Hydrogen for Europe

A new report co-financed by Concawe and a number of key stakeholders in the low-carbon and renewable hydrogen value chain details a study to assess the contribution of renewable and low-carbon hydrogen to achieving net-zero emissions in Europe by 2050. This article provides a summary of the analysis.

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Introduction

About the study

The Hydrogen for Europe study is the result of a cross-sectoral and multidisciplinary research partnership that aims to inform the debate on the contribution of low-carbon and renewable hydrogen towards European energy transition goals. Based on sound analytics and robust scientific modelling prepared by the research partners (IFP Énergies Nouvelles (research), SINTEF Energi AS (research) and Deloitte Finance SAS (project management)), and advised by industry, policymakers, academics and civil society, the partnership aims to chart science-based pathways exploring the potential of hydrogen in a decarbonised European energy system. The study builds on current European Union (EU) targets and ambitions by filling the knowledge gap on how hydrogen may contribute to shaping the EU's energy landscape, and by assessing the support needed to realise this ambition. The research was funded by 17 partners (see Figure 1).

Figure 1: The research consortium and funding partners to the Hydrogen for Europe study

Reseach consortium

Funding partners

Methodology: scenarios and modelling

The study explores a mix of solutions and considers technological, sectoral and geographical projections across two potential pathways depicting alternative futures that lead to carbon neutrality:

1. The Technology Diversification pathway is based on already-approved national targets, and assumes no obstacles to the deployment of different technologies, as well as perfect market foresight on investment decisions. This pathway considers an array of decarbonisation technologies, deployed as needed, which allows for the de-risking of investments through the creation of a more competitive and efficient zero-carbon energy system.
2. The Renewable Push pathway prioritises the deployment of renewable energy through increased targets (beyond current policy goals) for the share of renewables in gross final energy consumption by 2050. While this pathway does not result in significant changes in consumption patterns, it sees a key role for hydrogen in helping to absorb, store and transport the additional energy resulting from the increased generation of renewables.

The Renewable Push pathway differs from the Technology Diversification pathway by way of a series of targets for the share of renewables in gross final energy consumption; these targets are more ambitious for 2030 compared to today's policy (40% versus 32% in the Technology Diversification pathway) and include binding targets for 2040 (60%) and 2050 (80%).

The results for each pathway are generated using three scientific models which consider the system life cycle (MIRET-EU), costs and investments (Integrate Europe) and external competition (Hydrogen Pathway Exploration—HyPE). Both pathways otherwise assume a level playing field between technologies.

The scientific models

The Hydrogen for Europe study relies on a detailed model-based analysis with a full representation of the European energy system and its transition from 2020 to 2050. The modelling architecture combines two state-of-the-art partial-equilibrium models (MIRET-EU and Integrate Europe) which have been enhanced specifically to tackle the objectives of the study. Both models are research-oriented tools, built on sound mathematical formulations, that have transparent modelling frameworks and deliver robust results. The HyPE model developed by Deloitte for this project is used to explicitly assess the potential of imports from neighbouring regions, thus going further than what is usually represented in European hydrogen studies and reflecting the recent expectations for the role of imports.

MIRET-EU

The MIRET-EU model encompasses the entire life cycle of an energy system, from primary resource to utilisation. This model is well suited to help decision makers as it provides data over medium- to long-term time horizons, and can easily contribute to energy roadmaps by providing clear information on technologies and fuels in all sectors based on data and expert knowledge. This model allows for great flexibility, and can take environmental emissions into account, as well as almost all policies at all levels.

Integrate Europe

Integrate Europe is a cost-minimisation and investment optimisation model for energy systems that assesses how to bring available energy to users in the most economical ways possible while complying with environmental targets. This model promotes early investment in promising technologies, even if they are not yet competitive in the market, as it recognises that this is key to driving down costs.

