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Carbon-Neutral Hungary

Pathways to a successful decarbonization

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Carbon-Neutral Hungary

Pathways to a successful decarbonization

By Levente Janoskuti, Hauke Engel, Marton Bekes, Viktor Hanzlik, Andras Havas, and Soma Tamas

Preface and acknowledgment

At McKinsey, we see climate change as one of the defining issues of our age – an issue that will have profound effects on people, governments, and industries, as well as on individual companies. We believe that it is important for citizens, government officials, and business leaders to understand the pathways and actions required to limit climate change to what scientists deem to be acceptable levels.

The intent of this report is to present a cost-effective pathway for Hungary to meet its target to reach carbon neutrality by 2050, outlining the actions and investments required in each sector of the Hungarian economy. Our objective is not to predict the future, but to present our analysis of the costs and implications of the decarbonization efforts currently being discussed on European level. In doing so, we are attempting to provide what appears today as the most optimal route to achieving net zero carbon dioxide (CO_2e) emissions.

This report presents the results of McKinsey & Company's independent analysis based on the sources listed in the end-sources section in the Appendix. The preparation of this report was led by Levente Janoskuti, managing partner of McKinsey's Budapest Office, Andras Havas, partner in McKinsey's Budapest office, Viktor Hanzlik, partner in McKinsey's Prague office, Marton Bekes, associate partner in McKinsey's Budapest office, Hauke Engel, partner, on behalf of McKinsey's Sustainability Practice and Soma Tamas, consultant in McKinsey's Budapest office.

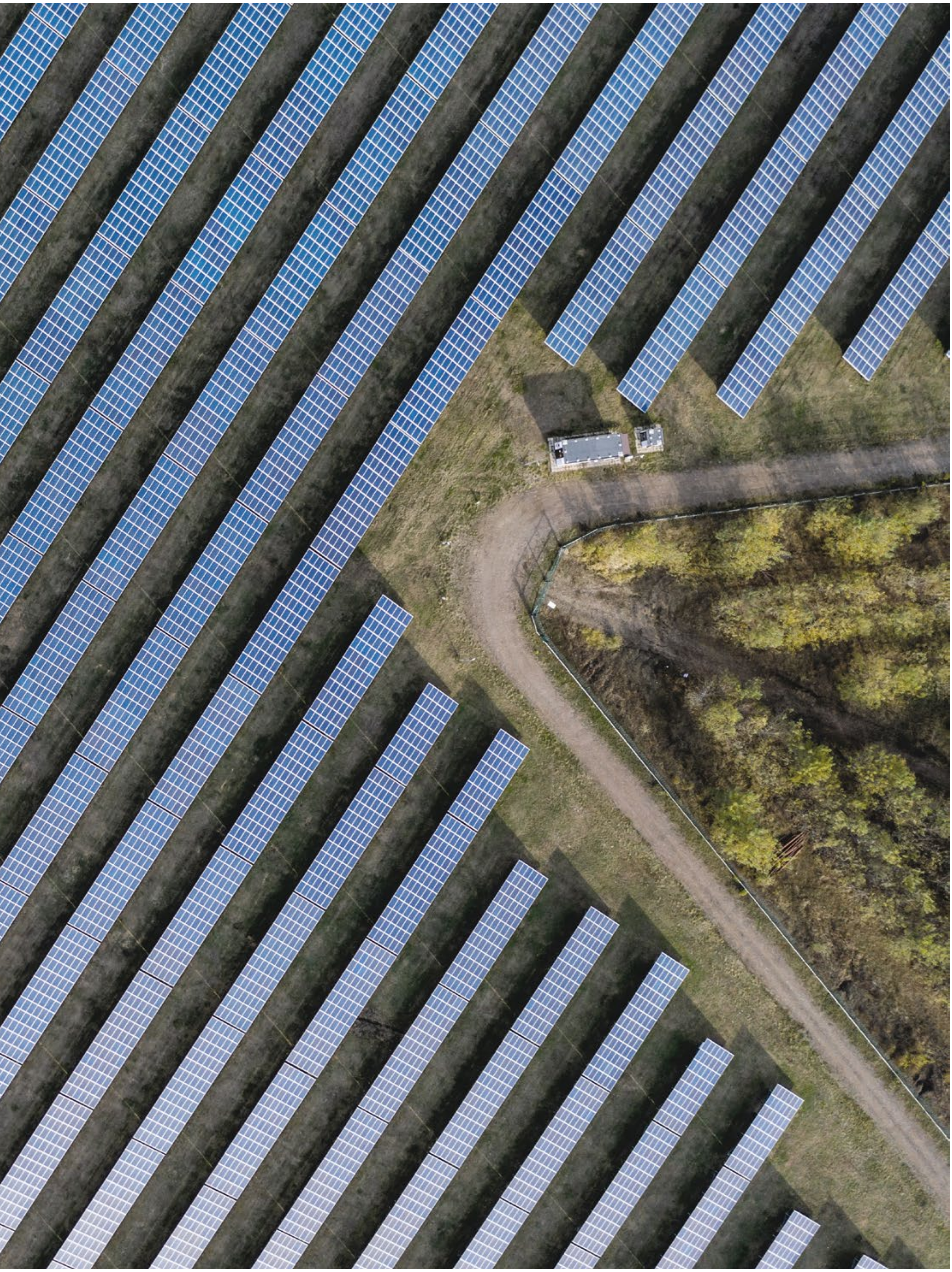
Several international McKinsey experts, consultants, and colleagues contributed significantly to this report. They include, in alphabetical order: Gergely Antal, Zsofia Balogh, Artem Baroyan, Lora Beltcheva, Julian Conzade, Celia Chaiban, Daniel Cramer, Thomas Czigler, Lauritz Fisher, Anna Granskog, Victor Guzik, Ondrej Hanuska, Catherine Hart, Christian Hoffmann, Hanna Kaustia, Hannah Kitchell, Jurica Novak, Erlend Oye, Mate Pocs, Sergio Nistal Prieto, Demian Roelofs, Leonardo Satori, Namit Sharma, Rita Simola, Balint Stellek, Antoine Stevens, Piotr Szabat, Gustaw Szarek, Michael Taksyak, Katarzyna Tluscik, David Toth-Almasi, Ferenc Vadasz, Balint Varga, Zsigmond Varga, Boris Vergote, Ulrich Weihe, Alexander Weiss, Yeye Xing, & Kristof Zekany.

We are grateful to Laura Dodge for editing the report, to Petr Kotesovec and Angela Toth for visual management and to Andrea Egri and Anna Szucs for supporting the publishing process.

Table of Contents

Chapter 1

Executive summary



Introduction

Prolonged heat waves, frequent droughts, heavy rains: these are just some of the effects that Hungary and the rest of the European Union (EU) are experiencing as a result of climate change. Scientists warn that the EU will face climate-related losses in biodiversity, infrastructure, and in livelihoods unless countries take steps to eliminate the man-made greenhouse gases that contribute to global warming.[1] Similar to its European Union (EU) partners, Hungary has pledged to limit global warming to 1.5 degrees Celsius (°C) by 2050.

To get there, Hungary aims to follow the broad targets set by the EU for carbon emissions reductions over the next three decades. By 2030, EU targets reducing greenhouse gas (GHG) emissions by 40 percent compared to the 1990 levels, which may be further increased pending implementation of 'Fit for 55,' a set of proposals under consideration. By 2050, the goal of the EU is to produce net zero-carbon emissions.[2] However, the actual process of decarbonization depends on the unique economic and social contexts of each EU country.

The Hungarian parliament recently passed a law declaring carbon neutrality a legally binding obligation[3] to reach by 2050, and public and corporate support for a low-carbon transition is intensifying. In the latest annual EU public opinion poll, most Hungarian respondents said that business and industry and national governments should be primarily responsible for tackling climate change; respondents also said that the cost of further global warming outweigh the investments required to meet this goal.[4] Likewise, an increasing number of companies in Hungary and across the globe are moving decarbonization to the top of their strategic agenda.

However, public support for tackling climate change is not sufficient to reach the net zero target. Substantial investment, land-use changes, implementation of new technologies, behavioral changes, and changes to the energy mix are key to reducing carbon emissions across the EU.

This report describes a potential cost-optimal pathway to net zero by 2050, including an ambitious 55 to 60 percent emissions reduction by 2030. It identifies actions in each major economic sector, assesses the corresponding costs and benefits, and examines how the net zero transition contributes to economic competitiveness and energy security.

The report's methodology incorporates McKinsey's net zero expertise in other countries, international benchmarks, as well as proprietary tools. These include, among other tools and resources, McKinsey Decarbonization Scenario Explorer (quantified impact of 500+ decarbonization levers), Global Energy Perspective (outlook on 55 energy products in 30 sectors in 146 countries until 2050), Hydrogen Insights (detailed perspective on hydrogen levers) and European Power Model (hourly dispatch optimization model of the European power system).

Many of the green investments could come with economic and social benefits

What is the cost-optimal pathway?

Hungary could choose from an array of pathways to deliver a carbon-neutral economy by 2050. Approaches vary depending on technologies available and deployed, the sequence of measures taken, and the level of stakeholders' commitment. This report outlines the cost-optimal pathway[5] – one that does not constrain GDP growth or consumption – based on currently available technologies (not all decarbonization technologies are available commercially and at scale), the associated costs, and the structure of the Hungarian economy.

The model uses the best available cost outlook to decide between competing technologies to be applied for decarbonization. Given the potential future technical advancements regarding these technologies, cost may evolve differently, leading to a slightly divergent pathway.

The model assumes agents are rational, economic decision makers who adopt lower carbon technologies when the total cost of ownership (TCO) of these technologies is lower than status quo solutions. It also assumes that uneconomic solutions are implemented as late as possible to meet emissions reductions targets. The model uses industry targets set on the national or European level and considers constraints in implementation due to lack of resources. It does not account for potential trends in consumer behavior, like eating less meat or producing less waste, which might have a positive impact on GHG emission reduction.

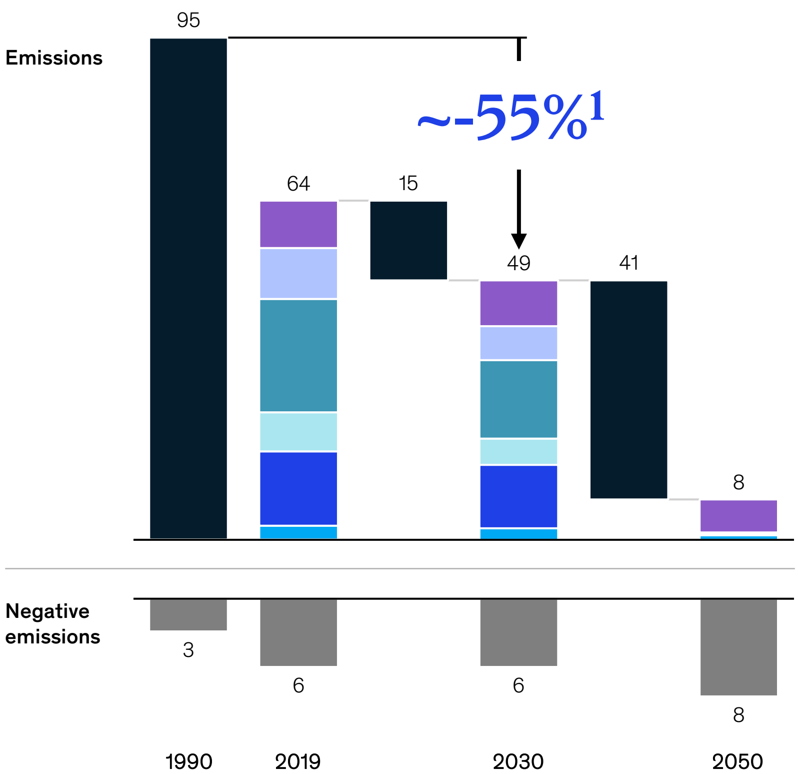
Main findings

Hungary's cost-optimized transition to decarbonization requires major capital investments –this analysis estimates an additional capital expenditure investment (CAPEX) of between €150 billion to €200 billion from now through 2050. Although this is a significant investment, overall, it might bring a positive return: on one hand, it moderates the exposure towards the negative effects of climate change, while increasing the cost effectiveness of all sectors. On top, it will also increase the gross domestic product, create new jobs, increase energy security, as well as the competitiveness of the Hungarian economy within & beyond the region.

Our model indicates that if Hungary follows the roadmap presented herein, it could reduce carbon emissions by 55 to 60 percent by 2030 and achieve net zero by 2050. The exhibit below offers specific percentage reductions for each sector of the economy.

Hungary could reach ~55-60% reduction by 2030 and Net Zero by 2050

MT CO_2e emissions



	Change (%) 2019 vs. 2030	Change (%) 2019 vs. 2050
Power	-33	-100
Transportation	-15	-99
Industry	-31	-98
Buildings	-34	-99
Agriculture	-14	-30
Waste	-16	-69

1. Including negative emissions

Source: UNFCC

Decarbonization pathways for each sector

Industry

Industry accounts for 33 percent of total carbon emissions, representing Hungary's largest source of carbon emissions and this sector will be one of the most challenging to decarbonize due to its complexity. Most of the mechanisms needed to reduce industry emissions in Hungary are cost-prohibitive or unavailable at scale, and we expect this to be the case until the 2030s.

In the interim, industry could reduce emissions by 30 percent by 2030 by improving energy efficiency in heavy industries; and offset some hard-to-abate industrial emissions with carbon capture, utilization, and storage. Any residual emissions would be offset outside the sector, for example, in natural carbon sinks like forests.

Looking at the sub-sectoral level, four sub-industries represent around half of all industrial emissions: iron and steel; upstream oil and gas; cement and lime; and refining. The iron and steel transition will be driven by the switch from coal-fired, blast furnace-basic oxygen furnaces (BF-BOF) used to melt iron ore in steelmaking with renewable energy resources-powered electric arc furnaces (EAF). The cement sector could cut 50 percent of its emissions by substituting with alternative fuels and improving energy efficiency, and the remaining 50 percent via carbon capture. Similar solutions – electrification, the use of alternative fuels (especially green hydrogen), declining demand for oil and gas, and carbon capture – could cut most emissions in the remaining sub-industries.

Transport

Hungary's transportation sector is the country's second largest source

30%

Industry could reduce emissions by 30 percent by 2030

Hungary would also need to invest between €30 to €40 billion into the power grid to be able to accommodate renewables, electric cars and many more changes

of carbon emissions with 22 percent in total, with the majority coming from road transport.

Falling battery costs and acceleration of uptake of battery electric vehicles (BEVs) at scale will make BEVs cost-competitive against traditional, internal combustion engine vehicles (ICEVs) in the 2020s. Our analysis indicates that Hungary's light commercial vehicles will complete the transition to electric power first, followed by passenger cars. The key levers to accelerate the transition will be the successful buildup of EV charging infrastructure and targeted incentives for EV users.

Heavy-duty and long-range trucks and commercial vehicles will transition from fossil fuels more slowly, given their need for longer lasting energy, which can be provided by either advancing battery technologies or hydrogen fuel cells. By the early 2030s, green hydrogen will become a competitive alternative in specific sectors of transportation, enabling the decarbonization of heavy-duty road transport.

Beyond switching to zero-carbon means of transportation, Hungary could further increase its high share of public transport (it currently accounts for about a third of passenger kilometers annually).[6] Further public transport usage can be incentivized via free or faster public transport; disincentives like congestion pricing; and increasing uptake of micromobility and shared mobility, such as e-scooters and carsharing.

Power

Reducing power sector emissions, accounting for 12 percent of the country's emissions is central to Hungary's ability to reach net zero. Decarbonization itself will help to drive demand for electricity upwards by 2.8 times by 2050, and the sector must meet this demand with carbon-neutral solutions. Our research indicates that

Reducing emissions in the power sector is central to Hungary's ability to reach net zero

Hungary should increase installed power capacity by a factor of about eight or nine to meet projected demand in 2050.[7]

Given the increasing maturity of solar and wind power generation technologies and Hungary's significant potential (especially PV), the power sector could immediately begin scaling up renewable power capacity and fully abating emissions by the mid-2030s. In addition, Hungary could aim to become a net power exporter from the early 2040s. By 2050, solar and wind resources could represent over 85 percent of total installed capacity.

However, the rise of solar requires a major increase in sources of flexibility. For example, gas turbines will remain part of the generation mix (with potentially new turbines), but will need to be refitted with carbon capture technology; batteries and seasonal storage systems are needed to integrate renewable energy sources into the power supply and accommodate their variability; and new interconnectors will be needed to facilitate increased cross-border power flows.

Buildings

Buildings contribute 15 percent to Hungary's total carbon emissions. Space and water heating in detached family homes is by far the largest source of the buildings sector's emissions. Our analysis indicates that Hungary could reduce buildings emissions by 34 percent by 2030, and by 99 percent by 2050.

Improving energy efficiency, rapid and widespread installation of heat pumps and electric stoves, replacement of gas boilers with hydrogen boilers, and converting to carbon-neutral district heating are the main measures needed for Hungary's buildings sector to achieve zero emissions by 2050. We expect increasing uptake of heat pumps in the mid-2020s, as the cost of installation becomes more affordable. Government incentives and subsidies for heat pump installation will likely accelerate the transition away from buildings' reliance on natural gas for heating by 2040. Starting in the mid-2030s, hydrogen boilers will provide an additional alternative for low-emission heating in buildings.

Given that most of the current buildings will be still standing in 2050, improving the energy efficiency of existing homes (such as via better insulation or advanced energy management systems) and ensuring that newly built homes are carbon-neutral is essential to reach these targets. Maximum initial decarbonization impact could be achieved by replacing coal used in buildings. The right balance of electrification, hydrogen heating, and district heating depends on the development of the local power generation mix as well as the speed at which the cost of green hydrogen declines.

Agriculture

Agriculture comprises 14 percent of Hungary's total carbon emissions. Three sources account for Hungary's agriculture sector emissions: farm animals, crop production, and on-farm energy use. Despite being the most difficult sector to reach zero emissions, we expect that sector emission will begin to significantly decrease in the 2030s as increasing numbers of farms implement measures such as feed changes to reduce emissions from enteric fermentation, as well as improved fertilization techniques to reduce emissions from crops.

As in the transport sector, the declining costs of BEV and FCEV will drive the electrification of agriculture machinery throughout the 2030s. By the 2040s, 100 percent of Hungary's agricultural machinery would be electrified, cutting 24 percent of the current emissions.

Assuming no structural change to the sector, our analysis indicates that agriculture sub-industry could eliminate a quarter of animal-related emissions by 2050 through proactive measures such as feed changes and anaerobic manure digestion, where waste undergoes microbial processes to generate biogas.

Application of technologies such as specialty crop nutrition additives and more efficient fertilization techniques could help reduce crop emissions by 20 percent by 2050. As electric machinery becomes increasingly economic and available, they could accelerate a reduction in emissions related to on-farm energy use. However, not all emissions from agriculture can be eliminated – remaining must be offset by nature-based or technological carbon capture.

Waste

The waste sector contributes 4 percent to Hungary's total GHG emissions. As wastewater treatment and discharge along with solid waste disposal are the main sources of sector emissions,[8] it can be concluded that Hungary could cut emissions from waste by improving waste management for wastewater as well as solid waste. To reduce wastewater emissions, methane capture mechanisms could be installed in water cleaning facilities.

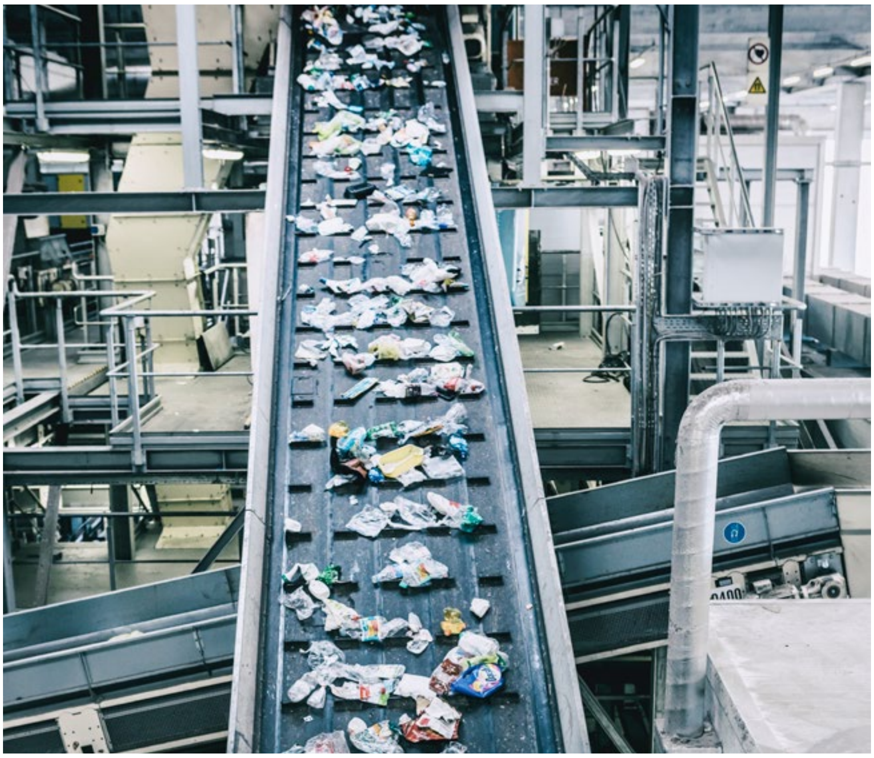
Methane capture and other waste-to-energy technologies, such as the emerging process of plasma gasification and more mature method of incineration could also help to cut solid waste emissions; and recycling and recovery mechanisms could divert waste from going to landfills.

Although the inherent nature of waste means that it cannot be eliminated, analyses indicate that by 2030, the share of industrial waste going to landfill in Hungary will fall to zero, while the share of municipal waste going to landfill could fall to 20 percent in 2030 and reach the zero-landfill target by 2050.

Technologies again could play a role in reducing emissions in this sub-sector. For example, our analysis demonstrates that technologies capturing and converting GHGs could reduce wastewater emissions by over 55 percent by 2050.

