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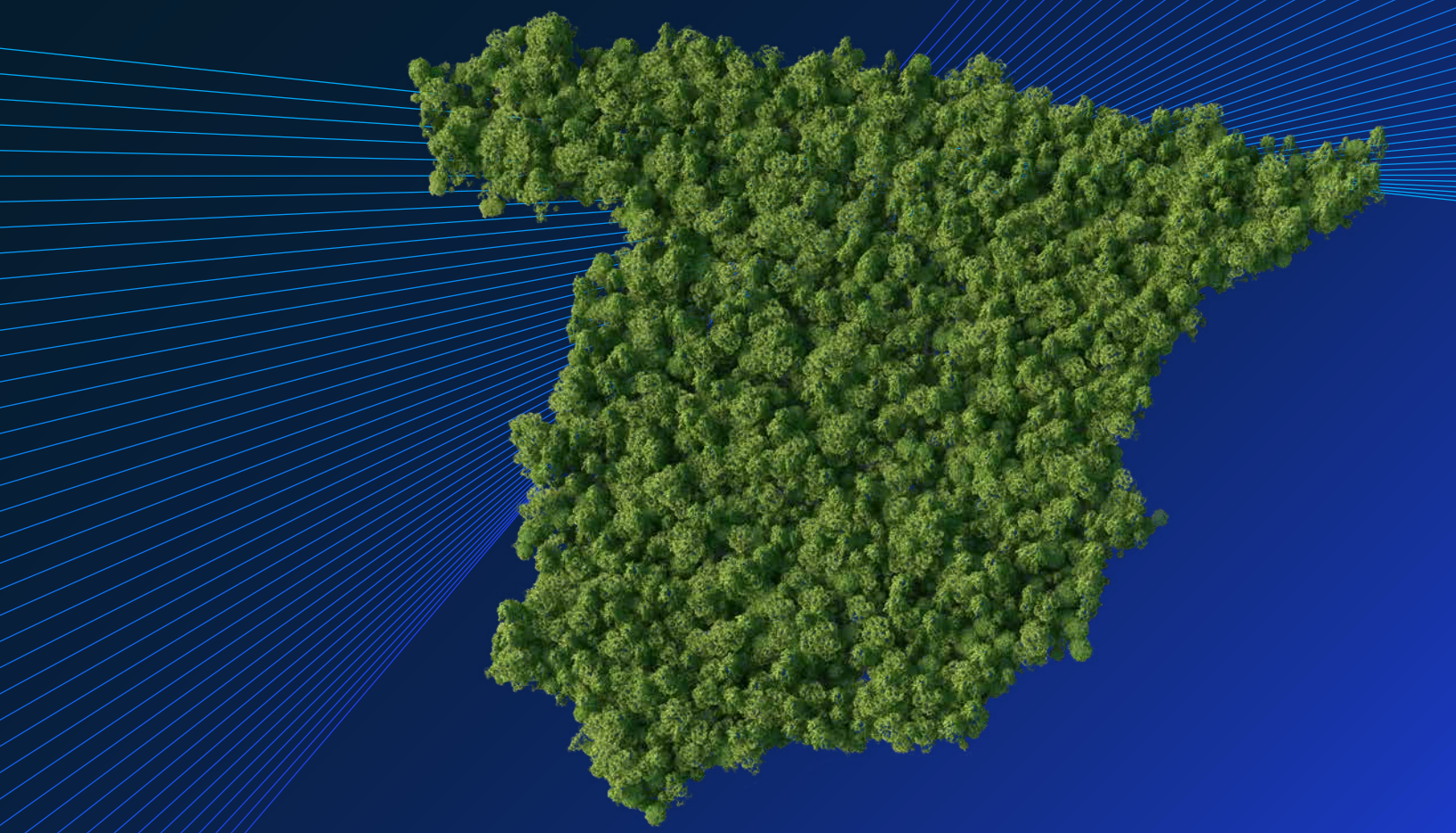
Net-zero Spain: Europe's decarbonization hub

Spain can reach net-zero emissions by 2050 through a society-wide effort that leverages the country's natural endowments and new technologies to unlock sustainable and inclusive growth.



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This report is a collaborative effort by Duarte Braga, Joana Candina, Joseba Eceiza, Bruno Esgalhado, David González, and Ignacio Marcos, representing views from McKinsey Sustainability.

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Executive summary

In a world that is accelerating efforts to combat climate change and in the midst of increasing economic and geopolitical uncertainties, Spain could play a starring role. The country's rich natural resources, developed infrastructure, and deep technical capabilities mean it is ideally situated to lead a green transition. Our analysis has identified five key characteristics for this transition (Exhibit 1): It is urgent, given the potential physical risks associated with rising temperatures. It is possible, as suggested by our net-zero scenario, and significant in its scale and scope. Furthermore, it will be tech-driven, because the development and deployment of new low-carbon technologies will be the critical enablers of the transition. And it will be rich in opportunities, because Spain can leverage its natural endowments and technical capabilities to lead Europe in the transition and create substantial socioeconomic impact along the way.

The urgency for Spain to redouble its efforts is not trivial. In a scenario in which global temperatures reach 2°C above pre-industrial levels, some parts of the country's southern region would see more than 45 days a year in which the daily maximum temperature exceeds 37°C. Several areas would face the possibility of more than six months of drought each year, leading to a potential 25 percent decline in water availability in critical basins. Moreover, there would be damaging impacts on yields in four critical crops—grapes, olives, tomatoes, and wheat—which together make up 40 percent of Spain's gross agricultural production value. The tourism sector would also be severely affected, with scorching temperatures deterring tourists from visiting during the summer season.[1]

As a member of the European Union, Spain is committed to meeting the targets of the trading bloc's climate agenda. The European Union has set an objective to reduce GHG emissions by 55 percent by 2030 compared to 1990 levels, with demanding timetables for individual industries. The proposals reflect the objectives of the European Climate Law and affect areas including renewable energy, energy efficiency, and the EU Emissions Trading System (ETS). Russia's invasion of Ukraine and the ensuing impact on energy prices have prompted

Exhibit 1

Five characteristics describe Spain's net-zero transition.

1. Urgent
2. Possible
3. Significant
4. Tech-driven
5. Rich in opportunity

[1] "Climate risk and response: Physical hazards and socioeconomic impacts," McKinsey Global Institute, January 16, 2020 (based on Representative Concentration Pathway 8.5).

Under the net-zero scenario, Spain could become a regional leader and clean-energy hub.

Europe to double down on these proposals, as announced in the REPowerEU plan. The Spanish regulatory agenda builds on many Spanish and EU initiatives, for example through the country's Integrated National Energy and Climate Plan (INECP),[2] which sets an ambitious target of a 31 percent decline in emissions between 2019 and 2030. This will help Spain catch up with the rest of the European Union, which has reduced its net emissions by approximately 28 percent since 1990, while Spain's net emissions have grown by 9 percent in the same period.