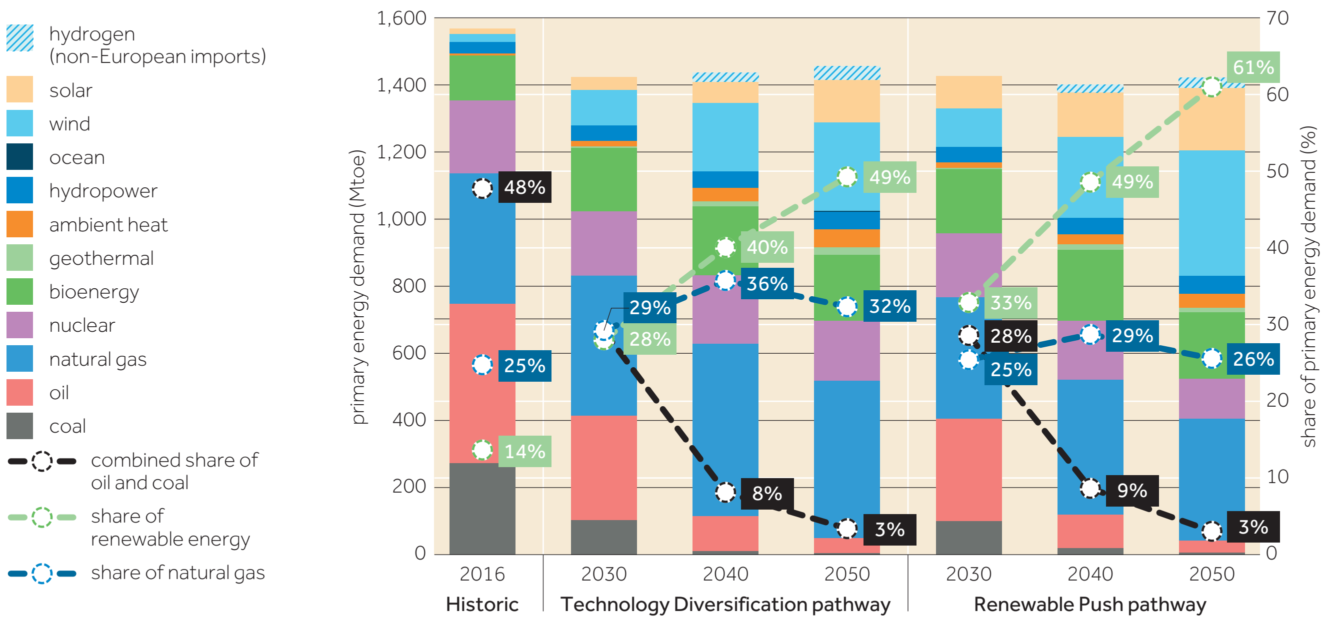
Hydrogen Pathway Exploration (HyPE)

HyPE provides the MIRET-EU and Integrate Europe models with low-carbon and renewable hydrogen imports from EU neighbours. This model represents competition between domestically produced hydrogen and imports, and is in line with the EU hydrogen strategy which focuses on clean hydrogen trade, and highlights the potential partnership with southern and eastern neighbourhood countries.

Primary energy demand and pathways to net zero emissions

In achieving net-zero emissions, the primary energy mix is fundamentally reshaped in the two pathways (see Figure 2). Primary energy demand sees a pronounced shift to renewable energy. The share of renewable energy in primary energy demand reaches up to 49% in 2040 and 61% in 2050 in the Renewable Push pathway, sustained mostly by significant investments in wind and solar. This uptake is mirrored by a declining role of oil and coal, for which the combined share of primary energy demand drops to 3% in 2050 in both pathways.

Figure 2: The evolution of total primary energy demand in the Technology Diversification and Renewable Push pathways, 2016 to 2050