Hydrogen

Hydrogen produced using renewable energy sources, or so-called 'green' hydrogen, is gaining attention as a vital cog in the wheel of decarbonization. Investments in green hydrogen production are accelerating worldwide, and in Hungary could produce



significant economic benefits. Green hydrogen has the potential to be deployed in hard-to-abate industries like iron and steel and cement making as a means for seasonal renewable energy storage (thus increasing power system resilience) and as a replacement for natural gas as a feedstock in industrial processes like ammonia production, among other uses.

Green hydrogen also has the potential to improve Hungary's energy security. Hungary's high number of sunny hours enables it to produce renewable power, including hydrogen relatively cheaply, and its extensive gas distribution and transmission infrastructure could serve as a backbone of hydrogen transport for domestic use as well as potentially for export.

Based on the falling costs of hydrogen applications, Hungary could use green hydrogen as a major decarbonization lever from the early 2030s, reducing up to 40 percent of emissions by 2050 while simultaneously accelerating economic growth.

Negative emissions

To meet the goal of net zero by 2050, Hungary will need to go beyond measures that lower carbon emissions – it must take steps that result in negative emissions. There are two ways to produce negative emissions: nature- and technology-based solutions; both helping to capture GHGs not directly in the point of emission.

Natural resources serve as a powerful antidote to man-made greenhouse gases. Hungary could enhance its natural 'carbon sink' through reforestation, proactive forest management, and by restoring peatlands. These solutions would offset 8 percent of Hungary's total carbon emissions, or about 6 megatons of CO_2 equivalent (MT CO_2e). Our analysis indicates that reforestation could offset, at least, an additional 1.2 MT CO_2e by 2050, translating to 3.8 percent share of land after accounting for existing forests, peatlands, urban areas, and croplands.

Technology-based solutions that offset carbon emissions will also be necessary for Hungary to reach net zero by 2050. These include existing and scalable Bioenergy with Carbon Capture and Storage (BECCS) mechanisms, which are discussed below, as well as emerging technologies such as Direct Air Capture and Storage (DACS), which Hungary could deploy from the late 2030s.

Green hydrogen also has the potential to transform Hungary into a net energy exporter

Chapter 2

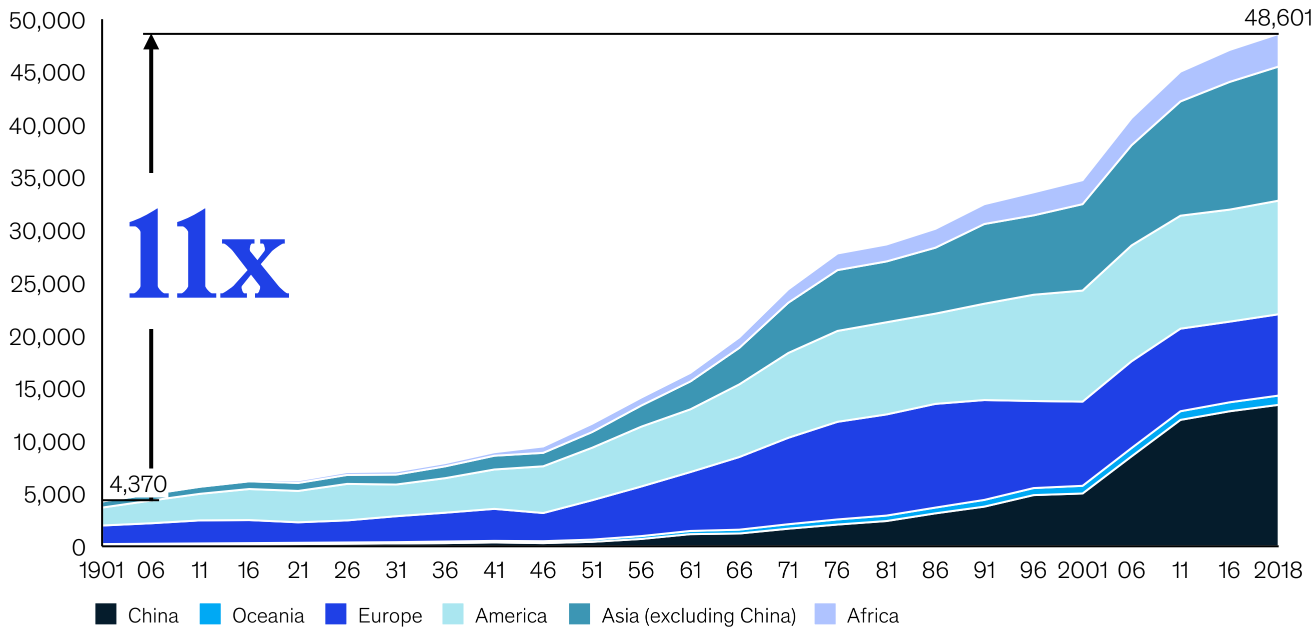
Decarbonization – a generational challenge


35°C
9:36

Man-made greenhouse gas emissions are warming the earth in dangerous ways.[9] From the melting of the Polar ice cap to changing migratory patterns of birds, the effects of climate change are both obvious and ubiquitous. The United Nations Intergovernmental Panel on Climate Change (IPCC) warns that unless humans limit global warming to 1.5°C by 2050 through the elimination of man-made greenhouse gas (GHG) emissions, climate-related catastrophes will further intensify.[10, 11]

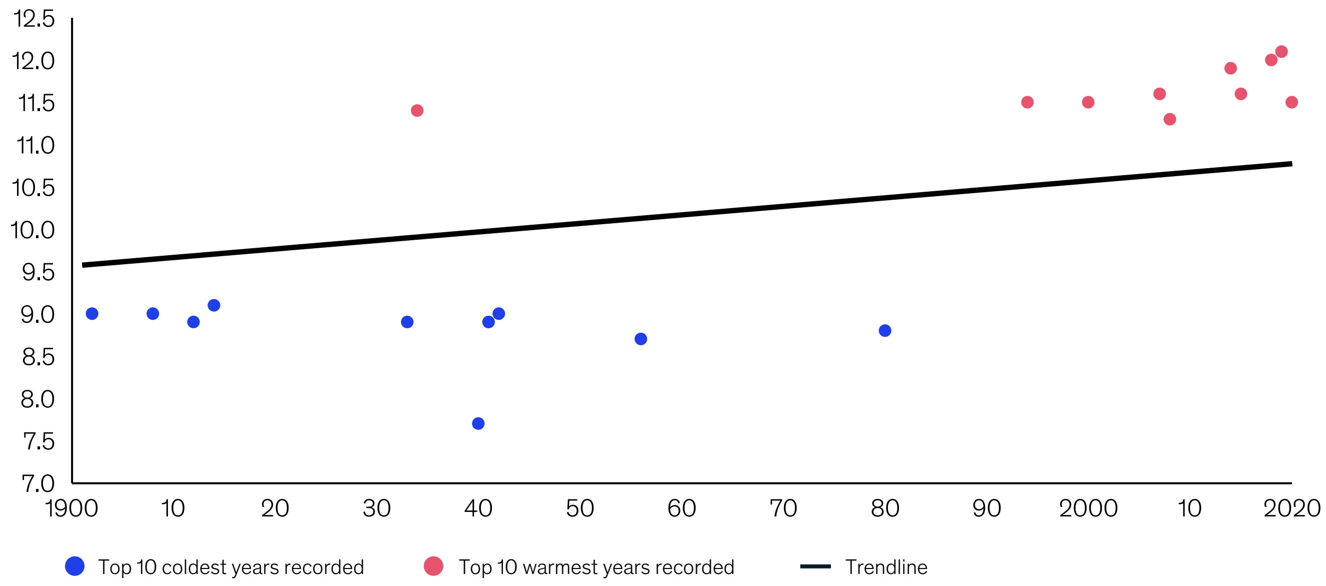
The global greenhouse gas (GHG) emission increased by ~11 times in the past 120 years

MT CO_2e



Over the past 120 years, the average temperature in Hungary has risen by 1.2°C

Average annual air temperature, °C



Source: KSH, OMSZ

Signs of global warming are already profound: average temperatures have risen 1.7 degrees Celsius since 1980.[12] and the number of heatwaves (days with mean temperatures above 25 degrees Celsius) increased by seven days annually since 1900.[13]

Meanwhile, climate change has ranked among the top three concerns of Hungarians in each of the past five years.[14, 15] In the latest annual European Union (EU) public opinion poll, for example, seven out of 10 Hungarian respondents said they believed that the cost of damages likely to result from climate change exceeds the investment required for decarbonization. In Hungary and across the EU, most respondents agreed that business and industry and national governments are primarily responsible for tackling climate change.[16]

Indeed, there are many signs that businesses, industry, and governments have started to reduce emissions. More and more companies are incorporating environmental impact into their strategies; banks are increasingly demanding phaseout of coal-fired power plants; and leading international industrial companies have started putting pressure on their suppliers to decarbonize as part of their efforts to meet sustainability goals.[17, 18] While these are good signs, all sectors should accelerate steps to decarbonize to reach the EU's medium-term milestones by 2030 and net zero by 2050.

To this end, the European Commission (EC) formulated the European Green Deal, a policy framework intended to accelerate greenhouse gas (GHG) emissions reductions across the European Union. Among the policies under consideration is a law that would require the bloc to reduce GHG emissions by 55 percent relative to 1990 by 2030 and reach net zero by 2050.[19] This 'Fit for 55' package, which was in proposal stage at the beginning of 2022 includes a robust set of interconnected legislations and initiatives on climate, land use, energy, transport, and taxation.

Hungary has already initiated its commitment to net zero by passing a law in 2020 that requires emissions reductions of at least 40 percent by 2030 compared to 1990 levels and becoming carbon-neutral by 2050.[20]

Considering the rapid acceleration of the decarbonization agenda in the general public, among companies and private individuals, this report sets out an ambitious objective of establishing the most efficient pathway for Hungary to achieve 55 to 60 percent emissions reduction by 2030 and 100 percent by 2050 while increasing its energy security of supply.

ETS vs. non-ETS targets in Europe

The European Union uses two main mechanisms to track and enforce the achievement of GHG reduction targets: the Emissions Trading System (ETS), explained below; and Effort Sharing Regulation, which sets a binding greenhouse gas emission target for each EU member state.[21]

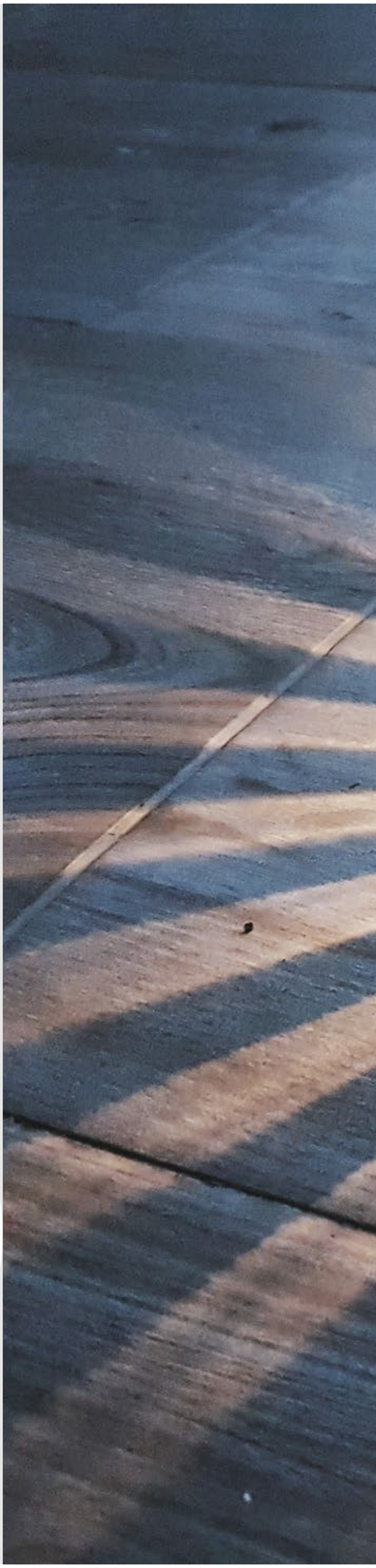
The ETS is a European Union-wide 'cap and trade' system which covers GHG emissions from over 11,000 heavy energy-using installations in the power and industry sector as well as domestic air transport. Under the scheme, a cap on the total amount of emissions is set for the sectors covered, and a corresponding amount of ETS allowance is allocated or sold to companies in their respective sectors. Companies must surrender allowances to cover allocated emissions, or they face fines. The permits are freely tradeable and incentivize companies to reduce their emissions to be able to sell their excess allowances or avoid having to buy additional ones. Companies, not individual member states, decide whether to acquire or sell allowances, reduce, or cease production, or to reduce the GHG intensity of production.

In theory, the scheme achieves the target level of emissions with the lowest societal costs. In Hungary, there are about 200 active permits held by various companies. In 2017, emissions covered by the ETS accounted for about 45 percent of the EU total, and 32 percent of Hungary's emissions.[22] For emissions not covered by the ETS (mostly from the transport, building, and agricultural sectors), there are binding targets for each EU member state defined by the decision on a joint effort. Failure to meet the targets may result in an infringement procedure and penalties against a member state. The European Commission is currently aiming to increase targets for ETS and Effort Sharing to meet the more ambitious targets of the Green Deal.

Chapter 3

Current emission – what is the starting point for Hungary?

3



Hungary's CO_2e emission grew by 2.4 percent compounded annually (CAGR) in the 20th century, resulting in an almost tenfold increase. Emissions began to abate in the mid-1980s as Hungary transitioned from a centrally planned, heavy industrial export economy to a more market- and service-driven economy. By 2019, emissions dropped to 64 MT CO_2e from 95 MT CO_2e in 1990, leading to an average annual decrease of 1.4% in this period.

At the same time, Hungary experienced an annual 1.7 percent increase in gross domestic product, demonstrating the potential of achieving significant economic growth without an increase in carbon emissions.

In the broader context of the European Union (EU), Hungary is the 5th country with the lowest emission in terms of per capita emission. Meanwhile, in terms of emission to GDP ratio, the situation is less appealing: in this indicator, Hungary's emission level – similarly to most Central and Eastern European countries – is above the EU average. For example, to produce one unit of GDP, Hungary emits four-times the amount of GHG compared to Sweden.

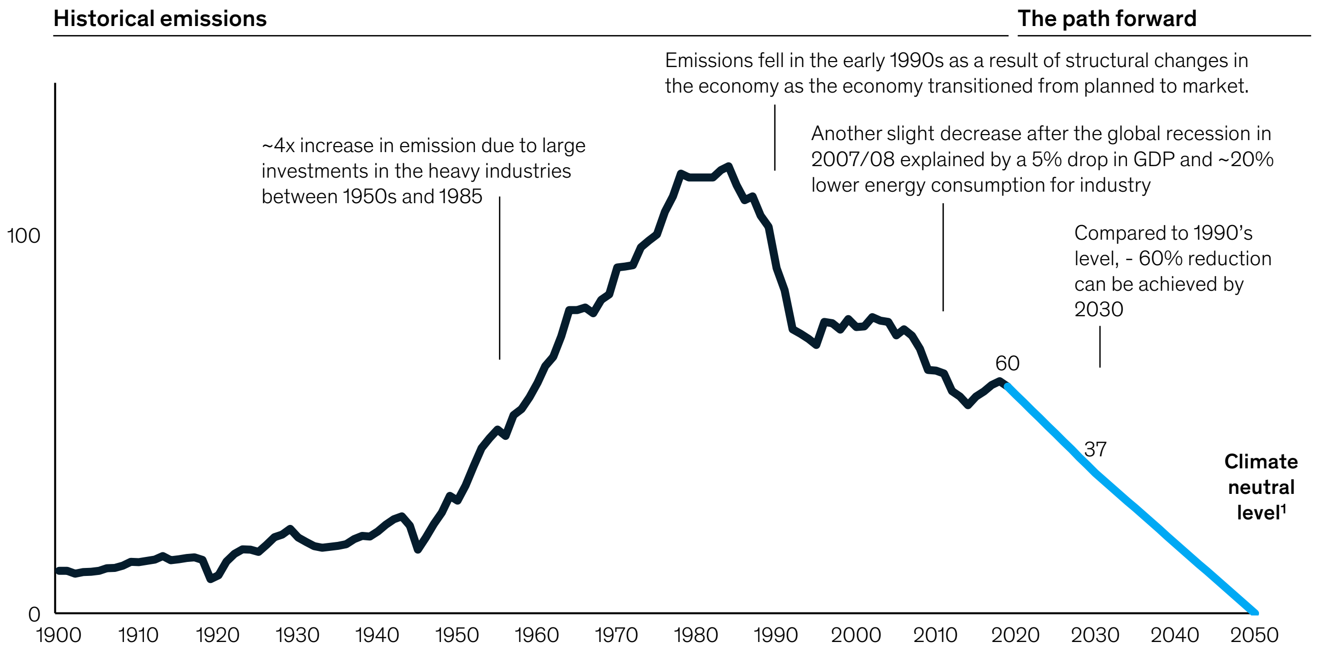
In Hungary, as in Europe, seven sectors account for all greenhouse gas emissions: power, industry, transportation, buildings, agriculture, waste, and land use and forestry (referred to collectively as LULUCF for land use, land-use change, and forestry). LULUCF are natural mechanisms to negate emissions. To achieve cost-optimal decarbonization by 2050, each sector will need to harness new and existing technologies in a specific and sequential process.

In the pages below, we summarize each sector's emissions reduction potential by decade, and then describe in greater detail how the sectors can achieve decarbonization in a cost-optimal manner.

LULUCF are natural mechanisms to negate emissions

Hungary's emissions level and targets

MT CO_2e, including land use and forestry[2]

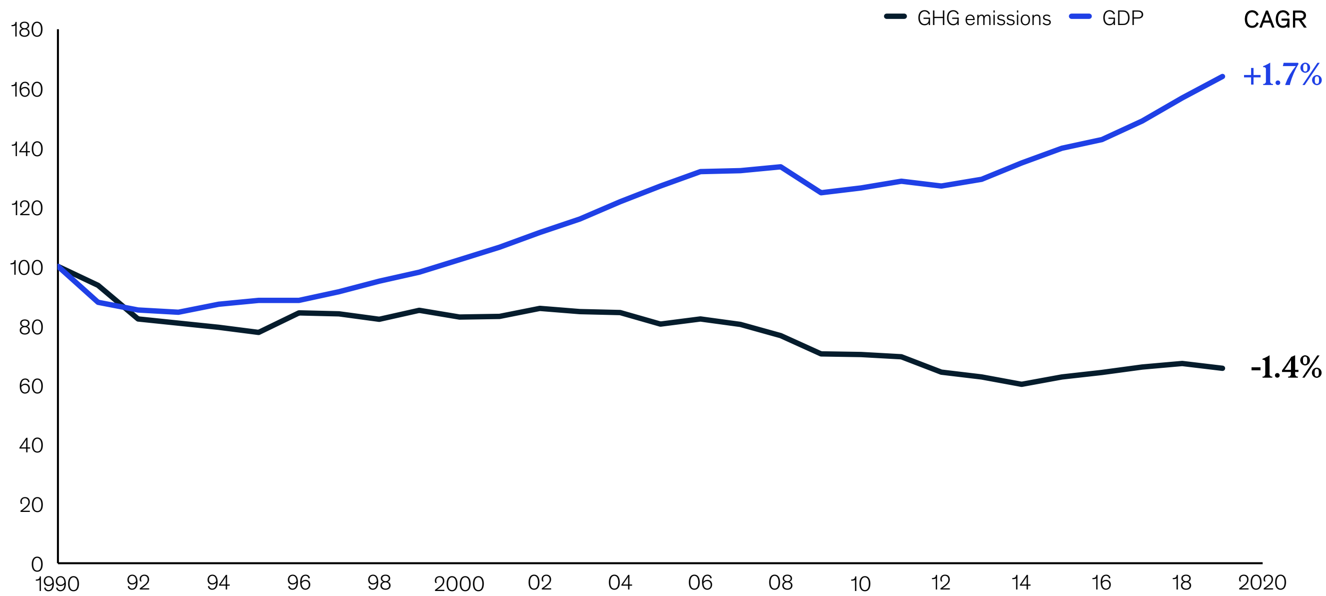


1. Emitted GHG are equal to absorbed GHG
2. Land use and forestry is commonly referred as Land Use, Land Use Change and Forestry (LULUCF)

Source: Sustainability Insights EMIT database, KSH, Eurostat

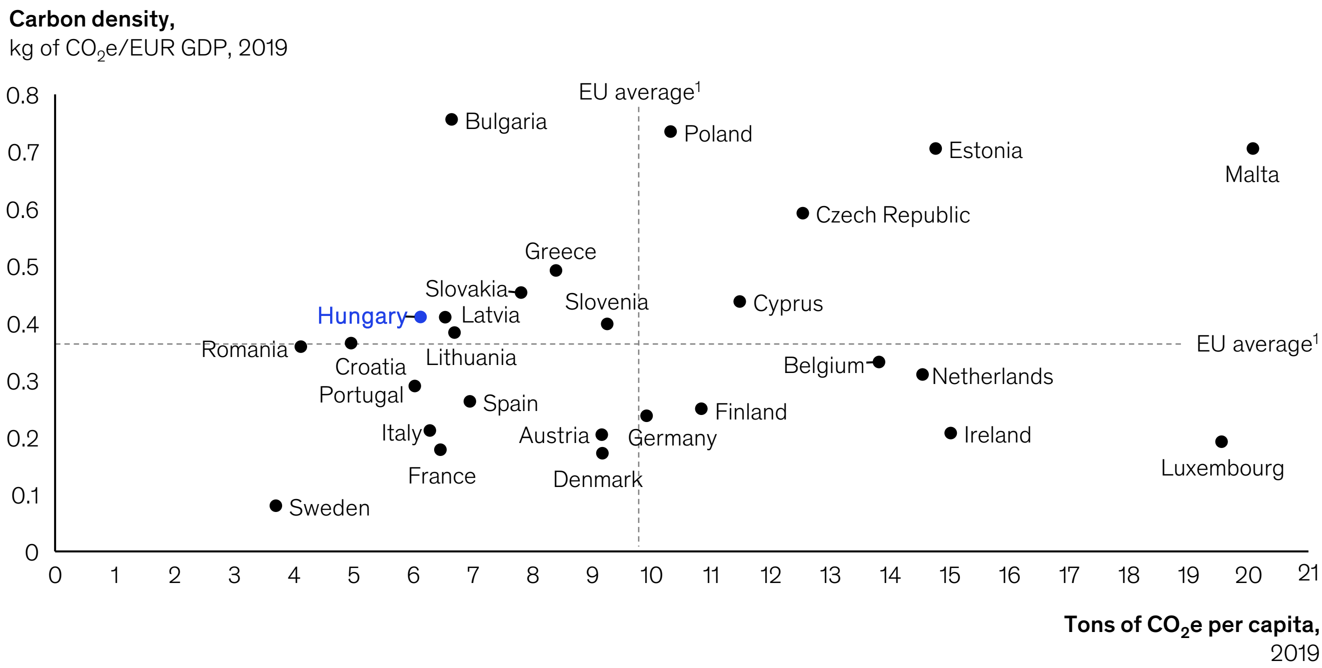
Hungary's emissions level and GDP evolution

