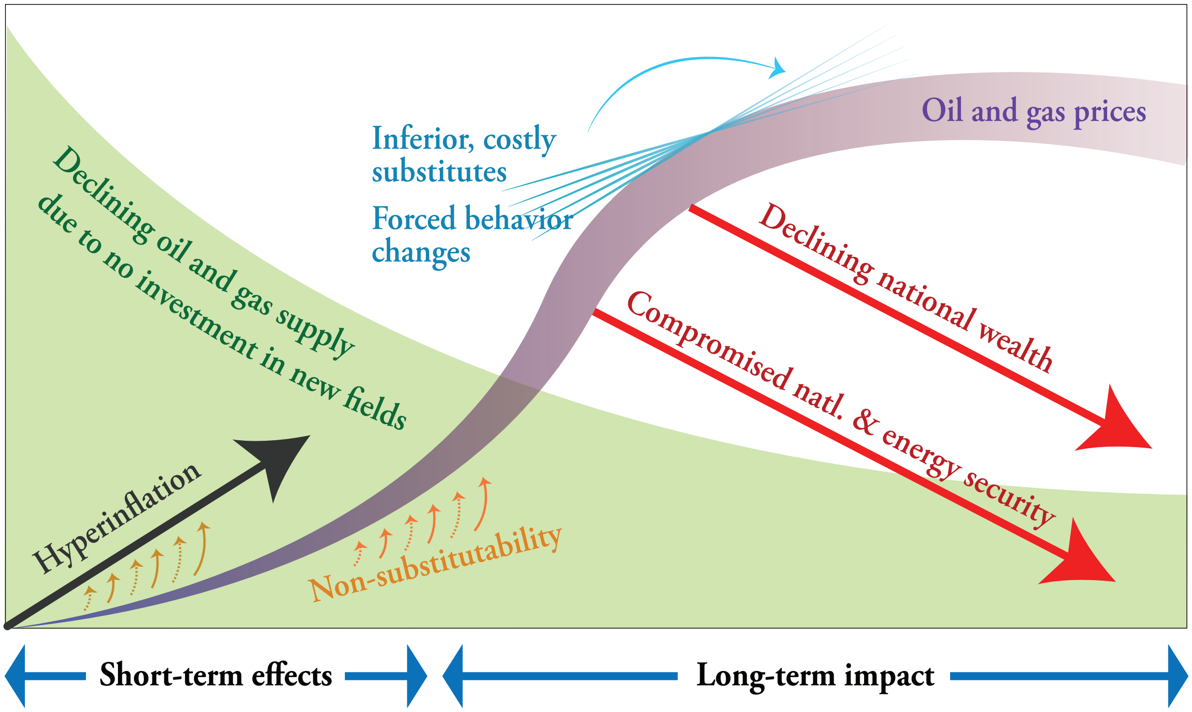
Figure 14. Potential Price Spikes by Price Elasticity Level Under Net Zero Scenario



Source: Energy Policy Research based on IEA NZE

While it is difficult to estimate the long-term increase of oil and gas prices and their impact on the economy under NZE, such price rises will have unambiguously adverse impacts on economic performance. For the first 10 years under NZE, we estimate that the global oil and gas fuel receipts will be between US$12.2 trillion and US$52.6 trillion more than under STEPS (US$45.4 trillion), equivalent to 1% to 4.1% of assumed GDP.[49] In other words, consumers will have to pay much more for much less oil and gas, not to mention a wide range of costs and risks associated with the transition to net zero. The volatility of oil and gas prices suggests that massive supply shocks would likely be felt sooner and be far costlier than the aforementioned estimates. Moreover, various other restrictions on fossil fuels, such as higher carbon prices, would further increase these prices.

Figure 15. Short- and Long-Term Implications of High Oil and Gas Prices



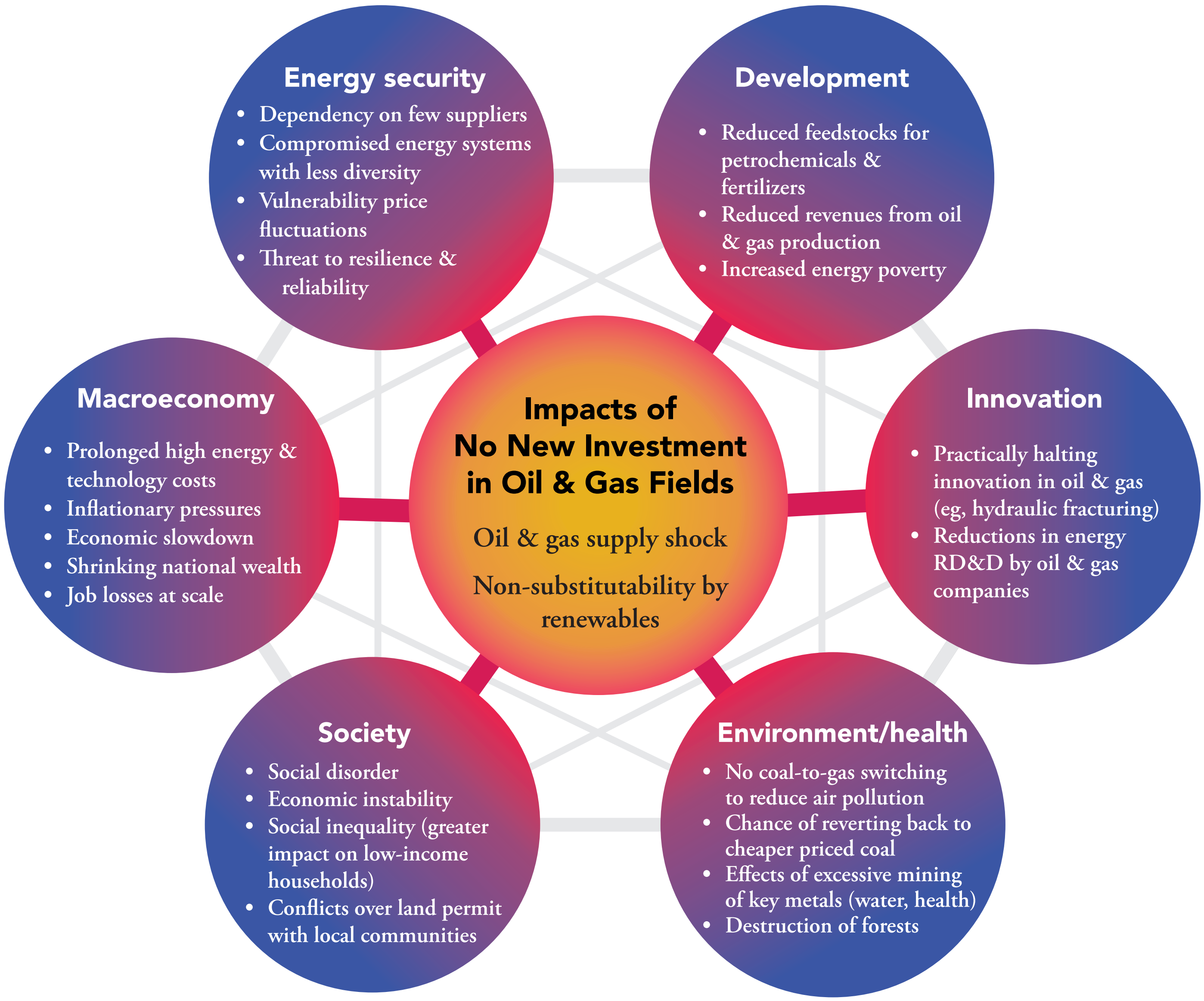
Source: Energy Policy Research

Without adjustments to these failure modes—i.e., if the world stays committed to net zero regardless of high costs—the recession will turn into an extended depression and ultimately impose radical negative changes upon modern civilization.

2.3. NZE Implications in Different Areas

The cessation of new oil and gas investment will likely manifest in two main forms. First, the reduction of oil and gas production at the pace suggested by NZE will quickly outpace any demand-side decrease globally, ushering the world into a widespread energy-supply shock. Second, the non-substitutability of hydrocarbons by renewables at scale indicates that there will not be sufficient means to aid the large majority of the world to fill the energy-supply gap. Assuming no immediate government and industry response to the short-term failure modes of the energy transition, NZE's negative consequences will quickly escalate and will lead to a multitude of implications across many areas of national and global importance. These can be divided into six major areas: macroeconomy, energy security, society, development, innovation, and environment and health.

Figure 16. Impacts of NZE in Six Main Areas



Source: Energy Policy Research

2.3.1. Macroeconomy

NZE's side effects will be felt at the macroeconomic level, from increasing energy prices and inflation to reducing national wealth and GDP.

Prolonged high energy prices. An energy-supply shock stemming from no investment in new oil and gas fields means prolonged high and rising energy prices, resulting in massive costs to the global economy. Several studies have estimated the impact of lesser supply disruptions and/or price shocks, with general agreement on the mechanisms through which oil price increases affect the world economy.

IMF (2000) describes the general mechanisms as:[50]

- a transfer of income from oil consumers to oil producers;
- a rise in the cost of production in goods and services;
- negative impacts on the price level and inflation;
- direct and indirect impacts on financial markets;
- changes in supply and demand eventually re-equilibrate the economy at a lower level than without the shock.

There are some rules of thumb as to the impact on GDP of higher oil prices. MacKillop (2012) mentions a US$10 oil price increase, reducing GDP by 0.5% (US$4/bbl in 2021 dollars).[51] The Congressional Budget Office (2006) suggested that for the U.S., where oil consumption was 2% of GDP, a 10% increase in oil prices translated into a 0.2% loss of GDP.[52] The recent experience in Europe with the ongoing Russian war in Ukraine and uncertain supplies of Russian oil and gas shows that economic vulnerability to supply shortages and higher prices might be lower than in the past, but remain substantial. An IMF review of estimates of the GDP impact of natural gas cutoffs (Table 10) suggests that a loss of 10% of supply could lead to up to a 1% lower GDP. Natural gas is less fungible than oil and coal because of its reliance on infrastructure; but clearly, economic vulnerability to higher prices remains.

Table 10. Impact of Russian Gas Cutoff on German Economy[53]

Study	Gas Loss	GDP Loss
ECB (2022)	10%	0.70%
OECD (2022)	20%	0.90%
Bachmann et al. (2022)	30%	Full model 0.2%–0.3% Simplified model 1: 1.3% Simplified model 2: 2.2%
Schnittker et al. (2022)	9%	1.50%
	36%	3.40%
German Council of Economic Experts (2022)	30%	2%
Bundesbank (April 2022)	40%	5%
Bundesbank (June 2022)	31% ('22/'23)	1.5% ('22), 6.75% ('23)
	11% ('23/'24)	4.5% ('24)
Di Bella et al. (2022)	12%	with frictions 3% without frictions 0.4%

Source: Lan, T., Sher, G., Zhou, J. 2022. The Economic Impacts on Germany of a Potential Russian Gas Shutoff (link)

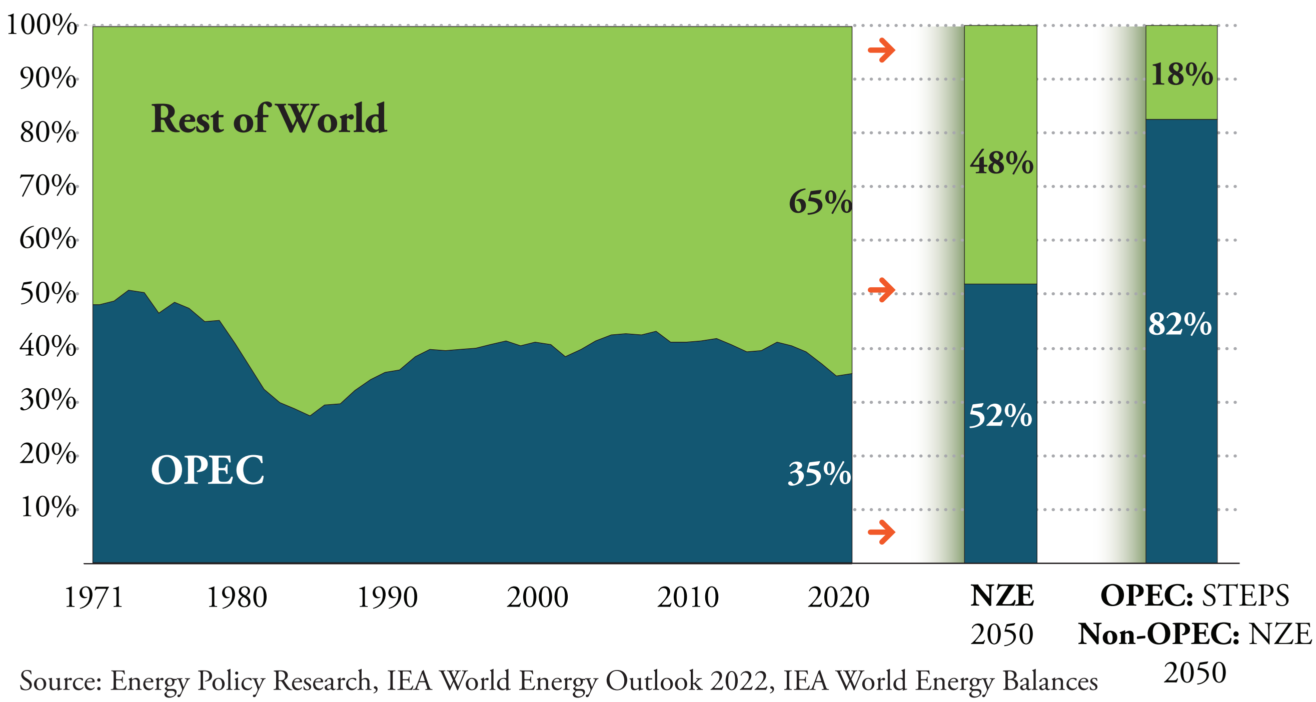
Inflation. Higher energy costs will exert inflationary pressures on the other parts of the economy. During previous energy crises—as we've witnessed since the Russian invasion of Ukraine—high oil and gas prices cause higher prices and costs in food, transportation, construction, and agriculture, among other economic sectors, with businesses passing high energy costs on to consumers. Producers that use hydrocarbons as a feedstock for petrochemicals and fertilizers also suffer from high oil and gas prices.

Lower GDP. Increased activity in green energy sectors may bring about short-term GDP growth, but because they are less efficient energy sources than hydrocarbons, their increased share of energy output will tend to depress productivity growth. However, GDP growth will be hit due to high energy costs (including a greater share of GDP for energy investment to generate lower energy output)[54] and the resulting inflationary pressures, which, in turn, will cause interest rates to be higher than they otherwise would be. As a result, developed economies will have lost significant shares of their national wealth by 2050.

2.3.2. Energy Security

According to the IEA, energy security is defined as "the uninterrupted availability of energy sources at an affordable price." However, pursuing NZE poses risks to key components of energy security: supply diversity, stable prices, and reliable and resilient energy systems.

Figure 17. OPEC Share of Global Oil Production

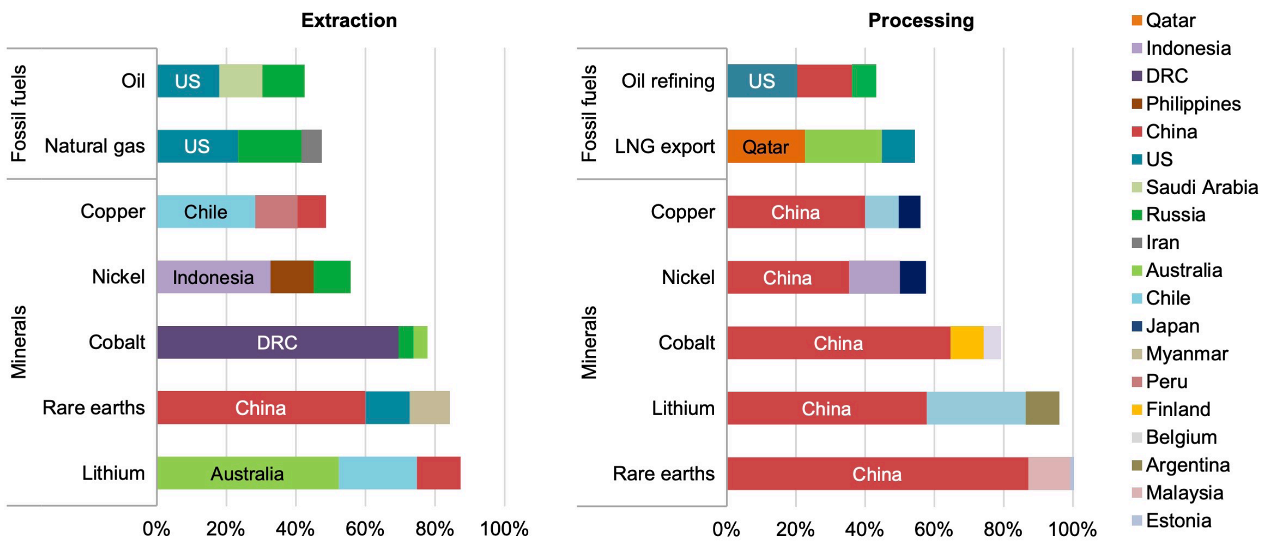


Source: Energy Policy Research, IEA World Energy Outlook 2022, IEA World Energy Balances

Dependency on fewer suppliers (oil and gas). Diversification is key to safeguarding energy security. However, under NZE, global oil and gas production will be concentrated in fewer countries, mostly OPEC members. In NZE, the share of OPEC's production in global oil supply increases from 35% in 2021 to at least 52% in 2050 if everyone, including OPEC, follows the IEA's net zero suggestions. However, if the "no investment in new oil and gas fields" net zero efforts are followed through in the non-OPEC world, including the U.S. and most of Europe, but not in OPEC and producers aligned with OPEC such as the Russian Federation, the percentage may reach 82% (Figure 17).

Dependency on China for critical mineral production and processing. The majority of the global critical mineral supply chains for alternative energy technologies are dominated by China's financing, production capacity, and processing capacity. Replacing oil and gas with metal-intensive renewables and batteries risks further reinforcing China's dominance in these critical minerals, at the expense of the energy security of most of the world.

Figure 18. Share of Top Three Producing Countries in Production of Selected Minerals and Fossil Fuels, 2019



Notes: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations.
Sources: IEA (2020a); USGS (2021), World Bureau of Metal Statistics (2020); Adamas Intelligence (2020).

Source: IEA, *The Role of Critical Minerals in Clean Energy Transitions (2021)*

Increased vulnerability to price fluctuations. The supply-side concentration of oil and gas production increases gives further market power to producers, thereby making supply more inelastic (i.e., output less responsive to high prices). Additionally, geographic concentration of production in the Middle East makes developed economies more vulnerable to price fluctuations caused by potential and perceived disruptions to production, including regional political events, terrorism, and military conflict.

Grid resilience, grid reliability, and cybersecurity issues. The intermittent nature of solar and wind power, coupled with limited dispatchable resources, increases the risk of systemwide blackouts and brownouts and will likely result in a significant reduction in grid reliability and resilience. Mitigating the threat of more frequent outages will lead consumers to invest in their own backup generation and batteries and will require system operators to invest in resources to maintain system frequency. As solar and wind power generation is more susceptible to weather-related events, the overall resilience of the grid will likely decline with further replacements of natural gas by renewables. Furthermore, as more distributed generation is connected to the system, the grid may become more vulnerable to cyberattacks.