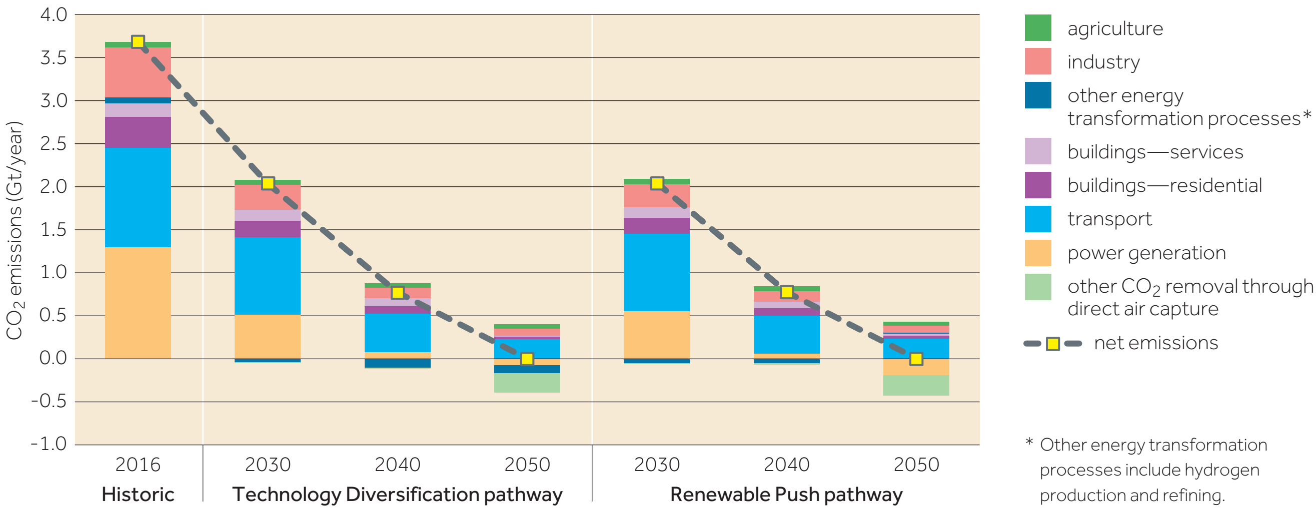


Natural gas is an element of continuity in the energy mix: the use of natural gas remains resilient in the Renewable Push pathway, where it provides important flexibility as a complement to renewables. Natural gas offers the greatest benefits when coupled with carbon capture, utilisation and storage (CCUS). Much of its use is thus transferred from final energy consumption to transformation processes, e.g. for hydrogen production, where low-carbon hydrogen helps to foster the growth of the hydrogen economy, or in power generation, where natural gas provides flexible power for load following and back-up generation.

At the final consumption level, energy efficiency and electrification play their expected role in the transition to net-zero emissions. Final energy consumption is reduced by nearly a quarter in 2050 when compared to 2005, achieving along the way the binding target of a 32.5% reduction by 2030 (compared to a business-as-usual scenario) for the EU member states. Electricity's share in gross final energy consumption increases by almost 50% between today and 2050, with step changes observed in industry, transport and buildings. While this confirms the high expectations put on electrification, it also highlights the complementary roles played by molecules and other energy carriers to decarbonise energy end-use; the Renewable Push pathway also foresees the accelerated deployment of renewables. In both pathways, more than half of total gross final energy consumption is supplied by non-electrified technologies in 2050.

The two pathways follow a progressive trajectory towards deep decarbonisation, and achieve climate neutrality by 2050 (Figure 3). By 2030, CO_2 emissions at the European level are reduced by 55% compared to 1990 levels. This reduction is led by fuel switching in the power and industry sectors. CO_2 emissions then continue to decrease precipitously to reach net-zero emissions in 2050. The results suggest that the development of a fully operational CCUS value chain (including carbon capture and storage from fossil fuels, biomass and direct air capture) is indispensable for the success of the energy transition. Negative emissions from biomass and direct air capture with carbon capture and storage (CCS) serve to offset the residual emissions from the hard-to-abate sectors.

Figure 3: The evolution of CO_2 emissions by sector in the Technology Diversification and Renewable Push pathways, 2016 to 2050