Although Spain's emissions have been declining over the past 15 years, since 2013 the rate of decline has lowered to approximately 2 $MtCO_2e$ per year.[3] This rate needs to be four times as fast if Spain is to reach its 2030 decarbonization goals, and five times as fast after that to reach net zero by 2050. On that basis, this paper considers two scenarios. The first is based on current policies, while a second posits a faster green transition. The latter, the net-zero scenario, proposes an ambitious pathway that is focused on accelerating Spain's abatement efforts. It would mean reducing emissions by 46 percent by 2030 (from 2019)—equivalent to reducing about 130 $MtCO_2e$—and achieving net-zero emissions by 2045 and net-negative emissions by 2050. This compares to a 33 percent reduction by 2030 and 85 percent by 2050 under the "current policies" scenario.

Under the net-zero scenario, Spain would be transformed into a regional leader and clean energy hub. However, achieving that goal will require significant capital investment. The net-zero scenario will require capital expenditures of €2.5 trillion for green technologies and processes by 2050. This equates to €85 billion per year on average, or around 6.2 percent of Spain's GDP. The key target areas for spending will be transport, power, and buildings. The investment in this scenario would support 1.1 million jobs per year on average over the 30-year period.

The most exciting innovations will be in three areas: electrification, green hydrogen, and biofuels. Spain has a history in renewable energy leadership. With more than 28 GW, it has Europe's second highest wind generation installed capacity after Germany. Paired with enviable solar resources, it can produce renewable energy at a lower cost than other European economies, and continue the rapid rate of decarbonization shown by its power sector over the past 15 years. This, in turn, means it could become one of the most competitive producers of green hydrogen, which is required for deep decarbonization in sectors that are hard to electrify or to abate. Biofuels would also be a key technology for Spain's decarbonization journey, serving as a transition technology across multiple use cases.

[2] Known in Spanish as the *Plan Nacional Integrado de Energía y Clima* (PNIEC), Ministry for the Ecological Transition and the Demographic Challenge, Spain, 2020.
[3] Metric megatons of CO_2 equivalent.

Regulation alone will not be sufficient to advance the change agenda in Spain. Instead, Spanish society needs to act collaboratively.

Some sectors are harder to abate than others, and some are more urgent due to their high emissions intensity. Spain's transport and industry sectors collectively account for more than 55 percent of the country's emissions and are therefore key areas of focus to reach net-zero emissions.[4] The stock of passenger cars, vans, and motorcycles would be 100 percent decarbonized by 2050. Domestic aviation, in turn, would see lower levels of abatement amid increased use of biofuels (60 percent of market penetration by 2050) and synfuel planes (20 percent market share by 2050).[5] Barring the use of bridging technologies such as carbon capture and storage, the industrial sector—from cement and steel production to oil refining and chemicals—would likely only see partial decarbonization. Ethylene, for example, would only accelerate its decarbonization from the 2040s, when emerging technologies such as electric cracking reach industrial scale. Cement, for instance, would be able to reduce its emissions only partially by 2050 without carbon capture and storage.

Regulation alone will not be sufficient to advance the change agenda in Spain. Instead, Spanish society needs to act collaboratively. And the next decade will be critical: more than €700 billion would have to be invested in green technologies by 2030 to accelerate the pace of decarbonization in line with our net-zero scenario.

We posit nine key elements that would produce an orderly and productive transition, including technological innovation, scaled supply chains and supporting infrastructure, and natural resources. We also envision three economic and social adjustments for the transition: initiating effective capital allocation and financing structures, managing demand shifts and unit cost increases, and addressing socioeconomic impacts. Finally, making progress will require enabling mechanisms including standards and market protocols, collaboration between the public and private sectors, and support from consumers. Through these combined efforts, Spain can overcome barriers to decarbonization, transition faster than its peers, and become a leading player in Europe's green transition.

[4] Greenhouse gas inventory data, United Nations Framework Convention on Climate Change (UNFCCC), 2019.
[5] Biofuels are produced from biomass, while synfuels are obtained from syngas, a mixture of carbon monoxide and hydrogen.

Introduction

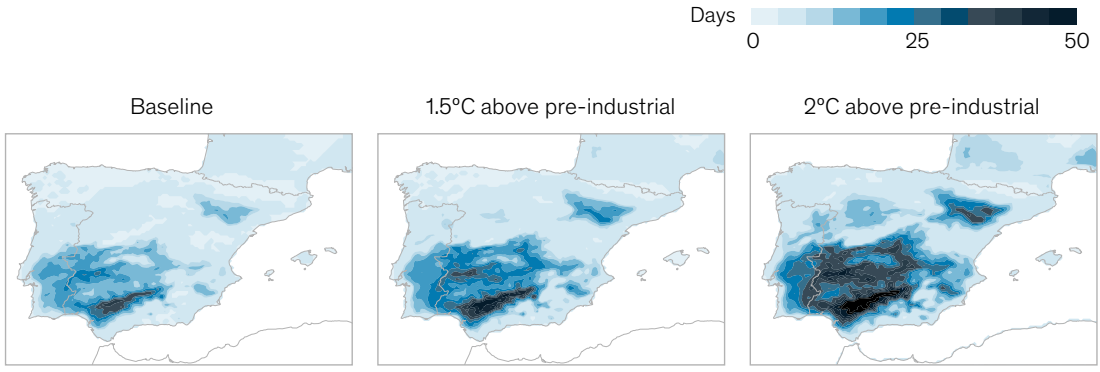
The physical manifestations of a changing climate are becoming increasingly visible across the globe. As average temperatures rise, acute hazards such as heat waves and floods become more frequent and severe, while chronic hazards such as drought and rising sea levels intensify. Spain, which has a Mediterranean climate characterized by hot and dry summers, is on the front line of these risks. In a scenario in which global temperatures reach 2°C above pre-industrial levels, some parts of the country's southern region would see more than 45 days a year in which the daily maximum temperature exceeds 37°C (Exhibit 2), approaching levels that would have severe impacts on everyday life and activities. It also faces the real possibility of more than six months of drought a year, leading to a potential 25 percent decline in water availability in critical basins by 2050.[6] In agriculture, harvests of four critical crops—grapes, olives, tomatoes, and wheat—would decline sharply. These crops account for 40 percent of Spain's gross agricultural production value. High temperatures could also deter tourists from visiting during the summer season, undermining a sector that accounts for about 12 percent of GDP and 14 percent of employment.[7]

Spain currently emits about 277 $MtCO_2e$ per year,[8] about 8 percent of the EU-27's total.[9] Indeed, while Europe as a whole has cut emissions by almost a third since 1990, Spanish emissions have risen. This puts the country far off the pathway to deliver the Paris Agreement target of a net-zero economy by 2050.

Exhibit 2

In a world with temperatures 2°C above pre-industrial levels, some regions in Spain would see twice as many days with maximum daily temperatures above 37°C.

Average number of days with daily maximum temperature above 37°C in a year, number of days



Source: *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, based on RCP 8.5; Food and Agriculture Organization of the United Nations (FAO)

[6] "Climate risk and response", January 16, 2020.
[7] *OECD tourism trends and policies 2020*, Organisation for Economic Co-operation and Development (OECD), 2020.
[8] Excluding international aviation and maritime transport. $MtCO_2e$ is metric megatons of CO_2 equivalent.
[9] UNFCCC Greenhouse Gas Inventory Data, 2019.