2.3.3. Social Issues and Instability

High energy prices and structural changes in the economy will have a profound impact on workers in the traditional energy sectors (those that are energy-intensive, such as manufacturing and agriculture) and will disproportionately affect low-income households.

Widespread job losses and income reductions. Under NZE, energy jobs grow from 65 million today to almost 90 million in 2030, with the share of clean-energy jobs in total energy jobs increasing from over 50% to almost 80% during the same period.[55] Over the same period, total energy supply falls from 591 EJ to 550 EJ.[56] Thus, 25 million more people employed in the energy sector produce 7% less energy in the space of 10 years. This represents a calamitous 33% decline in productivity per employee, from 9.1 terajoules (TJ) per employee in 2020 to 6.1 TJ in 2030. Ultimately, GDP growth and living standards are propelled by productivity growth, and the IEA's own numbers give the lie to the oft-made claim that net zero boosts growth. Here is the clearest possible demonstration that the reverse is the case: net zero is toxic for economic growth and will make most people poorer.

The IEA's job analysis does not include other indirect jobs, as well as induced and supported jobs. Induced jobs are those "created by wages earned from the projects and spent in other parts of the economy, thereby creating additional jobs," and supported jobs are those enabled "by the purchase where the equipment is a key enabler for another job."[57] By excluding a variety of additional jobs related to fossil energy, NZE ignores job losses in sectors benefiting from cheap fossil fuels. The impact of potential job losses was illustrated in the European Commission's 2021 report, which found that the number of jobs indirectly related to the production of coal, peat, and oil shale was equal to 70% of direct jobs in these industries.[58]

Wages are a key factor for people when choosing a workplace but are excluded from the IEA's GEC model. Despite high subsidies and the rapid growth in solar and wind jobs, reflecting their fundamentally poor economics discussed above, hourly wages in wind and solar energy subsectors are significantly lower than those of nonrenewable-energy workers. In electric power generation in the U.S., the median hourly wage in natural gas generation was US$34.02 (nominal), 39% higher than the median wage of US$24.48 in solar generation.[59] The only low-carbon subsectors with higher wages are in the nuclear industry, reflecting nuclear's high productivity.

Table 11. Energy Power Generation Wages by Sub-Technology, 2019

Energy Subsectors	Median Hourly Wages	Geographically Weighted Premium/Discount from Median Hourly Wages
Nuclear Generation	US$41.32	114.6%
Coal Generation	US$33.64	79.6%
Natural Gas Generation	US$34.02	76.5%
Wind Generation	US$25.95	34.9%
Oil Generation	US$24.49	25.7%
Solar Generation	US$24.48	20.9%
Other Renewable Generation	US$17.98	–8.6%

Source: NASEO, *Energy Futures Initiative's Wages, Benefits, and Change* report

Table 12. Energy Power Generation Occupations, 2019 Median Hourly Wages

	National Median Hourly Wages	Wage Premium Compared with National Median
Nuclear Engineers	US$54.55	185%
Power Plant Operators	US$49.18	157%
Nuclear Power Reactor Operators	US$48.33	153%
Gas Plant Operators	US$42.42	122%
Solar PV Installers (Electrician)	US$25.69	34%
Wind Turbine Service Technicians	US$25.44	33%
Solar PV Installers (Non-Electrician)	US$21.58	13%

Source: NASEO, *Energy Futures Initiative's Wages, Benefits, and Change* report

Increased burden on low-income households. Higher energy prices over decades will have the biggest impact on low-income households and households in poorer countries due to the significant proportion of their income spent on energy. According to the IEA, households in developed countries spend about 3% of their disposable income on energy, whereas those in developing countries spend about 10%.

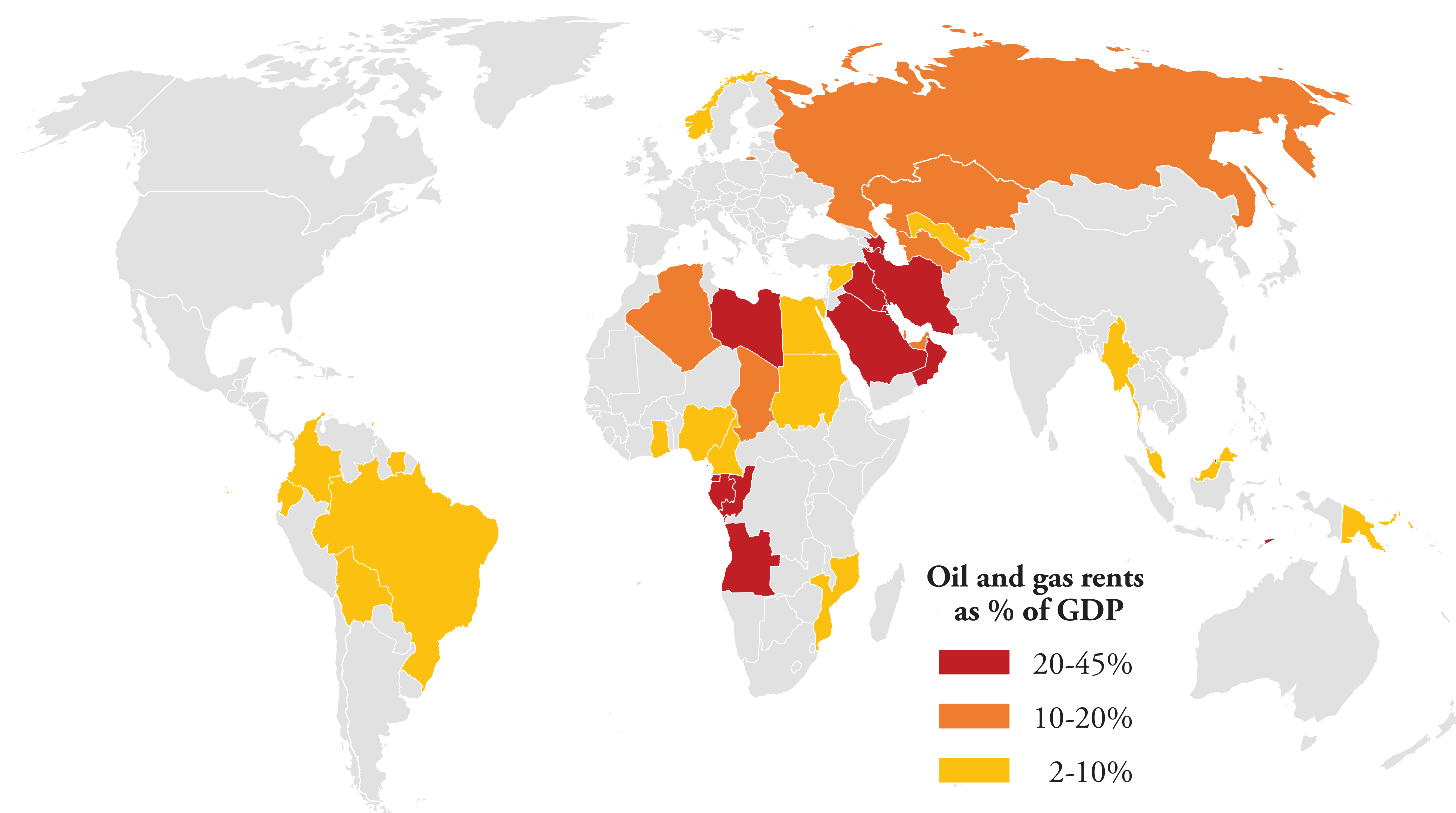
Economic instability and social inequality. Societal and structural changes caused by the energy transition resulting in job losses, disproportionate impacts on low-income households, and macroeconomic and inflationary effects rippling throughout the economy may significantly increase the chances of economic and social instability, distress, and even violence.

2.3.4. Development

The oil and gas sector generates large amounts of revenues for producing countries, helping them achieve development objectives through royalties and other taxes and fees. The role of the oil and gas rents (difference between prices and production costs) is particularly crucial in non-OECD countries: out of the 40 countries where oil rents were at least 2% of GDP in 2019, all except one (Norway) were non-OECD countries. Most of these countries are concentrated in Africa, the Middle East, and the former Soviet Union. As of 2019, there were 13 countries that derived at least 20% of their GDP from oil and gas rents. Although these countries' state budgets are vulnerable to global oil and gas price fluctuations, a prolonged decline in oil and gas exports could greatly hinder the development progress of many of these countries.

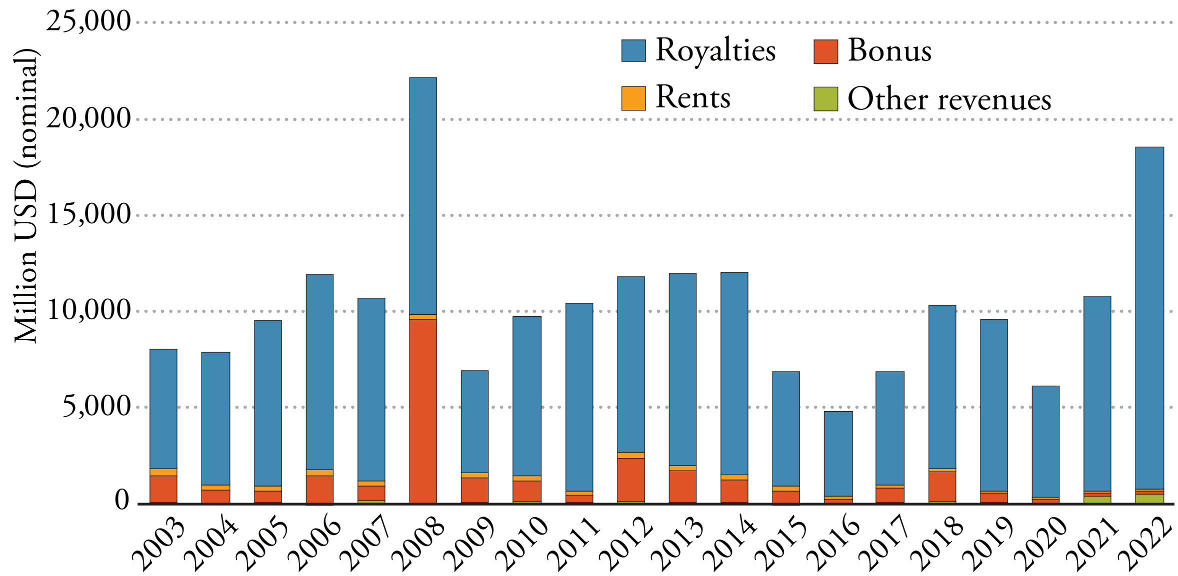
The benefits of the oil and gas sector also apply to developed countries like the United States. As shown in Figure 19, the federal oil and gas revenues amounted to almost US$20 billion in 2022, much of which is transferred to state and local governments to fund infrastructure, build hospitals, and support communities.

Figure 19. Countries Dependent on Oil and Gas Rents (2019)



Source: Energy Policy Research, World Bank national accounts data & Changing Wealth of Nations data

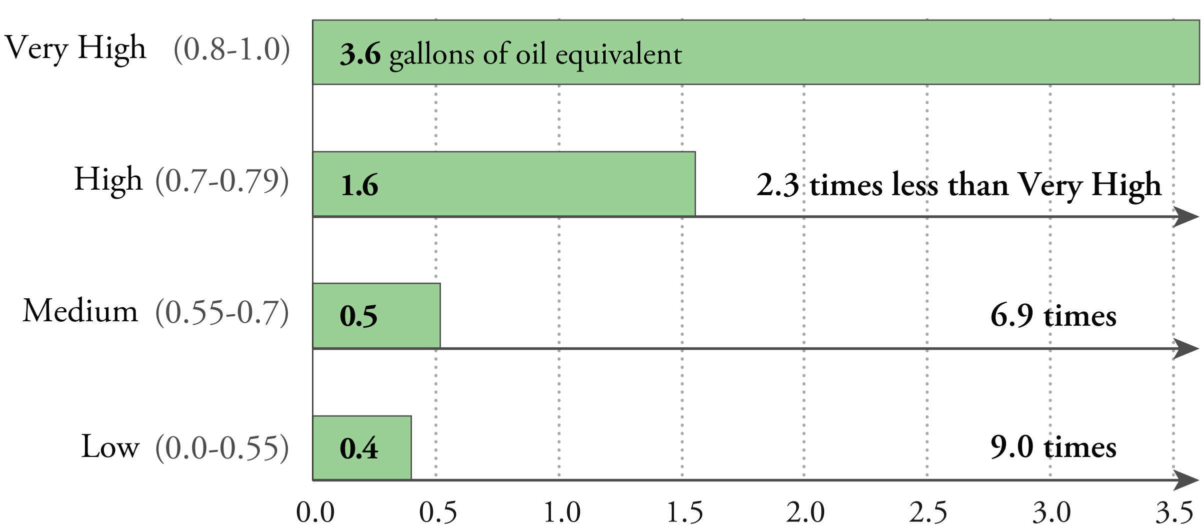
Figure 20. U.S. Federal Oil and Gas Revenues



Source: Energy Policy Research, U.S. Department of Interior

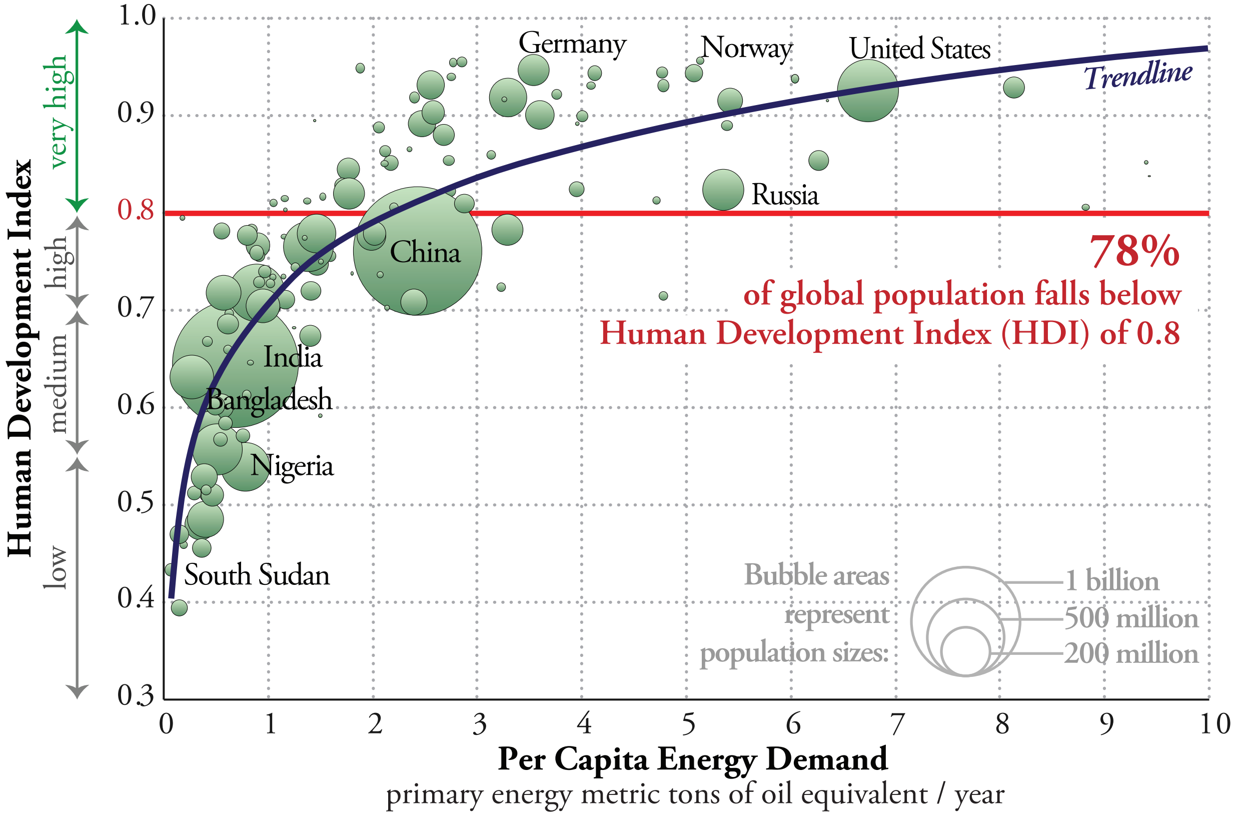
The other benefit of affordable, reliable energy sources is to provide much-needed energy to achieve higher levels of human development in developing countries. The Energy Policy Research Foundation's analysis of the relationship between primary energy demand per capita and the Human Development Index (HDI) scores shows a strong correlation between the two. In 2019, 78% of global population fell below the HDI score of 0.8, which separates "very high" scorers from the rest. The "very high" group, on average, used 3.6 gallons of oil equivalent per day, which is 2.3 times more than the next group's ("high") energy consumption and 9 times more than the "low" group's energy consumption. Stripping these poorer countries of access to oil and gas resources may impede their economic growth and human development.

Figure 21. Daily per Capita Energy Demand by Human Development Index (2019)



Source: Energy Policy Research, IEA, UN

Figure 22. Per Capita Energy Demand and Human Development Index (2019)



Source: Energy Policy Research, IEA, UN

2.3.5. Technological Innovation

The energy sector, as well as the industries that use hydrocarbons, has continuously innovated over the years. One of the more recent revolutions in the oil and gas industry—hydraulic fracturing—was a result of continued investment and innovation, no matter how small the starting point.

As energy researcher Gautam Kalghatgi noted, banning ICE vehicles will threaten innovation in making transportation more sustainable and efficient.[60] Instead, all attention and resources will be shifted to technologies that require decades of research and development before becoming commercially competitive.

Oil and gas companies are among the biggest funders of research, development, and demonstration in the energy sector, covering both conventional and alternative energy sources. Many oil and gas companies support RD&D in technologies such as CCUS, hydrogen, solar, wind, and even direct air capture (DAC).

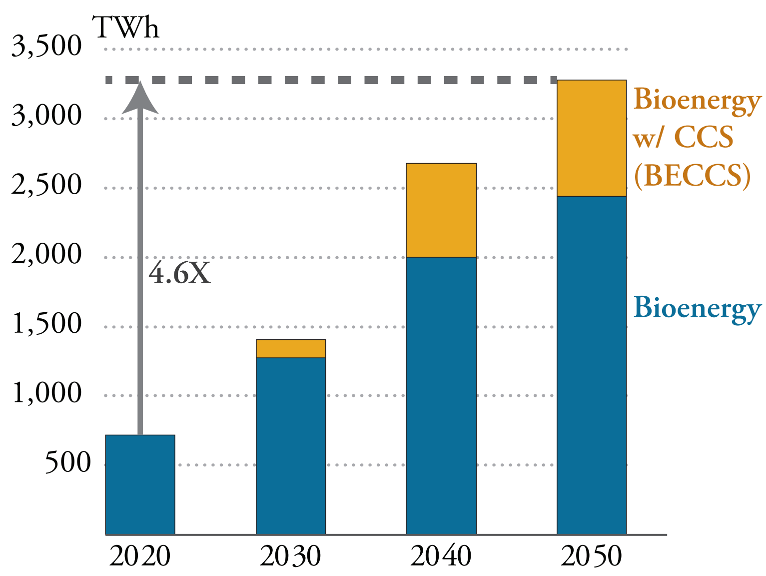
2.3.6. Environment and Health

Reducing oil and gas supply will contribute to various environmental and health effects around the world. First, it will likely lead to a resurgence of coal consumption, as many low- and middle-income countries may struggle to afford higher-priced natural gas for heating, cooking, and electricity generation. As a result, coal-to-gas switching in many countries may regress, increasing local air pollution and exacerbating health crises in many urban areas.