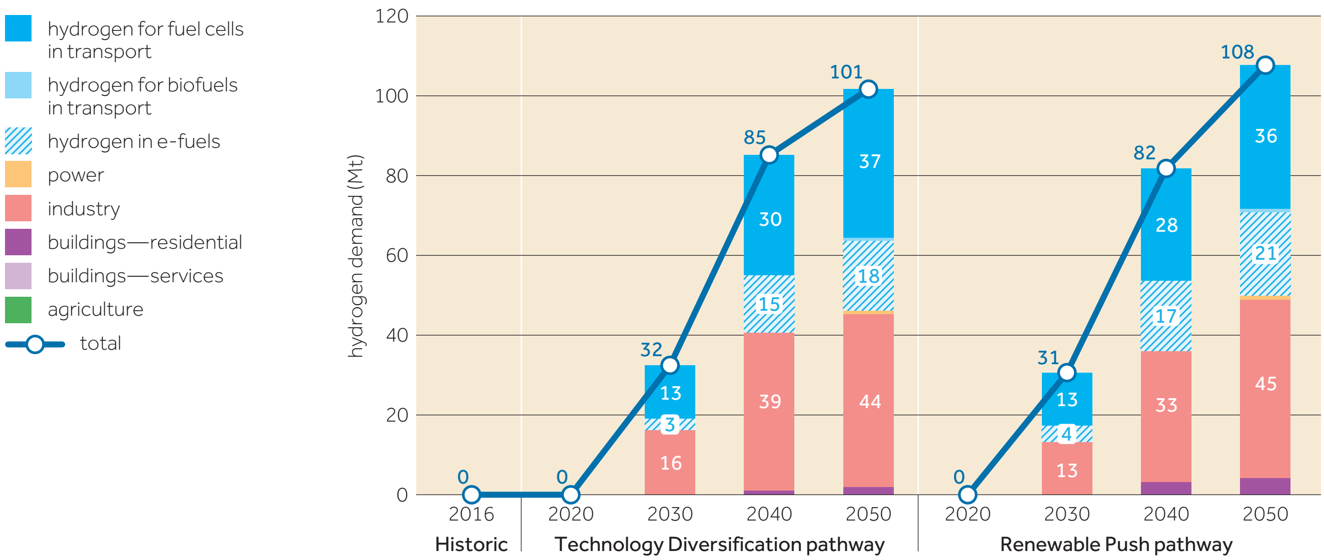
* Other energy transformation processes include hydrogen production and refining.

The hydrogen value chain

Hydrogen plays a major role in the decarbonisation of the energy sector. In light of the ambitious decarbonisation objectives, European hydrogen demand in these pathways exceeds 30 Mt by 2030, which is triple the current policy objective described in the EU's hydrogen strategy. The demand for hydrogen ramps up substantially in the 2030s and 2040s, and exceeds 100 Mt by 2050 in both pathways. This is equivalent to more than 3,300 TWh or around 300 Mtoe (in lower heating value). The Renewable Push pathway, which shows a stronger deployment of renewable energy, demonstrates hydrogen's complementarity with renewable energies, helping to absorb, store and transport the bulk of the additional energy from renewable sources.

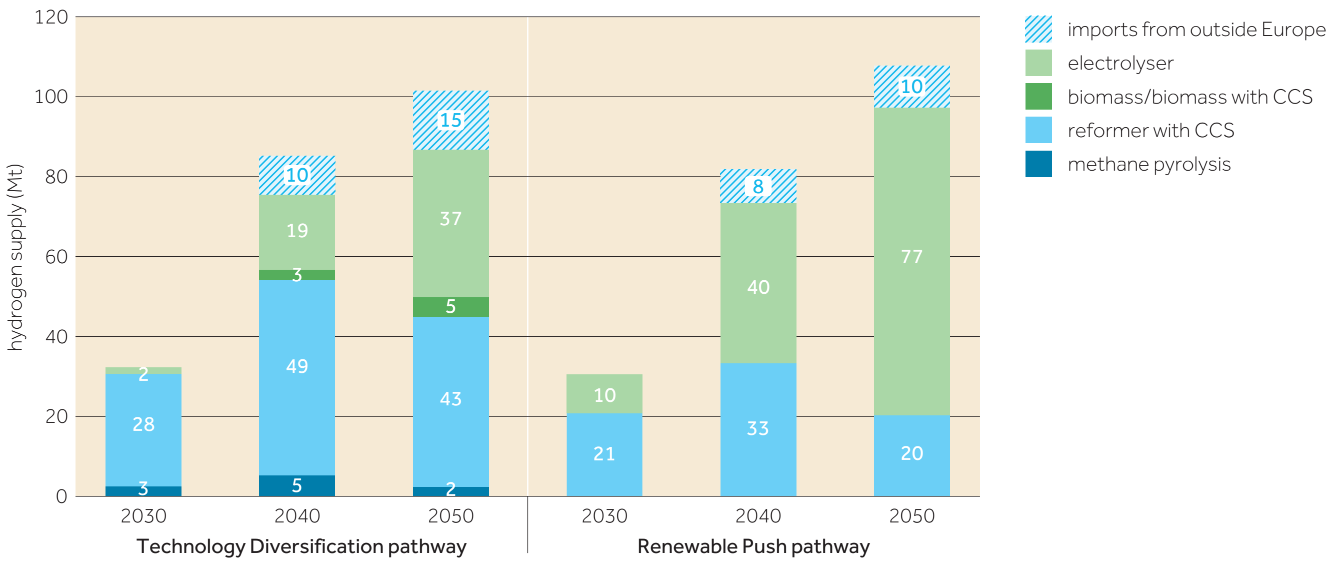
The sectoral breakdown of hydrogen demand confirms the versatility of hydrogen in decarbonising the energy system (Figure 4). Hydrogen can provide an answer to the challenges of deep electrification and the limits of energy efficiency improvements. It proves to be a cost-efficient solution for certain hard-to-abate energy uses in transport and industry.