In this report, we describe a scenario in which Spain could go further than expected under current plans, achieving a 46 percent reduction in emissions by 2030 and net-negative emissions by 2050 (see sidebar, "Our methodology"). This would require action on multiple fronts, from energy efficiency initiatives across industries to new consumer choices and electrification at scale. It would also need an economy-wide shift from fossil fuels to cleaner alternatives such as hydrogen and biofuels. Moreover, Spain would need to better manage its natural capital, including its forests, to absorb an additional 30 percent of CO_2 (about 12 $MtCO_2e$ per year) by 2050, which would partially compensate for hard-to-abate sectors.

To get to net-zero emissions, all sectors of the economy must act in concert. A significant part of the challenge involves transport and industry, which make up more than 55 percent of emissions (and 65 percent of net emissions).[10] In addition, meaningful change will be predicated on significant capital flows. We estimate that €2.5 trillion of investment in green technologies and processes would be necessary over the next 30 years, or around €85 billion a year on average, equivalent to 6.2 percent of projected yearly GDP.[11] Investment would support an average of about 1.1 million jobs per year.

To maximize the decarbonization opportunity, the private and public sectors, as well as wider society, will need to work together to support investment and transform behaviors. We will examine how stakeholders across the economy can achieve the momentum required to achieve sustainable and inclusive growth.

Our methodology

The different pathways for Spain were shaped in the Decarbonization Scenario Explorer (DSE), McKinsey's proprietary tool that allows us to model scenarios built on underlying activity levels (for example, transportation levels or tons of cement) that drive the country's emissions throughout the projected time horizon. The tool contains more than 200 technologies and shift levers across all sectors of the economy that allow us to build tailored abatement scenarios. Thanks to the bottom-up modeling of energy consumption, capital expenditures, operating expenditures, and emission factors, the tool granularly quantifies the greenhouse-gas abatement, investments, savings, and energy system implications of each scenario. The DSE has been used to produce decarbonization pathways for more than 45 countries and regions.

[10] Greenhouse gas inventory data, 2019; emissions (or gross emissions) is the total of greenhouse gases (including CO_2, methane, and others) emitted by all sectors of the economy. "Net emissions" refers to the gross emissions minus the absorption of greenhouse gases by the land use, land-use change, and forestry sector.

[11] The average of each year's investment requirement over that year's projected GDP from now to 2050, based on Economist Intelligence Unit data.

Regulatory and geopolitical drivers

Across Europe, regulators and policy makers have decisively joined the campaign against climate change. The European Union has set an objective to reduce GHG emissions by 55 percent by 2030 compared to 1990 levels, implementing a range of requirements designed to accelerate the transition. Some of the most important initiatives include the Corporate Sustainability Reporting Directive, set to come into force for fiscal year 2023; the EU Taxonomy; and the Sustainable Finance Disclosure Regulation. Moreover, in 2021, the European Union published "Fit for 55," a package of climate and environmental proposals for eurozone countries to accelerate their journeys on the path to net-zero emissions in alignment with the objectives of the European Climate Law. Each initiative also falls under the European Green Deal, which sets targets for net-zero emissions by 2050, economic growth decoupled from resource use, and no person or place left behind. In addition, NextGenEU—designed to help the region emerge stronger from the pandemic—budgets billions of euros for the ecological transition. Spain is expected to receive almost €70 billion in grants from the European Union, the second highest amount in grants after Italy. Through its *España Puede* recovery, transformation, and resilience plan, it will direct a significant share of those funds toward the ecological transition, including an urban and rural agenda (€14 billion), resilient infrastructure and ecosystems (€10 billion), and a just and inclusive energy transition (€6 billion).[12]

Recent global events have reinforced the need for regulation. The COVID-19 pandemic has highlighted the global nature of the climate crisis and the need for an urgent and coordinated response. Amid widespread supply chain disruptions, the pandemic has also highlighted countries' mutual dependence on energy and materials while spurring a stronger collective will to boost energy security and achieve a faster green transition.

The Russian invasion of Ukraine, which has affected economic sectors such as energy, has prompted similar imperatives. Europe is highly dependent on Russia for energy; Russian fuel sources account for 30 to 40 percent of Europe's gas consumption, about 20 percent of its oil consumption, and about 20 percent of its coal consumption.[13] Spain, however, is less dependent on Russia than other European countries are. Russian imports account for roughly 10 percent of Spain's natural gas consumption and 6 percent of its oil consumption.[14] Despite this relatively lower level of dependency, local energy prices have increased significantly, highlighting the importance of establishing a strong domestic resource.

The European REPowerEU plan, announced in May 2022, proposes a rapid decrease in the consumption of Russian fossil fuels and an accelerated energy transition. It will build on top of the NextGenEU plan and require an increase in investment of €210 billion by 2027, raising the target penetration of renewables by 2030 to 45 percent from 40 percent.[15]

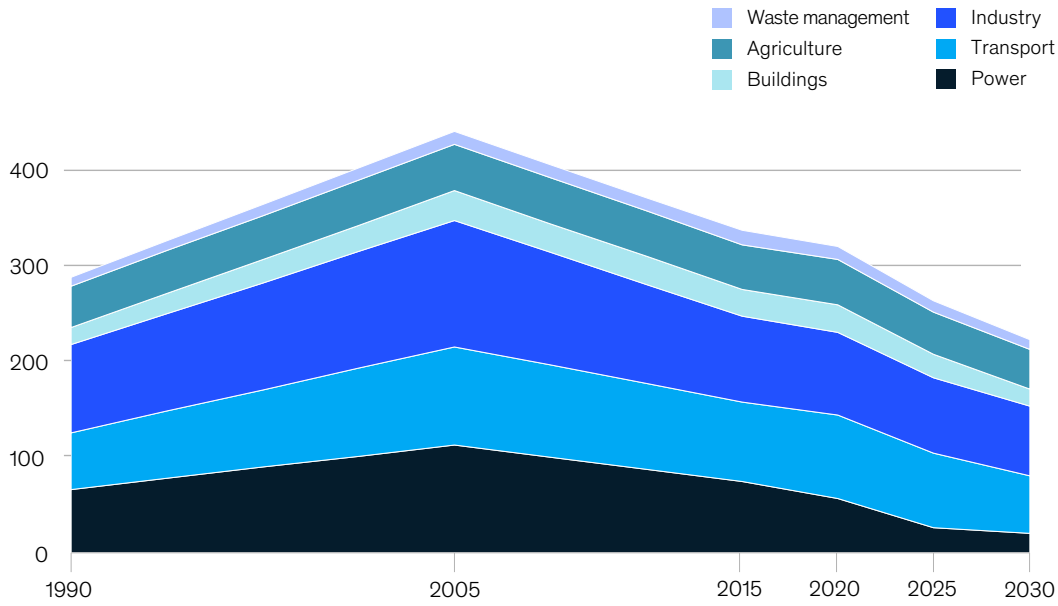
[12] *Recovery, transformation, and resilience plan: España Puede*, Government of Spain, June 2021.
[13] *Global energy perspective 2022*, McKinsey, April 26, 2022; includes the United Kingdom.
[14] "Estadísticas," Corporación de Reservas Estratégicas de Productos Petrolíferos (CORES), accessed August 15, 2022.
[15] "REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition," European Commission, May 18, 2022.