Second, the unprecedented quantities of critical minerals and materials necessitate excessive mining to scale up the production of EVs, lithium-ion and other types of batteries, solar panels, wind turbines, and wires of the grid network. Although mining is critically important for the modern economy, intensifying mining activity manifold poses various environmental hazards: exposing radioactive materials and dust, releasing toxic compounds and contaminant materials to the air and water, increasing sedimentation in rivers, erosion of lands, and excessive consumption of water.[61] When combined with lax environmental regulations and enforcement, mining critical minerals may lead to more frequent local environmental episodes and increased health risks to local populations.

Third, the inherently low density of alternative energy technologies, compared with conventional energy sources, requires much larger tracts of land for the same or fewer volumes of energy supply. Increased biofuel production may lead to deforestation at scale, while forests play a critical role in absorbing CO_2 emissions. Based on the current rate of land requirements, the annual production of bioenergy for electricity generation will likely need an additional land equivalent of the size of Mexico by 2050 (Figures 23–24). In addition to bioenergy production, our analysis suggests that installing utility-scale wind and solar around the world will require additional land the equivalent of the combined area of California and Texas by 2050 (Figures 25–26). This assumes sufficient or optimal transmission and storage infrastructure, the current rate of efficiencies, and only onshore wind.

Figure 23. Bioenergy for Electricity Generation in NZE

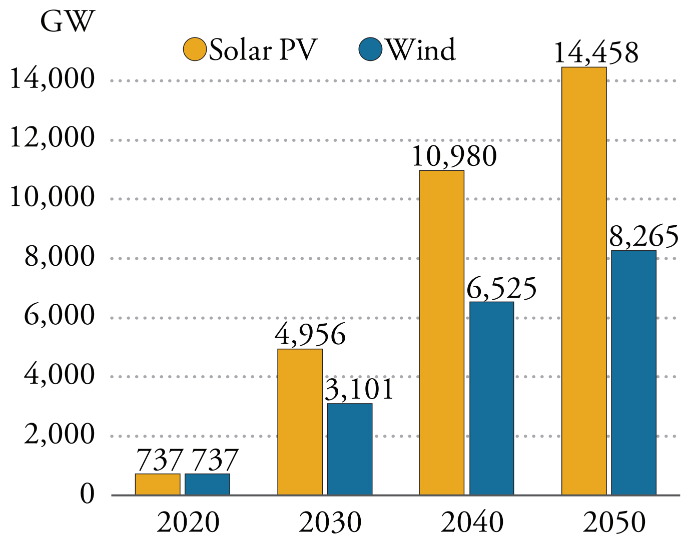


Source: IEA, *Net Zero by 2050* (2021)

Figure 24. Global Land Requirements for Bioenergy for Electricity Generation in NZE

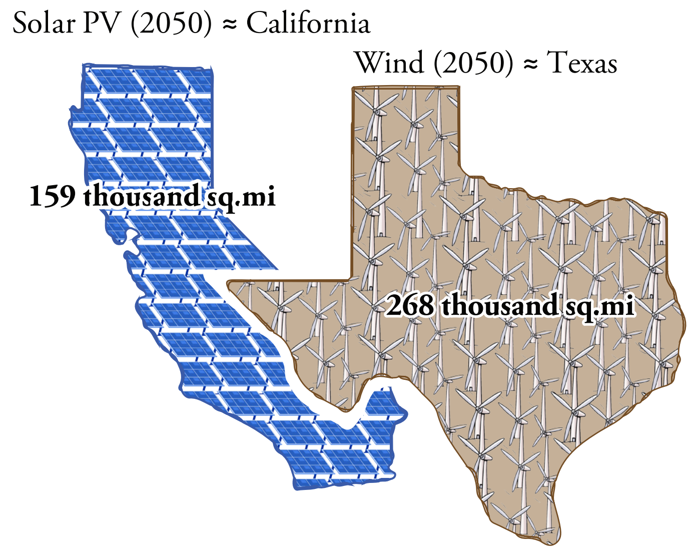
Source: Energy Policy Research. Land requirement calculations made using FreeingEnergy.

Figure 25. Global Solar and Wind Capacity in NZE



Source: IEA, *Net Zero by 2050* (2021)

Figure 26. Global Land Requirements for Solar/ Wind Farms in NZE



Source: Energy Policy Research based on NZE
Assumes sufficient/optimal grid infrastructure (transmission, storage) and current rate of efficiency

Chapter 3

Central Role of Oil and Gas in Modern Civilization

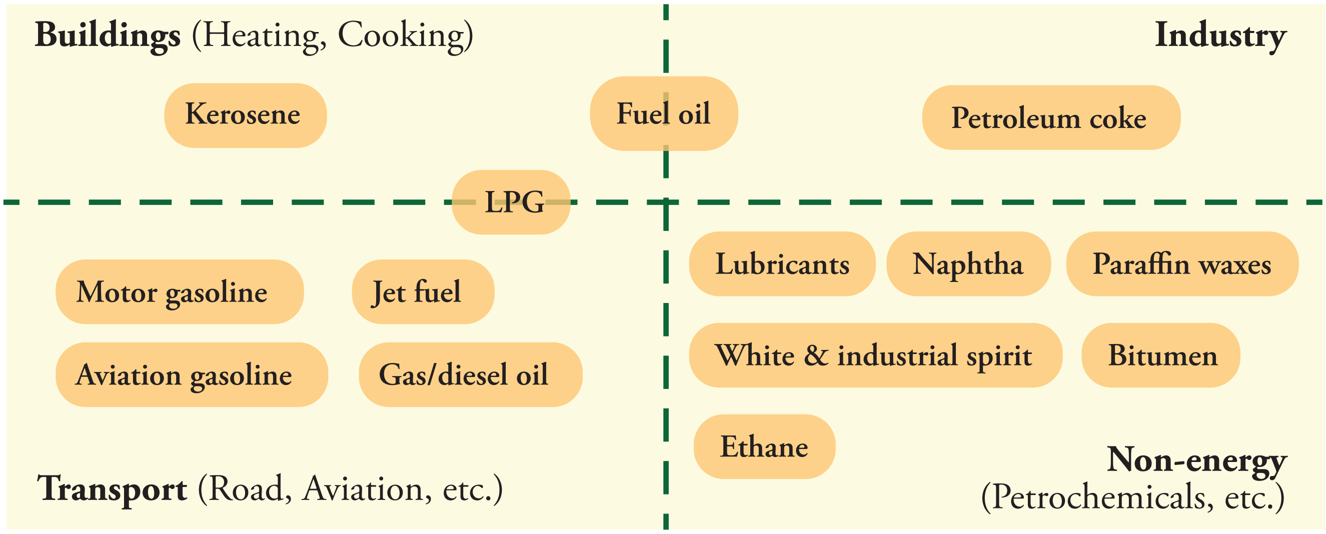
Highlights of Chapter 3

- Oil and gas play irreplaceable roles in modern civilization that are not reproducible with low-/zero-carbon alternatives.
- Both oil and natural gas have various applications in the main final energy sectors (buildings, transportation, and industry) as well as for non-energy purposes.
- The global transportation sector, which consists of road transport, aviation, shipping, and others, runs primarily on petroleum products. Although BEVs have experienced a surge in sales recently, it is unlikely that they will completely replace ICE vehicles due to technological and economic limitations.
- Natural gas has played a critical role in replacing coal in power generation and contributes to the reliability of the electric systems, which, if replaced by variable resources, will cause tremendous strain on the electric system, compromise grid reliability and resilience, and impose higher costs on end users.
- In industrial heat processes, where high to ultra-high temperatures are required, gas has no low-carbon commercial substitutes, making it an essential energy source.

3.1. Composition of Oil Demand

Oil is a crucial resource that plays an integral role in driving economic growth and improving the quality of life for people around the world. Oil has a wide range of applications: transportation fuels, heating and cooking, electricity generation, and serving as a raw material for petrochemicals to produce plastics and hundreds of other products.[62] The use of oil spans a vast number of applications across the three main energy sectors—transport, industry, and buildings—as well as for non-energy use (Figure 27).

Figure 27. Select Petroleum Products and Their Applications



Source: Energy Policy Research based on IEA classification

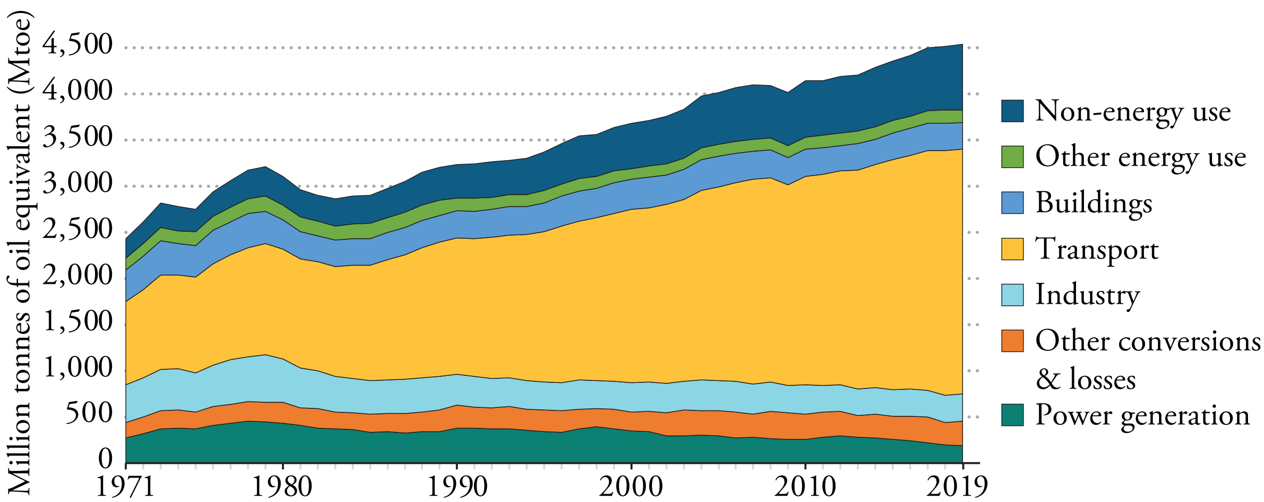
The 1970s twin oil price shocks (1973 and 1979) had a lasting impact on the composition of oil demand, particularly in power generation, industry, and buildings. The nominal annual U.S. crude oil purchase price had increased 10-fold, from US$3.18/barrel in 1970 to US$31.77/barrel in 1981 (4.7 times in real terms, when adjusted for inflation).[63] As a result of these shocks, OECD oil consumption in power generation more than halved in the seven years between 1978 and 1985 (278 million tonnes of oil equivalent [TOE] to 135 million TOE). During the same period, OECD demand for oil in industry and buildings (heating) declined by 31.2% and 30.6%, respectively. This trend has continued to the present day, with the share of power generation in total oil demand in OECD decreasing from 13% in 1978 to 2% in 2019, industry from 14% to 5%, and buildings from 15% to 6% (Figure 29).

In the U.S., the share of power generation in total oil demand decreased from 10% to 1% between 1978 and 2019, making it a negligible source of power generation in the country. During the same period, U.S. oil demand in buildings and industry decreased by a factor of four. These reductions were largely offset by an increase in transport and non-energy use, although total U.S. oil demand never reached its 1978 level.

The non-OECD countries have experienced a substantial increase in oil demand since 1970, having risen to 378% by 2019. A large portion of that demand increase was driven by China, which accounted for nearly 40% of the total increase. The growth of non-energy applications such as petrochemical feedstocks, in addition to the transportation sector, has been a significant driver of demand. Despite the impact of the pandemic, oil demand in developing countries is expected to continue its upward trend, based on historical patterns (Figure 30).

According to IEA data, annual global oil demand has risen rapidly over the past five decades, growing from less than 2.5 billion TOE in 1971 to over 4.5 billion TOE in 2019, with almost all the growth coming from non-OECD countries. Despite a temporary drop in oil demand due to the pandemic in 2020, global oil demand recovered somewhat in 2021 and is expected to reach pre-pandemic levels in 2023.

Figure 28. Global Oil Demand by Sector



Source: Energy Policy Research, IEA World Energy Balances database

Figure 29. OECD Oil Demand

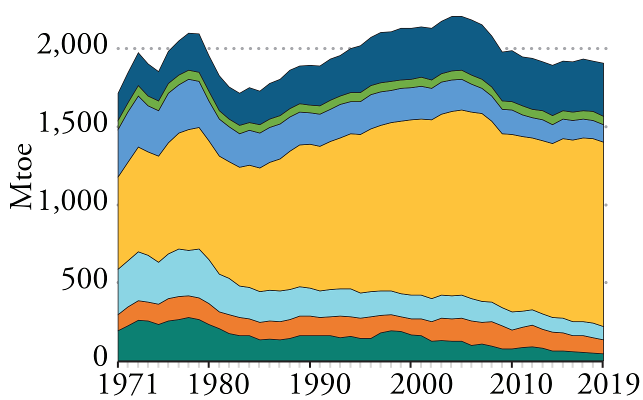
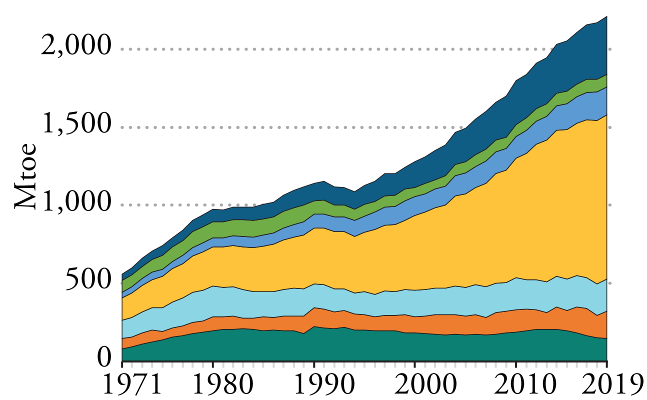


Figure 30. Non-OECD Oil Demand

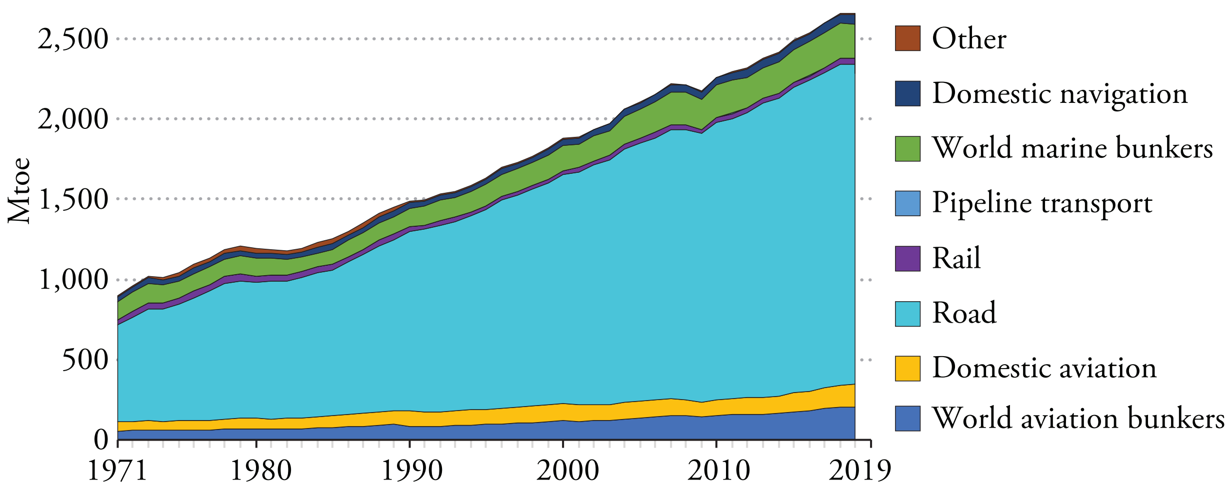


Source: Energy Policy Research, IEA World Energy Balances database

3.2. Concentration of Oil Demand in Transportation

Global oil consumption reached 94 million barrels per day (MMB/D) in 2021.[64] The transport sector is responsible for almost two-thirds of the global final consumption of oil, with road transport accounting for three-quarters of the demand in the transport sector.[65] In 2021, 1.3 billion passenger vehicles[66] on the road consumed about 25 MMB/D, making up half the road transport demand for that year. Additionally, road freight, such as heavy-duty trucks, accounted for over 15% of global oil demand (Figure 31).

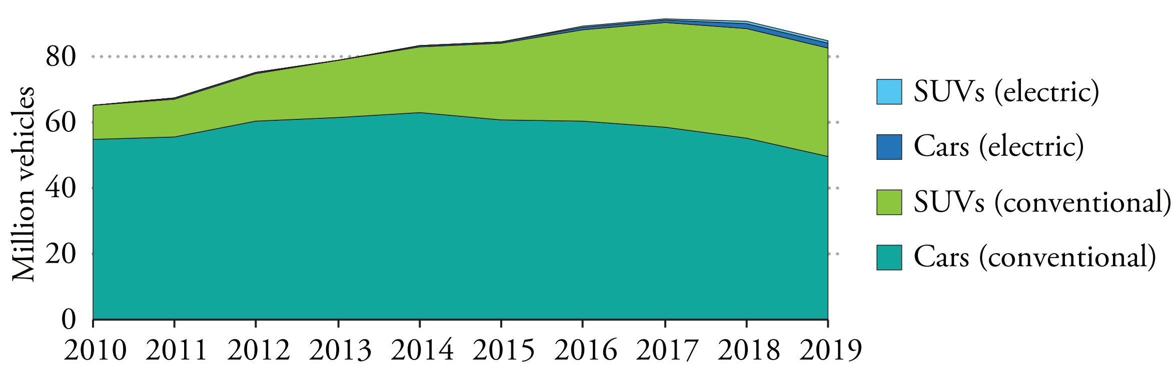
Figure 31. Global Oil Demand in Transport by Subsector



Source: Energy Policy Research, IEA World Energy Balances database

Between 2016 and 2020, 86 million new passenger cars were sold on average globally, with 15 million sold in the United States. Although passenger car sales have declined in recent years, the share of sport utility vehicles (SUVs), which require more gasoline than sedans, has hit record levels globally, rising from 16% of all passenger car sales in 2010 to 42% in 2020 (Figure 32).[67] Battery electric vehicle (BEV) sales are growing rapidly, but in 2021, total BEV stock accounted for less than 1% of the global passenger car stock.[68]

Figure 32. Passenger Car Sales by Size and Powertrain



Source: Energy Policy Research, IEA World Energy Balances database

3.3. Limitations of BEVs as ICE Substitutes

> ***"In transport, the share of electricity increases from less than 2% in 2020 to around 45% in 2050 in the NZE. More than 60% of total passenger car sales globally are EVs by 2030 (compared with 5% of sales in 2020), and the car fleet is almost fully electrified worldwide by 2050 (the remainder are hydrogen-powered cars). The increase in electric passenger car sales globally over the next ten years is over twenty-times higher than the increase in ICE car sales over the last decade."*** (*Net Zero by 2050*, p. 70)

There has been a widespread notion that replacing internal combustion engine (ICE) vehicles powered by petroleum with alternative energy vehicles will bring numerous benefits, including reducing greenhouse gas (GHG) emissions to zero. In response, many Western governments are planning to ban new sales of ICE vehicles starting in 2030 and are actively encouraging sales of BEVs and, in some instances, hydrogen fuel cell electric vehicles (FCEVs). Under the IEA's NZE scenario, electric vehicles will reach 60% of global car sales by 2030. However, substituting ICE vehicles with BEVs at scale faces numerous challenges and obstacles. Despite government efforts, BEVs are unlikely to achieve the target of replacing ICE vehicles due to a range of factors, discussed below.