Figure 4: The evolution of hydrogen energy-related demand by sector in the Technology Diversification and Renewable Push pathways, 2030 to 2050



In the two pathways, European hydrogen production rises steeply over the next three decades, relying on a diverse production mix comprising renewable and low-carbon technologies (Figure 5).

Figure 5: The evolution of the European hydrogen supply in the Technology Diversification and Renewable Push pathways, 2030 to 2050



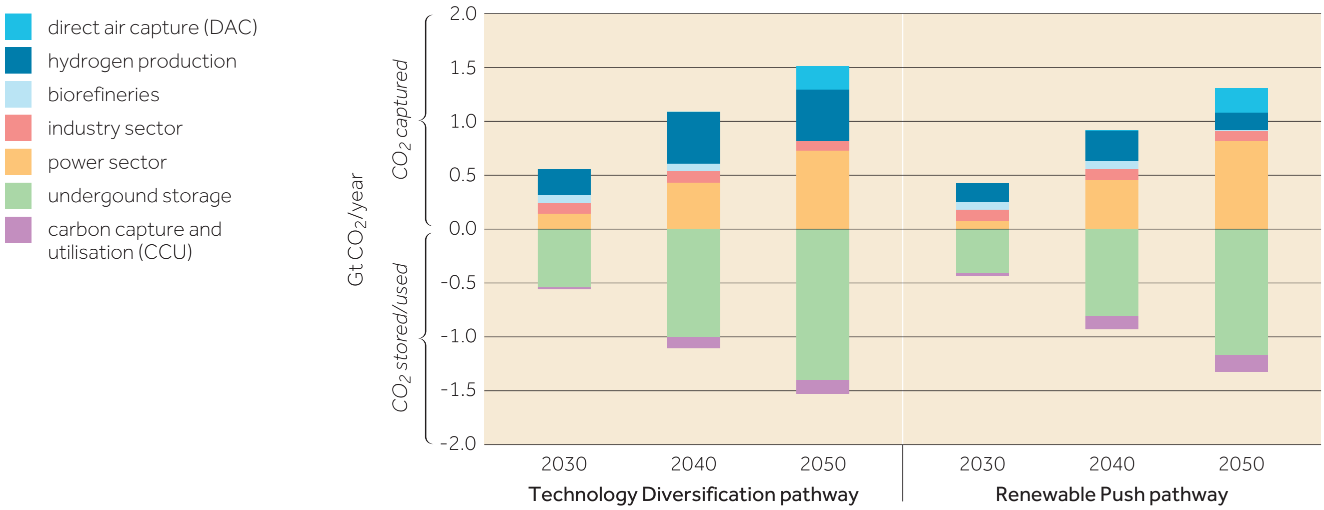
Some of the hydrogen needed in the transition to net-zero emissions is imported from outside Europe. The results show that imports of renewable and low-carbon hydrogen burgeon in the 2030s, including from North Africa, Russia, Ukraine and the Middle East. Imports play an important role in complementing European production of hydrogen, and in serving countries that have limited options for cost-efficient domestic hydrogen production. In the Technology Diversification pathway, up to 15 Mt of imports are able to compete on cost terms with domestic production, thus contributing nearly 15% to total hydrogen supply in Europe.