The Spanish climate agenda builds on EU regulatory initiatives and includes the Integrated National Energy and Climate Plan (INECP). The agenda sets out a range of sector-based sustainability targets up to 2030, including a 23 percent reduction in GHG emissions from 1990 levels (Exhibit 3). That translates into a 31 percent reduction from 2019 levels because emissions increased between 1990 and 2007. Other INECP targets include a 42.0 percent share of renewables in energy end use by 2030; a 74.0 percent share of renewables in electricity generation; and a 39.5 percent improvement in energy efficiency.[16] In addition, Spain's Climate Change and Energy Transition Law came into force in 2021, banning all new coal, gas, and oil exploration and production permits with immediate effect and prohibiting the sale of fossil fuel vehicles by 2040.

Exhibit 3

Spain aims to reduce emissions 23 percent from 1990 levels by 2030.

Evolution of gross emissions[1] by sector, $MtCO_2e^2$



Note: Values for 2020, 2025, and 2030 are estimates from the "target" scenario of the Integrated National Energy and Climate Plan (INECP). INECP data unavailable for 1995, 2000, and 2010.
[1]"Gross emissions" does not consider negative emissions from land use, land-use change, and forestry (LULUCF).
[2]Metric megatons of CO_2 equivalent.
Source: INECP

[16] *Plan Nacional Integrado de Energía y Clima (PNIEC)*, Ministry for the Ecological Transition and the Demographic Challenge, Spain, 2020.

Spain's decarbonization opportunity

Rich in natural resources and with highly competitive renewable energy potential, Spain boasts a privileged geographical position and a technically qualified economy. These factors present an opportunity for Spain to become a European leader in sustainability and a clean-energy hub, even after the increase in GHG emissions it experienced since 1990, driven by its economic growth. Much of the upside from the transition will fall to Spanish organizations that make sustainability a strategic priority. A McKinsey Global Survey shows that companies that generate the most value from sustainability place more importance than their peers on translating sustainability strategy into definite terms: they are significantly more likely to establish clear and focused priorities, set targets or goals, and develop KPIs for sustainability.[17]

Against this background, it is useful to plot a pathway to net-zero emissions, as well as to quantify the investment required and the potential effects on the labor market. Here we present our calculations and identify short- and medium-term levers in each sector. The upshot is a scenario in which Spain achieves net-zero emissions and becomes one of Europe's green leaders by 2050.

In 2019, Spain emitted about 314 $MtCO_2e$. Discounting emissions absorption through land use, land-use change, and forestry (LULUCF), net emissions were 277 $MtCO_2e$, 9 percent higher than in 1990.[18] By contrast, the EU-27 has cut its emissions by 28 percent over the same period. Still, Spain has reduced its emissions by 32 percent since the peak in 2007 (by 11 $MtCO_2e$ per year), though the rate of decline has been much slower since 2013 (2 $MtCO_2e$ per year). Compared to this latest rate of decline, Spain needs to accelerate its decarbonization rate by a factor of almost four to meet its 2030 goals, and by five thereafter to decarbonize fully by 2050.[19]

Spain's most productive abatement efforts to date have been in the electricity sector, with wind and solar power leading total installed capacity of renewable energy over the past decade. While continuing to decarbonize the power system is critical, the next challenge will be in the transport and industry sectors, which together account for more than 55 percent of Spain's emissions, eight percentage points higher than these sectors' share in total EU emissions.

The transport sector's emissions are largely produced by cars (57 percent of sector emissions) and trucks and vans (25 percent). Sixty-five percent of industrial emissions are associated with energy and 35 percent with processes, with a high contribution from nonmetallic minerals (26 percent), such as cement, and chemicals (15 percent). In the power sector, the largest contributor to GHG emissions is the combustion of natural gas (68 percent of sector emissions).[20]

[17] "How companies capture the value of sustainability: Survey findings," McKinsey, April 28, 2021.
[18] Greenhouse gas inventory data, 2019.
[19] 2019 is used as the baseline year as it is the last year representative of emissions trends prior to the disruption in emissions levels caused by the COVID-19 crisis.
[20] Greenhouse gas inventory data, 2019.

LULUCF is a carbon sink, absorbing 12 percent of all emissions, mostly via forest lands.[21] LULUCF will help counterbalance sectors that cannot fully abate their emissions by 2050.

Setting targets for 2030 and 2050

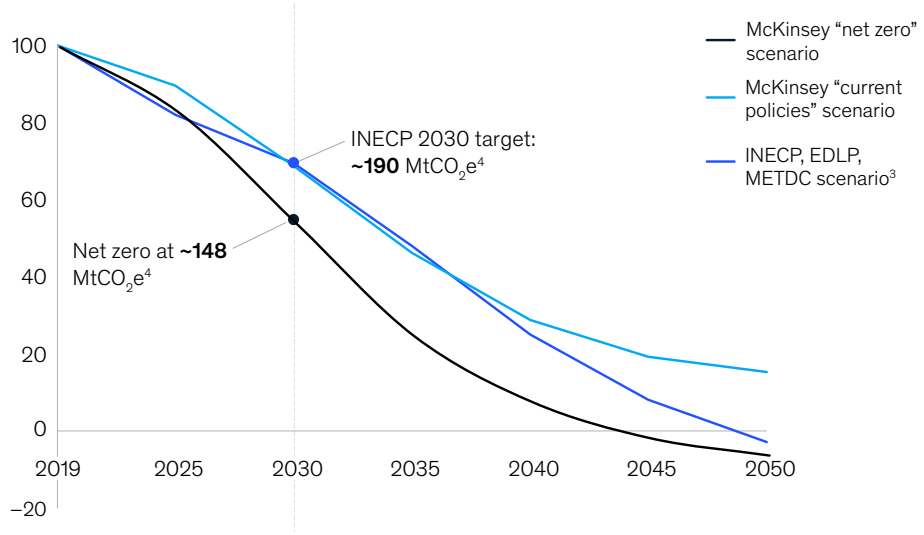
The INECP establishes targets for key sectors of the economy, including industry, power, and transport. Based on EU guidelines, the aggregate target is 23 percent emissions reduction compared with 1990, which translates to an approximately 31 percent reduction compared with 2019. However, since the publication of the INECP, the debate over decarbonization and the regulatory environment has continued to evolve. Based on current thinking and regulatory initiatives, we believe decarbonization rates could be higher. This report presents an alternative scenario that takes into account the most recent perspectives.[22]

To chart the potential pathways to net zero, we developed two scenarios in addition to the scenario presented by the INECP (Exhibit 4). The first is based on current policies, while the second is based on the goal of achieving net-zero emissions by 2050. To formulate the scenarios, we analyzed current and upcoming activity for a range of sectors and subsectors, based on an emissions factor for each conventional technology and activity. We then designed a road map for the implementation of green technologies that would displace conventional technologies.

Exhibit 4

Three alternative emission-reduction pathways show different emissions levels by 2050.

Greenhouse gas emissions[1] scenarios, % of emissions baseline[2]



[1]Includes land use, land-use change, and forestry.
[2]Baseline emissions in 2019 ($MtCO_2e$): 277 in Spain.
[3]Based on targets from the Integrated National Energy and Climate Plan, Long-Term Decarbonization Strategy (*Estrategia de Descarbonización a Largo Plazo* in Spanish), and Ministry for the Ecological Transition and the Demographic Challenge.
[4]Metric megatons of CO_2 equivalent.
Source: McKinsey analysis

[21] Ibid.
[22] The study does not include ambitions set out by the REPowerEU plan, because the plan has not yet been confirmed.