100% = 1990 level, including LULUCF



Source: Sustainability Insights EMIT database, KSH

Hungary has a relatively good position in the EU in GHG emissions per capita, but less favorable in carbon density

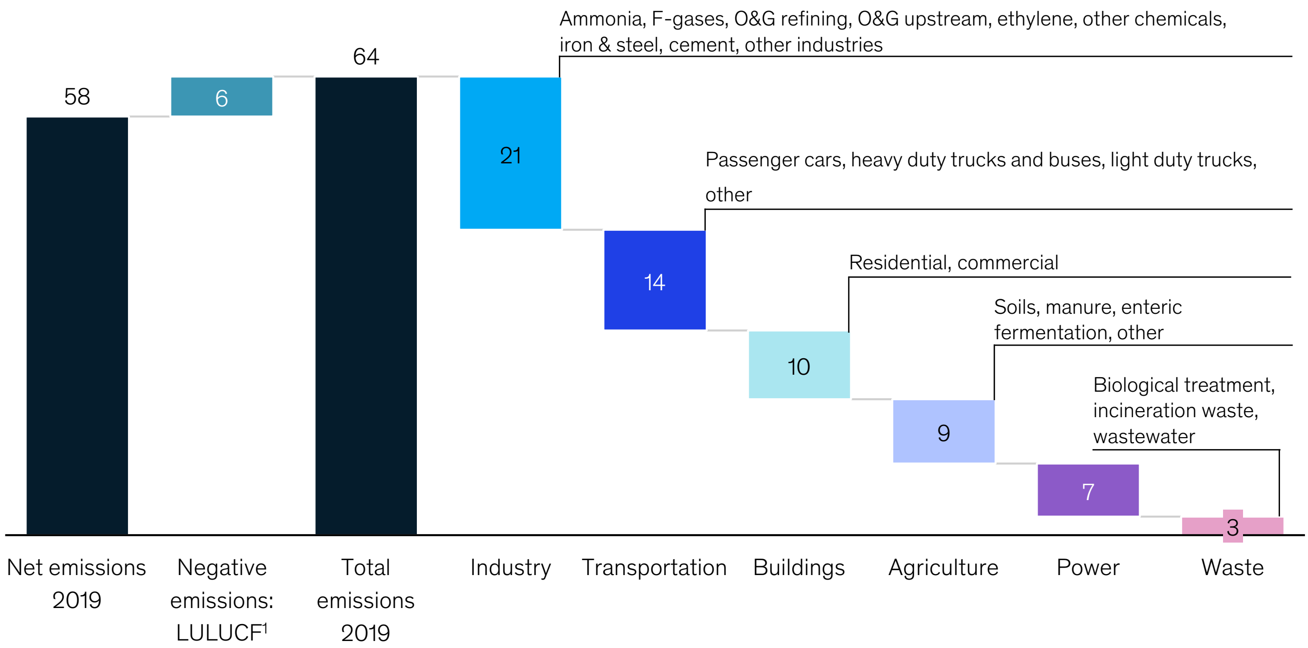


1. EU27 countries, simple average

Source: Eurostat, European Environment Agency, Sustainability Insights EMIT database

Emission baseline by sector

Industry level emissions, MT CO_2e, 2019

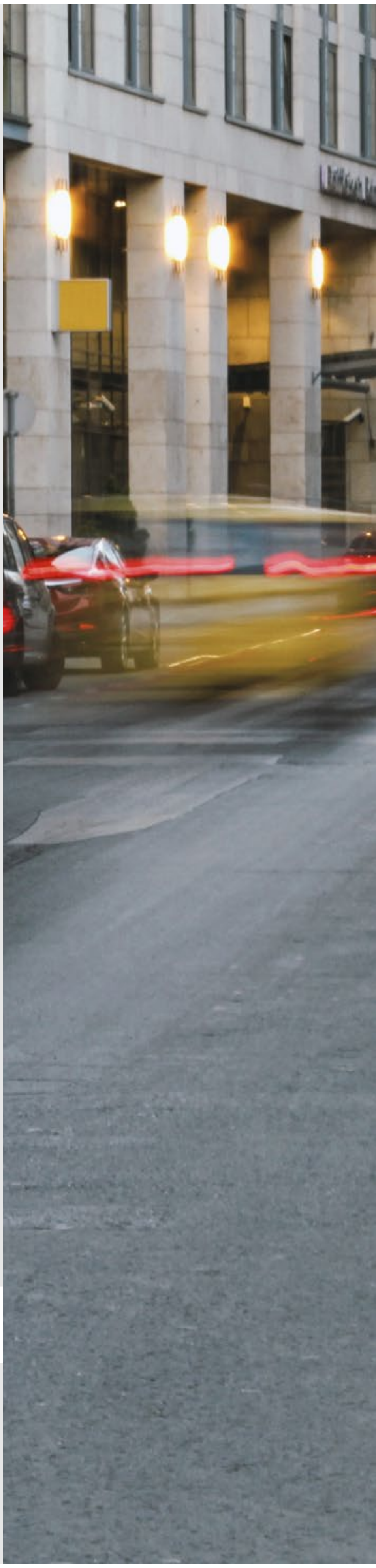


1. Land use, land use change and forestry

Source: Sustainability Insights EMIT database

Chapter 4

Sector-level decarbonization pathways



Industry

Introduction

Hungary has cut industry-related carbon emissions by more than half since 1990, as it transitioned to a market-based economy. Yet at 33 percent of total emission, industry emissions remain Hungary's largest source of pollutants.

One of the challenges is that emissions from heavy industries like iron and steel, oil refinery, and cement making are difficult to abate. These industries involve huge up-front investments in capital assets that are expected to last 30 years or more to provide adequate returns. Heavy industries are further complicated by value chains that are highly integrated and that may involve different energy technologies.

That said, there is mounting pressure on industry to decarbonize. Beyond the EU's goal of net zero, due to consumer expectations, companies across the world are increasingly willing to pay premiums for products made using low-carbon alternative energy sources. *(See case example on HYBRIT.)*

The challenge is that renewable and other green energy sources and technologies that industry needs to lower overall emissions are just beginning to come online. *(See in the "Role of Hydrogen" chapter)* When resources and technologies, including green hydrogen, carbon capture and storage, and advanced biofuels become more widely available, Hungarian industries will likely be able to accelerate their decarbonization efforts from the 2030s.

(There are exceptions: for example, Audi in Gyor has already begun investing in solar photovoltaic (solar PV) power).[23, 24]

Decarbonization has the potential to enhance industry competitiveness. Nearly two-thirds of Hungary's industrial output in 2021 was for export.[25] As CO_2 emissions will be increasingly targeted by European and national regulatory measures, demand for low-emission industrial exports will rise. Furthermore, the largest foreign investors such as companies like Audi, Mercedes, Bosch have already announced measures for decarbonizing their supply chains.[26]

"We are working on decarbonizing the supply chain together with our suppliers, for instance by (...) anchoring the use of green electricity in supplier agreements."

– Audi's vision for a sustainable future[27]

Although heavy industry emissions will be difficult to abate, the geographic distribution of industries in Hungary could facilitate the process

Six potential actions to cut industry emissions have been identified. Not all six levers apply to all industries, and some industries will need to pull various levers to achieve emissions abatement.

— **Demand-side measures:** Companies that currently use carbon-intensive materials such as cement could switch to wood in construction; lighter weight steels can replace heavier steel, reducing its overall demand; and recycled materials could replace the use of virgin plastics in packaging, which generally use less energy to produce

— **Energy efficiency:** Companies across the sector can reduce their dependence on fossil fuels by deploying the best-available, most energy-efficient technologies and appliances

— **Electrification of heat:** Sub-segment industries like food and ethylene can lower emissions by switching to electric furnaces, boilers, and heat pumps powered by zero-carbon electricity (especially solar PV). This measure can be immediately deployed in industrial processes requiring lower temperatures, in contrast with the very high temperatures needed to produce steel (1,800 °C), for which most electrified heat sources still lack the capacity

— **Hydrogen usage:** Where electric heaters are not a solution, industries may be able to replace certain feedstocks with green hydrogen (hydrogen produced from renewable power via electrolysis), thus reducing emissions

— **Alternative fuels:** Sustainably produced biomass may also be used in place of some fuels and feedstocks. Depending on the fuel or feedstock required, biomass in a solid (wood, charcoal), liquid (biodiesel, bioethanol), or gaseous (biogas) form can be used

— **Carbon capture technologies:** Carbon capture involves the collection and storage of exhaust gases produced by industrial processes, consequently preventing them from entering the atmosphere. CO_2 can be stored underground (CCS) or used as a feedstock in other processes through carbon capture and usage (CCU) (together, these technologies are referred to as CCUS)

Beyond these six levers, decarbonizing Hungary's industry sector will depend on increasing cost pressures via the EU Emissions Trading Scheme (ETS). *(See description on EU ETS in textbox.)*

Although heavy industry emissions will be difficult to abate, the geographic distribution of industries in Hungary could facilitate the process. As the map illustrates (see infographics), most iron and steel operations are concentrated in the central southwest, while petrochemical operations are largely in the northeast. This industry concentration could lead to the emergence of major decarbonized industrial clusters by economizing the rollout of industry-specific, low-carbon technologies and infrastructure like low-cost solar PV, hydrogen, and CCUS.

In Hungary 4 types of production drives ~50% of all industry emissions...

Total 22 MT CO_2e

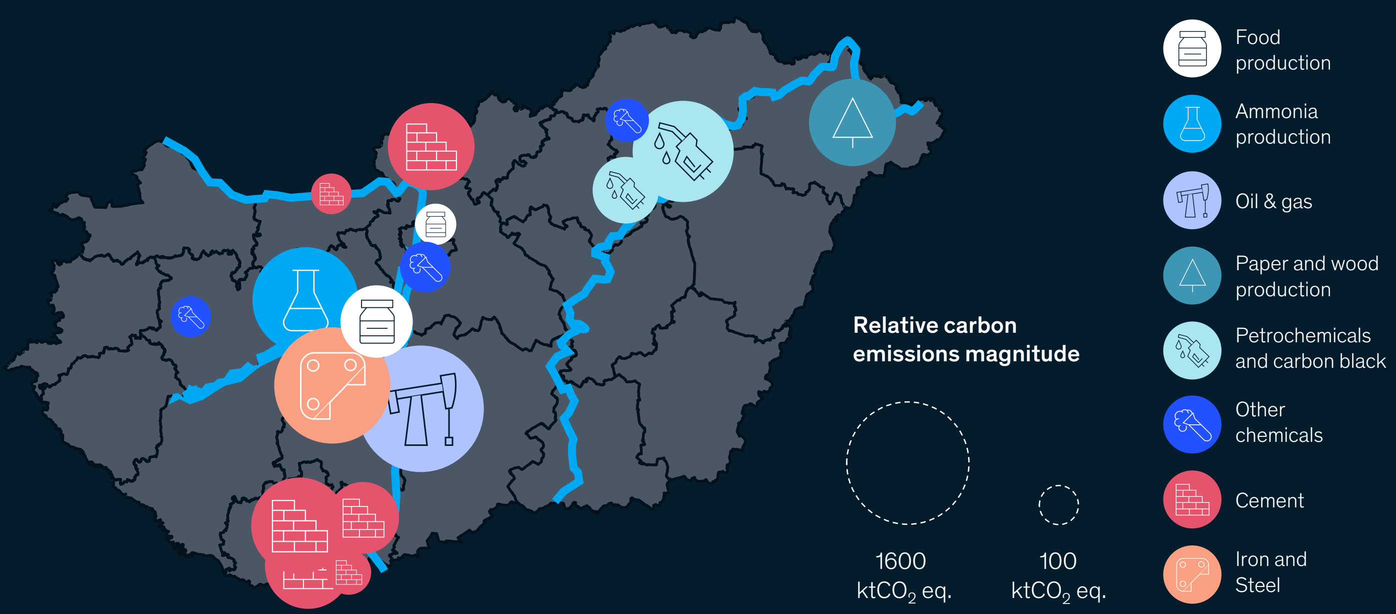
Share of industry emissions, %	Iron and Steel	Oil and Gas - upstream	Cement	Oil and Gas - refining	Petro-chemicals	F-gases	Ammonia	Other industry
	18	11	11	10	6	6	3	34

...where 6 key decarbonization levers can be applied to various extent...

✓ High decarbonization potential
(✓) Limited decarbonization potential

	Iron and Steel	Oil and Gas - upstream	Cement	Oil and Gas - refining	Petro-chemicals	F-gases	Ammonia	Other industry
Demand-side measures	(✓)	✓	(✓)	✓	(✓)	✓		
Energy efficiency	(✓)	(✓)	(✓)	(✓)	(✓)	(✓)	(✓)	(✓)
Electrification	✓				✓			✓
Green hydrogen	✓				✓		✓	✓
Alternative fuels			✓					✓
CCUS			✓	✓				

...... while the concentrated nature of industrial production provides possibility for green industrial hubs



Below, we provide examples of the low-carbon levers that Hungary needs to pull for four of its largest industries, which combined represent half of all the sectors' emissions: iron and steel (18 percent); upstream oil and gas (11 percent); cement and lime (11 percent); and refining (10 percent).

Iron and Steel

The iron and steel industry in Hungary produced 4 MT CO_2e emissions in 2019, making it the largest source of pollution among all industries. Each ton of steel produced emits almost two tons of CO_2e, which is roughly equivalent to the annual CO_2e emission of a new car in Hungary.[28]

Most iron is produced using a coal-fired integrated blast furnace-basic oxygen furnace (BF-BOF). BF-BOF reduces iron ore in a blast furnace, where the coal acts as a reductive agent, and the iron ore is then melted at temperatures around 1,200°C in the basic oxygen furnace. The high temperatures required are difficult to achieve using current carbon-neutral energy sources. To decarbonize the process, there are 2 essential components:

— **Sufficient supply of renewable energy** could replace the basic oxygen furnace with an electric arc furnace (EAF), which is a carbon-neutral alternative. However, shifting to EAF-based steel production requires the future supply of renewable electricity to be commercially available

— **Sufficient supply of high-quality steel scrap** or direct reduced iron (DRI) is also required, which can also pose a further limitation. If scrap is limited, steelmakers will need to mix lower-quality scrap with direct reduced iron to guarantee quality inputs. DRI can be produced using green hydrogen produced with renewable energy, which represents a technically-proven production method that enables nearly emission-free steel production

Increasing the share of EAF-based steel production could help in decarbonizing the steel industry, however, high-quality scrap is needed for high-quality end products, which means Hungary would need to increase its green hydrogen production capacity (or rely on imports) before steelmakers can fully avail themselves of this technology.

Hungary's steelmakers will be able to transition to the DRI-EAF process as technology develops and becomes more economic. However, the transition could require setting up a hydrogen ecosystem to ensure green hydrogen capacity for producing DRI locally. *(See in the "Role of Hydrogen" chapter.)* The transition time will depend on both natural 'trigger' points, such as when blast furnaces or coke batteries need replacing and when the cost of using polluting feedstocks exceeds their value.

The rise of green steel

Investments in green steel are on the rise worldwide and in Europe. Some of the continent's largest steelmakers are investigating the feasibility of at-scale, green steelmaking. For instance, Salzgitter[29] made a clear ambition to produce up to 30 percent of their yearly steel production volume as low-CO_2 steel via direct reduced iron with green hydrogen from 2025. By 2033, their aim is to fully replace their blast furnaces with direct reduction plants. ArcelorMittal plans to switch to full-scale DRI (with hydrogen) to feed a new EAF in Gijón[30] and the existing EAF in Sestao,[31] Spain by 2025.

Case example: HYBRIT[32]
In Sweden, HYBRIT, a collaboration between the steelmaker SSAB, state-owned utility Vattenfall, and mining company LKAB, received funding from the Swedish Energy Agency and the EU Innovation Fund to develop commercial-grade, fossil fuel–free steel using green hydrogen.

The technology involves replacing the blast furnace process, which uses carbon and coke to remove the oxygen from iron ore, with a direct reduction process that uses green hydrogen. HYBRIT successfully completed its first pilot production of green steel in 2020 and is currently developing prototypes for automakers such as Mercedes-Benz. HYBRIT aims to enter full commercial production in 2026.[33]

Cement and Lime

Cement and lime production in Hungary emits about 2.4 MT CO_2e annually, representing over 10 percent of all industrial emissions. Nearly half of the emissions result from the cement-making process, such as when turning limestone into lime; the other half of emissions result from heat generation, as cement kilns require temperatures above 1,600°C. As in the iron and steel industry, both emissions sources will need to be addressed to decarbonize cement making.

The analysis indicates that cement makers can reduce emissions by up to 10 percent by improving energy efficiency (depending on the technology used). Using alternative fuels like biomass in cement making will effectively eliminate remaining emissions by 2050. Hungary's cement manufacturers already use carbon-neutral fuels to supply up to 10 percent of the energy required, and they should be able to increase this uptake going forward.

Another 50 percent of cement-related emissions arise during cement clinker calcination. This intermediate step involves combining raw materials at extremely high temperatures to form clinker, which is the burnt component of cement that acts as a hardener when mixed with water. Emissions are released during the chemical reaction (calcination) and cannot be eliminated by using alternative fuels. To reduce these emissions, cement makers could use carbon capture (CCS) technologies, which should be available and economically feasible at scale starting in 2040.

Oil and gas

Upstream oil operations[34] and refining accounted for a combined total of 4.5 MT CO_2e emissions, divided almost equally. About 80 percent of these emissions are likely to be eliminated because of declining demand. However, additional levers such as carbon capture are needed in the meantime to help reduce emissions over the next three decades.

Oil and gas emissions result from three types of operations: extraction and drilling, fugitive emissions, and flaring. To decrease emissions from extraction and drilling, companies could shift to renewable power sources as a cost-effective alternative to diesel fuels. A second lever would be to reduce fugitive emissions comprised of methane by improving leak detection and repair, installing vapor recovery units (VRUs), or applying the best available technology (such as double mechanical seals on pumps, dry gas seals on compressors, and carbon packing ring sets on valve stems).

Nonroutine flaring can be a result of poor reliability which can be enhanced by improving operations through predictive maintenance and replacing equipment. In addition, operators can replace gas boilers with electric steam production systems to further reduce emissions.

Downstream operators can deploy similar techniques to cut their emissions. For example, operators can use vapor recovery units on large tanks and electrify processes using low- to medium-temperature heat. Operators can also take advantage of new, downstream-specific technologies such as waste heat recovery technology and medium-temperature heat pumps in refineries to reduce the amount of primary energy used in distillation.

Ammonia

Ammonia production is a significant source of emissions, accounting for 0.8 MT CO_2e in Hungary in 2019. Globally, most ammonia is used to make fertilizer, and demand for it and its byproduct, urea, is expected to grow 65 percent by 2050.

Ammonia production yields process emissions through the production of hydrogen via high-temperature steam methane reforming and through the combustion of fuel for heat and compression to pressurize gases in ammonia synthesis via the Haber-Bosch process.[35]

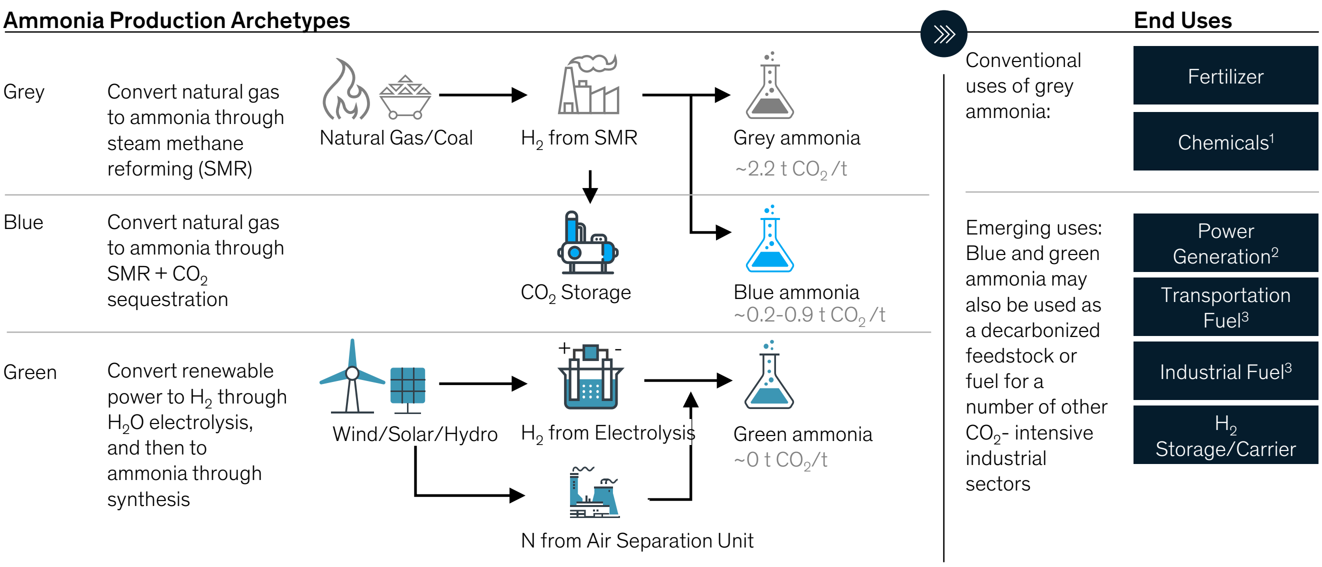
Our analysis focuses on two approaches to decarbonize ammonia production: the low-emission 'blue' and fully carbon-neutral 'green'.