Key results for the EU hydrogen economy

Carbon capture

The development of low-carbon hydrogen and of other technologies such as biomass with CCS is highly dependent on the parallel deployment of the CCUS value chain and the ability of CO_2 storage capacities to grow rapidly over the next 30 years. The Technology Diversification pathway reaches an injection capacity limit of 1.4 Gt/year in 2050. This injection capacity has been derived as a reasonable estimate from a survey of existing literature and expert knowledge. However, the modelling also shows that higher levels of CO_2 injection capacities would allow for a bigger role for low-carbon hydrogen (see Figure 6 on page 40).

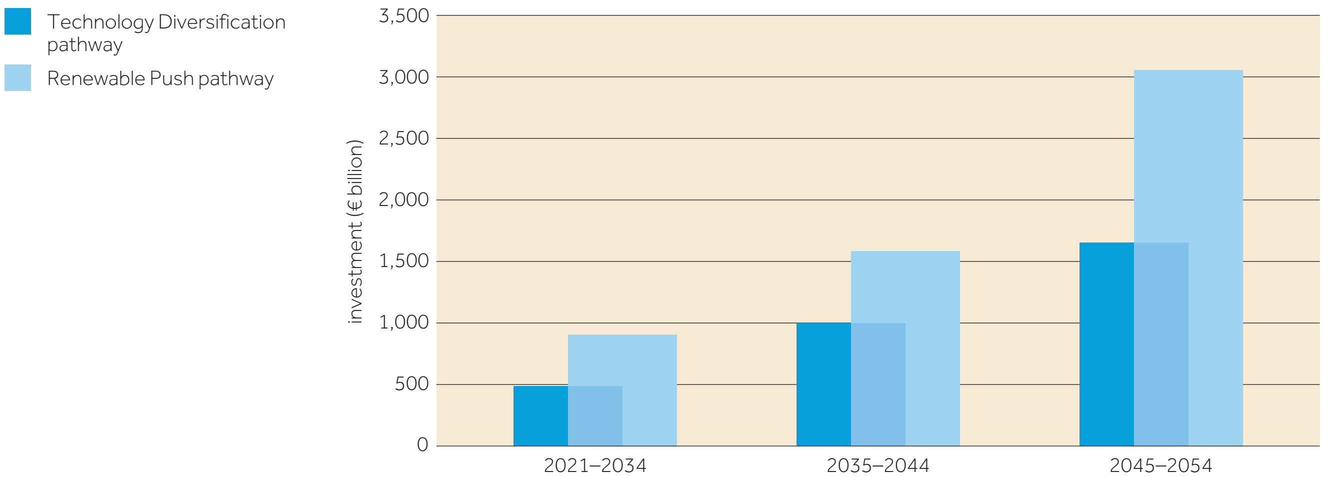
Figure 6: The evolution of CO_2 capture (positive values), use and storage (negative values) in the Technology Diversification and Renewable Push pathways, 2030 to 2050



Investments

Achieving high levels of renewable hydrogen and renewable energy in the system, in the latter half of the period to 2050, requires significant investments, underpinned by the accelerated deployment of renewable energy and electrolyser supply chains, and the optimal utilisation of renewable energy in Europe. In the Renewable Push pathway, more than 1,800 GW of dedicated solar and wind capacities and more than 1,600 GW of electrolysers need to be installed by 2050 to sustain the renewable hydrogen trajectory and reach more than 75 Mt of hydrogen output by 2050.

Figure 7: Investments in the hydrogen value chain (including off-grid renewables) per period supply in the Technology Diversification and Renewable Push pathways, 2021 to 2054