BEVs will continue to be more expensive than ICE vehicles. According to the IEA's Global Electric Vehicle Outlook 2022, the sales-weighted median price for BEVs in 2021 was about 45%–50% higher than that of conventional cars in Europe and the United States. The sales-weighted price difference in China was 9%, owing to the government's hefty financial support for BEVs over many years.[69] But the prospect for millions of Chinese BEVs entering the U.S. and Europe at scale are rather slim, as these countries are increasingly wary of China's "mercantilist" trade approach.[70]

Supporters advocate for price caps on EVs, higher subsidies for low-income households, and increasing other benefits and subsidies to scale up BEV sales across various income levels. However, these options will prove extremely costly to the U.S. or any OECD country in the long run, not to mention many developing countries aspiring to provide their constituents with the means of affordable transportation.

Scaling up EV batteries will require unprecedented amounts of critical minerals, drive up the BEV price, and make car prices susceptible to increasing fluctuations in mineral markets. The high demand for minerals and supply-chain disruptions have led to increased costs for BEV manufacturers. According to Ford, the cost for a Mustang Mach-E increased by US$25,000 per vehicle in 2022.[71] The IEA's Tae-Yoon Kim remarked that cathode materials, which used to account for 5% of the battery costs, now make up 20%, resulting in BEV manufacturers raising prices.[72] The rush to reach net zero emissions is resulting in sky-high costs for materials and equipment, as the mineral requirements for each of the major battery designs are substantial.[73]

Table 13. Battery Chemistry by Content, Kg (60 kWh Lithium-Ion)

Mineral/Metal	NMC811	NMC523	NMC622	NCA+	LFP
Lithium	5	7	6	6	6
Cobalt	5	11	11	2	0
Nickel	39	28	32	43	0
Manganese	5	16	10	0	0
Graphite	45	53	50	44	66
Aluminum	30	35	33	30	44
Copper	20	20	19	17	26
Steel	20	20	19	17	26
Iron	0	0	0	0	41

NMC811 Nickel (80%) Manganese (10%) Cobalt (10%)
NMC523 Nickel (50%) Manganese (20%) Cobalt (30%)
NMC622 Nickel (60%) Manganese (20%) Cobalt (20%)
NCA+ Nickel Cobalt Aluminum Oxide
LFP Lithium iron phosphate

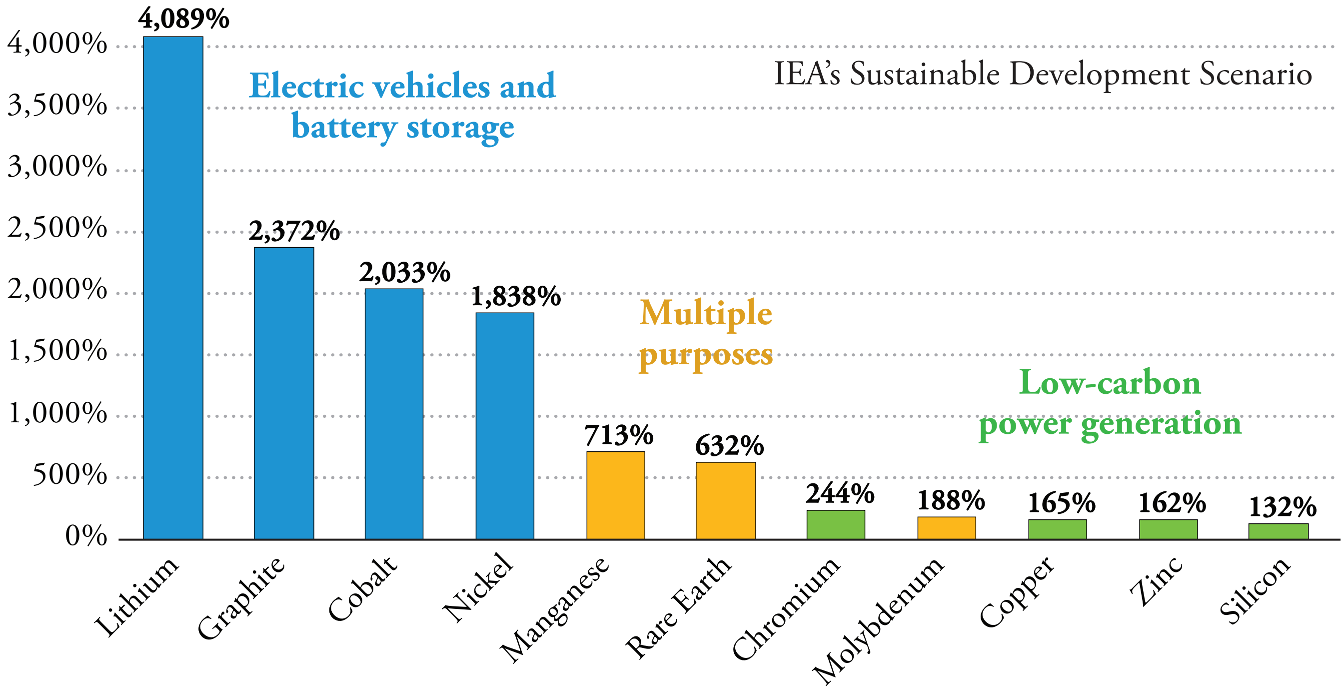
Source: Bhutada, G. VC Elements

The IEA estimates that to achieve the Paris Agreement goals,[74] the world will need unprecedented amounts of incremental production of the key minerals for EVs and battery storage. From 2020 to 2040, the annual global supply of lithium, graphite, cobalt, and nickel must increase by 1,800% to 4,000%. Note that this IEA estimate, which goes only to 2040, is much less ambitious than the NZE scenario (Figure 33). The detailed breakdown of the critical minerals under NZE is much less transparent in the IEA's publicly available data sources, but the massive scale of required growth can be vaguely inferred from the next two sentences in the *Net Zero by 2050* report:

> ***"Growth in battery demand translates into an increasing demand for critical minerals. For example, demand for lithium for use in batteries grows 30-fold to 2030 and is more than 100-times higher in 2050 than in 2020 (IEA, 2021)."*** (*Net Zero by 2050*, p. 71)

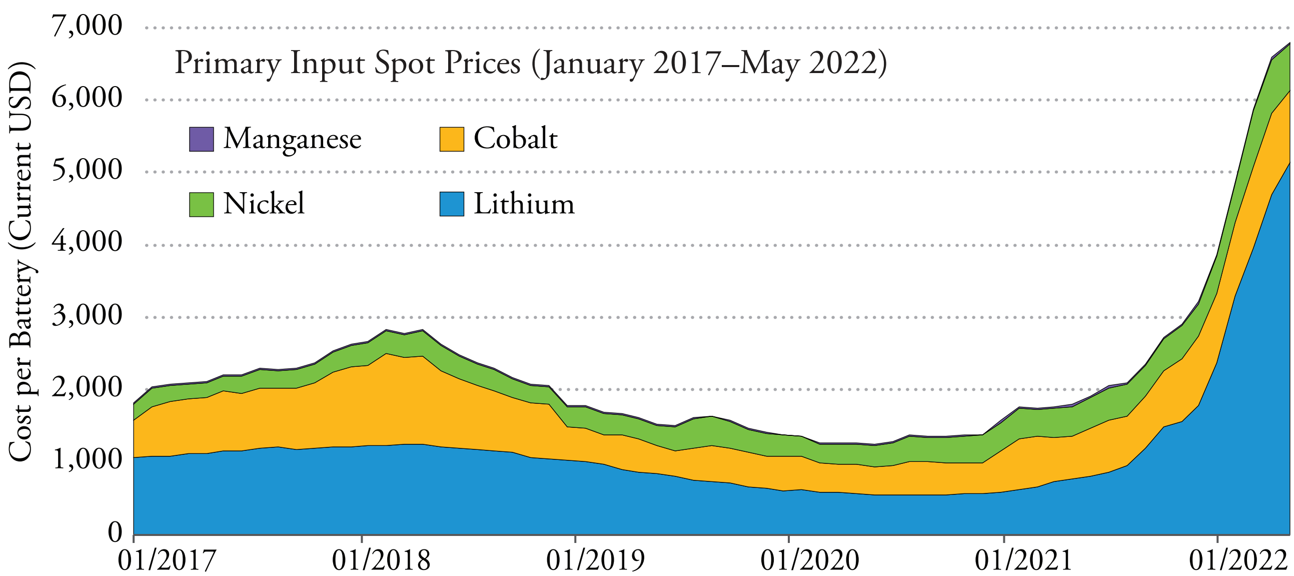
For EV batteries, marginal innovations are modest, and the focus has been limited to improving density and safety to give manufacturers a proprietary edge. As a result, BEVs are vulnerable to fluctuations in the prices of battery inputs. For example, the implied cost for a typical Tesla battery using spot prices for lithium hydroxide, cobalt, nickel, and manganese was approximately US$1,700 in 2017, but this implied nominal cost reached over US$6,500 in May 2022. Lithium hydroxide prices averaged US$80,750 per metric ton in May 2022, up 380% from US$16,813 in January 2017. May 2018 prices for cobalt, nickel, and manganese were up 183%, 97%, and 44%, respectively, from their levels in January 2017. [75]

Figure 33. Required Growth of Critical Mineral Supply (IEA's SDS scenario, 2020–40)



Source: Energy Policy Research, IEA, *The Role of Critical Minerals in Clean Energy Transitions* (2021)

Figure 34. Tesla Battery Cost Based on Monthly Average



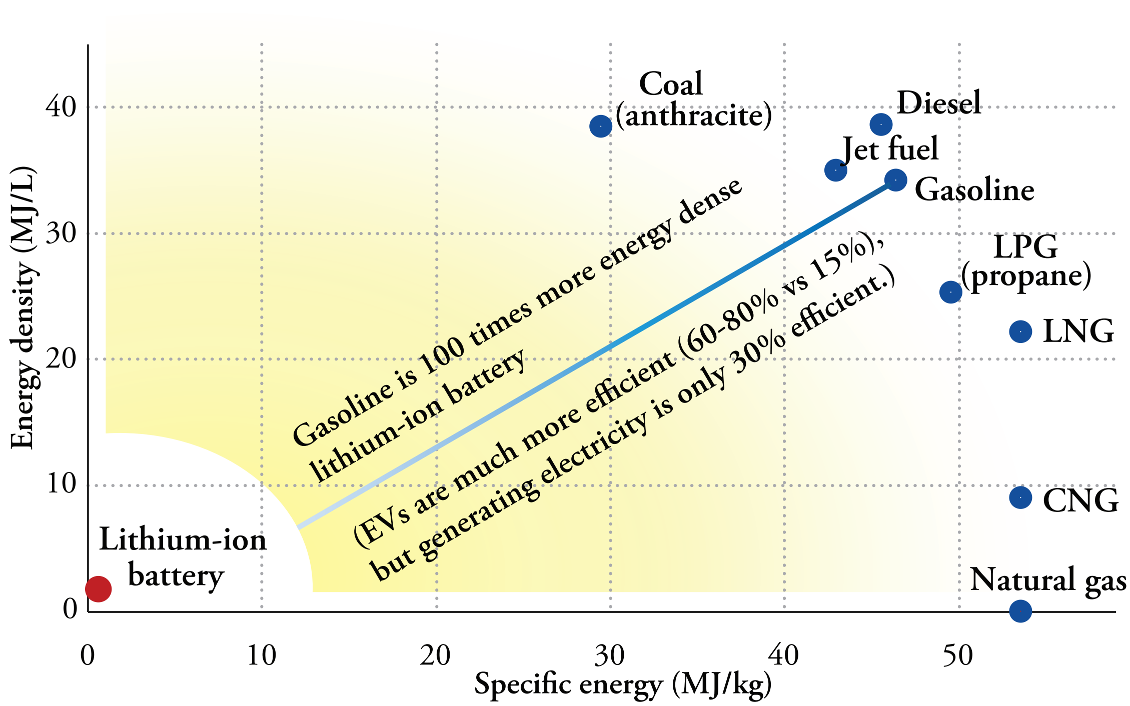
Source: Energy Policy Research, LME Monthly Data

BEVs have a massive GHG footprint, especially those manufactured and sold in China. The carbon footprint from power plant emissions and battery manufacturing is never zero and varies depending on location. China leads the world in EV sales and manufacturing, but it also consumes a large amount of coal. In 2020, coal accounted for 60.6% of China's primary energy demand and 63.3% of its electricity production, meaning that EVs powered by electricity generated in China indirectly emit substantial GHG emissions. This applies, to some extent, to any country that is not fully zero-carbon and still relies on fossil fuel-based electrical systems.

Additionally, because China produces 77% of global EV batteries—i.e., lithium-ion batteries—the GHG footprint of BEVs globally largely offsets their expected benefits as "low-carbon" alternatives to ICE vehicles. In other words, GHG emissions from manufacturing a Tesla Model 3's 80 kWh lithium-ion battery may be close to 16 metric tons of CO_2 emissions.[76] When combined with the GHG footprint from energy-intensive mining activities that unearth lithium, nickel, and other minerals, these numbers can quickly escalate to an extent that makes the whole EV campaign a hyper-wasteful extravagance.

The lack of EV charging infrastructure is a sticking point. As the availability of charging stations increases, the inconvenience of refueling decreases and the demand for BEVs rises. The IEA recommends that the number of charging stations should be equal to the number of BEVs, with most of them being home chargers. However, the cost of charging stations can vary greatly, depending on the source of the estimate. Home chargers can cost as little as US$750, but the cost can increase to US$1,700 with installation. A detached garage charging station can cost upward of US$6,900. Fast public charging stations require significant infrastructure upgrades and can cost as much as US$50,000. It is difficult to predict the exact mix of charging stations by 2030, but it is estimated that adding 400 million or more charging stations will easily exceed a cost of US$1 trillion in investment by that time.[77]

Figure 35. Energy Densities of Common Fuels, Li-ion battery



Source: Energy Policy Research, various sources

Battery density is another major challenge. Battery storage suffers from both low energy density (stored energy per unit of volume) and low specific energy (stored energy per unit of mass) compared with common fuel types. Lithium-ion batteries have an energy density 100 times less than gasoline, diesel, and jet fuel. Due to these challenges, apart from urban transportation, BEVs remain far less cost-effective compared with ICE vehicles, and the use of batteries is many decades away from replacing liquids in heavy-duty transportation modes, from aviation to marine bunkering.

Technology losses from BEV mandates. According to Gautam Kalghatgi, banning ICE vehicles in favor of BEVs will also deny "the benefits of any improvements" in ICE vehicle technology and cease research and development efforts in this area. He assessed that such an abrupt change would result in replacing the possibility of making large, affordable impacts on sustainability through improved ICE technology with hugely expensive, inefficient, and unproven technologies (i.e., BEVs).[78]

3.4. Composition of Natural Gas Demand

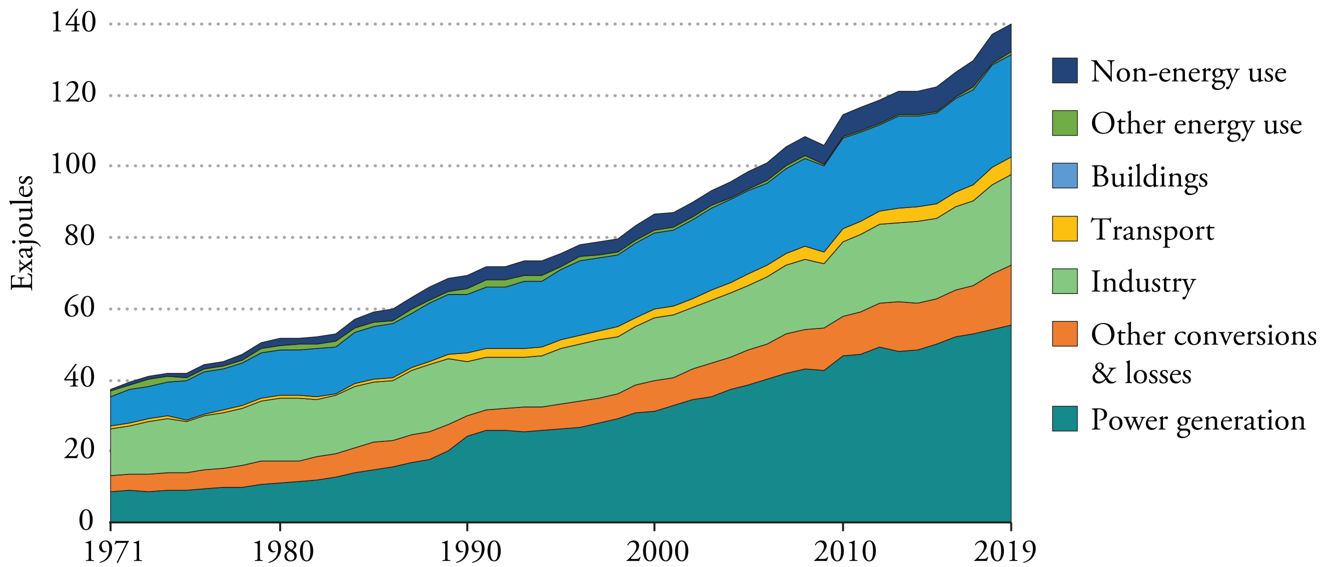
Natural gas is an essential part of the global energy balance, with a wide range of applications across the three main end-use sectors (industry, buildings, and transport) as well as power generation. In industry, natural gas serves as an important feedstock for the production of ammonia, hydrogen, and other chemical and petrochemical products. Natural gas is increasingly used as a clean transportation fuel source, particularly for heavy-duty vehicles and buses, and, as a clean alternative to coal, it is used for heating and cooking in residential and commercial buildings while reducing local air pollution in many developing countries.

Natural gas has made a significant impact on mitigating local air pollution, leading to a healthier living environment in many areas around the world. One of the latest beneficiaries of increased natural gas consumption is China, which implemented a campaign in its northern winter heating cities to switch from coal to natural gas in an effort to reduce local air pollution. Thanks to the coal-to-gas switching campaign, the level of particulate matter (PM10 and PM2.5) in China has declined substantially in recent years. However, apart from residential and commercial applications, the role of natural gas remains small in China's energy mix, as this fuel accounts for approximately 2% of China's electricity generation.