Under the current policies scenario, emissions would fall by 33 percent by 2030 and 85 percent by 2050 compared with 2019 levels (Exhibit 5). Power would be the only sector to reach net-zero emissions by 2050, while the buildings, transport, industry, and agriculture sectors would reduce emissions by 84 percent, 91 percent, 56 percent, and 54 percent respectively by that year. In addition, LULUCF would absorb about 42 $MtCO_2e$, 11 percent more than in 2019.

Our net-zero scenario proposes an ambitious pathway that is focused on accelerating Spain's abatement efforts up to 2030. Our analysis suggests that the pathway to net-zero emissions by 2050 would involve reducing yearly emissions by 46 percent by 2030 (from 2019)—equivalent to reducing about 130 $MtCO_2e$ per year.

Under this more ambitious scenario, it would be possible for Spain to reach net-zero emissions by 2045 and negative carbon emissions of 16 $MtCO_2e$ by 2050. The negative emissions achieved under the ambitious scenario would support Europe's wider decarbonization program, offsetting the emissions of countries that do not achieve the 2050 target (Exhibit 6). However, in the short term, significant investment will be required to catch up with the rest of the European Union, which has reduced its net emissions by approximately 28 percent since 1990, while Spain's net emissions have grown by 9 percent in the same period.

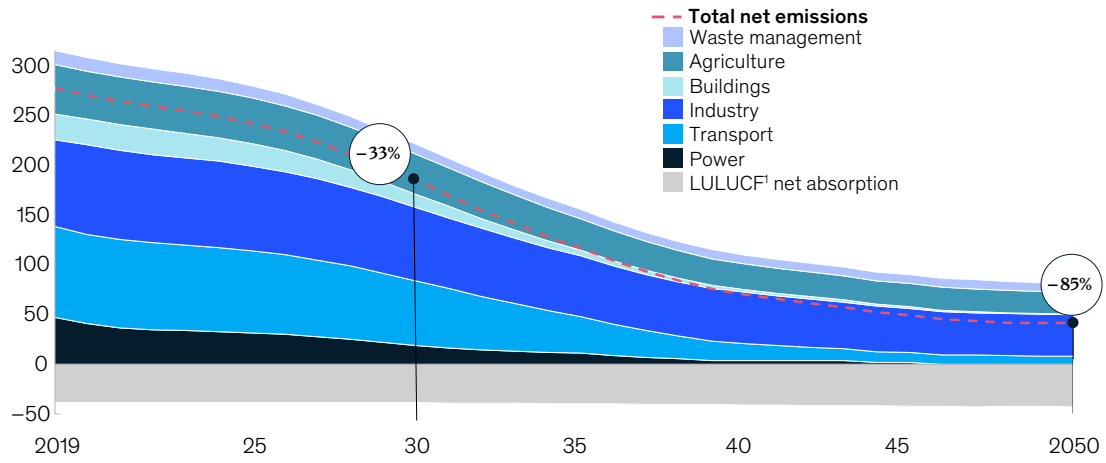
Contributions by industry

Some sectors are harder to abate than others, while others are more urgent due to their high emissions intensity. Because the transport and industry sectors account for more than 55 percent of Spain's emissions, they are key factors in the country's mission to reach net-zero emissions by 2050. The transport

Exhibit 5

Our current policies scenario suggests Spain could reduce its emissions by 85 percent by 2050.

Greenhouse gas emissions including LULUCF,[1] $MtCO_2e$[2]

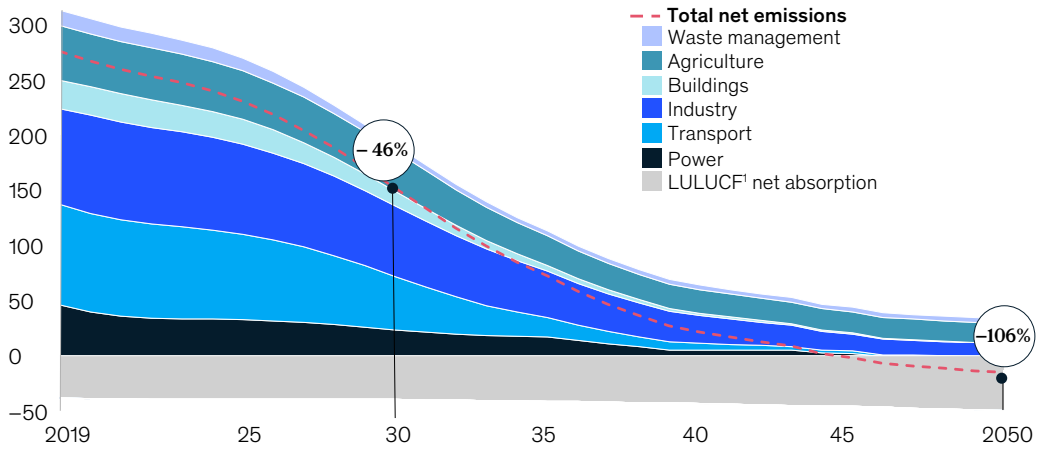


Note: Considers existing policies and announced projects and initiatives for decarbonization.
[1]Land use, land-use change, and forestry.
[2]Metric megatons of CO_2 equivalent.
Source: McKinsey Decarbonization Scenario Explorer

Exhibit 6

The more ambitious net-zero scenario would see negative emissions in Spain by 2050.

Greenhouse gas emissions including LULUCF,[1] $MtCO_2e$[2]



[1]Land use, land-use change, and forestry.
[2]Metric megatons of CO_2 equivalent.
Source: McKinsey Decarbonization Scenario Explorer

sector could see different approaches based on modes of transport. Under the net-zero scenario, the stock of cars, motorcycles, and vans would reach 100 percent decarbonization by 2050, with battery electric vehicles achieving 90 percent penetration and fuel cell electric vehicles (FCEVs) reaching 10 percent penetration. Aviation would be initially decarbonized through use of biofuels (reaching 60 percent of penetration by 2050) and increasingly shift to synfuel-based airplanes (20 percent share by 2050) starting in the mid-2030s.

The industrial sector encompasses a range of activities, from cement and steel production to oil refining and chemicals. These contribute significantly to Spain's emissions and would likely only see partial decarbonization by 2050. Cement producers, for example, could reduce clinker content in cement and shift to alternatives such as biomass and carbon capture and storage to reduce emissions by 2050.

Also, under the net-zero scenario, steel producers would progressively replace iron and steel blast furnaces—which account for roughly 30 percent of steel production in Spain—with hydrogen-fueled electric-arc furnaces that use direct-reduced iron (DRI-EAF), using green hydrogen made with renewable electricity.[23] By 2050, hydrogen DRI-EAFs would account for about 35 percent of production. Scrap-based EAF steel production, which produces lower emissions, would retain most of its current share of production (65 percent). This would allow the sector to reduce emissions more than 90 percent by 2050.

[23] "Net-zero steel in building and construction: The way forward," McKinsey, April 28, 2022.

The industrial sector encompasses a range of activities that contribute significantly to Spain's emissions and would likely only see partial decarbonization by 2050.