Blue ammonia:
Most ammonia production begins with making hydrogen using a natural gas–fueled steam methane reforming; the next step is called the water-gas shift, whereby air is added to carbon monoxide and steam to make carbon dioxide and hydrogen. The carbon dioxide is typically released in the atmosphere. Instead, producers could apply carbon capture and storage (CCS) technologies to this step. While they could eliminate much of the CO_2e resulting from this step, they cannot cut all emissions. Therefore, they will also need to transition to so-called 'green' ammonia production.

Green ammonia:
Green ammonia production refers to using electrolysis-derived hydrogen instead of natural gas–derived hydrogen as a feedstock. This adoption would enable ammonia production from water, air, and zero-carbon electricity. Hydrogen is produced from water and electricity in an electrolyzer; a nitrogen separation train would provide nitrogen from the air so the nitrogen can be combined with hydrogen for ammonia synthesis in the Haber-Bosch process. An alternative source of CO_2 would be then required for urea production because the conventional water-gas shift process used in conventional ammonia production would not produce CO_2.

Additional approaches to reduce emissions related to ammonia production include demand-side measures, such as by replacing urea-based nitrogenous fertilizers with cyanobacteria- (blue-green algae) and nitrate-based fertilizers where possible.

Green and blue ammonia are emerging products that can be used as inputs for chemical production and as power sources



1. E.g., urea, nitric acid, nitrates, ammonium salts, acrylonitrile, caprolactam, HCN;
2. Via traditional combustion methods or by 'cracking' it back into nitrogen and hydrogen;
3. E.g., directly in a 'solid oxide fuel cell' or by cracking it back into nitrogen and hydrogen

Source: Fertecon Ammonia Outlook, Plastics Europe, IFA, Argus Green Ammonia Conference 2021, expert Interviews

Buildings

Introduction

The buildings sector accounts for 15 percent of Hungary's CO_2e, making it the third largest source of emissions. Detached houses make up over 35 percent of all residences in Hungary[36] but contribute to over 60 percent of the buildings emissions by heating the space using gas boilers. Residential water heating (12 percent) and cooking (4 percent) also significantly contribute to buildings emissions.

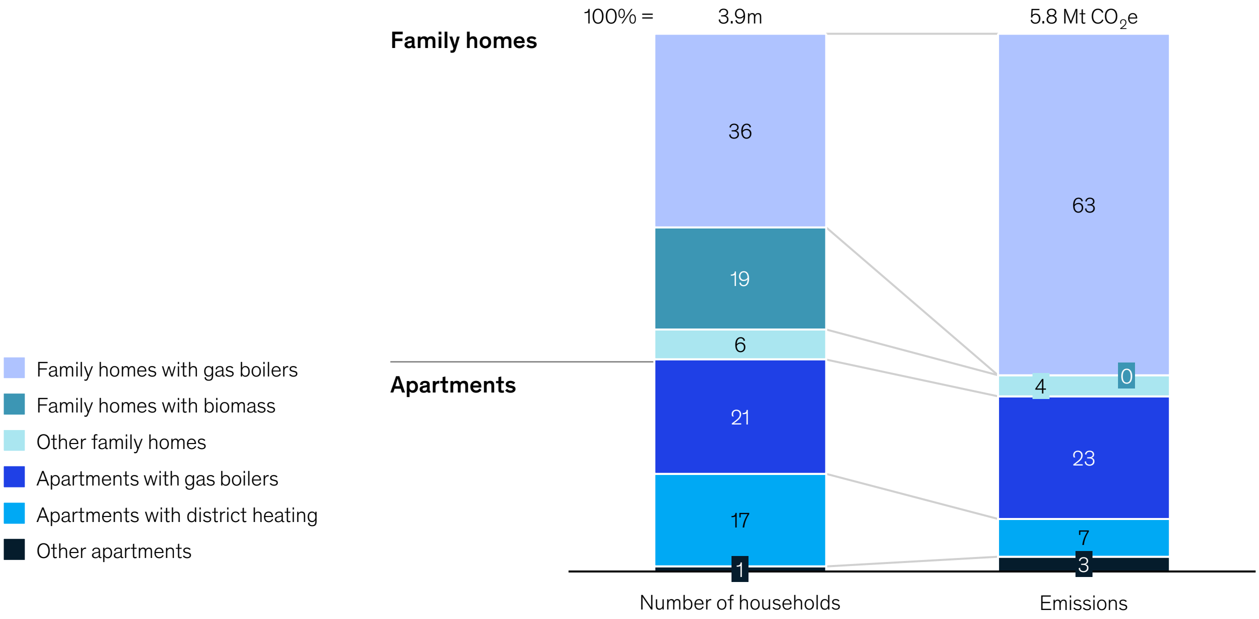
Apartments are the second largest buildings sector emitters; over half of Hungary's apartment blocks rely on natural gas delivered via individual boilers, while 43 percent use district heating.

Main decarbonization levers in Hungary

Hungary could decarbonize its buildings sector by focusing on four main areas: improving energy efficiency and installing advanced energy management systems; increasing installation of heat pumps especially in houses; switching to hydrogen boilers, mainly in apartments with gas boilers; and transitioning gas-fueled heating from a reliance on fossil fuels to geothermal or green hydrogen.

Family homes make up ~60% of residential building emissions; family homes with gas boilers are biggest emitters[1]

Number of inhabited dwellings and emissions,
% of total residential space and water heating



1. "Long Renewal Strategy on the basis of Directive (EU) 2018/844 with a view to fulfilling the eligibility conditions for the payment of cohesion funds for the period 2021-2027," Innovációs és Technológiai Minisztérium, energy.ec.europa.eu

Energy Efficiency

Improving energy efficiency in buildings can reduce the amount of energy needed for heating, thereby significantly offsetting emissions. Only 31 percent of residential buildings in Hungary are fully insulated.[37] Older buildings are less likely to be insulated. The average age of residential buildings is 55 years, slightly higher than the average age in the other V4 countries: Slovakia, Czech Republic, and Poland.[38]

In addition, most energy efficiency technologies are readily available and affordable. These include installation of energy-efficient insulation; use of sealants on windows; and the application of reflective, light-colored paint to a building's roof to reduce heat. More laborious but accessible measures include insulating rooftops; installing secondary windows to protect from extreme temperatures; and optimizing exterior insulation.

While the share of energy-efficient buildings in Hungary is rising, only 4 percent of the roughly 150,000 new energy efficiency certificates given in 2020 had a rating of BB or higher.[39, 40] Moreover, even if buildings in Hungary implemented all energy efficiency measures, the sector cannot go carbon-neutral as buildings would still use fossil fuels. Therefore, additional measures would be necessary.

Energy efficiency improvements

Air sealing and insulation

Air sealing windows and door frames, AC units, vents and cracks along walls can significantly improve energy efficiency in houses. Air sealing is estimated to reduce the need for heating by 20-30%. Air insulation for walls and roofs, usually installed once air sealing is done, can further contribute to energy savings.

Secondary windows

Homes lose an average of 18% of heat through windows. "Double glazing", applying secondary windows, can reduce this loss by 50%, while heavy curtains help reduce heat loss even further.

Roof retrofitting

Applying reflective, light-colored paint to building's roof improves energy efficiency and decreases the "warming" effect in the atmosphere as light colors absorb less heat than dark ones. Painting a roof white is estimated to reduce air-conditioning costs by up to ~40%, with the most significant savings expected in warmest regions. Green (vegetative) roofs can also keep the house cool while also absorbing CO_2.

Individual or smart meters

Individual meters can help consumers pay only for the energy consumption of their own household. However, an even better option is smart meters (costing ~ EUR 70) that measure rationale energy usage through remote connection to energy suppliers. They help improve energy efficiency as individual consumption can be accurately monitored.

Heat pumps

Heat pump installation could significantly lower emissions from single-family houses. Heat pumps take energy from environment or waste heat and pumps it to higher temperature to heat via the refrigerant cycle. Heat pumps are already widely available in Europe: 60 percent of houses in Norway; 40 percent of houses in Sweden; and 34 percent of houses in Estonia use heat pumps. But among these and 18 other European countries, Hungary ranks last in heat pump installations and sales.[41] Scaling up heat pump penetration would require improvements to the power grid to ensure that increases in peak load are sufficiently supported.

Heat pump uptake in Hungary is likely to rise alongside increasing access to renewable energy sources, while its emissions reduction potential is high due to the lower emissions from the power sector. Therefore, switching from a gas boiler to electricity-powered heat pump would have a higher emission reduction in Hungary than in regional peers with coal-heavy power sectors (e.g., Czech Republic, Poland, Bulgaria, Serbia). As the power sector decarbonizes further, heat pumps will likely eventually become entirely carbon-free. What's more, current heat pump technology makes it easier to install in single-family, detached houses relative to apartments.

One challenge is that the up-front cost of installing a heat pump anywhere in the world is more than three times that of a gas boiler – while its operating expense is below the gas boiler's. This initial price differential detracts from the long-term benefits of heat pumps despite their being nearly three times more efficient[42] than gas boilers at heating homes sustainably. Growing numbers of Hungarian consumers are likely to install heat pumps over the next several years as prices decline; the government has started to accelerate this process with targeted policy levers.[43]

Heat pump incentives

The UK offers direct grants to households switching to heat pumps. In Estonia, the government finances between 30 percent and 50 percent of green home renovation projects, including heat pump installation. The UK applies a reduced value-added tax (VAT) of 5 percent for any work related to clean energy products, including heat pump installation.

The majority of residential heating emissions can be eliminated by replacing gas boilers with heat pumps in single-family houses

Heat pumps use a small amount of electricity to transfer existing thermal energy from the outside environment into your home. Heat pumps can source energy from the air, water, or ground, and their efficiency is 4 times higher than that of conventional boilers.

4x

Heat pumps produce 4 times more heat than the electric energy they consume, compared to 0.9 times for gas boilers.

75%

In Hungary, installing a heat pump decreases the home's carbon footprint by 75% currently, and as power generation further decarbonizes – by 100%.

~10k

High upfront cost of ~10k EUR currently suggest that switching incentives are necessary until costs become more competitive.

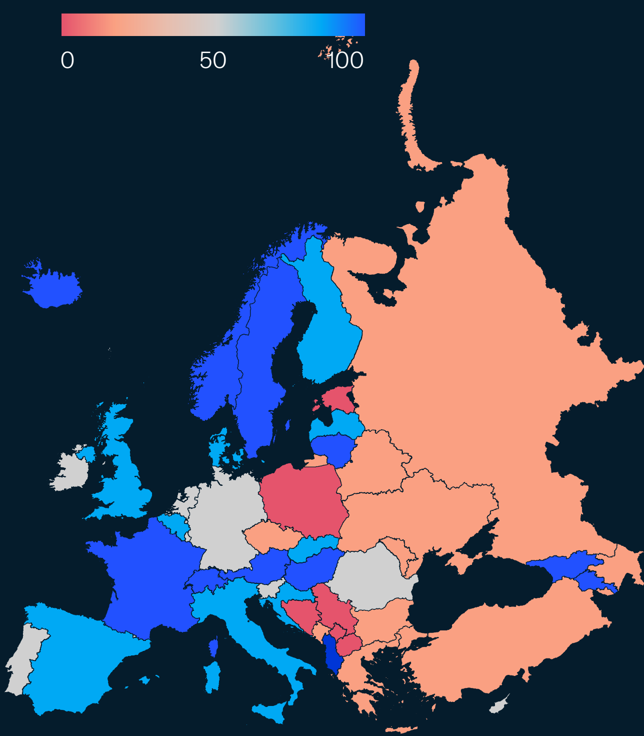
Hungary ranks last out of 21 European countries in heat pump penetration despite favorable conditions

Current heat pump installations in Europe

	Units sold per 1000 households, 2020	Total heat pumps installed per 1000 households, 2020
Norway	42	604
Finland	39	408
Estonia	29	343
Denmark	28	192
Sweden	24	427
Lithuania	15	54
France	14	107
Switzerland	12	121
Italy	9	91
Austria	9	92
Spain	7	52
Portugal	7	52
Netherlands	6	28
Czech Republic	5	32
Ireland	4	23
Poland	4	17
Belgium	4	24
Germany	4	31
Slovakia	2	12
UK	1	10
Hungary	1	3

Heat pump emission reduction potential in Europe

Heat pump emission reduction potential (%)



Scaling up heat pump penetration would require power grid improvements due to low reserve margin to ensure that high peaks in electricity demand during winter are well-managed.

Hydrogen boilers

Heat pump installation may be more difficult in apartments than in detached houses due to space requirements. There is also a financial disincentive because heat pump installation involves high up-front costs that current owners pay, but the financial benefits accrue over multiple years during which owners or tenants could change. Hydrogen-ready boilers are a reasonable alternative because they are more affordable and as easy to install as gas boilers. This technology is based on burning hydrogen, which produces only water as by-product *(See in the "Role of Hydrogen" chapter.)*

However, installation of fully (green) hydrogen-based boilers is not yet feasible because they depend on the availability of relatively cheap green hydrogen and the potential retrofit of the gas grid to carry hydrogen. To make this transition happen, the first step could be the installation of hydrogen-ready boilers in the households and blend hydrogen up to 20 percent to natural gas and then transport the mix through current pipelines.[44] *(See Winlaton, UK example below.)*

Our model suggests that Hungary will have the ability to mix green hydrogen into natural gas pipelines starting this decade, while the transition to fully hydrogen-fueled heating could begin when there is sufficient and affordable supply of hydrogen.

In addition to hydrogen boilers, residences could adopt alternative solutions such as biomass-based or solar thermal heating. For example, rural houses that currently depend on biomass will either continue to rely on sustainably produced biomass or convert to heat pumps.

Case example: Hydrogen pilot in the UK

Winlaton in the UK recently launched a trial to test whether its public gas network can tolerate 20 percent hydrogen in its pipelines.

Like homes in Hungary, most residences in the UK depend on natural gas for heating. According to Cadent, a company participating in the scheme, using a 20 percent blend of hydrogen across the UK gas networks would have the equivalent effect in reducing carbon emissions as would removing 2.5 million cars from the roads.[45] The pilot has been supplying a 20 percent hydrogen to 670 homes safely since August 2021, requiring no change in end users' behavior or appliances.

Climate-Neutral District Heating

District heating plants supply heat to almost every fifth household in Hungary through an extended infrastructure. There are over 170 district heating plants in the country, and the 10 largest, which all run on fossil fuels, supply 50 percent of the capacity.

Hungary could start cutting emissions from district heating plants, already in the 2020s, by replacing fossil fuel–based plants with geothermal or solar plants or by using excess heat from industry. From the 2030s, when the technology becomes available and cost-efficient, green hydrogen can be used to power new district heating plants, too. The exact pathway for the transition to clean energy–based solutions would require further research into the current district heating networks.

Plausible decarbonization pathway

To reach net zero, buildings emissions need to fall by 45 percent by 2030 and by 98 percent by 2050. To make this transition happen, all the houses with low or no insulation and apartment blocks should get high-level insulation. Whereas family homes can become carbon-neutral by installing heat pumps or switching to other alternatives, the optimal share remains for further analysis. Apartments could be decarbonized by using hydrogen boilers or clean district heating. As between 70 and 80 percent of the current building stock will be still standing in 2050, efforts could be focused on retrofits of existing stock while ensuring that newly built homes are carbon neutral.

45%

less buildings emissions by 2030 and 98% less by 2050 is needed to reach net zero.

Transport

Introduction

Transportation sector is the second biggest contributor to emissions in Hungary after industry, with a contribution of 22%, mainly driven by road transportation.

The sector released 15 MT CO_2e, largely from private passenger cars. Any effort to reduce carbon emissions in transport must therefore focus on road transport. Three major measures are needed to decarbonize the sector: rapid ramp-up of electric vehicles in passenger cars and light duty vehicles from the 2020s; replacement of diesel with hydrogen in the heavy-duty road transport from the 2030s; and incentivizing increased use of public transport and low-emission mobility solutions.

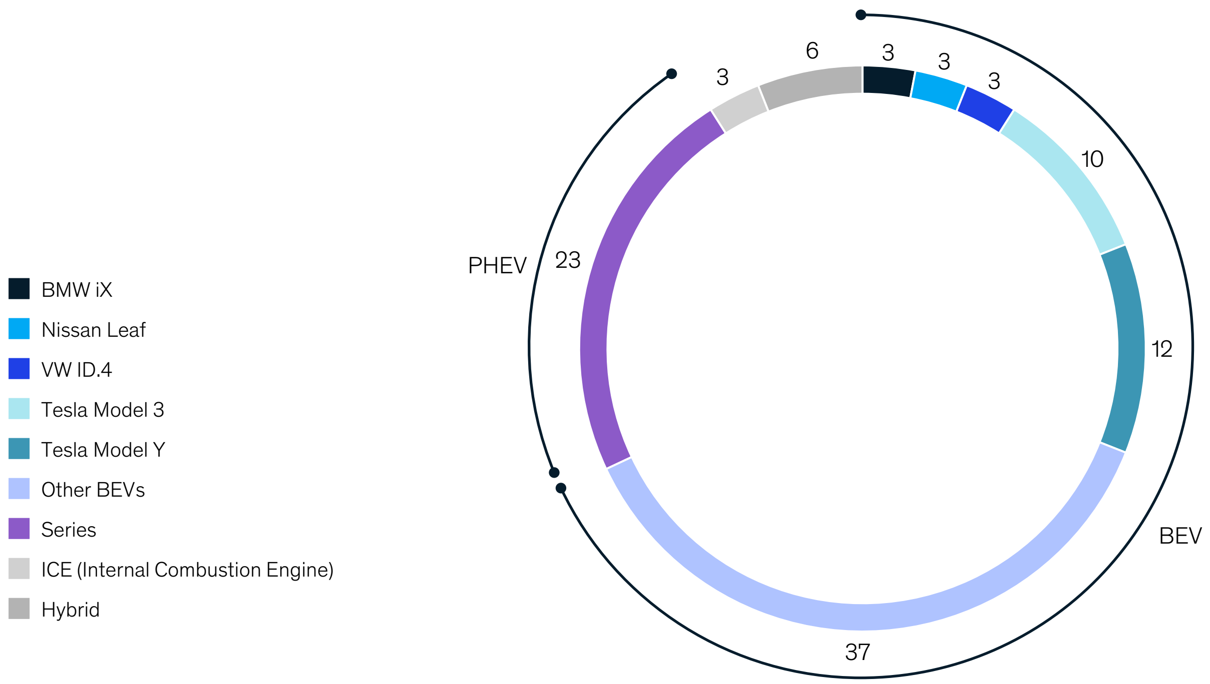
Electric Vehicles

Technological advances, declining battery costs, and increasing demand are driving major strides in the electric vehicle (EV) market. Given these trends, we expect EVs to be cost competitive against internal combustion engine (ICE) vehicles by about 2025. EV penetration is likely to accelerate further alongside an increasing supply of renewably sourced electricity. These trends should notably reduce the transport sector's CO_2 emissions going forward.

Automotive companies have plans to bring over 1,000 EV models to market by 2024; many companies[46] have also announced the phaseout of internal combustion engine vehicles starting from the 2020s. As we describe below, governments are supporting this transition with a variety of monetary and nonmonetary incentives. For instance, in Norway, BEVs comprised 68 percent of new sales in December 2021.

Electric vehicle penetration has accelerated

Norway, car sales, December 2021



By contrast, EV penetration in Hungary is 0.6 percent[47] and the EV share of new car sales reached 4.8 percent,[48] for battery electric and plug-in hybrids combined in 2020. Meanwhile, although fewer than 40 percent of Hungarians own cars,[49] those who do are highly dependent on them. Many Hungarian families share a single car, and the average annual distance travelled per car was 17,000 kilometers. The relatively high distance travelled by these ICE vehicles makes the per car emissions in Hungary exceed the EU average by 15 percent.[50]

Two approaches could increase EV penetration in Hungary: encouraging EV sales through direct and indirect, monetary and nonmonetary incentives; and lowering the barriers to adoption, most importantly by building an extensive EV charging infrastructure (EVCI).

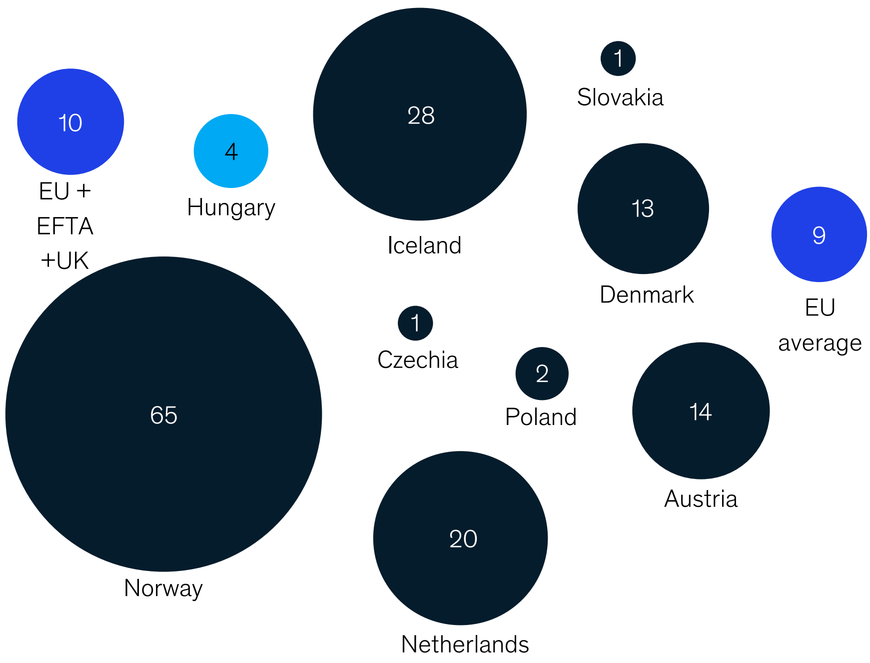
Direct monetary incentives include government grants or subsidies towards EV purchases. Germany, for example, offers €6,000 towards the purchase of an EV in 2022.[51] Indirect monetary incentives center largely on fiscal savings, such as lower sales or annual taxes for personal EVs or exempting EVs from registration or motor vehicle road taxes (Netherlands and Hungary). Additionally, corporate EVs may be exempt from benefit-in-kind taxation (Germany) and company vehicle tax (Hungary). Direct, nonmonetary incentives can include free public parking for EVs in congested urban spaces or fuel cost savings in the form of lower taxes on electricity.