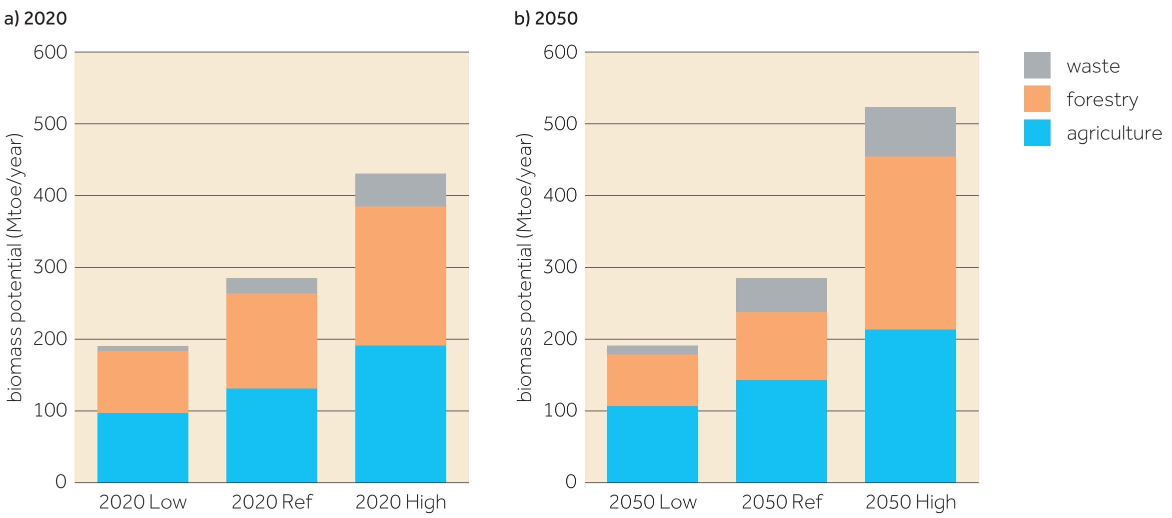
Considering the hydrogen value chain as a whole, the results show that trillions of euros in investment are needed to leverage the full potential of hydrogen in the energy transition (Figure 7). These investments need to start in a timely manner to ensure that demand and supply grow in lockstep, and to avoid technology lock-outs and mitigate the risk of stranded assets. The difference of more than €2 trillion in capital spending between the two pathways demonstrates the higher capital intensity of a pathway focusing on renewable assets and electrolysers. As such, one of the main challenges of the Renewable Push pathway is the ability to mobilise almost twice as much capital over the next 30 years to accomplish the hydrogen uptake.

The trajectory drawn by the Technology Diversification pathway shows the lowest investment costs. It is important to remember that this is founded on two principal paradigms: technology neutrality, assuming a comprehensive approach to decarbonisation that includes the potential of all technologies; and reliability, transparency and effectiveness of the policy framework. It assumes that all barriers and uncertainties are addressed along the way by policymakers and industrial leaders.

Sensitivity analysis for bioenergy

The Technology Diversification pathway uses the alternative 'Business as Usual' trajectory from ENSPRESO for bioenergy potential in Europe. The sensitivity analysis considers the ENSPRESO Reference trajectory (see Figure 8) for bioenergy potential. Compared to ENSPRESO's alternative 'Business as Usual' trajectory, the Reference trajectory has around 45–50% greater bioenergy potential in Europe over the period to 2050, due to the wider utilisation of forest resources and related market developments.

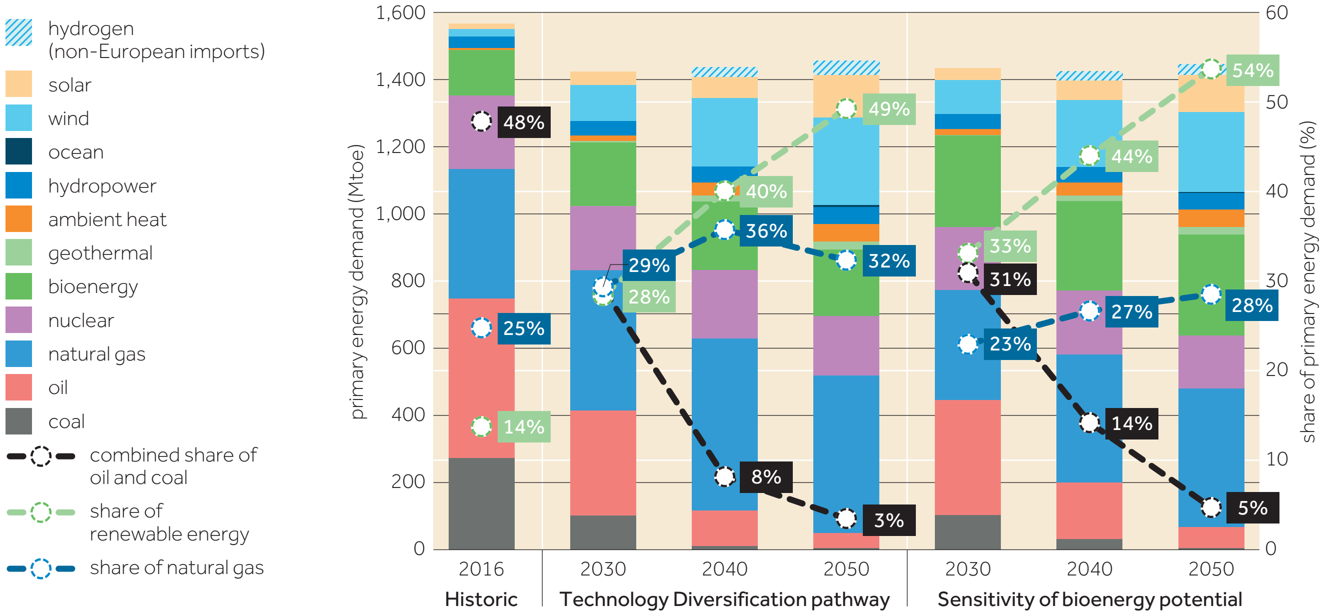
Figure 8: Concawe's elaboration based on the ENSPRESO report [1]