The chemical and agricultural industries, mostly producing or using ammonia, ethylene, and fluorinated gases, could get to 100 percent decarbonization by 2050 but would see divergent pathways by 2030. Green technologies and initiatives for ammonia production would rely on green hydrogen, rather than steam methane reforming (SMR) with natural gas, as well as SMR with biogas. By 2030, olefins production, while continuing to use conventional steam cracking, would begin transitioning to using internally generated low-carbon circular hydrogen and carbon capture and sequestration (CCS). From the 2040s onwards, the industry would progressively switch to electric cracking once the technology is competitive at scale and renewable power is available and cost competitive, potentially reaching very high levels of penetration by 2050. In addition, fostering waste circularity via improved plastic waste management, recycling, and the development of renewable carbon feedstocks would not only help to reduce sector emissions and the Scope 3 emissions of the manufacturing value chain (for example, in sectors ranging from electronics to consumer goods) but would also have environmental benefits, such as plastics-waste pollution reduction, more efficient recycling, and increased plastics circularity.

Petroleum refining would decline as demand for oil-derived products falls due to electrification and the use of alternative fuels such as biofuels. The use of electricity-based heating for refining activities, along with other alternatives such as green hydrogen, would replace conventional technologies.

A higher level of decarbonization in hard-to-abate industry sectors before 2030 in other EU countries would potentially force an accelerated decarbonization of the Spanish industry to avoid competitive disadvantages. In such a scenario, CCS could play a role as the most economic available technology by 2030.

Building usage would also be fully decarbonized by 2050. Fossil-fuel-based equipment for heating and cooking such as gas boilers and stoves will be completely phased out in favor of equipment using green energy such as heat pumps and biomass boilers.

Agriculture would see a smaller reduction in emissions by 2050 than other sectors. It is currently responsible for about 18 percent of Spain's net emissions, driven by cattle, crops, and the use of combustion engine farm machinery.[24] The latter can be decarbonized by switching to electrical equipment, while other sources of emissions, such as those from cattle, could be partially tackled via feed additives and changes in consumer preferences.[25] Furthermore, improving business and consumer practices across the whole food value chain would help reduce waste and have a positive impact on sector emissions.

[25] "Curbing methane emissions: How five industries can counter a major climate threat," McKinsey, September 23, 2021.
[24] Greenhouse gas inventory data, 2019.

Forests: Spain's green ace to tackle climate change

Forests are the most time-tested way to remove carbon dioxide (CO_2) from the atmosphere, leveraging a technology developed over millennia: photosynthesis.

Spain has almost 19 million hectares of forest cover, accounting for more than a third of all land, making it one of the most forested countries in the European Union. Today, these forests and the whole of the LULUCF[1] sector contribute to the removal of 38 metric megatons of CO_2 equivalent ($MtCO_2e$) every year—equivalent to removing 12 percent of Spain's total gross emissions. Scaling up reforestation and afforestation to increase forest cover, improving forest management techniques, preventing forest fires, and protecting underwater seagrass ecosystems could remove an additional 12 $MtCO_2e$ per year, according to our conservative estimates. Reforestation, with two-thirds of that incremental impact, could be Spain's green ace toward decarbonization.

[1] Land-use, land-use change, and forestry.

Through enhanced forestry management, LULUCF could absorb an additional 12 $MtCO_2$ (30 percent) per year, which would provide critical compensation for hard-to-abate sectors (see sidebar, "Forests: Spain's green ace to tackle climate change"). Northern Spanish autonomous communities Castile and León, Aragon, Galicia, and Catalonia have the highest potential for CO_2 absorption.

Key levers to achieve net zero

In a wave of innovation, we see three key levers to facilitate Spanish decarbonization: electrification, hydrogen, and biofuels.

Electrification would be a primary lever, especially for transport and industry

The shift to electrified technologies is critical across sectors and must be accompanied by significant investment in renewable-energy generation capacity and increased grid resilience.

Spain is a significant producer of renewable energy. With more than 28 GW, it has Europe's second highest wind generation installed capacity after Germany. Its natural advantages, such as a high number of sunny days, mean the country can produce renewable energy at a lower cost than other European economies can. As an example, solar photovoltaic PPA[26] offer prices for 2021 show that 25th percentile prices were 40 percent lower in Spain (€34.0 per megawatt-hour) than in Germany (€56.6 per megawatt-hour).[27]

Given the right policy approach and levels of investment, Spain could outcompete its peers on developing clean-energy alternatives based on electrification, such as green hydrogen. Hence, by 2050, we expect to see a doubling of the electrical power supply, supporting an array of new electric applications, from cars and cookers to green-hydrogen electrolyzers.

Green hydrogen would be a primary lever to reduce CO_2 emissions

Clean hydrogen is required for deep decarbonization, especially in hard-to-electrify and hard-to-abate sectors. Indeed, global demand for green hydrogen is expected to rise between fivefold and sevenfold by

[26] Power purchase agreement.
[27] "PPA price index," LevelTen, based on data up to Q2 2021.

Given the right policy approach and levels of investment, Spain could outcompete its peers on developing clean-energy alternatives based on electrification, such as green hydrogen.

2050.[28] In Europe, blue hydrogen from natural gas will be outpaced by green hydrogen from water electrolysis, which will eventually have a lower cost (probably by 2040) and allows for full decarbonization. Our net-zero scenario suggests that in Spain alone, not including any potential capture of the broader European market, supply of hydrogen would grow more than sevenfold by 2050.

Spain could become one of the most competitive green-hydrogen producers globally, mainly because of its ample supply of solar energy. This creates compounding opportunities, such as potential leadership in hydrogen-based fuels such as green-ammonia bunkering or aviation synfuels.

In addition to highly competitive renewable electricity, Spain's advantages include technology advancements from expanding manufacturing capabilities, a strong network of potential hydrogen off-takers, excellent infrastructure and location to unlock market liquidity, a supportive regulatory backdrop, and the financial ecosystem to facilitate investment. These combined benefits mean Spain can produce green hydrogen at a levelized cost of €1.4 per kilogram (kg), compared with €2.1 per kg in Germany, for example.

Moreover, Spain has existing natural-gas interconnections with northern Europe that could enable hydrogen exports and outcompete alternative routes for hydrogen imports from inside and outside of Europe. For instance, hydrogen landed costs in Germany are projected to be €1.9 per kg when importing it from Spain versus €2.1 per kg from Norway and Algeria, the other most competitive origins. If Spain can capture roughly 30 percent of Europe's hydrogen market, which is projected to be between €44 and €58 billion by 2050, hydrogen could add about 1 percent of GDP to the Spanish economy.[29] The net impact is a historic opportunity to transform Spain into an enabler of European decarbonization.

Biofuels would displace conventional fuels

Biofuels would be a key technology for Spain's decarbonization journey, driven by their relative technical similarity to fossil fuels but with a net-zero-emissions footprint. They would serve as a transition technology across multiple sectors, specifically in hard-to-abate sectors such as aviation, where carbon-free synthetic fuels would take longer to scale (until the mid-2030s).

[28] *Global Energy Perspective 2022*, April 26, 2022.
[29] McKinsey analysis based on *Final report of the High-Level Panel of the European Decarbonisation Pathways Initiative*, European Commission, November 2018.