Natural gas has also played a vital role in sustaining rapid population growth in the past century, as it is a key input in the production of nitrogen-based fertilizers, which revolutionized modern agriculture by radically increasing the yields of food and feed grain crops. Additionally, natural gas is used to heat greenhouses, dry crops, and power irrigation systems in agriculture, making it an integral part of the global food-supply chain.

Natural gas demand increased enormously in the past five decades. In the OECD, the total growth between 1971 and 2019 was 138%. In non-OECD, the change was even more dramatic growth: 656%. In both cases, natural gas demand grew in all three end-use sectors, power generation, and non-energy uses (Figure 36).

Figure 36. Global Natural Gas Demand by Sector



Source: Energy Policy Research, IEA World Energy Balances

Figure 37. OECD Gas Demand

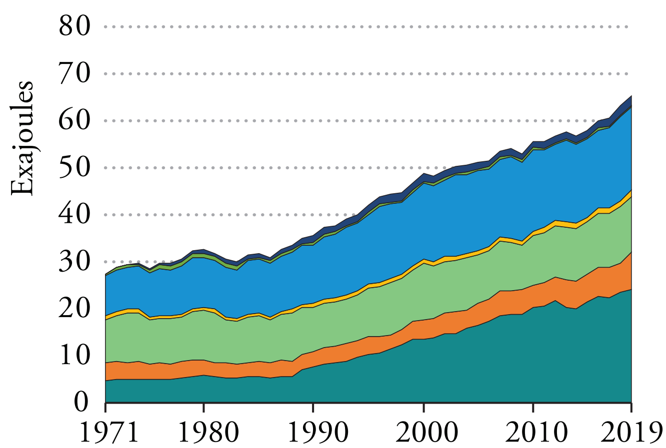
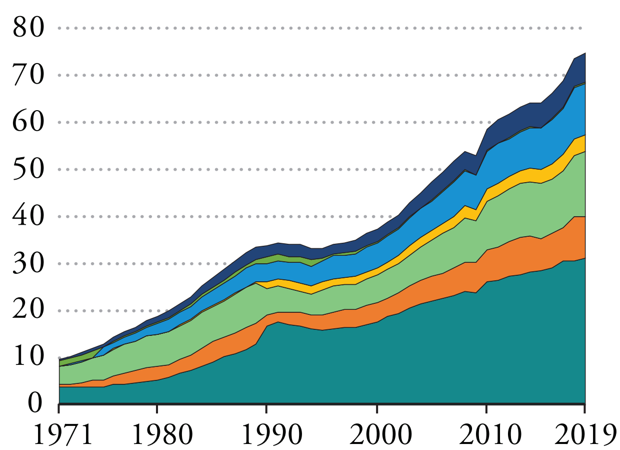


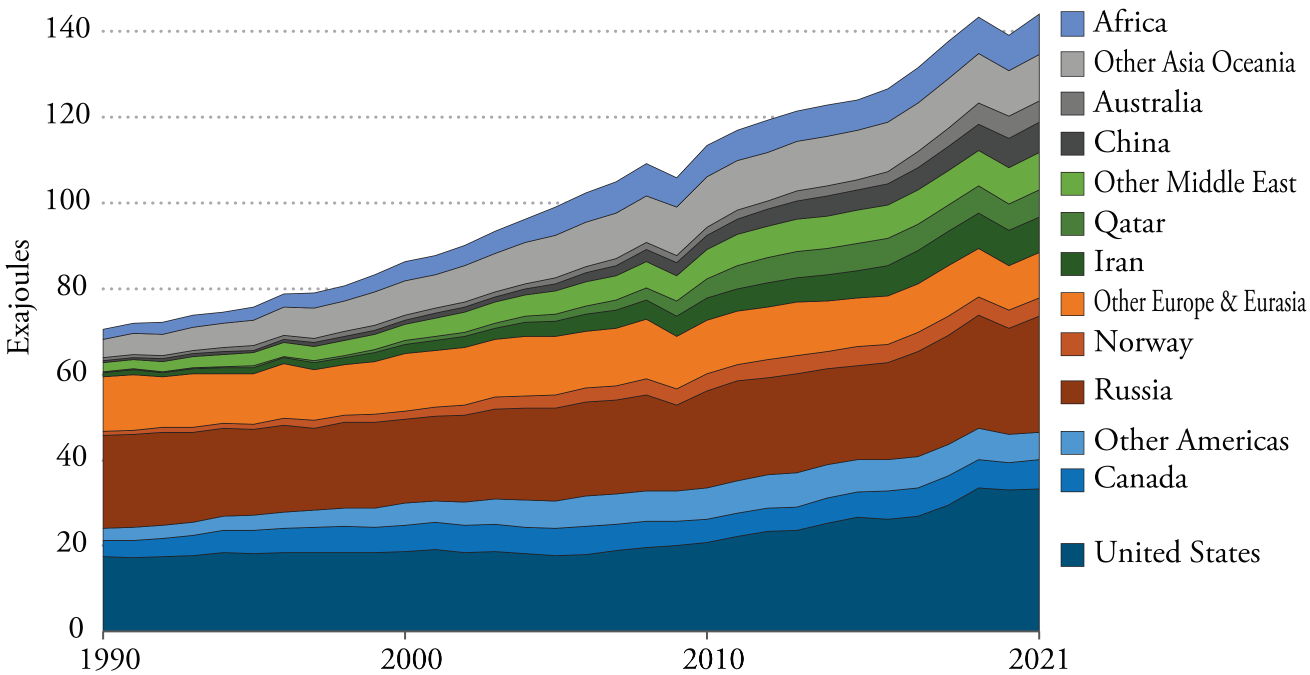
Figure 38. Non-OECD Gas Demand



Source: Energy Policy Research, IEA World Energy Balances

Global natural gas consumption growth benefited from additional new supplies around the world. The U.S., owing to the shale revolution, played a key role in that growth, accounting for 41% of the global incremental gas supply between 2010 and 2021.[79] Unlike most other energy fuels and technologies—particularly, the critical minerals supply chain for clean energy, which is dominated by China and a few other countries—natural gas supply sources are well balanced, with production relatively evenly distributed among major regions (Figure 39).

Figure 39. Natural Gas Production by Region



Source: Energy Policy Research, IEA World Energy Balances

3.5. Importance of Natural Gas for Reliable and Resilient Electric Grids

Electric grids play a central role in the functioning of modern society, and any failure to maintain their reliability (ability to avoid outages) and resilience (ability to withstand and recover from extreme conditions) can have catastrophic social and economic implications. The basic operational requirement of a modern electricity grid is the maintenance of frequency,[80] which is maintained by balancing load (consumption) with generation (supply). If there is a falloff in generation, or where generation cannot be ramped to meet increasing load, the frequency degrades. If this imbalance becomes prolonged, even for a short interval, there is an increased possibility of major damage to generation equipment, coupled with service-territory blackouts, resulting in massive economic losses.

Dispatchable energy sources and intermittent sources are two completely different players in power generation and, therefore, should be valued differently. Some even like to use an analogy of team sports, where fossil energy is likened to reliable, uninjured players, such as a starting quarterback in football, while intermittent renewables are compared to injured or inconsistent players.[81]

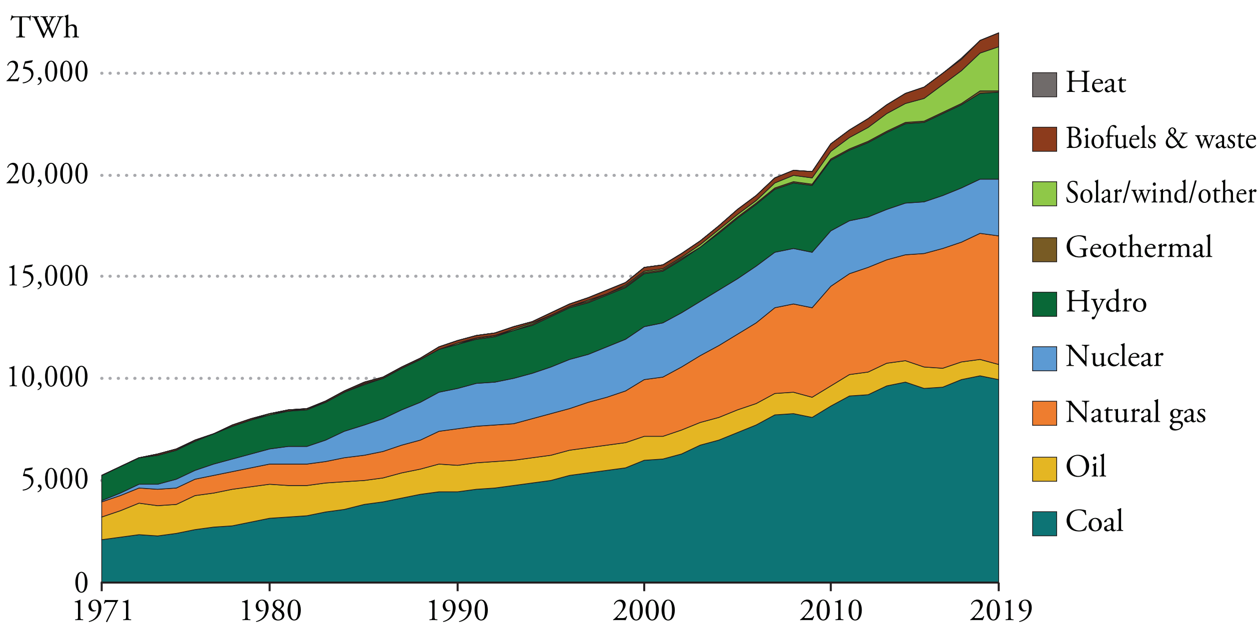
Replacing significant shares of the baseload power provided by coal, natural gas, and coal with intermittent, or inverter-based, resources like solar and wind risks creating a large imbalance. This is echoed in the North American Electric Reliability Corporation's (NERC) recent long-term reliability assessment, which points to four resource mix trends posing major challenges to grid reliability: integration of inverter-based resources (i.e., solar and wind); increasing levels of distributed resources (home solar systems, etc.); the pace of retirement of nuclear, coal-fired, and natural gas generators; and the need for more robust planning approaches to ensure that solar and wind have "the capability to support voltage, frequency, and dispatchability." In other words, an aggressive push to net zero grids will very likely lead to serious damage to the electric system unless all the above conditions are met.

3.6. Rise of Natural Gas Displacing Coal in Electricity Generation

Natural gas has been displacing coal steadily as an electricity source in recent decades. In OECD, the share of natural gas in electricity generation output surpassed that of coal in 2016. According to the IEA data, electricity output from natural gas reached 3,051 TWh for the first time, accounting for 27.6% of the total output in OECD in 2016. This coal-to-gas switching in the power sector resulted in massive reductions in CO_2 emissions and brought a net positive impact on reducing local air pollution. The IEA's 2019 report, "The Role of Gas in Today's Energy Transitions," shows that coal-to-gas switching was responsible for about one-fifth of total U.S. emissions savings between 2010 and 2018.[82]

In non-OECD countries, the role of natural gas has grown significantly but has not been able to displace coal at the same pace as in OECD countries. In fact, coal continues to constitute nearly half of all electricity output in non-OECD countries, while natural gas's share remains below 20% due to its higher cost, compared with that of coal. In these countries, economics plays an even more significant role in determining the fuel mix, despite the attractive potential of natural gas to reduce PM2.5 and PM10 levels in many Asian cities where air pollution has become a health crisis. Because of the high sensitivity of energy prices in non-OECD countries, a forced effort to transition to even costlier renewables and other alternative technologies risks these countries reverting back to coal instead of switching to natural gas.

Figure 40. Global Electricity Generation by Source



Source: Energy Policy Research, IEA World Energy Balances database

Figure 41. OECD Electricity Generation by Source

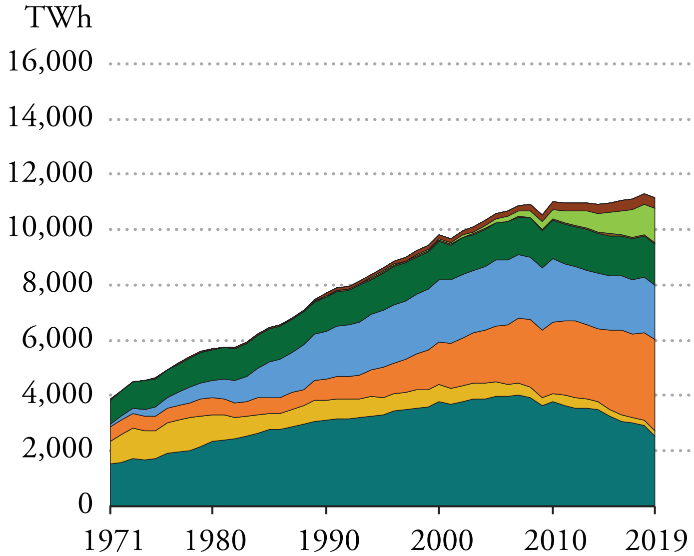
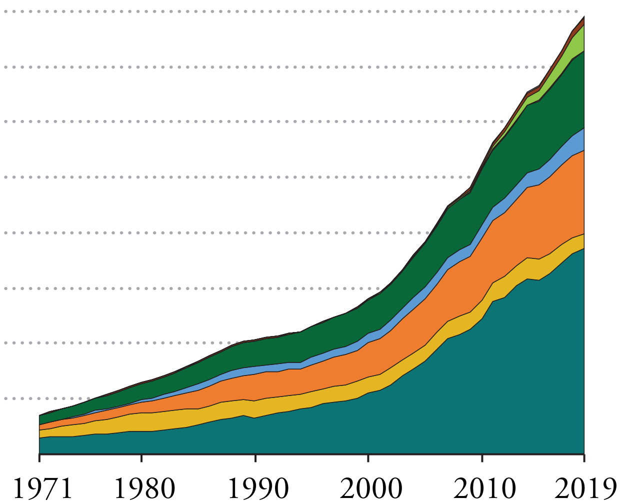


Figure 42. Non-OECD Electricity Generation by Source



Source: Energy Policy Research, IEA World Energy Balances database

3.7. Reality of Decarbonizing Industrial Heat Processes

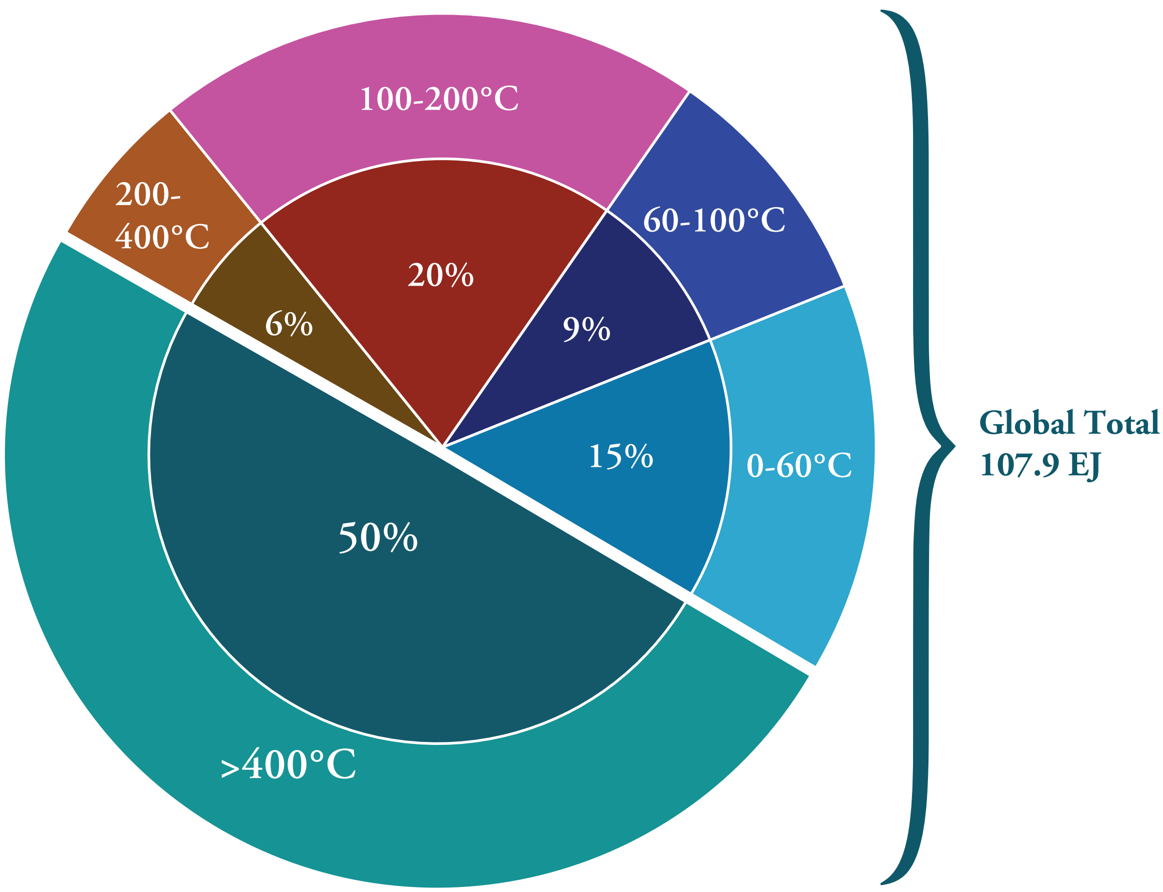
Industry remains out of reach from decarbonization efforts, as many of its subsectors continue to be "hard-to-abate" not just in economic but also in physical terms. As discussed in Chapter 4's section on Technology Readiness Levels, many applications to decarbonize industrial sectors are at or below early commercialization levels. One of the main challenges of a net zero industry is meeting medium- to high-temperature heat requirements in various industrial applications, from iron and steel production to chemical production to food processing. Compared with the residential or commercial sector, the large majority of manufacturing processes require heating temperatures exceeding 100°C (212°F).

Industrial heat demand temperatures (or "grades") vary from under 100°C (low temperature for food processing, etc.) to 500°C (high temperature used for forging and making of glass) to over 1,000°C (ultra-high temperature for steelmaking, etc.). The low-temperature requirements can be met by direct electrification through heat pumps.[83] However, it is extremely difficult to replace hydrocarbons used for higher-temperature heat due to the underlying limitations of renewable energy—most notably, the lack of energy density required for high temperatures, as well as their intermittent nature, which may hinder the continued operations of an industrial facility.

Given that almost 95% of iron and steel production, over 70% of nonmetallic minerals, and over 65% of chemicals in the U.S. require industrial heat temperatures of at least 500°C, the task of decarbonizing the industrial sector remains beyond daunting. Globally, almost half of all industrial heat requires temperatures of over 400°C (Figure 43). As the OECD world accelerates its transition efforts, demand for minerals and materials that require highgrade industrial heat processes will only escalate, inadvertently leading to more demand for hydrocarbons.

IEA's *World Energy Outlook 2019* raised additional challenges in industrial heat processes that would further complicate the transition. Those include the long lifetimes and slow turnover of capital stock, as well as the highly integrated nature of industrial processes that require a whole-system approach rather than gradual replacements of individual parts.[84]

Figure 43. Global Industrial Heat Demand by Temperature Range (2018)



Source: IEA, *Solar Energy Policy in Uzbekistan: A Roadmap* (2022).

