CARBON-FREE EUROPE
AN INCLUSIVE CLIMATE INITIATIVE

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UNDERSTANDING RISKS IN NET-ZERO PATHWAYS FOR EUROPE

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INTRODUCTION

Carbon-Free Europe (CFE) advocates for the European Union (EU) and its Member States to reach carbon neutrality by 2050, and do so in a way that helps strengthen energy sovereignty and economic opportunity. We recently conducted modelling analysis to identify five different pathways for the EU and United Kingdom (UK) to get to net-zero by 2050. Each pathway examines different economic, technological, and land-use constraints, so that policymakers, analysts, and the public can evaluate the benefits and challenges for themselves.

While there are many ways for Europe to reach carbon-neutrality, some pathways are more risky than others. Particularly at a moment when Europe and the world must move to clean energy, policymakers and advocates often emphasise the opportunities of getting to net-zero. We examine those, and they are plentiful, in a separate analysis.

This analysis, however, looks at what needs to happen to reach net-zero for each pathway, and the different risks that could reduce the likelihood of that pathway becoming reality. These risks are perhaps even more important to understand as decisions are being made in real time: on what technologies to include in the taxonomy, how to balance sovereignty, cost, and elimination of emissions, and how to ensure energy reliability. As we analysed these results, three critical points emerged that should help inform EU, Member State, and UK decisions.

KEY TAKEAWAYS

1. **The greatest chance of achieving carbon neutrality by 2050 is to use every available clean energy technology.** Technologies and fuels are unpredictable and the EU and UK should hedge their bets by investing in and deploying a diverse portfolio of clean energy technologies.

2. **The least likely pathway to net-zero is one that relies exclusively on renewables and shuts out the use of nuclear and carbon storage.** While all pathways are likely to have a high amount of renewables, fully decarbonising will require additional options to ensure reliability, lower costs, energy sovereignty, and overall feasibility of meeting climate targets.

3. **Rapid electrification of buildings, transportation, and industry is essential for reaching net-zero.** Even with energy efficiency, electricity demand will increase dramatically, at least 3 times higher than 2022 when including hydrogen production. No matter what pathway Europe pursues, this is a huge infrastructure challenge both to electrify and build out the necessary clean energy to power everything.

THE EU AND UK TODAY

In 2019, 71% of the EU's energy came from fossil fuels (13% from coal, 22% from gas, and 36% from petroleum products like crude oil). Nuclear energy supplied 13% and renewables provided 15%. The most emissions come from the transportation sector (31%) followed by power (29%), industry (22%), then buildings (14%). 2019 is a good baseline year to understand Europe's long term energy demand and supply since impacts from the pandemic have heavily skewed data from 2020-2021. For example, energy demand in 2020 dropped around 10% below 2019 levels. We anticipate high rebounds in expected energy use and emissions.

In the UK, 78% of energy supply comes from fossil fuels (3.5% from coal, 39.5% from gas, and 35% from oil, assuming 2019 data). Nuclear energy supplied 9% and renewables provided 4%. The most emissions come from transportation (35%), followed by residential and commercial buildings (25.6%), electricity (21%), and industry (9.4%).

ABOUT OUR ANALYSIS

CFE, in partnership with Evolved Energy Research, analysed five different pathways for the EU and UK to reach net-zero emissions by 2050: 1) Core, 2) Slow Demand Transformation, 3) 100% Renewable Primary Energy, 4) Limited Renewable Siting, and 5) Domestic Preference.

All pathways achieve a 55% reduction from 1990 levels in energy and industrial emissions (for the EU and UK) by 2030 and net-zero by 2050.

Since there is uncertainty in knowing how Europe will achieve full decarbonisation, each pathway explores different choices Europe might make and/or barriers Europe might face. The model then applies constraints to reflect these various circumstances and finds the optimal way to get to net-zero within those restrictions. The results show us five pathways that all reach net-zero emissions by 2050 – but not all pathways are created equal. Below we discuss what needs to happen to reach net-zero for each pathway, and the different risks that could reduce the likelihood of that pathway becoming reality.