Advanced biofuels can not only achieve a significant reduction of GHG emissions compared with fossil fuels, especially when using low-emission-intensity feedstocks, but also use biowaste that would otherwise cause GHG emissions or pollution (for example, methane emissions from food rotting in landfill).

Many biofuels, such as bio-gasoline or bio-jet, are functionally equivalent to petroleum fuels and fully compatible with existing infrastructure. Thus, they do not require any significant modification to current engines or infrastructure, making them especially useful for reducing emissions in the short term and limiting possible stranded assets across many sectors such as oil and gas and transport.

As an example of their potential impact, our net-zero pathway for Spain projects that demand for biofuels (including bioliquids and biogas) will more than double by 2050, and will account for roughly 60 percent of all fuel consumption in domestic aviation and more than one-third in domestic maritime transport, serving as a key lever to reduce emissions in some of the hardest-to-decarbonize sectors.

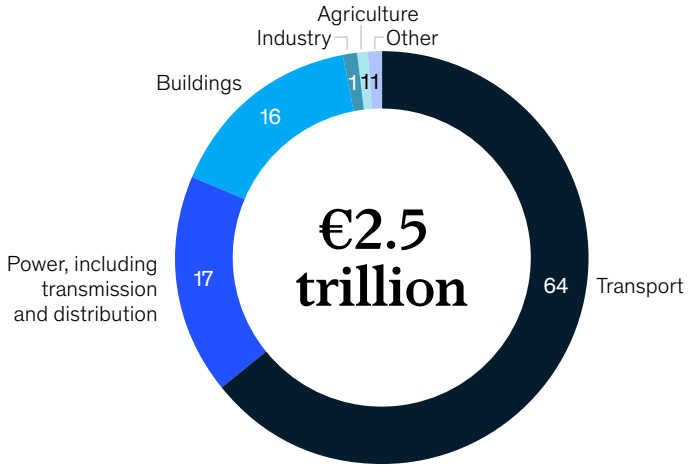
The socioeconomic impact of decarbonization

The required reallocation of capital is significant. First, our net-zero scenario would require accumulated capital expenditures of €2.5 trillion for green technologies and processes by 2050 (Exhibit 7). This equates to €85.0 billion per year on average, or about 6.2 percent of yearly GDP, which is only one percentage point higher than the 5.2 percent of yearly GDP in investment expected in the current policies scenario. The key areas of investment will be transport, power, and buildings.

Exhibit 7

The accelerated net-zero scenario would require an accumulated €2.5 trillion of capital expenditures to reach net-zero emissions by 2050.

Capital expenditures for clean technologies and techniques until 2050, % of €2.5 trillion



Source: McKinsey Decarbonization Scenario Explorer, "net-zero" scenario for Spain

Biofuels would be a key technology for Spain's decarbonization journey, driven by their relative technical similarity to fossil fuels but with a net-zero footprint.

Transport will require €1.6 trillion in capital expenditures from 2021 to 2050, amounting to 64 percent of total investment. This would enable the switch from internal-combustion-engine (ICE) vehicles to nonemitting alternatives. About €430 billion, or 17 percent of total investment, will be required in the power sector, including investment to develop transmission and distribution networks. Getting buildings ready for the transition will require capital expenditures of €400 billion through 2050, or around 16 percent of the total. This will be used for retrofitting buildings and installing low-carbon appliances such as electric heat pumps and electric stoves.

The significant capital expenditures required through 2050 would be partially offset by reductions in operating expenditures in some sectors, such as transport. Over time, as technologies continue to mature, the cost of clean fuels such as green hydrogen and sustainable fuels is expected to decline, further improving the economic equation of the transition. Operating expenditures on green technologies and techniques would total €1.3 trillion, driven mainly by the transport, building, and industrial sectors. The transport sector would require €435 billion, directed mostly at electricity and alternative fuels. The buildings sector would require €412 billion, mainly for electricity and maintenance of boilers, insulation, heat pumps, and electrical components. Finally, the industrial sector would need €330 billion, destined mostly for electricity and alternative energy sources.

In the net-zero scenario, capital expenditures and operating expenditures would support 1.1 million jobs on average each year, including in the production, repair, and installation of machinery and equipment, and in the construction and power sectors.

Some sectors could be burdened with stranded assets, which we estimate could reach €10.4 billion by 2050. As a share of yearly GDP, this estimation is less than half of the magnitude of stranded assets globally. This is because at a global level, about 80 percent of stranded assets will pertain to fossil fuel power plants, primarily coal-fueled, which account for 34 percent of power generation (versus less than 5 percent in Spain). Spain's relatively low cost of stranded assets compared with Europe is driven mostly by steelmaking, which represents around 40 percent of expected stranded assets in Europe. While around 54 percent of steel in Europe is currently produced through high-emitting blast furnaces, this share in Spain is roughly half, at approximately 28 percent. In terms of sectors, stranded assets in oil refining could be up to €4.3 billion, €2.1 billion in steel, and €1.2 billion in both power and ammonia. Cost-efficient retrofitting (for example, carbon capture and storage) or repurposing (for example, toward biofuels or hydrogen) could reduce these high costs.

Key roles for stakeholders

Getting to net-zero emissions will take more than regulation. All parts of Spanish society need to take responsibility and work together to make change happen. The good news is that the path to net-zero emissions can result in a positive business case. Globally, about 65 percent of annual capital spending is assigned to high-emissions assets. But in a scenario in which the world reaches net-zero emissions by 2050, this pattern would reverse: McKinsey research shows that 70 percent of capital outlays through 2050 would be spent instead on low-emissions assets.[30] At a regional level, the transition could also create millions of jobs and reinforce Europe's position as a global leader on sustainability. Spain has the opportunity to be a catalyst for this transformation by building on its history of renewable energy adoption, betting on its potential to drive growth in new technologies such as green hydrogen and sustainable fuels, and investing in its rich natural endowments to support the transition.

The next decade will be critical in positioning Spain on the right side of the transition equation. Spain is exposed to significant physical risks under worsening climate change scenarios, which could affect both lives and livelihoods across multiple sectors of the economy. The rate of reduction in emissions that Spain has seen since 2013 needs to be four times as fast in order to meet the country's 2030 targets. Inaction would not only make the decarbonization challenge even higher in later years, but also lock in the impact from the emissions that are not reduced.

Against this background, nine key elements can form the basis of an orderly and productive transition (Exhibit 8). The first three elements relate to the physical building blocks of the transition. First, innovation and scale-up of clean technologies is a critical enabler of any viable decarbonization plan. It is estimated that 85 percent of today's emissions in Europe can be abated with already demonstrated technologies,[31] some of which are mature (for example, electric-arc furnaces for steelmaking) or in early adoption (such as electric cars). Additional investment in R&D is required to continue developing less mature technologies and enable the deployment of more mature ones. Spain has a history of early adoption of clean technologies, such as solar PV and onshore wind, which explains the approximately 50 percent reduction in power sector emissions since 2005. Expanding renewable-energy capacity and investing in developing and deploying new clean technologies such as green hydrogen will be critical. The Spanish government, through its Ministry for Ecological Transition (MITECO), has laid out road maps for multiple key clean technologies, such as hydrogen, energy storage, and offshore wind, to name a few.