Chapter 4

Understanding Additional Headwinds to Net Zero

Highlights of Chapter 4

- NZE is unlikely to succeed because of the high costs of intermittent resources, the unwillingness of developing countries to participate, and various other risks and challenges discussed in this analysis.
- Intermittent renewable resources have contributed to an increase in electricity costs. Solar and wind integration costs are rising, as more grid infrastructure is required for marginal capacity of these resources.
- According to the IEA, half the emissions reductions required under NZE are expected from technologies that are at prototype or demonstration stages today. Moving from prototype to commercialization requires decades, and without breakthroughs, there will continue to be a technological gap by 2050.
- The most likely outcome under NZE is an incomplete, two-speed transition, where most developing countries do not fully follow through on their announcements.

4.1. Limitations to Additional Cost Improvements in Solar and Wind

In NZE, the further adoption of solar and wind is of critical importance, as their share of electricity generation goes up from 10% in 2021 to 69% in 2050. To achieve large-scale, low-carbon electrification around the world, continued cost reductions are needed in solar PV and offshore wind. Under the NZE scenario, in four key regions,[85] solar PV capital costs drop by 57%–63% by 2050, and offshore wind by 60%–68%. Similar rates of decline are assumed in their levelized cost of electricity (LCOE). By 2050, offshore becomes cheaper than onshore wind in some markets.[86]

The prospect of rapid reductions in the cost of intermittent renewable energy resources has created optimistic expectations on wind and solar displacing fossil fuels. A more detailed assessment, however, reveals that further decreases in the cost of renewable energy technologies face a series of challenges. The dominant crystalline silicon PV technology's cost decline in the past decade was almost exclusively attributable to Chinese solar-panel manufacturing practices that leveraged economies of scale, and advanced processing techniques, as well as "mercantilist" support from the Chinese central and local governments.[87] This is evidenced by the slower commercialization and limited growth of other types of solar energy generation, such as copper indium gallium selenide (CIGS) and cadmium telluride (CdTe).[88] Between 2018 and 2021, the reduction in the cost of solar modules and wind turbines slowed significantly, and, since 2018, renewable contract prices actually increased (Figure 45).[89] The per-watt capacity cost of solar modules and wind turbines is likely to experience a much slower decline in the future, compared with what NZE projects.

Figure 44: Estimates of Wind Indices Integration Costs

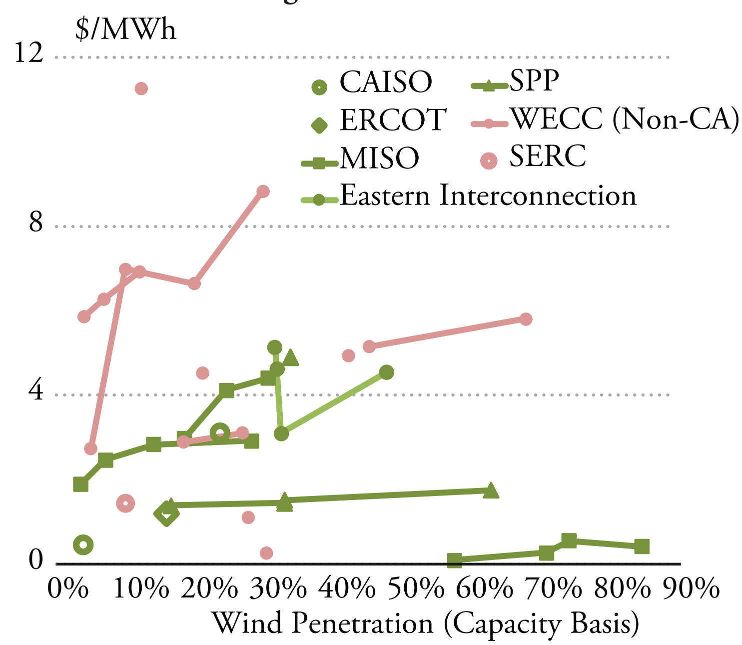
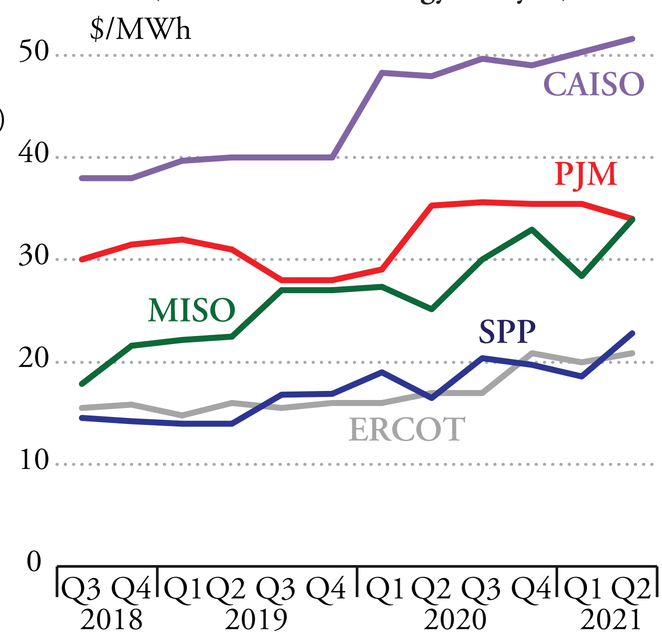


Figure 45: Wind Energy PPA Price (Level 10 Power Energy Analysis)

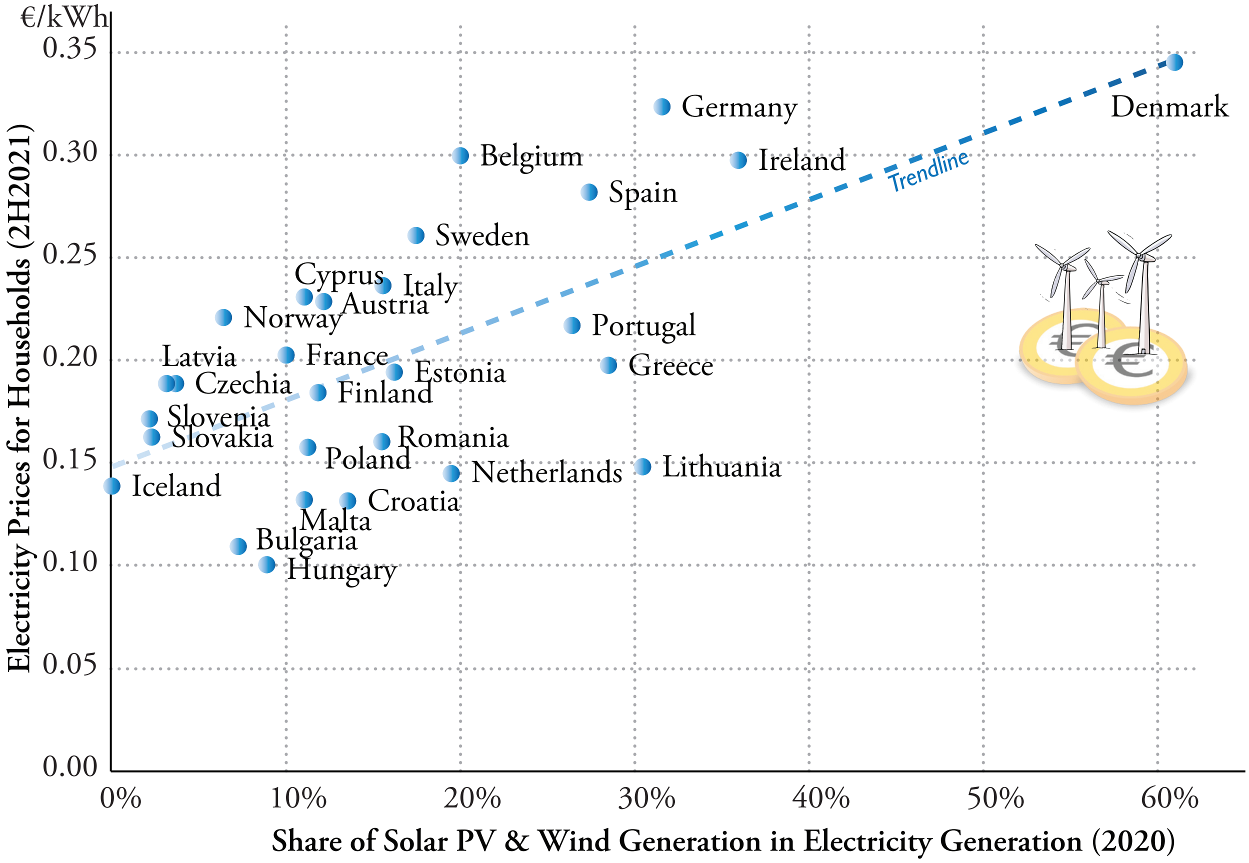


Source: U.S. DOE, *Land-Based Wind Market Report*, 2021 Edition

Renewable technologies require additional high-voltage transmission lines to connect renewable power generators to distant demand centers and large increases in intermittent renewable power sources. Intermittent power continues to suffer from inadequate storage capacity, which forces system operators[90] to constantly modify their day-ahead, hour-ahead, and real-time planning and operating procedures. This heightens the level of grid vulnerability, particularly from cyber security risks.[91]

Electricity prices in Europe confirm this relationship between intermittency and integration costs. System integration costs of renewables can outweigh their expected efficiency improvements as the volume of intermittent supply rises on the power grid. Our analysis based on data from Eurostat shows a trend of rising electricity prices for households in 28 European countries (second half of 2021) with the share of intermittent renewables in power generation (2020).

Figure 46: Solar and Wind Penetration and Electricity Prices in Europe



Source: Energy Policy Research, Eurostat, IEA

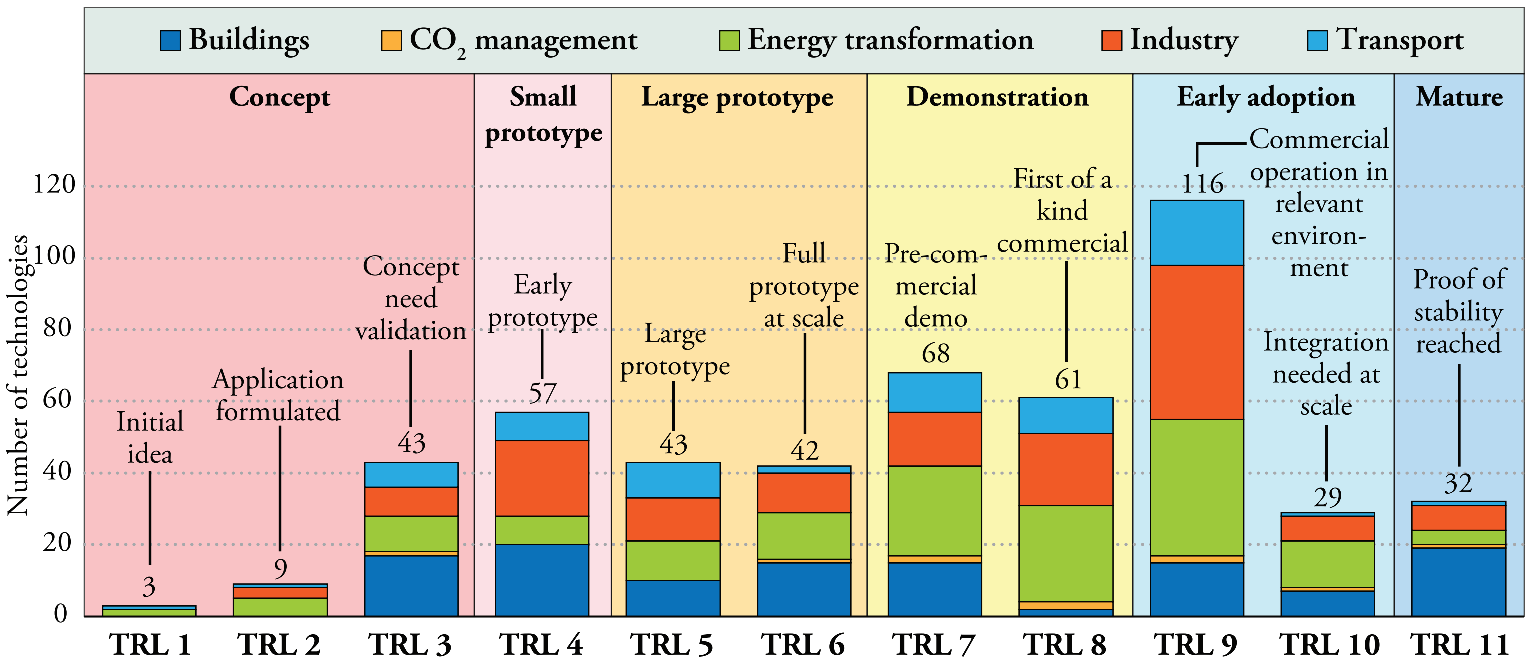
4.2. Two-Thirds of Technologies at Demonstration or Lower Stages

"Energy Technology Perspectives 2023" (*ETP-2023*), one of the IEA's flagship reports, acknowledges that "getting to net zero is not possible without more innovation". According to the report, under the NZE scenario, about 50% of all emissions reductions in 2050 come from technologies that are at prototype or demonstration stages today.[92]

The IEA has an extensive database of 503 individual clean energy technologies at various stages of Technology Readiness Levels (TRLs).[93] The IEA's 11 TRLs are divided into five main groups: Concept (1–3), Prototype (4–6), Demonstration (7–8), Early Adoption (9–10), and Maturity (11). Of the 503 technologies, 326 (almost 65%) are at the "demonstration" or lower stages. A total of 116 technologies (23%) are "in commercial operation in relevant environment" but need "evolutionary" improvement to be competitive. Only 29 technologies (less than 6%) at TRL 10 (one level below maturity) have achieved some commercial competitiveness. There are 32 mature technologies, including large-scale light-water nuclear, hydropower, pumped storage, and fossil-based CCUS for ammonia production, but they are not expected to affect the transition to a noticeable degree.

It takes many years to move from one TRL to another (and 20–70 years from prototype to commercialization, according to the IEA),[94] and it is common for new technologies to stagnate into long periods of no progress and, in many cases, never become commercially competitive. *ETP-2023* asserts that it is necessary to shorten innovation cycles to close this gap in the NZE scenario.

Figure 47. Readiness Levels of 500 Technologies for NZE



Source: Enery Policy Research, IEA ETP Clean Energy Technology Guide

Compared with the technologies at lower levels, the 32 mature technologies at TRL 11 have the greatest possibility of being deployed at scale. However, 19 of them are solely in the buildings sector, which constitutes a proportionally smaller share (direct emissions in buildings was 8% in 2021) of total global emissions. Further, many of the building energy technologies have a relatively modest impact on the transition. For instance, potential markets for some air-to-air heat pumps are limited to northern heating regions in the U.S., Europe, and China. Technologies like smart metering and time-of-use metering, which offer two-way communication with the grid or shift power demand away from peak hours, are likely to be more impactful, but scaling them up globally may face serious opposition from consumers, on the grounds that there are no direct cost savings after investments in related infrastructure and equipment.

Cost and commercialization become a serious challenge in energy-intensive sectors such as industry and energy transformation.[95] There are 14 technologies at TRL 10 and TRL 11 in industry, but only two are of high or very high importance to net zero emissions (ammonia and high-temperature electromagnetic heating for large-scale processes), while potentially much more impactful technologies remain at TRL 9 and below. The zero-carbon production (using carbon capture, utilization, and sequestration) of iron and steel, cement kiln, aluminum, and high-value chemicals[96]—the pillars of modern society—remains extremely expensive and is at pre-commercial demonstration stages.

On the TRL scale, lithium-ion batteries are currently the only competitive battery storage technology, and their use in transport will continue to grow on the back of strong BEV sales. However, this potential growth in the transport sector may be thwarted by sluggish growth in charging infrastructure, rising feedstock costs, and various disadvantages inherent in batteries, such as long charging times, shorter range, and high cost. For grid-scale storage, pumped hydropower is the only cost-competitive option; lithium-ion batteries, flywheels, and liquid air energy storage are deployed in niche markets with massive subsidies from governments and international organizations.

4.3. Critical Mineral Supply Challenges

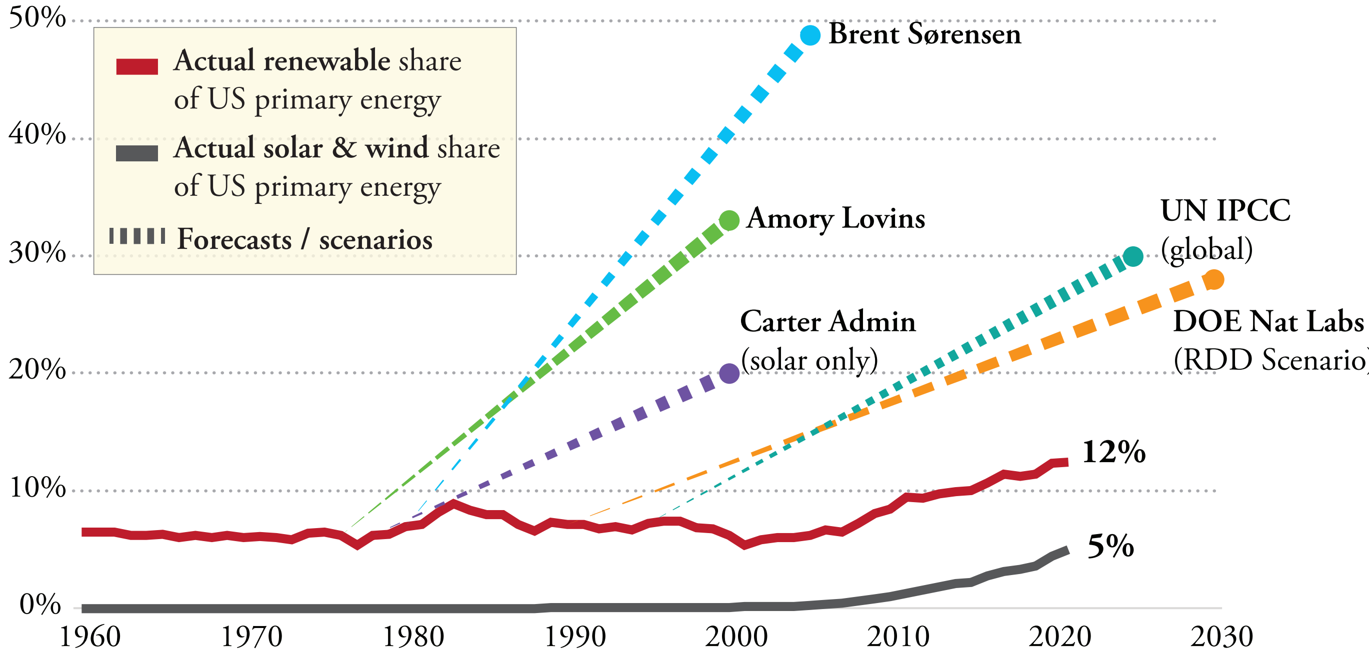
Under NZE, the world will need to mine enormous amounts of critical minerals used for solar panels, wind turbines, batteries, and grid networks. As discussed in Chapter 1, the incremental need for critical minerals, particularly lithium, graphite, cobalt, and nickel, will be at least 1,800% by 2040, even in a less aspirational scenario.[97] In the more aspirational NZE, these percentages will likely escalate quickly for all critical minerals. In *WEO-2022*, the IEA admits that although 80% of NZE demand for copper (which is on the lower end of the scale-up list) might be covered by announced production plans, "meeting the additional demand could be very challenging."[98]

An increasing focus on ecological preservation, more frequent land-use conflicts (and the difficulty of obtaining mining rights), and long project lead times all contribute to the progressively challenging critical mineral supply chain with each additional site of production capacity. A review of mining literature (including the IEA's critical mineral report) reveals that an average project lead time from discovery to production takes at least 10 years but is more likely to be closer to 30 years.[99] Making things worse, the mining industry's exploration expenditures remain nowhere near what NZE requires. For example, S&P Global Market Intelligence reported in March 2022: "Global nonferrous exploration budgets reached US$11.2 billion in 2021, barely more than half the peak of over US$20 billion in 2012, helping drive a multiyear slump in major base and precious metals discoveries."[100] Another S&P article (September 2022) asserts that mining companies are jeopardizing the energy transition by underinvesting in copper mines in favor of short-term returns.[101]

4.4. Problem with Ambitious Scenarios and Targets

The Global Energy and Climate Model (GEC), the IEA's new energy system modeling approach integrating its two main models (World Energy Model and Energy Technology Perspectives Model), is undoubtedly a complex and sophisticated model that builds on the agency's vast expertise and large databases. However, history has shown that mistaken assumptions can lead to major flaws in forecasting and scenario analysis. Such failures have been a consistent feature in previous forecasts predicting the transition from conventional to alternative energy dating back to the late 1970s. Figure 48 (from a JPMorgan analysis) demonstrates that many scenarios, forecasts, and goals in the past decades have underestimated the challenges of transitioning to alternative energies at scale.