RISKS TO ACHIEVING NET-ZERO PATHWAYS

There are many types of risks to consider when planning for a net-zero future, including resource, economic, technological, and social risks. Discussing some key risks for each pathway shines light on potential challenges and fail points. These range from risks of innovative clean energy technologies not coming down in cost to large scale infrastructure projects requiring intercontinental coordination, financing, and manufacturing. All pathways come with a degree of risk, but an honest conversation around the likelihood of accomplishing various pathways is essential for smart policy making.

CORE PATHWAY

> **Description: This pathway achieves emissions targets with high levels of electrification (in transport, buildings, and industry), improvements in energy efficiency, and significant deployment of all available clean energy technologies. Clean energy technologies have central cost and availability assumptions. Parts of heavy industry that cannot be electrified are decarbonized with hydrogen (iron and steel) and carbon capture (cement). Residual fossil emissions in industry and transportation are offset by a modest amount of direct air capture.**

This is the lowest-risk, lowest-cost pathway because it assumes the deployment of every possible clean energy technology. It includes viable innovative technologies we expect to be commercially available with existing clean resources like renewables, hydro power, and nuclear power. By combining renewables with firm, dispatchable resources like geothermal, hydro, carbon capture, and nuclear, this pathway allows for technologies to be deployed where they are most cost-effective to decarbonise different parts of the economy.

Even with energy efficiency, we still see a threefold increase in electricity demand. The buildout of clean energy technologies to meet that demand is no small feat. Supply chains will need to rapidly ramp up for critical minerals, solar panels, wind turbines, steel, cement, uranium fuel sources, transmission lines, and more. This is not just a risk for this pathway, all pathways see at least a threefold increase in electricity demand and will face similar infrastructure challenges.

The Core pathway also includes two additional risks that are inherent in every strategy to decarbonize industrialised economies. First, there is a risk that the innovative technologies we still need at commercial scale to displace fossil fuels in all sectors of the economy will not be cost competitive. Second, social and/or political factors may prevent us from enacting the policies that help us develop, finance, and deploy at scale clean energy technologies that are vital to displacing fossil fuels. This could take the form of local opposition to the siting of solar or wind projects, to broader mobilisation against the use of specific clean technologies, like carbon capture.

This pathway relies on a significant buildout of transmission and hydrogen pipeline infrastructure to transfer high-quality clean energy resources to demand centres. This will require ramping up the manufacturing and financing of large-scale projects while overcoming siting challenges. Clean hydrogen production will also need to be rapidly scaled, which assumes costs will decline for various methods of clean hydrogen production.

Some remaining emissions will need to be offset by direct air capture in the later years, another currently expensive technology that needs to significantly come down in costs to deploy at scale.

SLOW DEMAND TRANSFORMATION

> **Pathway Description: The EU and UK do not rapidly electrify buildings, surface transportation, and industrial processes that currently rely on fossil fuels. This leads to a higher reliance on liquid fuels (for example gasoline, diesel, or liquefied natural gas as opposed to electricity), which will need clean alternatives like zero-carbon fuels (for example, low-carbon hydrogen or ammonia) and advanced liquid biofuels (for example, cellulosic ethanol or renewable hydrocarbon fuels. Today's first generation biofuels include ethanol and biodiesel), a more costly option in the long run than a highly electrified system. Direct air capture is required to offset residual emissions in 2050. This is the only scenario that assumes a slower demand-side transformation.**

While the EU has ambitious electrification targets, there are real world cost and infrastructure barriers that could get in the way. This pathway assumes that economic, political objections, and technology issues delay the demand-side switch electrification of buildings and industries that currently rely on natural gas, and light, medium, and heavy-duty vehicles powered by petroleum.

For this pathway to happen, Europe would need to massively expand its use of biomass resources in the 2030 to 2040 time frame. This assumes increased social and political willpower to expand biomass production as well as sufficient resources. It also assumes widely available, cost-competitive advanced biofuels, which don't yet exist.