Sufficient, publicly available electric vehicle charging infrastructure (EVCI) is critical to ensuring uptake.

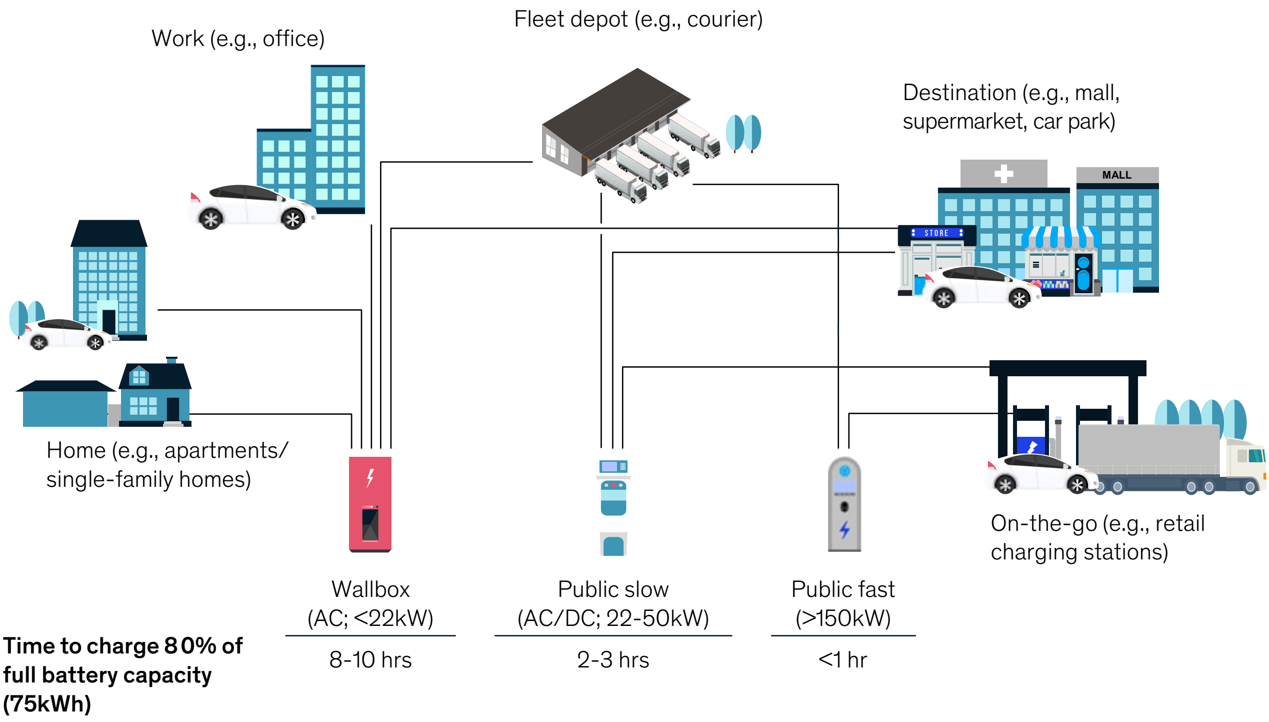
Drivers charge their EVs in one of five ways: using an at-home EV chargers, charging at their workplace, accessing fleet depots (for couriers, private or public EV fleets), charging at a destination (such as supermarkets and car parks), or accessing on-the-go charging stations.

EV share in new car registration

%, 2021

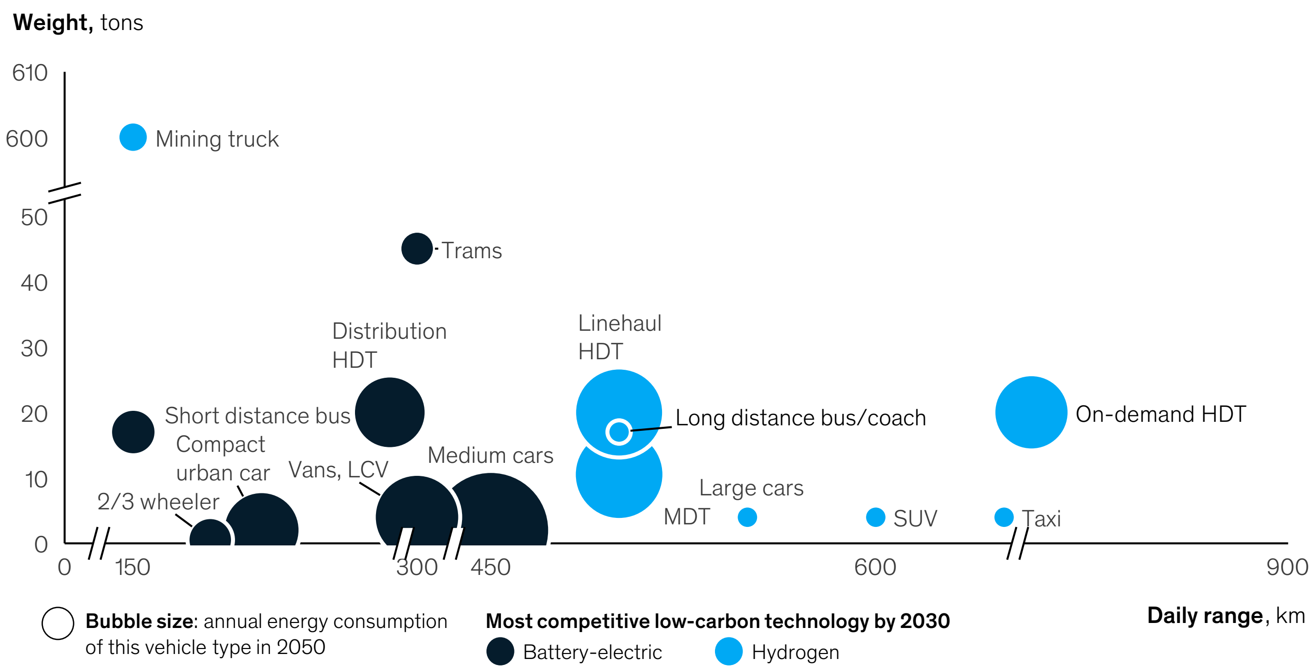


Increasing EV penetration requires EV chargers across 5 main use cases



Source: McKinsey experts

Hydrogen will be the most competitive low-carbon fuel in the high-range, heavy-duty segment



While EV owners can typically afford to install residential EV chargers, public EV chargers require major investment due to their higher capacities (150kW+ DC charger). Countries leading the transition to electric transport have done so through government investments and incentives to expand EV charging infrastructure. For example, in 2022, the United States announced that it would invest US$5 billion to build a national EV Charging Network with 500,000 chargers.[52] The French government offers subsidies towards EV charging point installations to install EVCI (up to 40 percent of the purchase and installation costs for companies and public entities; and up to 50 percent for apartment blocks).[53]

Hungary had 2,264 public recharging points in 2021 including 505 fast chargers (over 22 kilowatt (kW)).[54] Assuming a target of one charging station for about every 14 EVs, Hungary would need to build roughly 200,000 additional public EV chargers by 2050, from which around 11 percent should be fast chargers.[55] This is in addition to residential charging stations, which rely on existing wall sockets or chargers. EVCI will also need clean power generation, a reliable grid for transmission and distribution, as well as transformers to step down voltage, so that EV chargers can provide metered and protected electricity to EVs. The investment need for this infrastructure is estimated at an additional €2.8-3.8 billion in capital expenditures.

In combination, these measures could raise the share of EV passenger cars to a third of Hungary's car fleet by the mid-2030s, and to 90 percent by 2050.

Passenger cars are not the only vehicles that will be relying on easy access to an extensive charging network. Electrified light commercial vehicles, referred to as vans, also depend on EVCI infrastructure, albeit to a lesser degree. Vans account for 8 percent of the transport sector emissions and these can be eliminated by electrification. This process should be quicker than that of EV passenger cars. Some van models have already reached cost parity due to lower range requirements, leading to a smaller-sized and more highly utilized battery. In addition, some vans return to fleet charging hubs in the evening, so they do not need access to an extensive public charging infrastructure. Our estimates indicate that emissions from vans will decrease by over 70 percent by 2030 and reach zero in 2050.

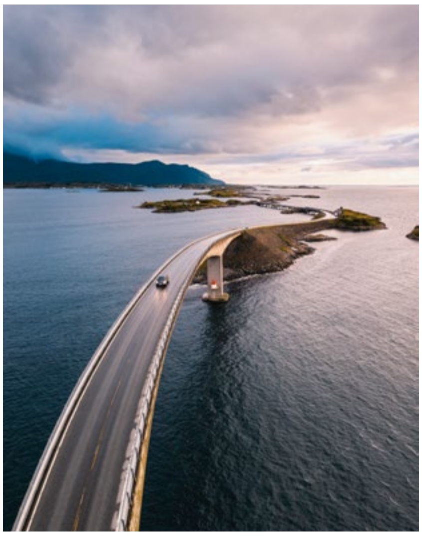
Hydrogen in heavy-duty trucks

While most short-distance vehicles, including vans, buses, or medium-sized cars will run on electric batteries, a large share of heavy-duty and long-range vehicles, which account for 23 percent of transport emissions, will switch to hydrogen.

Hydrogen fuel cell vehicles rely on a hydrogen fuel cell propulsion system. The system consists of a stack of fuel cells that combine hydrogen from an onboard fuel source with oxygen to create an electrical current that powers the motor and other system electronics. Fuel cells last longer and can be recharged more quickly than electric batteries. Vehicles also host a rechargeable battery to store short-term energy generated from regenerative braking, which can provide supplemental energy.

Due to a nascent technology and a lower uptake, hydrogen trucks are a few years behind electric vehicles. Nevertheless, the first models by original equipment manufacturers (OEMs) are already on the roadways, and a combination of improvements in electrolyzer efficiency and the general decrease in green hydrogen production costs should make these trucks cost competitive from the late 2020s. As further discussed in the Hydrogen chapter, Hungary should have sufficient green hydrogen production capacity to power fuel-cell electric vehicles (FCEVs).

As with EVs, the transition to hydrogen-powered transport requires establishing a countrywide network of hydrogen refueling stations; this network also needs to be connected to major European transport arteries to facilitate regional trade.



EV penetration in Norway

Norway leads the world in EV penetration due to a mix of progressive regulatory measures and a vast and reliable charging network. The Norwegian government offers significant subsidies towards the purchase of an EV; it exempts EVs from road and ferry tolls; and in many instances, offers EVs special privileges, such as the use of bus lanes and free parking. As of 2022, the country counts over 16,000 charging stations, including 3,300 fast chargers, available every 50 kilometers on main roads.[56]

Public transport

Public transport is a key factor in reducing emissions. Hungary already has a robust public transport network, which accounted for 28 percent of passenger kilometers.[57]

Public transport usage can be incentivized via free or faster public transport, for example, via increased number of priority lanes for buses, further extended network, and increased reliability of public transport; or disincentives like congestion pricing, which have lowered the number of private vehicles on the roads and, consequently, emissions. A combination of these could help reverse the trend of declining share of public transport and maintain Hungary's advantage in this regard.

Hungary could also benefit from micromobility and shared mobility trends, such as the increased use of bicycles, e-scooters, and car sharing. London offers a strong example of this trend. Since 2015, Santander Cycles, a public bicycle sharing system, have been used for about 300 million kilometers of travel, helping to eliminate nearly 20,000 tons of CO_2 emissions. Recent figures indicate that new user registrations grew by 193 percent between March 2020 and 2021.[58] In Hungary, MOL Bubi is a public bicycle sharing system in use since 2014, which has become an integral part of the urban transport system.[59]

New mobility solutions might also reshape urban landscapes favorably. *(See the Paris example, below.)* In larger Hungarian cities, especially in Budapest, greening of central arteries could lead to further shift from car to new mobility solutions as well as mitigate some of the local adverse effects of global warming.

Munich's integrated mobility concept

Munich is an example of the integrated mobility concept. The Munich Transport Company (MVG) launched an application that enables commuters to view and choose from both public and private transport providers, including car-, bicycle-, and e-scooter shares as well as taxis in a single, integrated platform. Because the app allows users to filter their choice by time, cost, and environmental impact, it has the potential to reduce private car use in the city.[60]

Bike- and pedestrian-friendly transport in Paris

In 2007, Paris began to reassign roads previously used by cars for use by pedestrians, bikes, and buses only. This policy reduced the use of private vehicles in the city by 5 percent from 2010 to 2018, while increasing the number of daily cycling trips by 30 percent and walking trips by 9 percent. The City of Paris aims to continue investing in bike- and pedestrian-friendly transport options so that regularly frequented venues such as supermarkets and offices can be accessed via a 15-minute bike ride or walk.[61]

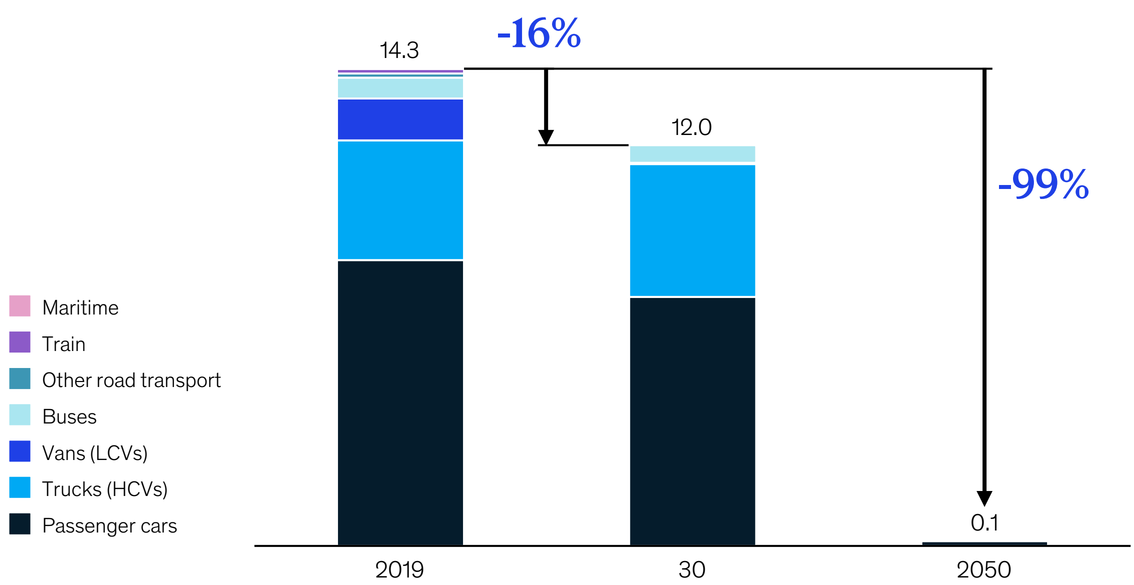
To reach net zero by 2050, as much as 99 percent of transport emissions must be eliminated

Plausible decarbonization pathways

To reach net zero by 2050, as much as 99 percent of the transport emissions must be eliminated. Remaining emissions will come from older ICE vehicles and planes. Until 2030, only 15 percent of transport emissions will be cut, as zero-emission technologies will not become cost competitive until the mid to late 2020s, after which uptake will still be slower. While zero emission vehicle sales will be significant by 2030, it will take until 2040s for the fleet to be fully replaced given the average lifetime is 10-15 years for cars, vans, and trucks. Aviation and shipping have only a few abatement options. Emissions can be reduced by switching to advanced biofuels or synfuels. Policy makers could strengthen decarbonization efforts with measures such as harmonizing technology standards and refueling infrastructure at airports and harbors.

99 percent emissions decrease in transportation is achieved by using 100% electric vehicles on roads and green fuels in aviation, rail, and maritime.

MT CO_2e

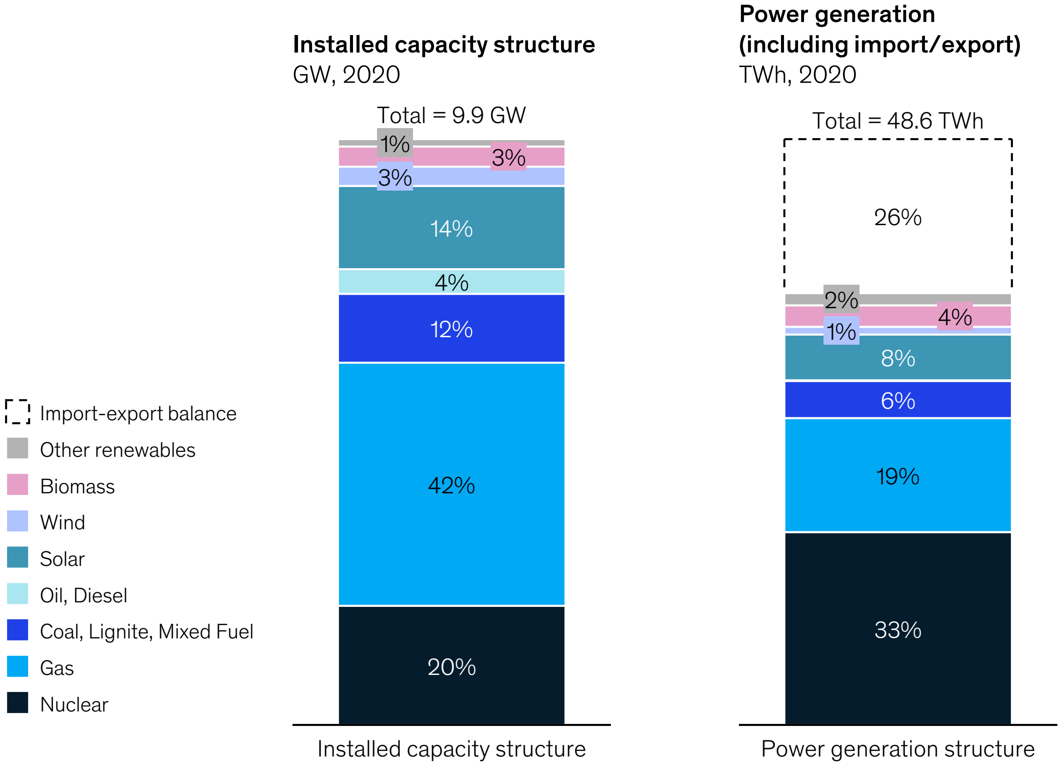


Power

The power sector decarbonization is a cornerstone of Hungary's carbon neutrality by 2050. Power producers face the dual challenge of having to reduce dependence on fossil fuels while expanding generation capacity using variable renewable resources to meet surging electricity demand. At the same time, the sector needs an upgraded power grid infrastructure to accommodate renewables, reverse flows, and increased volatility.

Hungary is at a relatively good starting point compared to its neighbors. The Paks nuclear power plant supplies over a third of generation capacity. Per capita power sector emissions totaled 0.8 tons CO_2e vs. 3.8 tons in the Czech Republic; 2.8 tons in Poland; and 2.5 tons in Germany. Although Hungary has many gas-fired power plants, the most polluting coal assets account for only 8 percent of the total power generation (compared to 70 percent in Poland). Nonetheless, Hungary is one of the Europe's most import-dependent countries, with a net electricity import of 26 percent.

Better starting point is due to lower share of coal-fired power plants, albeit it comes with high import dependence



NOTE: Numbers may not sum due to rounding.

Source: MEKH

To reduce emissions further, Hungary should first close the highly polluting coal-fired Matra Power Plant and equip its gas-fired power plants with carbon capture, utilization, and storage (CCUS) or reconfigure them to carry blended hydrogen.

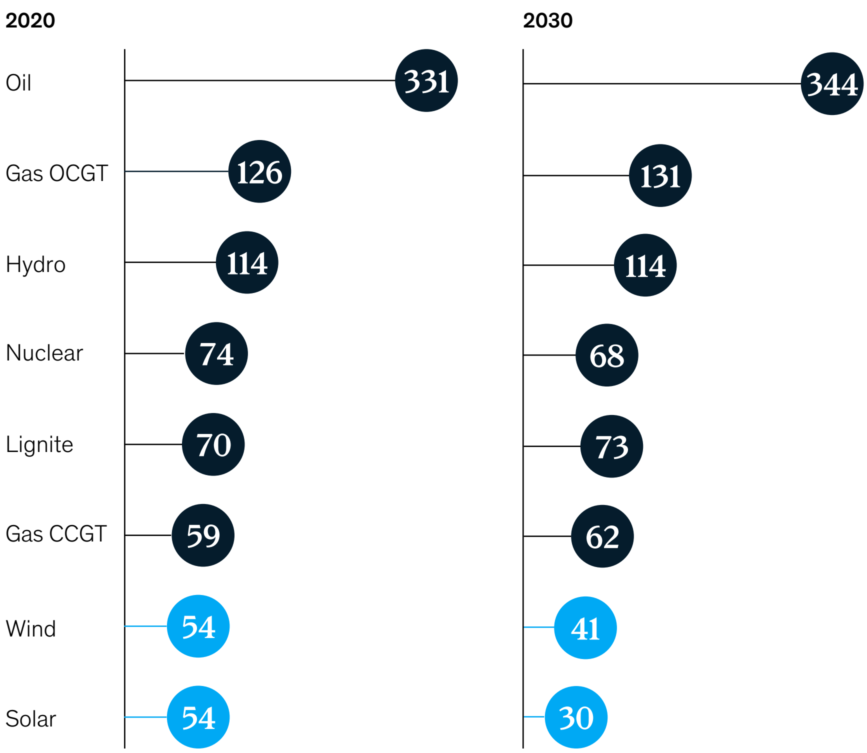
The greater challenge will be to meet the surge in electricity demand over the next three decades. Our estimates indicate that efforts to decarbonize across economic sectors, including increasing uptake of battery-powered electric vehicles (BEV) in the transport sector; of electric furnaces in industry; and of electric space heating in residential and commercial buildings, will push electricity demand up by an additional 1.8 times. At the same time, the projected use of green hydrogen to decarbonize selected sectors, like heavy-duty trucks (see in the "Role of Hydrogen" chapter), will further increase power demand.