[1] https://www.sciencedirect.com/science/article/pii/S2211467X19300720?via%3Dihub

The higher potential of bioenergy in Europe leads to a more important role for this energy source in terms of primary energy demand. In 2030 and 2050, bioenergy represents 19% (+40% increase in supply compared to the Technology Diversification pathway) and 21% (+50%) of total primary energy demand, respectively, in Europe in the sensitivity analysis. Bioenergy displaces natural gas but also solar PV, wind and nuclear in the energy mix, the shares of which are lower in this sensitivity analysis.

Figure 9: The evolution of total primary energy demand in the Technology Diversification pathway, and the sensitivity of bioenergy potential, 2016 to 2050



Bioenergy plays a greater role in power generation and in hydrogen production, where it is combined with CCS (BECCS).

The higher potential of bioenergy does not significantly impact the level of hydrogen demand in the long term. By 2050, hydrogen demand in the sensitivity analysis stands at around 100 Mt, similar to the level reached in the Technology Diversification pathway. However, some notable shifts are observed in the evolution of hydrogen demand over the outlook period. The growth of hydrogen demand (and thus of the whole hydrogen economy) happens later in the sensitivity analysis, mostly because the use of BECCS allows for more negative emissions and shifts some of the need for hydrogen to the end of the period. In the sensitivity analysis, hydrogen demand is half its 2030 level observed in the Technology Diversification pathway (around 15 Mt compared to 30 Mt), but gradually catches up from 2030 to 2040 (-24%) and 2050 (-2%).

These changes lead to slightly different numbers regarding cumulative investment in the hydrogen value chain. Total cumulative investments in the hydrogen value chain are lower in the sensitivity analysis. They stand at around €2.9 trillion, which is around €0.2 trillion less than cumulative investments in the Technology Diversification pathway, with marked decreases in investments in all categories except biomass. The overall energy system cost, discounted over the outlook period, is about €2.5 trillion lower (-2.5%) in the sensitivity analysis than in the Technology Diversification pathway.

Conclusion

European hydrogen production and use could increase dramatically, driven by policy, with the demand for hydrogen potentially exceeding 100 Mt. The transport sector accounts for more than half of hydrogen demand, followed by industry, particularly the steel and chemical industries.

Both low-carbon and renewable hydrogen are necessary to enable a fast, lower risk and more cost-effective pathway to net zero. A mix of hydrogen types will be needed regardless of the policy path chosen. By 2050, more than half of total gross final energy consumption will be supplied by non-electrified technologies such as low-carbon hydrogen and biomass.

The development of renewable hydrogen requires more than 1,800 GW of dedicated solar and wind capacities to be installed by 2050 (3 to 4 times the current installed capacity in the EU, see Figure 10) and more than 1,600 GW of electrolysers, implying a difference of more than €2 trillion in capital spending.

The development of the hydrogen value chain relies on a dedicated energy infrastructure that includes transport and distribution, storage and refuelling options, and which connects supply and demand. Nearly 15% of the hydrogen needed in the transition to net-zero emissions could be imported from outside Europe.

Figure 10: The evolution of installed renewable energy capacity for electricity production in Europe, 2000 to 2019