For the first decade or so, this scenario is fairly affordable compared to other net-zero scenarios because there is less spent on electrification of industry, buildings, and transport. However, in the long-run, the remaining liquid fuels in the system will need to be rapidly replaced by zero-carbon fuels, a very expensive endeavour. Much of this will need to be imported as well, as Europe is constrained in its resources for zero-carbon fuels due to limited biomass supplies and limits on renewables availability to produce electric fuels. This will leave customers exposed to high zero-carbon fuel prices, decreasing social support for the transition.

Because this scenario delays the demand-side transformation, reaching net-zero by 2050 requires a larger deployment of direct air capture in the last few years to compensate for the slow efforts near the beginning and the residual fossil energy in the system. This, of course, assumes direct air capture technologies will be commercially available and cost-effective. It will also mean potential social challenges with significant carbon storage.

Lastly, this delay in the transition may complicate infrastructure decisions for maintenance of things like gas distribution pipelines. Should countries invest in the maintenance for continued use in the short- to medium-term or hold off knowing the pipelines will instead need to be upgraded to accommodate hydrogen or new pipelines built entirely?

In short, there is a path forward if we fail to rapidly electrify, but that path will be much more difficult and costly. A lot needs to fall in place for this pathway to succeed.

100% RENEWABLES

> **Pathway Description: The EU and UK choose to eliminate all fossil fuels, retire existing nuclear plants by 2050, and not build any new nuclear or use carbon capture sequestration. All energy is sourced from renewables. This dramatically increases demand for renewable generation not only for electricity, but also for hydrogen production and to produce other zero-carbon fuel substitutes for transportation and industry. Zero-carbon fuel substitutes (biomass for coal and eventually zero-carbon gas to replace natural gas) are used as back-up power for renewables.**

This assumption reflects the position of some countries and NGOs in the European Union that net-zero by 2050 can be achieved with renewables alone. Our model found that, while this is technically possible to achieve, there are significant risks with the renewables-only pathway policymakers must take seriously.

The first risk is resource availability. This pathway relies on a huge amount of renewables to meet electricity demand that will need to be 400% greater in 2050 than it is today. This is more than 30% greater electricity demand than in the other pathways. Approximately 40% of increased electricity generation will need to go toward hydrogen production alone. Renewables would not only directly power buildings, cars, and industrial facilities, but also power the significant amount of hydrogen production needed to decarbonize other areas of the economy. Historically, the EU has deployed renewables at an average rate of 23 GW per year (from 2011-2020). EU Member States would have to deploy four times that every year (closer to 106 GW annually) to get the over 4 terawatts (TW) of renewables required to meet demand growth. There are also real uncertainties about how much renewable resource potential in the EU there really is, as expansion of solar, on- and off-shore wind, and the necessary transmission lines has a greater footprint than other clean energy sources. As we've seen in countries across the EU, there is growing opposition to siting of wind, solar, biomass, and transmission. It is also not clear that supply chains and manufacturing capacity could be scaled at the rate needed to deploy renewables for this pathway.

Finally, the largest risk in this scenario is cost. It costs €97 billion more a year by 2050 compared to the Core scenario. This is primarily because of the necessity to displace all of the residual fossil fuels in the system with zero-carbon fuel alternatives. Additionally, limiting electricity production to only renewables means that lower quality renewables are deployed on the margin to displace the existing nuclear or other more cost-effective nuclear technology deployments. Specifically in countries with lower quality renewables like in Eastern Europe, this can be challenging. In this pathway, much of the zero-carbon fuels supply will also need to be imported, again increasing costs and likely coming with some social opposition. This scenario would also likely significantly increase the price on carbon in the long-term due to limiting the deployment of technologies like nuclear that the model otherwise finds cost effective. Based on findings, limiting Europe to renewables as the only tool to reach carbon neutrality is one of the least likely, and therefore least effective, ways to get to net-zero by 2050.