To summarize, Hungary will need 2.8 times more electricity in 2050 than it requires today. Decarbonizing the power sector is central to meeting the net zero ambition.

The increasing cost competitiveness of solar and wind resources vs. fossil fuels puts Hungary in a strong position to meet growing demand. In fact, solar and wind are already cost competitive against nonrenewable sources. Their uptake is likely to accelerate as carbon prices on fossil burning rise and as renewables technology develops further.

Power decarbonization will be driven by cost-competitive renewables

Levelized cost of electricity by source,
USD/MWh, excluding balancing, grid, etc. costs



In addition, Hungary has advantageous natural conditions for renewable power generation. For example, given its position to the equator, Hungary receives more hours of sunshine per year—2,100-2,500[62] per year depending on region, than the Czech Republic, Germany, and Poland, which receive between 1,400 and 1,700,[63] 1,500-1,800,[64] and 1,500-1,800[65] hours, respectively. Solar resources currently supply 8 percent of Hungary's power generation, and there is significant potential for them to provide more. We estimate that Hungary's solar generation capacity could be increased 20 times over the next three decades, accounting for up to 72 percent of its installed capacity.

Hungary's wind power resources, as measured by wind speed and density, are not as robust as solar power but have strong potential. If harnessed effectively, Hungary could expand its wind-propelled power generation capacity by as much as 46 times over 2020 levels by 2050.

As renewable energy sources become more cost effective to deploy, Hungary could transition from a net power importer (imports account for 26 percent of power generation mix) to a net exporter. According to our analysis, if it follows the roadmap presented herein, Hungary could export up to 3 percent of its generated power in total by the early 2030s.

Taken together, wind and solar resources could make up 94 percent of Hungary's power generation capacity by 2050 – a major shift from their current share of 17 percent.

Renewable resources could also be used to produce green hydrogen, which could replace fossil fuels in industry or transport by as early as 2030. By 2050, the green power used for hydrogen production will equal 31 gigawatts (GW) of installed solar PV capacity.

Thus far, our analyses have demonstrated that renewable resources could supply most of Hungary's electricity by 2050. As RE-sourced capacity grows, the power sector must overcome the challenge of generating renewably sourced electricity that matches real-time demand. In a climate such as Hungary's, periods when solar- or wind-resourced electricity supply is high may not match up with demand. For example, less solar electricity is available on cold and dark winter evenings. What's more, as Hungary and its trading partners reduce reliance on fossil fuels by retiring baseload coal power plants, there is greater potential for power shortages.

There are three main mechanisms by which the sector could ensure consistency in the power supply: maintaining a small amount of nonrenewable power generation, or balancing capacity; expanding energy storage and conversion; and upgrading the power grid and infrastructure.

First, Hungary could maintain the operation of several gas-fired plants while equipping them with carbon capture devices. CCUS technology captures carbon dioxide before it reaches the atmosphere, which can then be sequestered into geological formations or depleted oil fields.

Second, with the dropping cost of green hydrogen and electrolyzer, there is a broader range of options in terms of seasonal/daily storage and peak capacity. From the mid-2020s, electrochemical batteries, such as lithium ion (Li-ion) batteries, are becoming increasingly commercially viable – Hungary could deploy them at scale to provide daily flexibility (potentially also using vehicle-to-grid technologies as EVs ramp-up.). The emergence of green hydrogen (see separate chapter) will also contribute to both daily and seasonal flexibility by using H_2 as a vector for energy storage, which is then deployed in power plants converted for hydrogen instead of gas use.

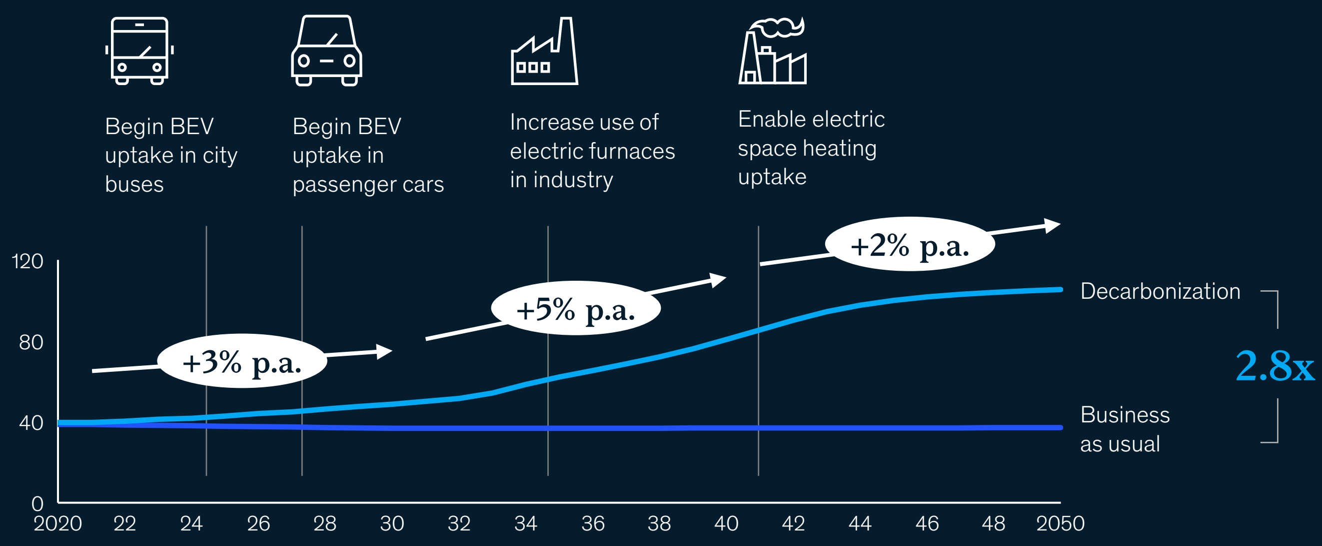
Assuming no cross-border flows, approximately a combined 6 GW of balancing and energy storage capacity could be necessary to ensure seamless power supply on days with peak hours by 2050.

Third, Hungary will need to significantly upgrade its entire power grid and interconnector infrastructure to meet the economy's electricity demand sustainably by 2050. Hungary has lagged behind its peers in power distribution and transmission investment by up to 33 percent.[66] Following the closure of the CAPEX gap, throughout the next 30 years Hungary would need to invest €30 to €40 billion in the power grid, with additional investments required for increased cross-border flows, reverse flows, and dealing with the increased volatility inherent to renewable resources.

If harnessed effectively, Hungary could expand its wind-propelled power generation capacity by as much as 46 times over 2020 levels by 2050

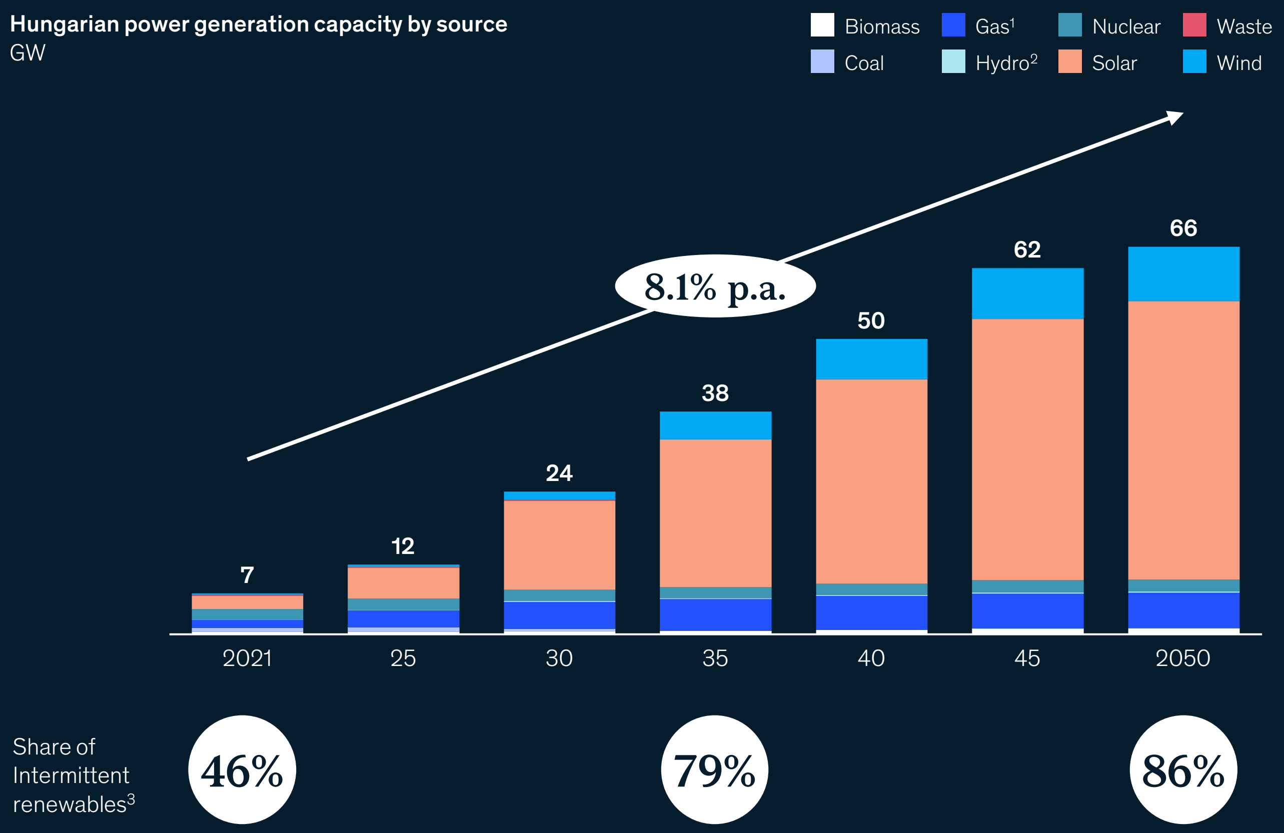
As electricity demand grows by 2.8 times by 2050, decarbonizing power will become a key enabler to decarbonize other sectors

A potential increase in electricity demand for the next 30 years
Electricity demand, TWh, annually



By 2035, renewables can make up 79% of installed generation capacity in Hungary

Hungarian power generation capacity by source
GW



1. Potentially substitutable with hydrogen
2. Other includes geothermal, and marine
3. Intermittent renewables include solar and wind; wind ramp-up assumes that current regulatory bottlenecks will be lifted, however, not immediately

Source: McKinsey Energy Insights' McKinsey Energy Insights Reference Case 2020, Irena Renewable power generation costs in 2018

Waste management

The waste sector contributes 4 percent to Hungary's total carbon emissions; in 2019, it released 3 MT CO_2e

Introduction

The waste sector contributes 4 percent to Hungary's total carbon emissions; it released 3 MT CO_2e. Wastewater treatment and discharge, along with solid waste disposal, are the main sources of sector emissions. The remaining 5 percent of sector emissions are accounted for by incineration and biological solid waste treatment.[67]

The most effective way to reduce waste-related emissions is to prevent creation of waste. Consider, for example, that each person creates 364 kg of municipal waste each year in Hungary. Behavioral changes at the consumer, producer, and processing levels can deliver economic value and environmental benefits, but these are difficult to measure. Therefore, rather than focusing on preventing waste, this report outlines measures to reduce emissions from waste treatment.

Wastewater

Wastewater contributes to over half of waste sector emissions due to GHGs that are released during water treatment, like methane and nitrous oxide, and from the energy used during wastewater treatment plant operations.

To reduce wastewater emissions, Hungary could use technologies related to capture and conversion of GHGs. For example, as much as 80 percent of the methane emissions[68] released from water during treatment can be captured. Assuming this technology is implemented at 70 percent of water cleaning facilities, up to 56 percent of emissions from wastewater treatment and discharge could be reduced by 2050. What's more, emissions captured during treatment can result in secondary value propositions. For example, the biosolid sludge that results from wastewater treatment can be reused as fertilizer feedstock, and methane can be captured for biogas.

Solid Waste

In the management of solid waste, avoiding the use of landfills is top priority. This contributes to decarbonization in two ways. First, any reduction in organic waste, which emits mostly methane when disposed in landfills, lowers emissions directly. Second, solid waste management via recycling enables industry to replace raw materials with recycled ones, thus indirectly reducing waste-related emissions (for example in case of metals). This analysis focuses on the first type of abatement, because it is directly impacted by waste management practices.

Emissions from landfills come from the anaerobic decomposition of organic materials, a process through which bacteria break down organic matter, such as food waste, in the absence of oxygen. Landfill emissions are relatively high because they contain mostly methane, which is 25 times more potent GHG than CO_2.[69] Additionally, waste placed in landfills continue to emit GHGs for about 20 years.[70]

Hungary's roughly 19 million tons of solid waste is made up of waste from construction, industry, municipal waste, agriculture, and hazardous waste. While construction waste is highest in volume (43 percent), it does not contain organic waste and, therefore, is not a source of emissions. Agriculture and hazardous waste do have organic components, but is rarely put in landfills, so the analysis focuses on industry and municipal waste.

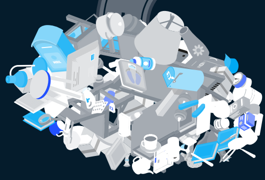
Waste management could be decarbonized by recycling & transforming waste to energy

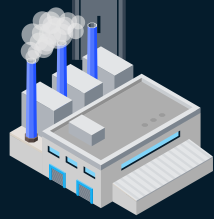
Waste creation

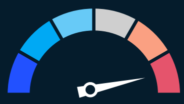
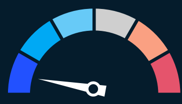
As little as possible waste should be created through reducing food and other green waste, as well as reusing or repurposing products.

Waste collection

Waste collection trucks could become carbon neutral by being electrified or using green hydrogen as fuel





	Landfill	Recovery (waste-to-energy)	Recycling
Emission level	 High	 Medium/low	 Low
Share of municipal waste going to different treatment types			
Today	52%	14%	36%
Net Zero Ambition	0%	30%	70%
	Waste could be diverted from landfills, and existing landfills could be equipped with methane capture mechanism	Energy could be recovered through incineration or by processing waste into a fuel source, like biogas	Recycled materials could be used as raw materials in production; green waste could be composted or used as feedstock

To reduce emissions, the share of waste going to landfill from industry should fall to zero by 2030 from the current level of 38 percent. Municipal waste going to landfill will also fall, but more slowly, reaching 20 percent in 2030 and zero by 2050.

As Hungary diverts waste away from landfill, other waste management solutions like recycling and recovery by way of waste-to-energy technologies will likely become more prevalent. Waste, coupled with CCS can also serve as a fuel in district heating plants. Hungary currently recycles 55 percent and 35 percent of industry waste and municipal solid waste, respectively. By 2050, 70 percent of all waste should be recycled.[71]

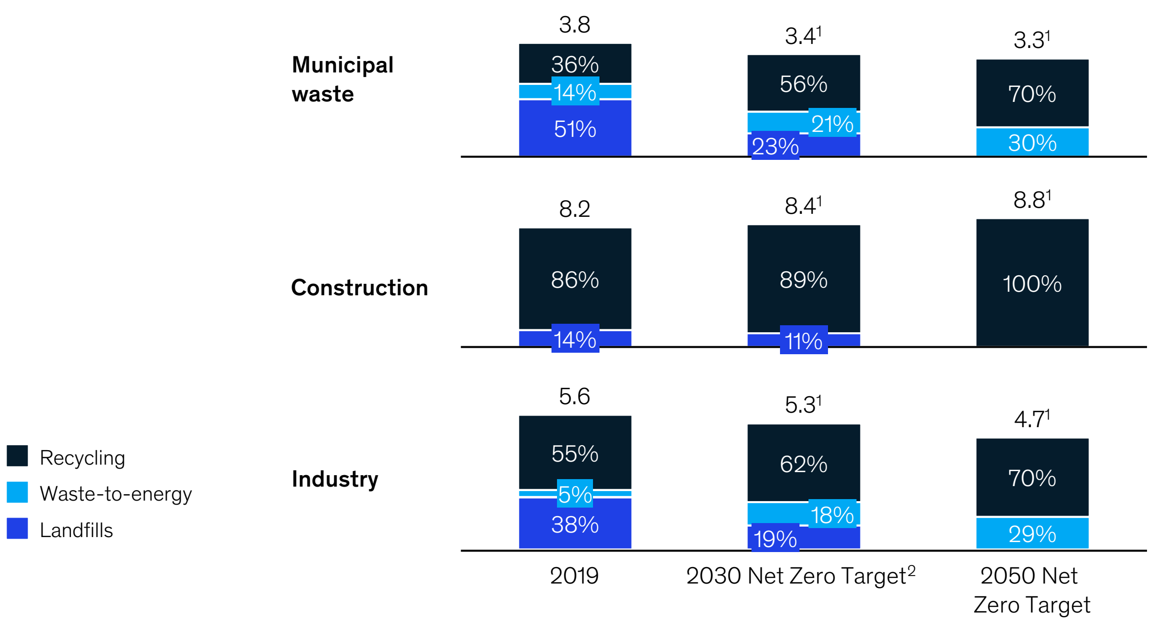
Several waste-to-energy technologies are available to treat waste that is not recyclable by using thermal, mechanical, chemical, and biochemical methods to produce energy. For example, incineration with methane capture is a mature technology whereby waste is burnt and turned to ash, flue gas, and heat, which can then be used as energy. Equipping methane capture in incinerators prevent GHGs from entering the atmosphere.

Gasification or anaerobic digestion of organic waste is another mature technology that can be used to make synthetic gas or biogas which can be reused as a source of green energy. Meanwhile, emerging technologies like plasma gasification and thermal gasification processes that convert solid waste to energy – neither of which is widely used in Hungary[72] – could be used going forward. However, there are some successful examples of using gasification for energy in industrial applications in Germany and Finland.[73]

Our analyses indicate that these and other measures could enable industry and municipal waste sectors to reduce solid waste emissions by 20 percent by 2030 and by 94 percent by 2050 compared to 2019 levels.

By diverting waste away from landfills to recycling and waste-to-energy treatments, 42% of solid waste emissions are abated

Waste by treatment types, MT



NOTE: Numbers may not sum due to rounding.

1. 2030 and 2050 total waste estimates are based on historical figures and population projection without waste reduction efforts
2. Based on EU targets of 65% recycling rate and 10% landfill in 2035

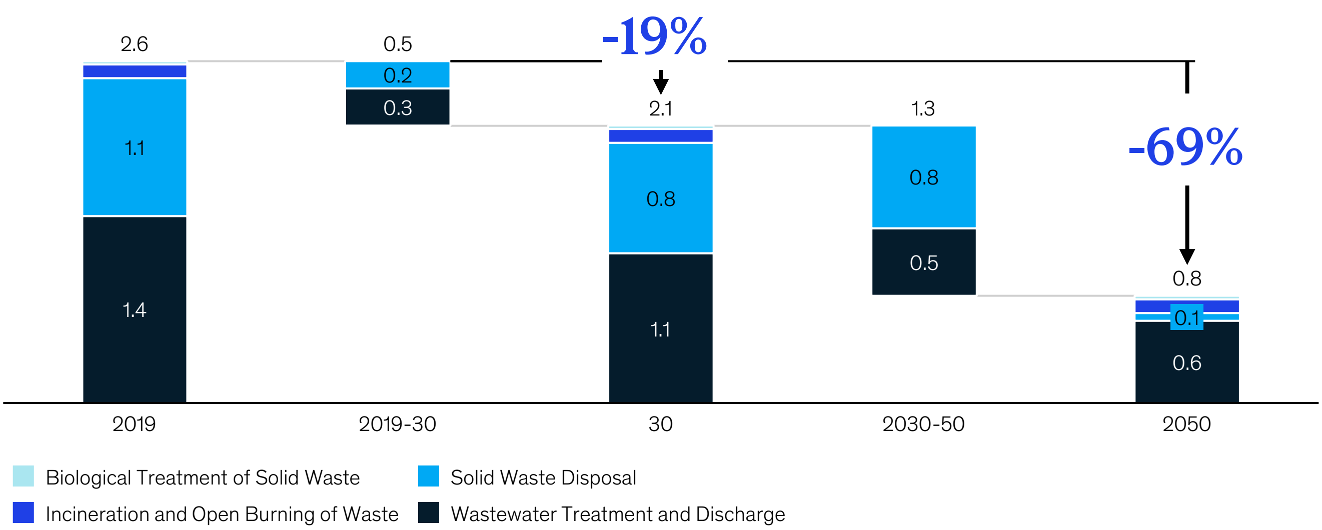
Source: KSH, McKinsey analysis

Plausible decarbonization pathways

Looking at emission reductions achieved through improvements in wastewater management as well as solid waste disposal, total waste sector emissions will decline by 69 percent in 2050. Improvements in solid waste management will contribute to 55 percent of the reductions, and improvements to wastewater management for the remaining. Carbon neutrality by 2050 cannot be achieved in the sector due to lead time of landfill emissions. If solid waste targets are met and with further improvements in technologies, emission would further decrease in the future.