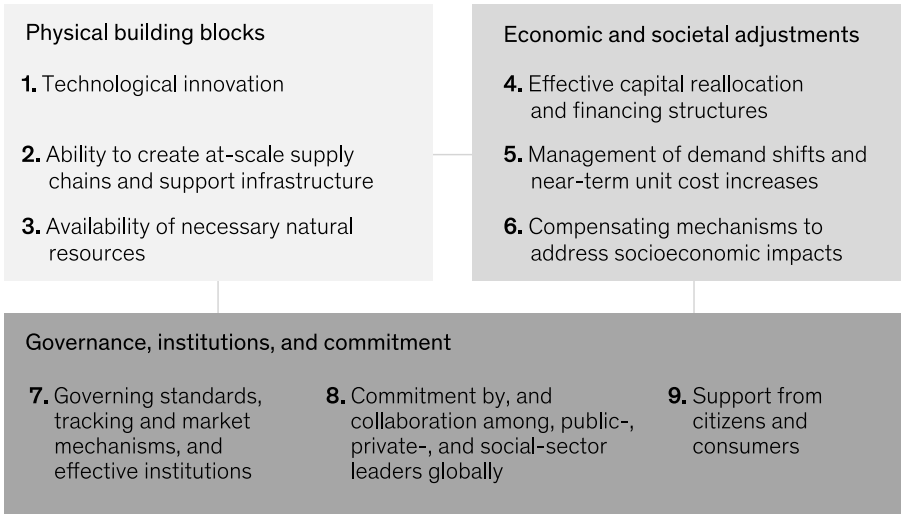
Second, creating more resilient at-scale supply chains and support infrastructure will be fundamental to allow for the scale-up of clean technologies. For example, decarbonizing road passenger transport in Spain by shifting to electric vehicles can happen only if a strong network of EV charging stations is available. Having a clear road map for the deployment of technologies and supporting supply chains and infrastructure can prevent delays and optimize the scale-up of clean technologies.

Third, ensuring availability of the natural resources necessary to build and scale up the technologies and supporting infrastructure is paramount. These natural resources include raw materials that are being used

[30] "Playing offense to create value in the net-zero transition," *McKinsey Quarterly*, April 13, 2022.
[31] "Solving the net-zero equation: Nine requirements for a more orderly transition," McKinsey, October 27, 2021.

Exhibit 8

We see nine requirements for solving the net-zero equation and ensuring an orderly transition.



at scale today, such as copper and nickel, and others that are relatively less common but will play a large role in the transition, such as lithium, cobalt, and rare earths. Land is another important natural resource in Spain's transition. As we plan to grow our solar PV capacity by more than ten times current levels, land will become a critical factor. Moreover, if Spain's forested lands are expected to play an increasingly important role—absorbing about 30 percent more carbon dioxide than today—appropriate management of such areas must be ensured. As significant shares of areas available for reforestation are public, regional (autonomous communities) and provincial governments have an important role to play. Water is another critical natural resource, particularly in Spain, where water scarcity is expected to increase in some regions when analyzing higher temperature scenarios. The scale-up of green hydrogen, which is based on water electrolysis and is expected to play a major role in Spain's transition, will increase demand for water. Properly managing competing demand for these scarce natural resources will be fundamental to ensure their availability.

The second set of key elements is related to the necessary economic and social adjustments, starting with ensuring the effectiveness of the capital reallocation and establishing enabling financing structures. Our net-zero scenario estimation of around 6.2 percent of Spain's expected yearly GDP in clean-technology capital investment for the next 30 years implies a significant commitment, both in magnitude and in the shift from high-emitting assets to low-emitting ones. Managing the risk of stranded assets, which we estimate at €10.4 billion, would be important for more exposed sectors such as oil refining and steelmaking. The scale and speed of these changes in capital allocation emphasize the need for effective financing structures to enable them and mitigate potential risks.

The second element in this set refers to the need to manage demand shifts and near-term cost-unit increases. As policies, technologies, and investor and consumer preferences increasingly tilt demand toward low-carbon products and services, high-carbon ones face significant challenges. A very clear example of this shift is in demand for fossil fuels, which our net-zero scenario estimates could be reduced significantly by 2050. In turn, demand for clean sources of energy—such as electricity from renewable sources or biofuels and green hydrogen—is expected to grow. As the demand balance changes, new opportunities can emerge for both incumbents and start-ups, which are already actively developing low-carbon value propositions in Spain.

Some of these changes, due to either high up-front capital investments or the application of costly zero-carbon technologies in operations, could increase unit costs of goods and services. In many cases, scale economics has the potential to bring those costs down, as has happened with solar PV and onshore wind generation in the past. In other cases, additional technology developments are needed to bring costs down. The private and public sectors should collaborate in implementing the necessary adjustments to mitigate the potential disruption brought about by these shifts.

That leads to the third element in this set, related to the compensating mechanisms to address potential socioeconomic impacts. Often, these impacts can be geographically focused in areas with denser concentration of high-emitting industries, as the change in demand toward low-emitting products and services creates a reallocation of labor across companies and sectors. Moreover, the revenue of regional, provincial, and municipal governments can be affected, reducing their capacity to provide support to the most affected communities. Incentives for economic diversification and local investment in green technologies would be fundamental to retain and attract companies. Reskilling programs, building on existing local capabilities and interests, will be critical to ensure that local populations are employable and make a smooth transition. All of these initiatives will require deep collaboration among all levels of government.

The last set of elements required for an orderly transition refers to the governance and institutional framework and commitments. The first of these builds on the requirement of clear standards, tracking and market mechanisms, and effective institutions to drive this transition. The sheer magnitude, speed, and complex systemic nature of the transition we see in our net-zero scenario suggests that a strong institutional framework is needed to enable capital deployment, manage uneven impact across stakeholders, keep momentum high, and address all other potential challenges that are bound to emerge. The role of Spain's Ministry for the Ecological Transition (MITECO) is an example of the type of institutional relevance that this challenge requires, and its collaboration with regional and municipal leaders, along with the private sector, is fundamental.

A strong commitment to driving the transition and collaborating with other stakeholders is required from the public, private, and social sectors. An orderly transition will depend on coherent, reliable policies from the public sector and on sound transition strategies from private-sector organizations to reallocate capital and transform their product and service portfolios. Spain is moving forward in these requirements, with clear public policies and road maps, such as the climate change and energy transition law and the

Integrated National Energy and Climate Plan, and growing commitments from the private sector, where all of the largest national companies[32] have made decarbonization or climate-related commitments. Furthermore, low-carbon products and services are increasingly being offered in Spain by both established and sustainability-focused start-ups. This momentum should be built upon, ensuring that small and medium-size companies are also developing clear climate strategies, that these strategies are implemented, and that policies and regulations accompany the changes and technology improvements. Social organizations can promote this collaboration in the public and private realms.

Last, the support from citizens and consumers at large will be a fundamental factor. Rising awareness of potential climate risks and the magnitude of the challenge should drive citizen decision making in support of policies that promote a just transition and in the demand for clean goods and services. A well-informed and engaged public can be a significant catalyst for collaboration among the public, private, and social sectors.

These steps toward an optimal transition are both practical and achievable. Taken together, they present a significant economic and social opportunity. Through commitment to execution, Spain can accelerate its decarbonization, build world-leading industries, and lead Europe in combating climate change in the next decade and beyond.

[32] Above €5 billion in revenues.

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