LIMITED RENEWABLE SITING

> **Pathway Description: Renewable electricity development is restricted to reflect land-use constraints and growing local opposition in many parts of the EU and UK to the siting of grid-scale solar PV and onshore wind projects. In all other pathways, we assume 2.53% of total landmass of the European Economic Areas (EEA) could be used for solar, 4.87% of total landmass for onshore wind, and 14.95% of waters off the coast for offshore wind. In this limited scenario, this is reduced to 1.40% of total landmass for solar, 1.88% of total landmass for onshore wind, and 10.16% of coastal water for offshore wind. The result of these restrictions is that the electricity generation portfolio includes less onshore wind and solar, replaced with more offshore wind and nuclear. These changes in the supply portfolio lessen the need for new transmission lines.**

Total wind and solar capacity decreases to 2081 GW compared to 2377 GW in the Core pathway. This reduction in renewable capacity mainly comes from a decrease in onshore wind deployment. The limitations on onshore wind deployment results in solar being built in areas that were uneconomic in our Core pathway (Northern and Eastern Europe) and triggers an increased reliance on offshore wind that, while slightly more expensive, doesn’t face the same land-use restrictions. This pathway has the heaviest reliance on floating offshore wind. The constraints on higher-quality renewables due to land-use barriers increases costs of the transition.

As a result of limited renewable deployment, the energy system becomes more reliant on innovative advanced nuclear technologies that we assume come down in cost and are more widely deployed in countries without bans. Energy from new nuclear builds, which could also include generation 3 reactors, becomes critical to produce both electricity and hydrogen. There’s risk in relying on the deployment of new nuclear energy, given economic constraints and social resistance to nuclear technologies in different EU Member States. Of course this risk is seen in all pathways except the 100% Renewables scenario, which comes with its own challenges.

DOMESTIC PREFERENCE

> **Pathway Description: EU Member States and the UK prioritise domestic energy supplies and reduce transborder infrastructure coordination (electricity imports, hydrogen, and other zero-carbon fuels). The model assumes tariffs on the flow of energy between countries and adds a 5x cost multiplier on new infrastructure for electric transmission and hydrogen pipelines. There is also no buildout of large intercontinental infrastructure (hydrogen pipeline/transmission lines to Africa). Without access to these imports, there is more development of lower-quality renewable resources and increases in share of generation from nuclear and geothermal. Some amount of new infrastructure is unavoidable, though, revealing critical transmission needs for certain countries.**

This pathway is made even more relevant due to Europe's dependence on Russian natural gas, oil, and coal. Countries may decide to pursue a pathway that affords them more energy sovereignty by reducing reliance on imports. If they do decide to focus inward, there will be more limited interconnections across borders and continents. With less ability to transfer energy resources, many countries will need to deploy renewables up to resource constraints – the max amount theoretically achievable. As discussed earlier, land-use, social, and economic obstacles make this level of renewable deployment very difficult to achieve

As a result of the constraints, this pathway is €19 billion more per year by 2050 than our Core scenario. This is due to a combination of countries' limited resource diversity (which increases the need for backup generation) and the deployment of lower quality renewables (given the inability to access higher quality resources) or higher cost technologies like geothermal.

The lack of resource sharing may unevenly allocate the costs and benefits of decarbonization. Countries with less access to renewables will have higher costs because they will need to build more quantities of more expensive clean energy technologies, for example geothermal, new nuclear, and carbon capture. Similarly, the overbuild of renewables without a diversity of complementary sources can increase costs. The most cost-effective pathways complement high-quality renewable development with complementary technologies like nuclear.

Focusing on domestic demand and supply may decrease the reliability and resiliency of the system. Interconnections with other countries allow for cost-effective transfer of high-quality resources to demand centres and provide backup when failures or lulls in energy production occur in certain locations. It may make sense for a unified EU to encourage transmission and hydrogen pipelines between EU Member States and allied countries, while importing electricity from North Africa and eliminating imports from Russia.

CONCLUSION

Europe has committed to cut emissions by at least 55% by 2030 and reach carbon neutrality by 2050. This is absolutely critical for climate change and, as the Russian invasion of Ukraine has laid bare, reducing the security risk posed by importing fossil fuels. As policymakers look to align current laws with emissions targets through the Fit for 55 package, they should consider the risks and opportunities of different net-zero pathways. Our analysis suggests that the EU and UK should be careful not to lock themselves into a pathway rife with potential fail points. Instead, the EU and UK should design solutions that ensure the development and deployment of diversity of clean energy technologies, keeping as many options as possible on the table to reduce risks.