Hungary would achieve a 69% reduction in GHG emissions by 2050 compared to current levels

Waste emission, MT CO_2e



Case example

Solid waste management involves carefully separating recycling, electronics, scrap metal, compost, plastics, diapers, and other types of waste, which can be inefficient and ineffective even at the household level. New technologies making it easier to sort and consolidate waste could help to improve solid waste management, as demonstrated in the city of Yavne in Israel.

In 2012, a neighborhood of Yavne, Neot Rabin, began using a pneumatic waste collection system, also called an automated vacuum collection system (AVAC). Multifamily apartment buildings in Yavne are connected to a network of underground pipes leading to a centralized garbage storage unit. Residents on each floor dispose waste in either a dry or wet garbage chute which connects to an underground unit. Once a week, the waste is pumped or vacuumed through pipes to an aggregated storage center at speeds of between 50 kilometers and 80 kilometers per hour. The waste is then stored in sealed containers for sorting and compaction. Finally, waste is transferred to containers that are removed by trucks and transported to final disposal sites.

Based on efficiency gains in collection, Yavne expanded the waste collection system throughout the municipality, connecting both private residential units and public areas like parks, school, and streets. Other municipalities also began using centralized pneumatic pumps to manage waste.

While the AVAC system requires high up-front investments and public training, it has significantly lower operating costs compared to non-aggregated systems. What is more, it has the potential to reduce waste sector emissions by lowering the energy cost of waste collection and facilitating recycling and reuse of materials.[74, 75, 76]

Agriculture

Introduction

Agriculture accounts for 14 percent of Hungary's total carbon emissions; it released 9 MT CO_2e in 2019. The agriculture sector's share of emissions per capita are on par with regional averages and as in the rest of Europe, most result from the enteric fermentation from animals, with crop production (driven by fertilizers) and on-farm energy being the second and third major sources of agricultural emissions respectively.

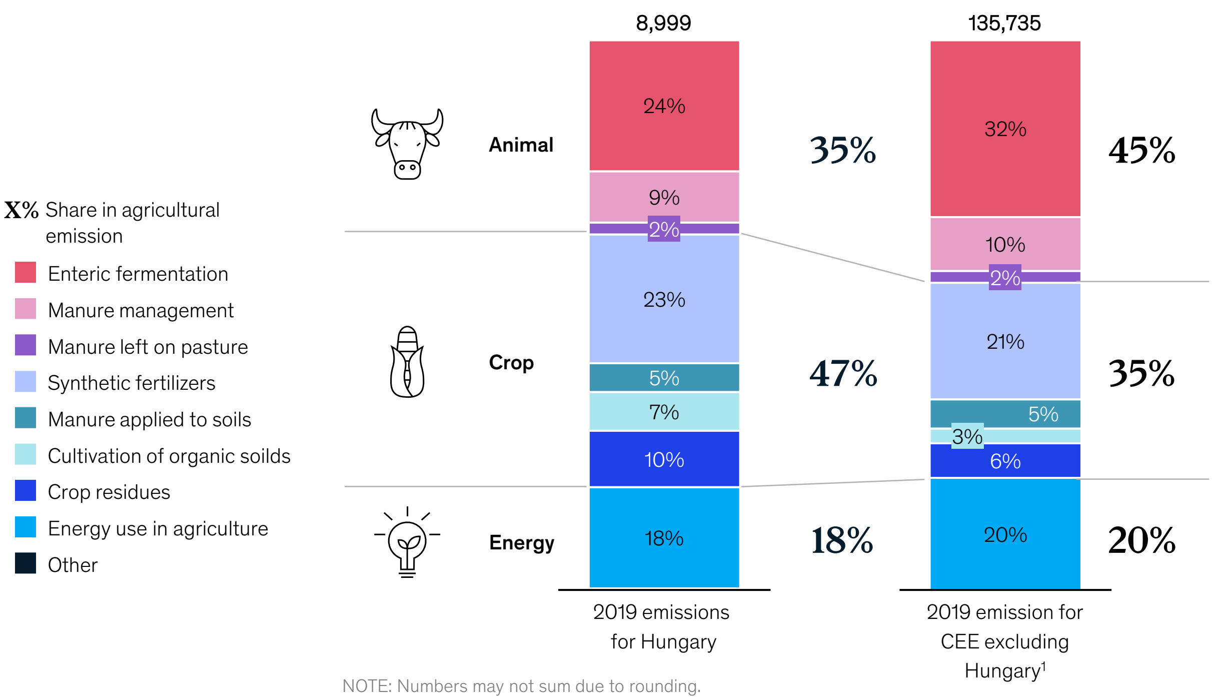
Hungary hosts fewer cattle compared to other Central and Eastern European countries, but they account for as much as two-thirds of emissions from enteric fermentation. This reflects the fact that ruminant animals such as beef are 10 times more carbon-intensive than poultry, and 30 times more carbon-intensive than vegetable protein.

At about 47% of the total emission, crop emissions in Hungary are relatively high owing to widespread use of synthetic fertilizers, which contribute to half of all crop emissions.

On-farm energy contributed about 18 percent to Hungary's agriculture sector emissions, just slightly lower compared to neighboring Central and Eastern European peers.

In Hungary, a smaller share of emissions comes from animals and a larger share from crops than in the rest of CEE

Total emissions, ktonne



NOTE: Numbers may not sum due to rounding.

1. Average share of emission by source of V4 countries, except Hungary

Main decarbonization levers in Hungary

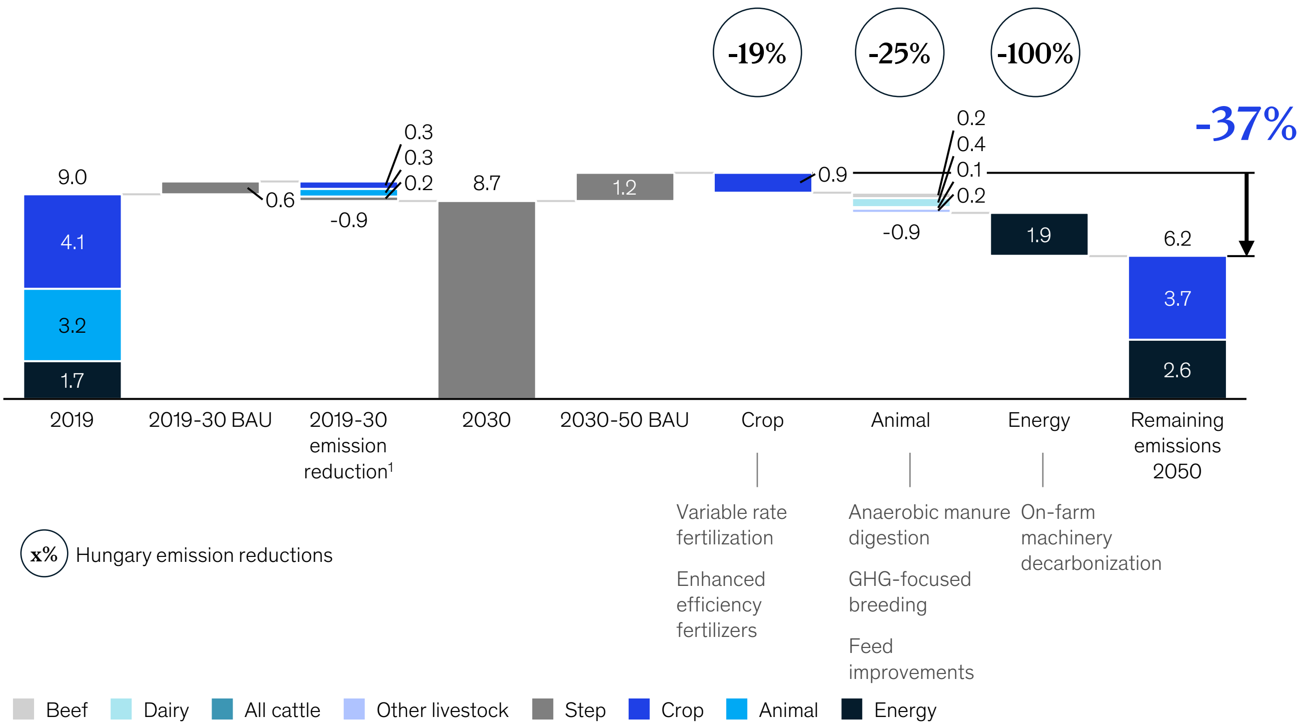
Agriculture is the most difficult sector to attain net zero emissions due to the inherent nature of emissions from enteric fermentation. Many of the required technologies are in an early stage and the dispersed nature of the agricultural activities make it more difficult to monitor. Nevertheless, we estimate that, with targeted measures, Hungary could reduce emissions in the agriculture sector by as much as 37 percent over the next three decades. However, most reductions will occur after 2030, given the time and incentives required to adopt the technologies that will make emissions reductions possible. Note that our analysis does not take into consideration additional measures needed to ensure the sector's sustainability, such as ensuring biodiversity and water availability.

Pulling the following levers below could bring emissions down by 37 percent by 2050

Reducing emissions from enteric fermentation is the most important step for Hungary to take in decarbonizing agriculture. It can start by adopting newly available technologies that effectively reduce emissions from ruminant animals. For example, anaerobic manure digesters can lower GHG emissions from dairy cow and swine manure. Farmers can also use specific types and mix of feed to reduce animal-related emissions, such as seaweed, fats, and tannins, to lower methane and nitrous oxide concentrations.

Hungary would achieve a 37% reduction in GHG emissions by 2050 compared to expected BAU levels

Agriculture emissions, MT CO_2eq



1. Based on Oxford Economics forecast

Source: McKinsey Sustainability Insights

Our analysis suggests that if adopted, these technologies will cut total emissions from animals by about 22 percent; however, some emissions are inherent to livestock and cannot be completely eliminated.

Therefore, farmers must also focus on reducing emissions related to crop production – an area where advanced technologies that can replace the use of synthetic fertilizers would be especially helpful in Hungary.

For example, natural stimulants such as seaweed extract can enhance crop yield and ability to uptake nutrients already available in the environment (both naturally available and delivered by fertilizers), thereby lowering requirement for fertilizer application and related nitrous oxide emissions. Similarly, enhanced efficiency fertilizers, including nitrous oxide inhibitors can help to slow down the rate at which synthetic fertilizers break down into smaller chemical compounds. This process leaves more nitrogen available to crops and less nitrogen to create other harmful gases.

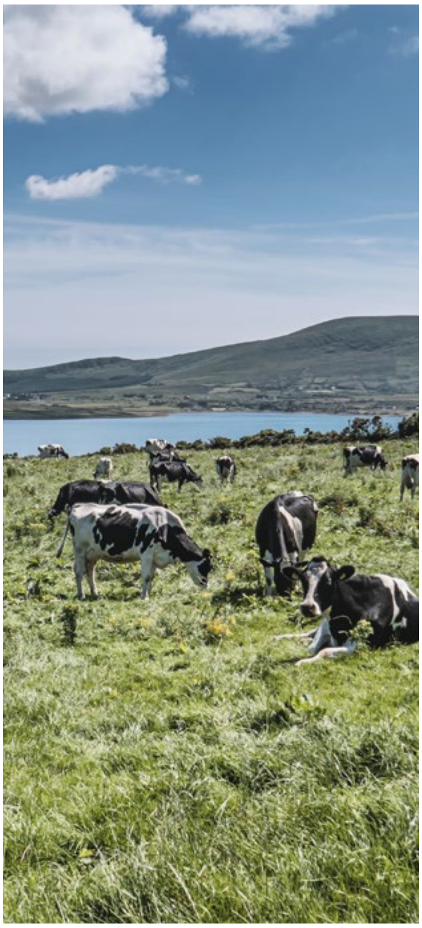
On-farm energy use by machinery contributed 1.9 MT CO_2e in Hungary. Nearly all these emissions can be eliminated by replacing fossil-fueled farm machinery, such as tractors, with battery-powered electric vehicles or hydrogen-fuel ones. Current share of electricity of all fuel use in agriculture is 12 percent, as most agriculture machinery still runs on fossil fuels, mostly diesel and natural gas.[77] We expect first battery-powered, then hydrogen-fuel farm machinery to become increasingly competitive against ICE machinery over the next decades, and for farm machinery to become zero emitter by 2050.

Beyond technological adaption, shifts in consumer behavior could lower agricultural emissions. Cattle and sheep account for 35 percent of agricultural emissions (mostly methane) and reducing meat and dairy consumption could significantly cut these emissions. Although European and global trends show a shift to more plant-based diets, the share of vegetarians in Hungary is below 2 percent.[78] Our analysis therefore does not consider a change in the Hungarian diet or to animal husbandry.

On-farm energy use by machinery contributed 1.9 MT CO_2e in Hungary

Absent these changes, Hungary's agriculture sector could lower its emissions by about 37 percent following the measures outlined above. Nonetheless, considering the structural specificities of the sector, execution quality of outlined measures will be equally important. Hungary has 234,000 mostly medium-sized farms, and half of them are under lease. Any changes to land use or technologies deployed on the farms could require the owners' permission. Because newer technologies can involve significant investment, owners of small- to medium-sized farms may be reluctant to adopt them unless they can be used at scale. Here, bespoke solutions to decarbonization may be helpful, such as the ones that have been created by farmers in Denmark.

Governments could also consider mobilizing decarbonization efforts in agriculture by offering funding towards net zero measures. The EU Green Deal has set sustainability target for the agriculture sector to meet by 2030, although these are not yet legally binding. Importantly, the European Union agreed to make environment and climate action central to its common agricultural policy (CAP) plan for 2023 to 2027. It plans to provide the equivalent of €16.9 billion in funding for farming, food industry, and rural community developments in the coming five-year cycle.[79] Increasing sustainability requirements for applicants to secure funding could contribute to more widespread implementation of new, low-emission technologies.



Case study: Arla Foods lowering GHG emissions

Arla Foods is a global dairy cooperative that originated in Denmark and Sweden in 1990 and has expanded to 10,000 farmers across Europe. Arla recently doubled its goal to cut their Scope 1 and 2 emissions (related to operations including transport) from 30 percent to 63 percent by 2030. They also intend to cut Scope 3 emissions by 30 percent.

To date, Arla has successfully lowered emissions throughout its value chain by collecting and analyzing data from farmers, producers, and delivery services to measure their carbon footprints and to identify the support they need to reduce emissions. To incentivize information sharing, Arla offers an incentive of 1 EUR-cent/kg of milk to farmers for information on the types of fuels and animal feed they use, how many animals they own, the types of fertilizers they use, and their waste management techniques. Over 90 percent of Arla farmers have participated[80] in carbon footprint reporting. Arla uses this data to target investments in carbon reduction solutions,[81] such as transitioning to electric battery-powered machinery[82] and increasing consumption of renewably-sourced electricity. Additionally, Arla is partnering with solution providers, such as DSM,[83] to try new feed additive to reduce methane emissions of dairy cows by around 30 percent.

Similar action may be useful for Hungarian agricultural associations/aggregators to achieve emission abatement in the agriculture sector.

Negative emissions

In 2019, the LULUCF sector offset 8 percent of Hungary's total carbon emissions, or about 6 MT CO_2e

Introduction

Given current technologies and consumer behavior, Hungary is not likely to eliminate all emission sources by 2050; therefore, negative emissions sources, both nature- and technology-based, could be used to offset the hardest-to-abate emissions. Nature-based solutions also known as Land Use, Land-Use Change, and Forestry (LULUCF) sector, are vital already today to counterbalance the positive emissions sources. The LULUCF sector offsets 8 percent of Hungary's total carbon emissions, or about 6 MT CO_2e. Whereas the technology-based solutions such as carbon capture and storage are nascent: there are few scaled solutions on a global level and no existing prototype in Hungary.

Decarbonization options

Nature-based solutions

Forestland, which is effective in capturing carbon dioxide, was responsible for 95 percent of the emissions offset. Maintaining or improving forest management and reforestation are therefore critical to Hungary's ability to achieve net zero by 2050. Carbon sink potential is the difference between biomass growth and biomass loss and represents the amount of CO_2 that can be captured. Forestland's carbon sink potential depends on the coverage, age, and species distribution of its trees. For example, as trees reach maturity, their growth slows down and carbon sink potential decreases. A tree's wood density also affects its carbon sink potential. Fast-growing and lightweight poplar species store much less carbon than denser oaks. Therefore, as part of tree cutting and planting efforts, the growth cycles and density of specific tree species should be also considered.[84]

According to the European Environment Agency's projections,[85] the abatement potential of LULUCF in Hungary will decline by 80 percent over the next 18 years by 2040 if no additional measures are taken, given the age of existing forests and their expected life cycles. Our analysis assumes that the abatement potential of Hungary's LULUCF could drop by as much as 90 percent by 2050 compared to 2021 if no measures are taken. However, several levers can be applied to increase the carbon sink potential of this sector.

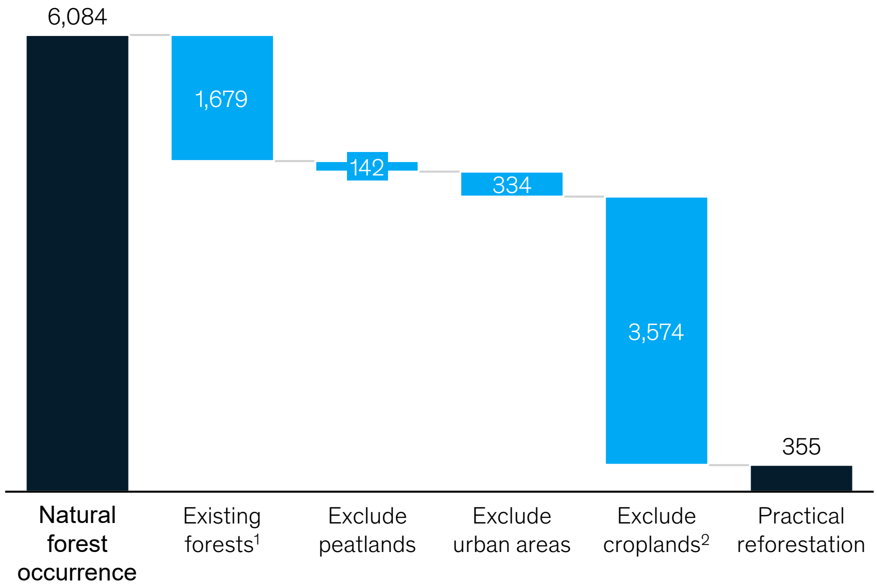
Reforestation (combined with peatland restoration) has the potential to abate an additional 5 megatons of CO_2e. It can sequester carbon in the long and short term because forests capture carbon and convert it into biomass, while restoring peatlands would avoid emission that otherwise would have happened. Reforestation would involve converting non-forestland to forest in locations that historically supported forestry or where forests are ecologically appropriate or desirable. Based on our analysis, Hungary's reforestation potential applies to a 3.8 percent share of land after accounting for existing forests, peatlands, urban areas, and croplands. Achieving this rate of forestland growth is in line with the current forestry strategy's goal to reach 28 percent of land covered by forests, with additional measures for forest management and upkeep. The largest potential for reforestation by land area is in the Bács-Kiskun and Veszprém counties. Emissions stemming from peatlands can be addressed by restoring the degraded ones through, for example, water table management and re-vegetation.

Forest land's carbon sink potential depends on the coverage, age, and species distribution of its trees

Around 350,000 hectares could be sustainably reforested in Hungary, excluding existing forests and unsuitable areas

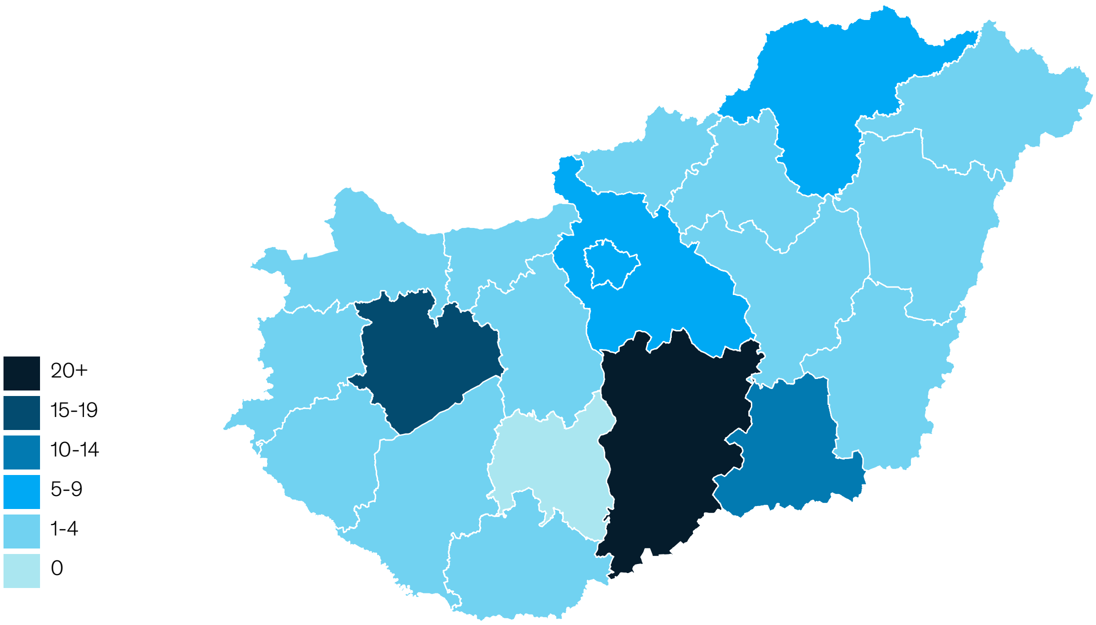
Reforestation potential

1000 ha



Reforestation potential by country

'% of total area



1. Areas with more than 25% tree cover
2. Includes part of grasslands (where Natural Climate Solutions other than reforestation could be implemented)

Source: McKinsey Nature Analytics

Extending current forest management practices throughout the country and introducing agroforestry practices could produce a further 1 MT CO_2e emissions reduction. Natural forest management can alter the carbon stored in natural forests by, for instance, favoring species with dense wood or by delaying harvesting. In addition, systems to integrate trees into croplands at levels that do not reduce crop yields (for example, through windbreaks, alley cropping, and farmer-managed natural regeneration) could be introduced.