Figure 48. Renewable Share of U.S. Energy Demand: Reality vs. Expectations



Source: Recreation of chart from EIA, JPMorgan Asset Management, Vaclav Smil
Note: Renewables include wind, solar, hydropower, geothermal, biomass.

NZE is even more ambitious than previous aspirational scenarios. Renowned scientist Vaclav Smil called these net zero goals not aspirational but "delusional" because they are well beyond our realistic reach.[102]

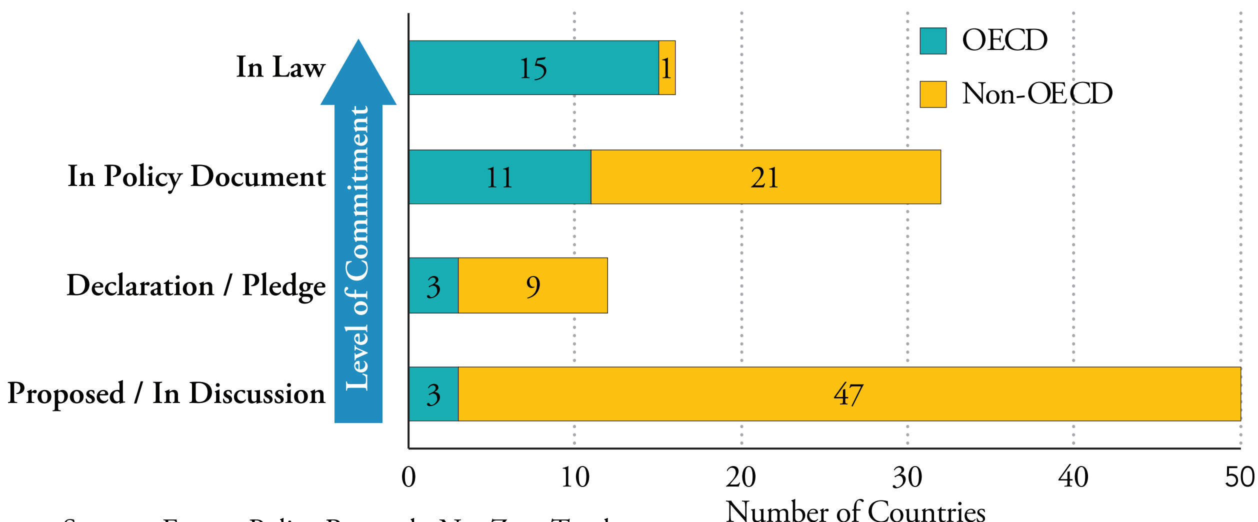
4.5. A Two-Speed Transition

> ***"All countries co-operate towards achieving net zero emissions worldwide."*** – A principle of NZE (GEC Model, p. 7)

NZE requires all countries to cooperate toward net zero emissions by "working together in an effective and mutually beneficial way, and recognizing the different stages of economic development of countries and regions, and the importance of ensuring a just transition."[103] This assumption ignores the complex global political environment and national interests. As has already been happening, the transition efforts will more likely emerge as a two-speed transition, in which non-OECD countries pay lip service to net zero goals without fully following through on their commitments or simply being incapable of making any significant progress by 2050. In fact, the early indications of this divergence have been on display during climate negotiations where developing countries, as a prerequisite to committing to net zero, demand that developed countries act on their Paris Agreement pledge to mobilize US$100 billion per year for developing countries.

Despite the seemingly high level of support for net zero from governments around the world, only a few have shown tangible commitment by making it into law (however unlikely and ambiguous they may be). Because a 2050 target date is well into the future, government leaders—OECD and non-OECD alike—find it politically risk-free to make pledges to achieve net zero emissions without giving much thought to whether such an effort justifies its costs or without making an unbiased and realistic analysis of the scale of the transition. Currently, 110 countries have proposed or committed to net zero by 2050, of which 78 (71%) are non-OECD countries and 32 (29%) are OECD countries.[104] However, only one non-OECD country, Fiji, has passed it into law; 15 OECD countries have passed it into law (Figure 49).

Figure 49. Two-Speed Transition: Net Zero by 2050 Level of Commitment



Sources: Energy Policy Research, Net Zero Tracker

Conclusion

The IEA asserts that the "Net Zero by 2050" scenario would enable a smooth energy transition that ensures constant fuel and electricity supplies, minimal stranded assets, and reduced volatility in energy markets. However, a comprehensive evaluation reveals that the net zero path is anything but smooth, imposing enormous costs and risks on the economies of the West.

NZE would inflict a double whammy on the West. The first blow comes from NZE's recommendation to cease investment in new oil and gas fields beyond those already approved. There is no evidence that the world is experiencing falling demand for hydrocarbons, and policies to restrict supplies would lead to rapid and sustained increases in oil and gas prices. The second blow comes from the switch to a near all-renewable electrical grid, which would have electricity prices soaring more than threefold. These would be body blows to the economies of the West. Even if OECD countries remained fully committed to net zero despite these costs, it is highly unlikely that there would be a sustained two-speed transition. As the developing world fails to meet the energy requirements essential for economic development, most will remain heavily reliant on so-called legacy fuels (fossil fuels and nuclear fuels, when possible). These fuels can deliver sustained, cost-effective, and resilience energy to support economic growth. Renewable and low-carbon energy will play an important role, but it will not see massive introduction until major technological and cost concerns are overcome. Much of the developed world is likely to remain committed to pursuing a costly path toward a net zero future, but cost concerns and failure modes are likely to see a growing realization that the goal is not achievable without accepting substantial constraints to economic growth.

Abbreviations

B/D	Barrels per Day
BCM	Billion Cubic Meters
BEV	Battery Electric Vehicle
BOE	Barrels of Oil Equivalent
CCUS	Carbon Capture Utilization and Storage
CdTe	Cadmium Telluride (solar cell)
CIGS	Copper Indium Gallium Selenide (solar cell)
EIA	U.S. Energy Information Administration
ESG	Environmental, Social, and Governance
EJ	Exajoule (10^{18} joule)
ETP	*Energy Technology Perspectives*
EU	European Union
FCEV	Fuel Cell Electric Vehicle
FSU	Former Soviet Union (countries)
GEC	Global Energy and Climate (Model)
GHG	Greenhouse Gas Emissions
HDI	Human Development Index
ICE	Internal Combustion Engine
IEA	International Energy Agency
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MMB/D	Million Barrels per Day
MMBtu	Million British Thermal Units
NZE	Net Zero by 2050
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaic
RD&D	Research, Development and Demonstration
SDG	Sustainable Development Goals
SDS	Sustainable Development (scenario)
STEPS	Stated Policies (scenario)
TOE	Tonnes (metric tons) of Oil Equivalent
TRL	Technology Readiness Level
WEO	*World Energy Outlook*

Appendices

Appendix 1: Incompatibility of NZE and Sustainable Development Goals

The IEA claims that the NZE scenario integrates three objectives of the UN 2030 Agenda for Sustainable Development: tackling climate change (Sustainable Development Goal #13); achieving universal access to modern energy services by 2030 (SDG 7); and reducing the health impacts of air pollution (SDG 3.9).[105] However, an attempt to achieve net zero in developing countries is fundamentally incompatible with other sustainable development goals, as the transition cost will make it extremely difficult to provide developing countries with reliable, affordable energy services by 2030. Also, the increased penetration of intermittent energy technologies will significantly slow down, if not halt at once, the cost-effective coal-to-gas switching efforts to fight local air pollution in highly polluted areas in developing countries and will very likely force these countries to continue using coal for heating and cooking.

Appendix 2: The Price Elasticity of Demand

The price elasticity of demand refers to the change in demand relative to changes in price, so that an elasticity of –0.1 means that if prices rise 10%, demand will drop 1%, or one-tenth. In theory, it is possible to estimate price elasticities using data price and demand (or supply) data, but the practice has proved much more difficult for a variety of reasons.

First, crude oil prices are not paid by consumers except in rare instances (some power producers historically burned crude). Thus, the demand response is to the price for products such as gasoline and diesel fuel, which are only partly related to crude oil prices. Refining and transportation costs vary somewhat from place to place, although most notably in small, isolated markets; but government policies—especially taxation—mean that prices for gasoline range from negligible in some oil production countries to three times that for crude oil in most European nations. Thus, a change in crude oil prices does not have the same effect across the board, and this also varies over time.

The second problem is that consumers' ability to respond to prices changes over time, based on a variety of factors. In the U.S., households switched from heating oil to natural gas in the 1980s; but in many places, natural gas supplies are not available or are available only to a limited degree. Also, after a long period of low oil prices, the availability of more efficient capital equipment from boilers to automobiles might be limited. In the 1970s U.S., few small car models were manufactured, whereas now, they are much more available. Now, electric vehicles might be preferred should oil prices soar, but automakers are unlikely to be able to accelerate production quickly.

Finally, there are few or no instances when prices change and then remain stable, allowing for an estimate of demand response to that level of price increase. The spikes in the 1970s lasted for 11 and six years, respectively, before being mostly reversed in 1986, which saw demand growth resume. How much more demand would have been reduced if that had not happened is a subject for conjecture but hardly definitive.

These problems are reflected in the variety of estimates made by different studies over the years, with many illustrated in Table 14 (collected by Michael Lynch).

Table 14. Estimates of Price Elasticity of Demand

	Year	Price Elasticity		Region
Long Run				
Liddle and Huntington	2020	–0.34	Energy	
Liddle and Huntington	2020	–0.66	Gasoline	High-income Europe
Liddle and Huntington	2020	–0.25		Non-OECD
Huntingon, Barrios, and Arora	2019	0.5	Crude Oil	OECD
Huntingon, Barrios, and Arora	2019	0.99	Gasoline	OECD
Huntingon, Barrios, and Arora	2019	0.89	Natural Gas	OECD
Huntingon, Barrios, and Arora	2019	–0.15	Crude Oil	LDC
Huntingon, Barrios, and Arora	2019	–0.61	Gasoline	LDC
Huntingon, Barrios, and Arora	2019	–0.5	Diesel	LDC
Huntingon, Barrios, and Arora	2019	–1.36	Natural Gas	LDC
Dahl	2014	–0.43	Oil	
Dahl	2014	–0.61	Gasoline	
Dahl	2014	–0.67	Diesel	
Dahl	2014	–1.5	Natural Gas, Industry	
Dahl	2014	–0.56		
Labandeira et al.	2016	–0.526	Gasoline	
Labandeira et al.	2016	–0.31–(–1.16)	Energy	
Labandeira et al.	2016	–0.566	Natural gas	
Uría-Martínez et al.	2018	–0.26	Crude Oil	
Uría-Martínez et al.	2018	–0.611		
Uría-Martínez et al.	2018	–0.823	Oil Products	
Gately and Huntington	2002	–0.24	Oil	OECD
Gately and Huntington	2002	–0.18		Non-OECD
Short Run				
Caldara et al.	2016	–0.13	Consensus	
Labandeira et al .	2016	–0.194	Gasoline	
Labandeira et al.	2016	–0.184	Natural gas	
Uría-Martínez et al.	2018	–0.074	Crude Oil	
Uría-Martínez et al.	2018	–0.106	Crude Oil	
Uría-Martínez et al.	2018	–0.143	Oil Products	

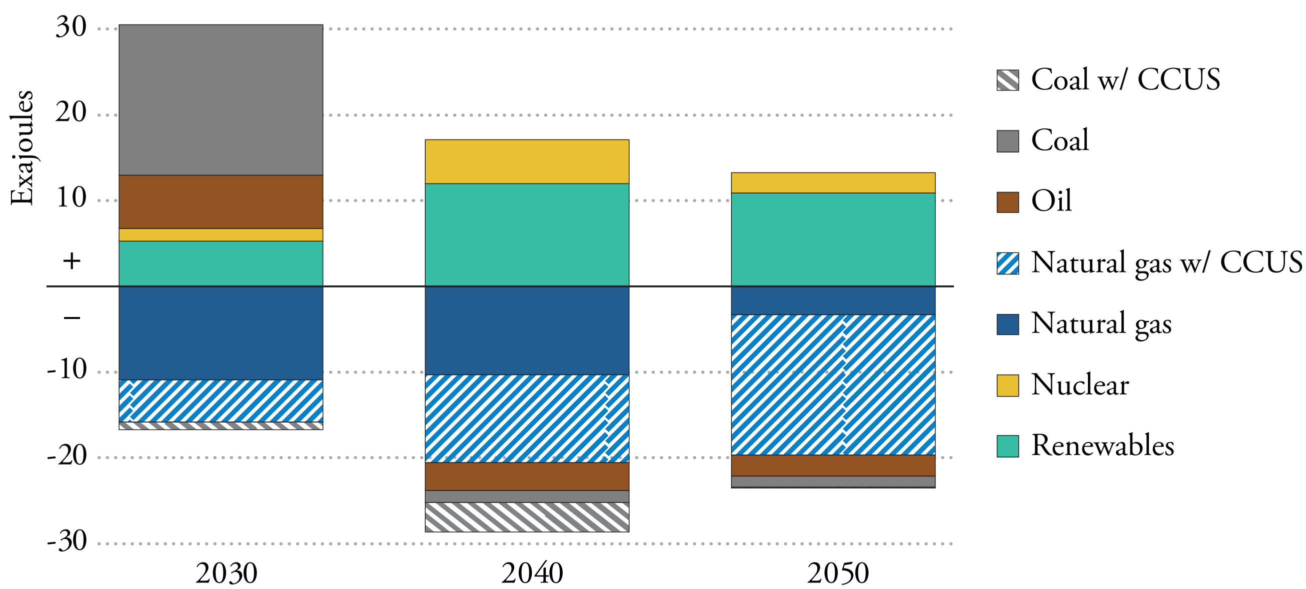
Source: Michael Lynch

Appendix 3: The Effects of the Russia–Ukraine War on NZE

Since the IEA published its first standalone Roadmap on NZE in May 2021, the world has witnessed many unexpected events—most notably Russia's invasion of Ukraine and the resulting energy crisis in Europe. Governments throughout Europe had to face the hard reality of energy security and secure the supply of conventional fuels from other sources while supporting Ukraine's efforts to restore its territorial integrity. The war signified the impossibility of reaching net zero without compromising energy security, as European countries had to extend the closing dates of their coal power plants and sign new liquefied natural gas (LNG) deals before the winter. Against this background, the IEA released the *World Energy Outlook 2022* (*WEO-2022*) which included updated NZE figures.

Compared with the *Net Zero by 2050* report (2021), the updated NZE in *WEO-2022* has higher oil demand in the mid-2020s and requires higher short-term supply from OPEC (partly due to lower Russian production). The IEA argues that "investments with shorter lead times and quicker payback periods, including extending production from existing fields" are necessary to close this gap.[106] According to the IEA's estimate, this will result in OPEC's increasing its share of the global oil supply from 35% in 2021 to 52% in 2050 (Figure 50). However, this share could be much higher, as oil demand in 2050 will likely be much higher than NZE. In a combined scenario, where non-OPEC countries comply with NZE but OPEC countries maintain their STEPS production levels, the share of OPEC will be 82% by 2050. Note that even this mixed scenario assumes that about half the global oil supply is lost, compared with STEPS.[107]

Figure 50. Updated NZE (*WEO-2022*) vs. Previous NZE (NZE report 2021)



Source: Energy Policy Research, IEA. Net Zero by 2050 (2021), IEA. World Energy Outlook 2022

The updated NZE scenario also has lower Russian natural gas production and overall lower gas consumption globally, compared with the *Net Zero by 2050* report. This reduction in gas demand gives way to coal demand due to higher price differentials between the two fuels. The natural gas prices across the scenarios are higher in *WEO-2022* than in the previous iteration, reflecting the impact of Russia's invasion of Ukraine. Higher oil demand and higher coal demand until the 2030s, compared with the original estimate, mean that the world must use even less fossil energy, abated or unabated, in the 2040s and 2050s.[108]

Appendix 4: Oil and Gas Production and Price Without Approved Projects

Projected Oil and Gas Production Under No New Oil and Gas Fields Scenario

Figures 51 and 52 are based on the IEA's projections made in 2020, which were normalized such that the most recent year's (2018) oil and gas production volumes is equal to in the production volumes in 2021. According to the adjusted IEA projections, after investment in existing fields (orange), global oil production will more than halve, from 89.9 million barrels per day (MMB/D) in 2021 to 41 MMB/D in 2040. Natural gas production will also halve, from 4,036 billion cubic meters (BCM) to 2,046 bcm during the same period. The average rate of decline is 4% for oil and 3.5% for natural gas. Without investment in existing fields (dark green alone), these numbers would be 20 MMB/D and 879 BCM, respectively.

Figure 51. Adjusted IEA: Oil Production

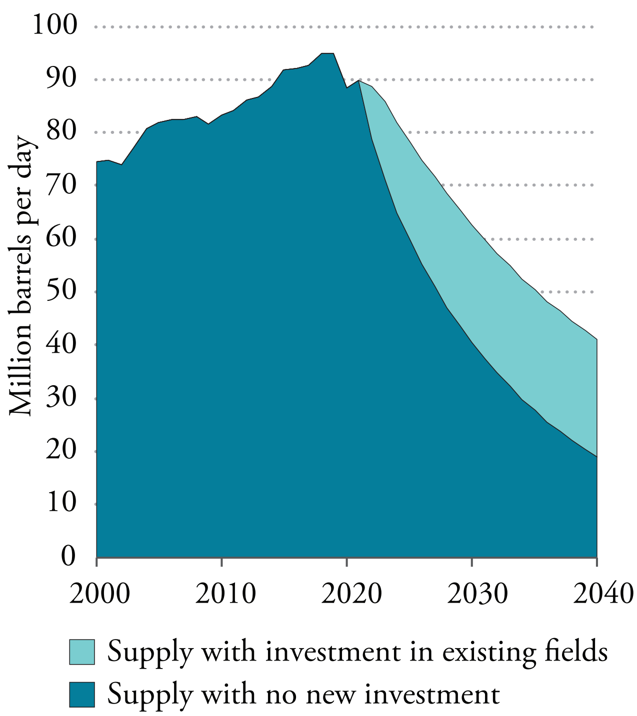
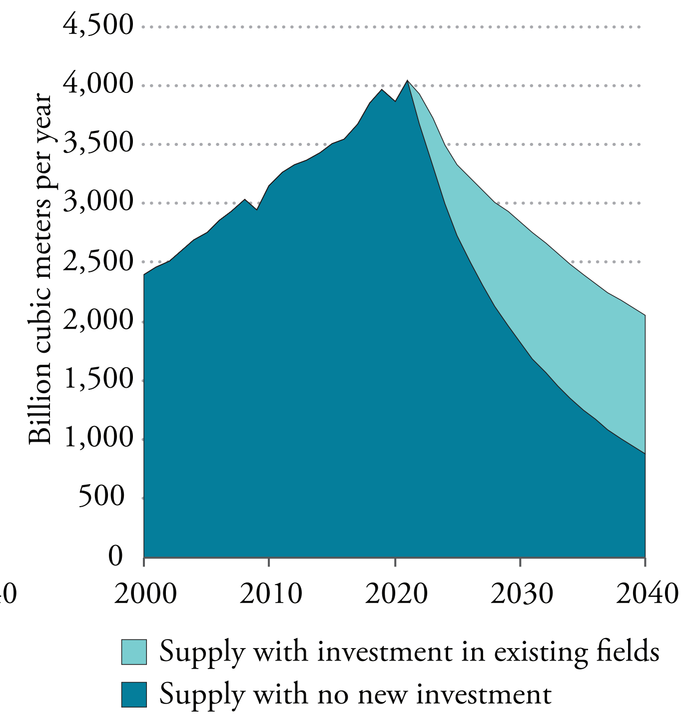


Figure 52. Adjusted IEA: Gas Production



Source: Energy Policy Research, IEA, *The Oil and Gas Industry in Energy Transitions* (2020), BP

Energy Policy Research Foundation's Michael Lynch's analysis, based on observed decline rates by region and field type, shows that the IEA's projections might be underestimating the potential decline. According to Lynch's analysis, the decline in oil and gas production between 2021 and 2040 will be even steeper than in the adjusted IEA estimate (Figures 53–54). In

Lynch's analysis, oil production drops to 28 MMB/D and natural gas to 981 BCM, with the average annual decline rates of 6% and 7.2%, respectively. The decline-rate assumptions used here are listed at the end of this appendix. Due to the large differences between the adjusted IEA estimates and Lynch's estimates, this report considers both of them as upper and lower bounds.

Figure 53. Lynch: Oil Production

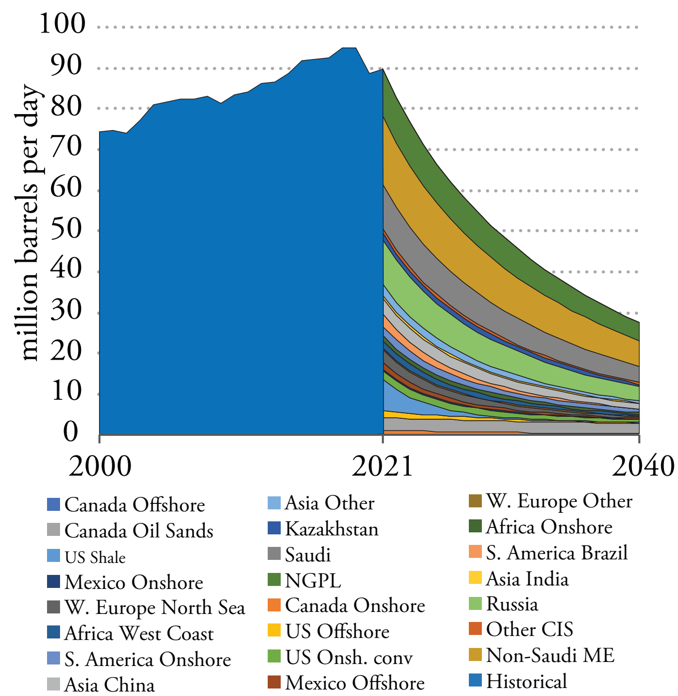
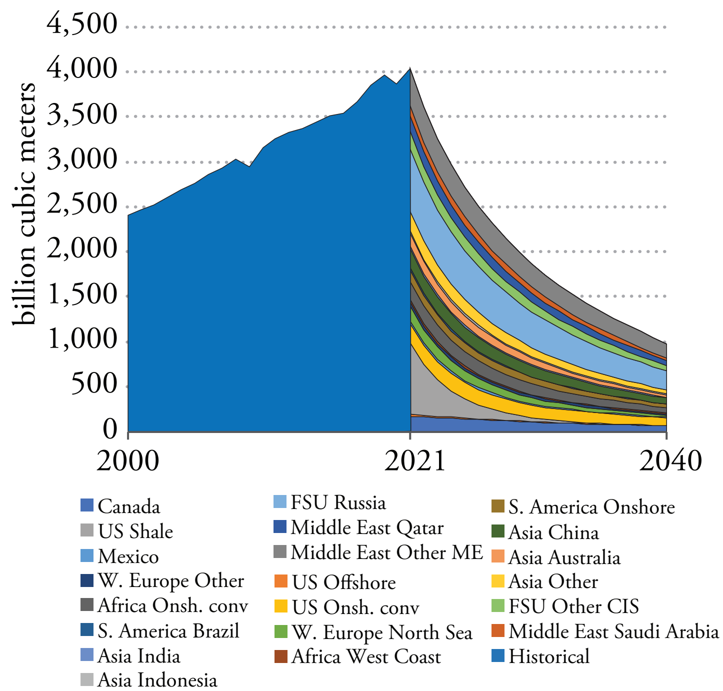


Figure 54. Lynch: Gas Production



Source: Energy Policy Research, Michael Lynch

The decline rates described here are used to project regional production, and then the aggregate global decline rate is normalized such that it matches the actual 2021 data from *BP Statistical Review of World Energy 2022*. Natural gas production data are also taken from *BP Statistical Review of World Energy* for years up to 2021. The 2022 estimates have been removed from the report's original analysis due to data availability as well as to align with the IEA's NZE scenario's latest year.

Table 15. Oil Decline-Rate Assumptions

Country / region	Type	Decline Rate
Canada	Offshore	10%
	Onshore conventional	5%
	Oil Sands	1%
US	Offshore	12%
	Shale	28%
	Onshore conventional	6%
Mexico	Onshore	5%
	Offshore	10%
Western Europe	North Sea	10%
	Other	5%
Africa	West Coast	8%
	Onshore conventional	5%
S. America	Onshore conventional	6%
	Brazil	13%
China		6%
India		6%
Other Asia		8%
Russia		6%
Kazakhstan		5%
Other CIS		5%
Saudi Arabia		5%
Other Middle East		5%
Natural gas plant liquids		5%

Table 16. Natural Gas Decline-Rate Assumptions

Country / Region	Type	Decline Rate
Canada		5%
US	Offshore	12%
	Shale	28%
	Onshore conventional	5%
Mexico		6%
Western Europe	North Sea	10%
	Other	5%
Africa	West Coast	8%
	Onshore conventional	6%
South and Central Americas	Onshore conventional	6%
	Brazil	12%
China		6%
India		6%
Australia		8%
Indonesia		7%
Other Asia		8%
Russia		6%
Other CIS		6%
Qatar		6%
Saudi Arabia		6%
Other Middle East		5%

Price Elasticities of Demand and Oil and Gas Prices

A basic uncertainty involves the initial year price that the elasticity is operating from. In the past five years, the price has varied from deeply negative to well over US$100 in nominal terms. The most recent annual crude price was US$94.9 in 2022. Using this base price, Table 17 shows the first five years' price levels needed to cope with the estimated drop in supply, according to Lynch's and IEA's production projections, depending on the short-term price elasticity of demand.[109] Price elasticity of demand is a measure of the responsiveness of the quantity demanded of a good or service to changes in its price.

Table 17. Short-Term Price Response (in constant USD 2022)

	Price Elasticity	Year 1	Year 2	Year 3	Year 4	Year 5	Year …
Crude (Year 0 = US$94.9—WTI Spot in 2022)							
Based on Lynch's production projections	–0.1	169.6	295.2	502.6	840.5	1,384.3	…
	–0.15	144.7	216.1	317.4	459.6	657.9	…
	–0.2	132.2	181.2	244.9	327.2	433.1	…
	–0.3	119.8	149.4	184.4	225.7	274.3	…
Based on IEA's production projections	–0.1	107.4	141.2	207.9	302.8	430.6	…
	–0.15	103.2	124.9	164.2	214.2	274.5	…
	–0.2	101.1	117.1	144.7	177.7	215.3	…
	–0.3	99.1	109.5	126.7	146.0	166.5	…
Natural Gas (Year 0 = US$6.45—Henry Hub Spot in 2022)							
Based on Lynch's production projections	–0.1	13.2	26.1	49.5	90.9	162.8	…
	–0.15	11.0	18.1	28.9	45.0	68.7	…
	–0.2	9.8	14.6	21.2	30.0	41.9	…
	–0.3	8.7	11.5	15.0	19.2	24.2	…
Based on IEA's production projections	–0.1	8.2	12.4	20.2	30.1	40.5	…
	–0.15	7.6	10.2	14.5	19.2	23.7	…
	–0.2	7.3	9.2	12.1	15.0	17.6	…
	–0.3	7.0	8.2	10.0	11.6	12.9	…

It seems unlikely that the price could increase this much for a lengthy period without triggering a major recession, and long-term effects would start to come into play in the medium term (more capital equipment replacement and radical behavioral changes that forcefully alter modern lifestyles). Using both Lynch's and IEA's production estimates, short-term oil price elasticity of –0.3 for each year implies an increase of 75% to 189% just in the first five years. For natural gas, the price increase range is 100%–275% during the same period. The price elasticities of –0.1 have even larger increases: 350%–1,350% for oil and 520%–2,400% for natural gas in the first five years. Demand for oil and gas may become more price elastic over time because of various adjustments, but these efforts will severely incapacitate the economic well-being and national security of most of the world.

Endnotes

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2 Myllyvirta, L. et al. (Feb 2023). *China permits two new coal power plants per week in 2022*. Centre for Research on Energy and Clean Air (link).
3 BloombergNEF. "Energy Transition Investment Trends," Jan. 2023 (link); idem, "Global Investment in Low-Carbon Energy Transition Hit $755 Billion in 2021," Jan. 27, 2022 (link); *BP Statistical Review of World Energy 2022* (link)
4 IEA, "Net Zero by 2050: Summary for Policy Makers," Last accessed Feb. 22, 2023 (link).
5 IEA, *Net Zero by 2050* and *World Energy Outlook 2022* reports.
6 IEA, *Net Zero by 2050*, p. 14.
7 According to the IEA, the global oil supply in 2021 was 183 EJ, of which 152 EJ came from the energy use of oil. Under NZE, the annual global oil supply is projected to decrease to 40 EJ in 2050: 29 EJ for non-energy use and 11 EJ for energy use. The decrease in annual oil supply for energy use from 152 EJ to 11 EJ represents a 13.8x contraction; see *WEO-2022*, table A.1c.
8 GDPs of all regions are expected to grow to various extents: Russia's compound annual average growth rate (CAGR) is 0.1% between 2021 and 2050; India has the highest CAGR, of 5.2%, during the same period. Africa (4.1%), Middle East (3.2%), and much of Asia Pacific (China, 3.4%, ASEAN, 3.8%) enjoy high growth rates, while the Americas (U.S., 2%, Latin America, 2.4%) and Europe (1.6%) will have relatively slow growth rates.
9 IEA, *World Energy Outlook*, Oct. 2022, p. 134 (link).
10 Under its new modeling framework—Global Energy and Climate Model (GEC)—the IEA has three scenarios: NZE, STEPS, and the Announced Pledges Scenario (APS). APS assumes that all existing climate commitments by governments will be successfully met on time. We largely omit this scenario in this analysis, as APS is still less aspirational than NZE. In previous iterations of *WEO*, the IEA employed various other scenarios, most notably, the Current Policies Scenario (projection based on existing policies) and the Sustainable Development Scenario (compatible with the Paris Agreement goal of 2-degree scenario).
11 Balula, L. and Bina, O., "Summary – Literature Review of Key References for Scenario Building," WP4 Brief, URBACHINA, Oct. 21, 2013.
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13 Note that the crude price was much higher in 2022. For example, WTI Spot Crude was USD 94.9 (nominal).
14 Note that although the *WEO-2022* uses a different US$ real term (2021 US$) from the *Net Zero by 2050* report (2019 US$), future price figures remain the same as in the *Net Zero by 2050* report.
15 IEA, *Global Energy and Climate Model: Documentation*, Oct 2022, p. 21 (link).
16 Fatih Birol, "Europe and the world need to draw the right lessons from today's natural gas crisis," LinkedIn, Jan 13, 2022 (link).

17 The historical rate is from the United Nations, "World Economic Situation and Prospects: May 2022 Briefing, No. 160," May 3, 2022 (link).
18 The EU ETS has garnered much attention as a good example of pricing carbon emissions, but since it only covers electricity, energy-intensive industry, and aviation (~40% of the bloc's total emissions, according to the EU – EU Emissions Trading System [EU ETS] link) emissions from road transport, heat production, and energy production in other sectors are covered by national ETSs. According to the World Bank's Carbon Pricing Dashboard (link), all OECD countries, apart from a few wealthy Western and northern European small nations (except UK), had an average carbon price of less than US$53 as of 2022. Non-European OECD had even lower prices, with Chile, Colombia, and Japan at less than US$6 in 2022.
19 Constant dollar value, per the U.S. Census Bureau, is "a value expressed in dollars adjusted for purchasing power"; "Current versus Constant (or Real) Dollars," Last accessed Apr. 10, 2023 (link). It is used to compare dollar values between in periods and is inflation-adjusted.
20 The U.S. inflation rates from World Bank, "Inflation, consumer prices (annual %) - United States" (link).
21 IEA, "Do we need to change our behaviour to reach net zero by 2050?" Oct. 29, 2021 (link).
22 IEA, *Net Zero by 2050*, p. 67.
23 IEA, "Do we need to change our behaviour to reach net zero by 2050?"
24 Abatement in this context means using Carbon Capture and Storage (CCS), or Carbon Capture, Utilization and Storage (CCUS). Oil includes its consumption for all purposes, including non-energy uses such as using it as petrochemical feedstocks.
25 The IEA employs the physical energy content method when calculating primary energy equivalent and assumes high conversion efficiency rates for electricity produced by hydro and non-thermal means (wind, solar, etc.) and low rates for thermal means (geothermal, coal, nuclear, etc.). However, the conversion efficiency gains of renewables will be significantly offset by various transformations (e.g., hydrogen production) required for a low-carbon transition; IEA, "Key World Energy Statistics Methodology: Conversion factors and unit abbreviations," 2021 (link).
26 One exajoule (EJ) per annum equals about 484,000 barrels of oil equivalent per day.
27 It could be argued that Soviet statistics were highly inflated before the Soviet collapse, leading to the large drop in numbers. But even that case would support the findings of this analysis that energy transition is hard and rare.
28 On economic recessions, see: Weber, I., *How China escaped shock therapy: the market reform debate*, Abingdon, Oxon: Routledge, 2021, p. 6. ISBN 978-0-429-49012-5. OCLC 1228187814; on poverty, see: Round, J., and Kosterina, E., "The construction of 'poverty' in post-Soviet Russia", Perspectives on European Politics and Society, 2005, 6:3, 403-434, DOI:10.1080/15705850508438926.
29 Romero-Torres, J., "Energy Efficiency: Why Not Enough is Being Invested," ADB, Oct. 12, 2017 (link).
30 World Bank, "Energy intensity level of primary energy (MJ/USD 2017 PPP GDP) – China," Last accessed Jan. 5, 2023 (link).
It is worth noting that China is known for its repeated incidents of inaccurate energy and environment data, and local authorities have had incentives to provide falsified data in key

years such as 2015.

31 According to the IEA, zero-carbon ready buildings are "highly energy-efficient and resilient buildings that either use renewable energy directly or rely on a source of energy supply that can be fully decarbonized, such as electricity or district energy"; Delmastro, C., and Gordon, M., "Pathways for delivering zero-carbon ready buildings by 2030," IEA, Oct. 27, 2022 (link).

32 In the *Net Zero by 2050* report, index 2020=100, 2030 target=50 and 2050 target=20. IEA, *Net Zero by 2050*, table 2.3, "Key global milestones for energy efficiency in NZE."

33 European Commission, "Questions and Answers on the Renovation Wave," Oct. 14, 2020, (link).

34 World Bank, "GDP (current US$) – Japan, France."

35 IEA, *Net Zero by 2050*, p. 119.

36 Ibid., p. 171.

37 IEA, *World Energy Outlook 2022*, p. 107.

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39 IEA, *World Energy Outlook 2022*, p. 24.

40 This is different from the natural decline rate which is associated with the complete cessation of investment in all fields, including the existing ones.

41 Note that the updated gas supply is downgraded from *Net Zero by 2050*.

42 IEA, *Net Zero by 2050*. p. 101.

43 OECD, Energy Prospects to 1985, Paris (1974).

44 Caldara, Dario, Michele Cavallo, and Matteo Iacoviello, "Oil Price Elasticities and Oil Price Fluctuations," International Finance Discussion Papers 1173 (2016), p. A.6. Additional price elasticity estimates can be found in Appendix 3. It presents several estimates for demand elasticities, primarily by academic researchers, but they are mostly static estimates. Initial reductions in demand are much easier as demonstrated by the behavior in the 1970s, when much of the savings occurred from fuel-switching by large users, especially power plants that replaced heavy fuel oil with coal. The unused fuel oil was then cracked into lighter products. Some of the estimates do take this into account.

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46 Note that predicting oil price is extremely hard, as many factors contribute to global oil and gas prices. Price elasticity of demand is a helpful way to understand the relationship between price and demand, but it should not be taken as a fail-proof formula.

47 The Year 0 figures are from 2022 and can be different from the figures in Chapter 2 on IEA oil and gas price assumptions due to different years' dollar values adjusted for purchasing power. Additionally, the crude oil price here is WTI spot, which is historically lower than the OECD's average import price used by the IEA.

48 In this analysis, Year 0 is 2022, in accordance with the latest NZE, and thus 2030 would be Year 8.

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106 IEA, *World Energy Outlook 2022*, p. 134.
107 In STEPS, the IEA's assumed OPEC oil production is 43.1 MMB/D in 2050. Non-OPEC's production in NZE in 2050 is 9.2 MMB/D.
108 IEA, *World Energy Outlook 2022*, p. 134.
109 Note that predicting oil price is extremely hard, as many factors contribute to global oil and gas prices. Price elasticity of demand is a helpful way to understand the relationship between price and demand, but it should not be taken as a fail-proof formula.

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