Beyond forestry, LULUCF includes the areas of croplands and grasslands, whose appropriate management can also contribute to negative emissions. For instance, grazing management can be employed to sequester carbon by changing the timescale of livestock feeding cycles, especially in wetter regions with high forage growth rates.

By increasing measures, LULUCF absorption potential can be slightly increased compared to 2019 levels, however it would be a significant improvement compared to the expected decrease of 80-90%. This report assumes that the sector's negative emission potential would equal to 6 MT CO_2e. However, to ensure that this potential is realized by 2050, implementation of these measures should begin in the 2020s. This is in line with the EU Green Deal's aim to increase negative emission of the LULUCF for the period from 2026 to 2030 to 310 MT CO_2e at the EU level, which means a 37 percent increase compared to previous period from 2021 to 2025.

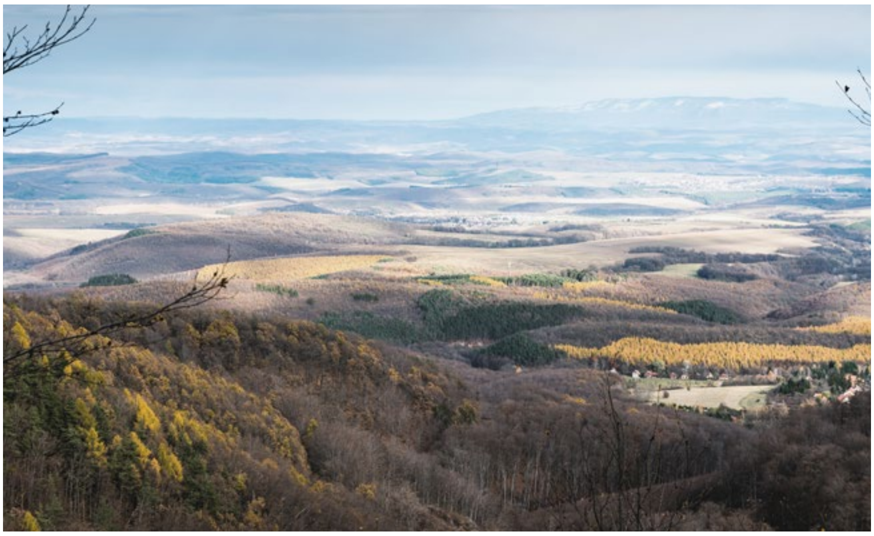
Technology-based solutions

Technology-based solutions could help Hungary offset the remaining 2 MT CO_2e that cannot be neither eliminated nor offset by the LULUCF sector. There have been recent developments in two main areas, namely in Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture and Storage (DACS).

BECCS captures the carbon released from biomass energy production (for example, in cement and lime production) and buries it underground instead of releasing it into the air. Today, it exists globally around 1 MT scale BECCS plants and the technology is ready to scale up.

DACS captures carbon from ambient air where CO_2 is present at a much lower concentration than in flue gases in the industry or power and heat sectors. As the DACS technology is still nascent today with less than a dozen of pilot projects in place and with the first commercial plant scaled at ~1 MT expected to be operational by 2024 or 2025. Therefore, this likely would be one of the last steps to offset the most difficult emissions required to be reduced to achieve net zero emissions.

Technology-based solutions could help Hungary offset the remaining 2 MT CO_2e that can't be neither eliminated nor offset by the LULUCF sector



The role of Hydrogen

Hydrogen's increasing role

In just the past few years, green hydrogen has moved to center stage of the decarbonization agenda as a vital ingredient in the global transition to net zero. Over 500 large-scale, green hydrogen projects representing US$160 billion in investments are underway globally. In Europe, the EU aims to have 40 GW electrolyzer capacity to produce green hydrogen by 2030, which would be equal to 340 times of 2020 European capacity.[86]

Several properties of hydrogen make it an ideal tool to reduce carbon emissions: it is an energy source in which the only by-product when burned is water. It also has high energy density, which makes it a highly efficient fuel for vehicles that cannot be electrified – such as long-distance buses, heavy-duty transport trucks, planes, and marine transport. Moreover, hydrogen can replace natural gas as a feedstock in industrial processes such as ammonia production, as well as serve as a reducing agent in the production of iron (DRI), helping replace the highly polluting blast furnace technology. And, once produced, hydrogen can serve as a seasonal energy storage, thus increasing power system resilience.

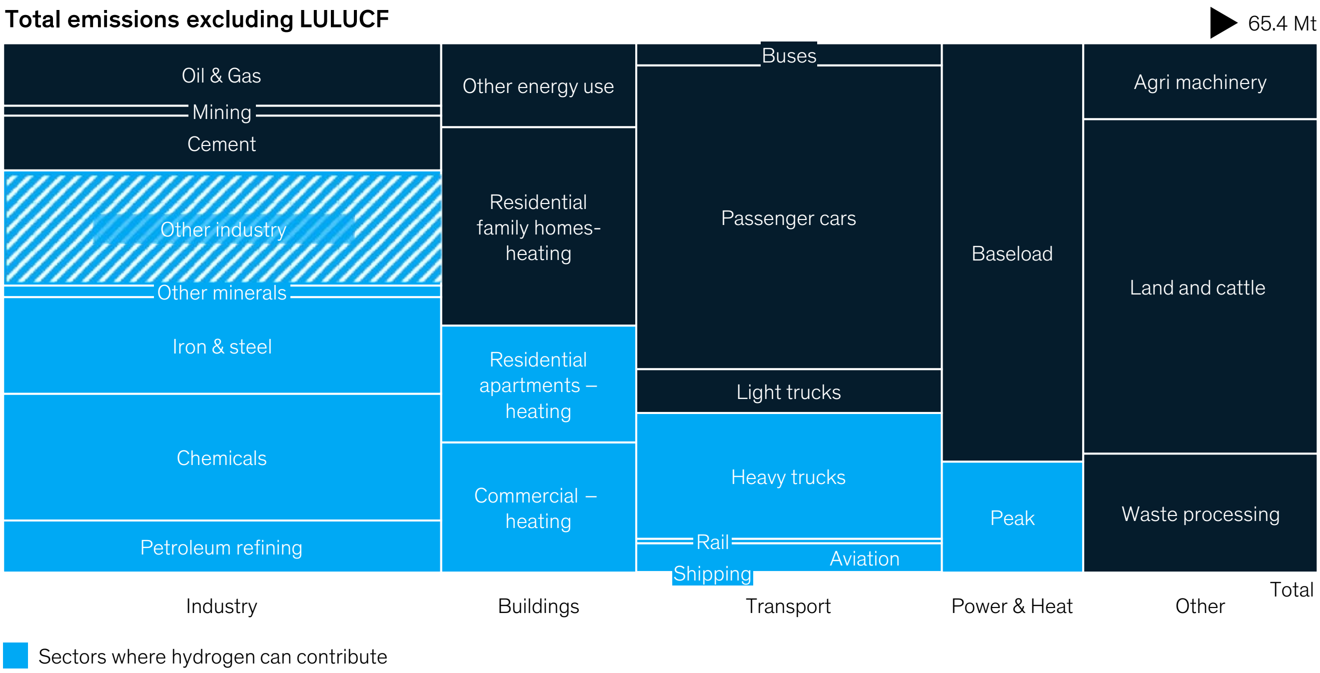
Hungary's hydrogen advantage

Most of the hydrogen currently produced is made by burning natural gas. This type of hydrogen is referred to as 'grey' because it results in carbon emissions. In contrast, green hydrogen is produced by splitting water into hydrogen and oxygen using electricity from renewable energy sources, such as solar and wind power, in a process called electrolysis. Green hydrogen is rapidly becoming cost-competitive due to the falling cost of electrolyzer and renewable power.

Hungary has a particular advantage on this front. The high number of sunny hours mean that it is relatively cheap to produce hydrogen based on renewable power sources, namely solar. In addition, it has an extensive gas distribution and transmission infrastructure, which can serve as a backbone of hydrogen transport. Based on the falling costs, hydrogen applications are becoming competitive rapidly throughout the 2020s and hydrogen will likely be a major decarbonization lever from the early 2030s. Considering the ambitious regulatory agenda (e.g., 40 GW electrolyzer capacity in the EU by 2030), there may be some subsidies which could further accelerate the process.

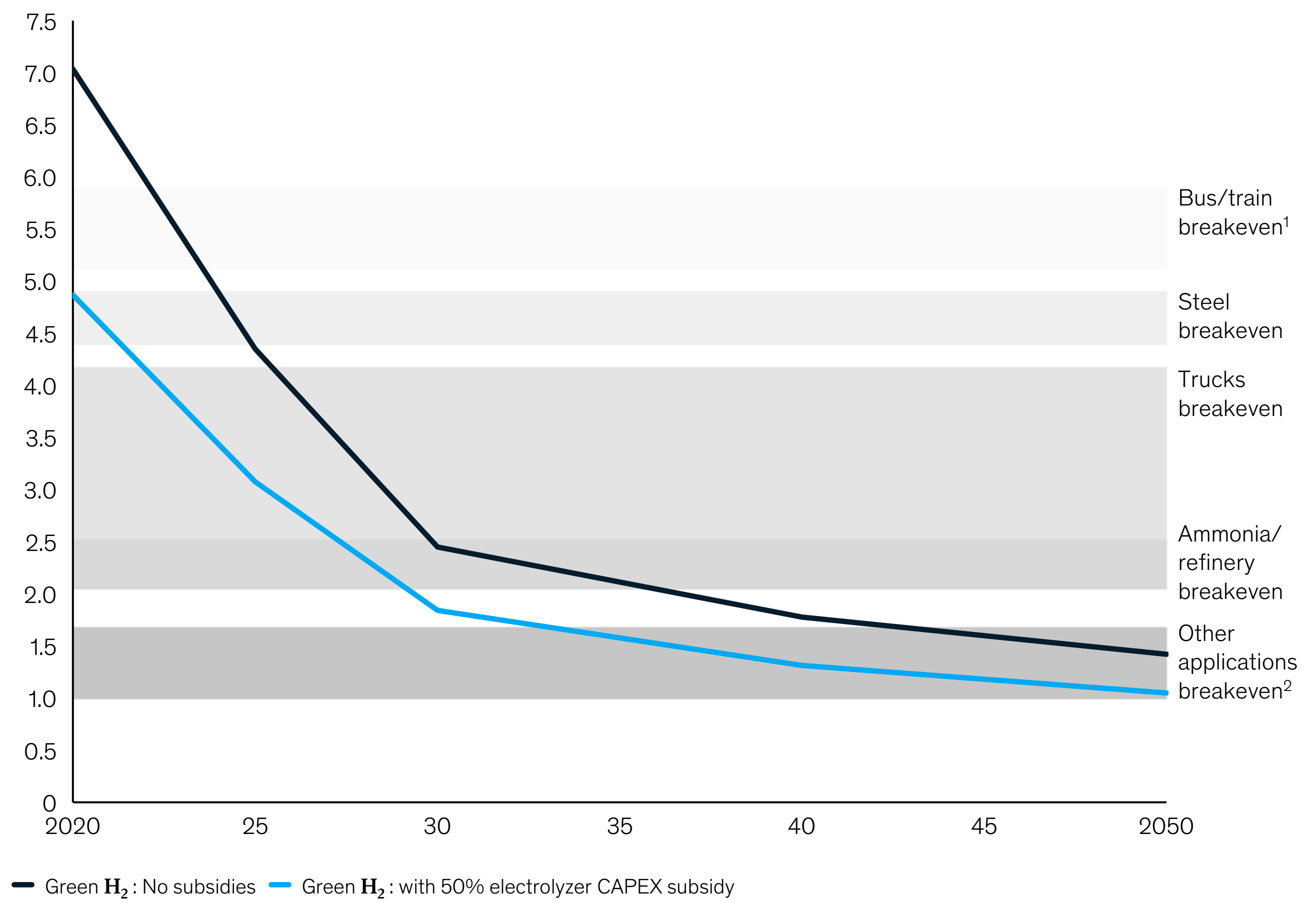
Based on the falling costs hydrogen applications are becoming competitive rapidly throughout the 2020s and hydrogen will likely be a major decarbonization lever from the early 2030s

Green hydrogen is a key instrument in decarbonizing certain sectors



Multiple green H_2 applications will break even in Hungary in the 2020s

Indicative H_2 economics, Hungary, USD/kg



1. All use case breakeven costs assume 100 USD/t CO_2 carbon price
2. Other applications include power generation, high-heat industrial processes, building heating, and boilers

Hydrogen demand

Hydrogen will likely play a key role in Hungary's decarbonization. By 2050, if Hungary achieves its net zero commitments, energy use coming from hydrogen will be larger than that of oil and gas combined. Not only could it contribute to decarbonization of 40 percent of Hungarian emissions, but it could also accelerate economic growth across multiple sectors and transform Hungary into a net energy exporter. Decarbonization of various sectors would create a significant demand for green hydrogen in Hungary.

Next steps in Hungary

As a first practical step on that journey, Hungary could start developing so-called Hydrogen Clusters – industrial parks in which renewable energy players, hydrogen producers, and large end consumers collocate. Such parks can later become the epicenters of hydrogen distribution to other end users and export.

Hydrogen could play a significant role in a carbon-neutral Hungarian economy – as fuel, industrial feedstock, and energy storage

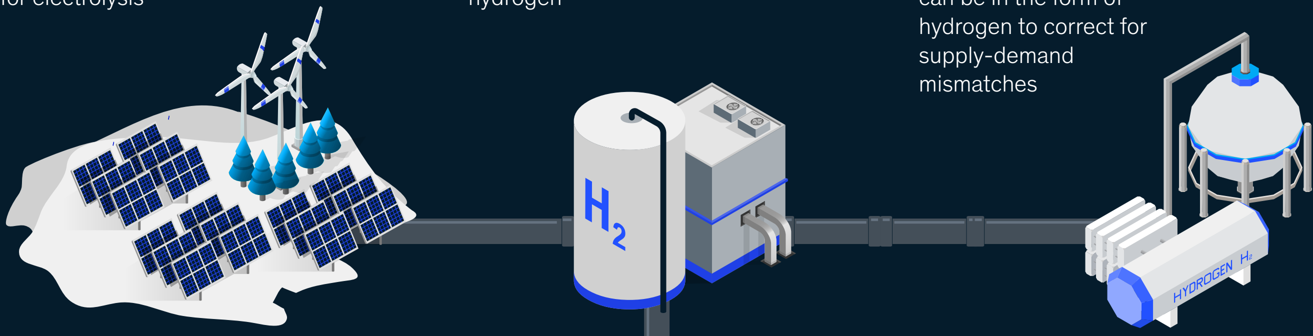
Production

Solar PVs and wind turbines produce renewable electricity for electrolysis

Electrolyzer facility converts renewable electricity into hydrogen

Energy storage

Power storage for excess renewable energy can be in the form of hydrogen to correct for supply-demand mismatches



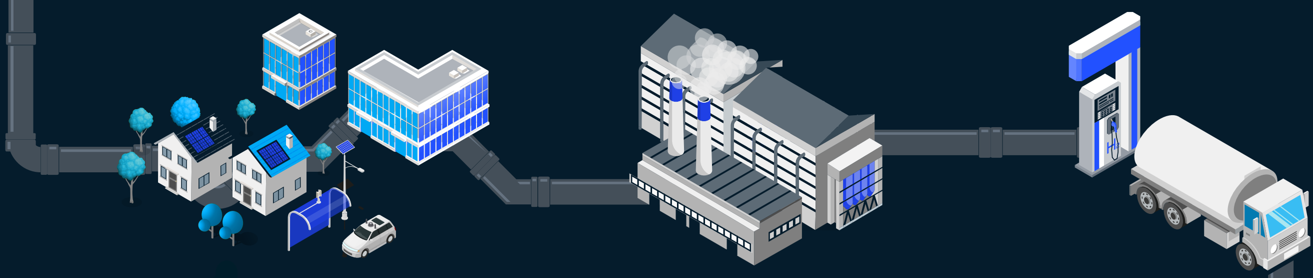
Hydrogen infrastructure can leverage retrofitted gas pipelines to transport hydrogen to end-users

Usage as fuel and feedstock

Residential and commercial heating can run on hydrogen by leveraging distribution through retrofitted gas network for households, or by using directly in district heating production

Iron and Steel plant can use hydrogen as a reducing agent for production of direct reduced iron, which is the input material for electrified steel furnace

Long-haul buses and heavy-duty trucks can run on hydrogen fuel instead of diesel

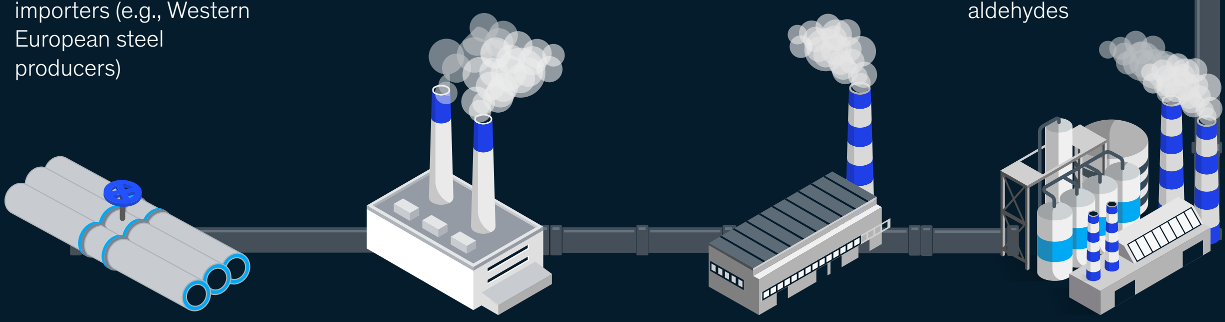


Export of hydrogen can go through pipelines retrofitted from previous gas transmission lines to major hydrogen importers (e.g., Western European steel producers)

High-Heat industrial processes, that can't be electrified, can switch to hydrogen for their fuel use

Ammonia plant can source green hydrogen to produce carbon-free ammonia and fertilizers

Chemicals plant can use hydrogen for production of methanol and other alcohols or aldehydes



By **2050** Hydrogen demand will exceed oil demand in Hungary

~40% Hydrogen will contribute to decarbonization of 40 percent of Hungarian emissions

Chapter 5

Decarbonization's costs and economic impact

5

Although decarbonization would require significant initial capital expenditures, the increase in capital outlays would be partially offset by operational savings through greater energy efficiency.

The decarbonization pathway presented has the potential to enable Hungary's competitiveness in multiple industries (e.g., in automotive) or create new opportunities for export. Our analysis suggest that the net zero transition will increase competitiveness in sectors making up 30 percent of GDP; in addition, it will directly increase Hungary's GDP annually by 2 to 2.5 percent while creating 80,000 to 100,000 jobs.

The economics of our decarbonization pathway

Over the next 30 years, decarbonizing Hungary would require between approximately €150 and €200 billion in incremental capital expenditures (capex) (that is, beyond the capex that would be needed in a business-as-usual scenario). A quarter of investments are expected until 2030. At the same time, operational costs are expected to decrease by €100 to €150 billion by 2050, moreover, these cost decreasing effects stay in place also for the later decades.

Decarbonization's investment and return profile

Till 2030 investments are mostly absorbed by solar power capacity and power grid extensions. In the 2030s, majority of investments will be needed for infrastructure, including further power grid improvements, and scaling up EV charging infrastructure.

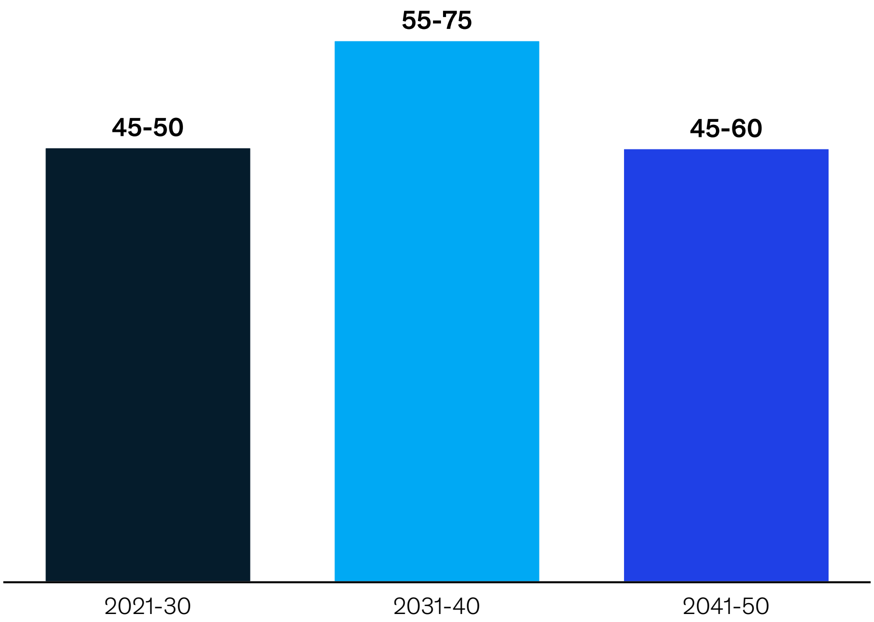
In most situations, economic actors are expected to recoup their decarbonization investments through operational savings, such as in the case of electric vehicles or heat pumps and increased insulation. As a result, decarbonization will increase the competitiveness of about 30 percent of the economy and directly contribute to a GDP increase of between 2 and 2.5 percent annually.

Investing in Hungary's decarbonization is also a unique opportunity for strengthening the country's competitiveness. Hungary can first strengthen its export-oriented industries by encouraging investments in the future value chains, such as by attracting more foreign direct investment in electric vehicle and charging infrastructure production, or by making export-oriented industries less carbon-intensive through electrification. Hungary could also strengthen its export potential in new industries or sectors under transformation.

Hungary's decarbonization process could create 80 to 100 thousand jobs

About EUR 150-200 billion of CAPEX need is incremental, compared to no climate action

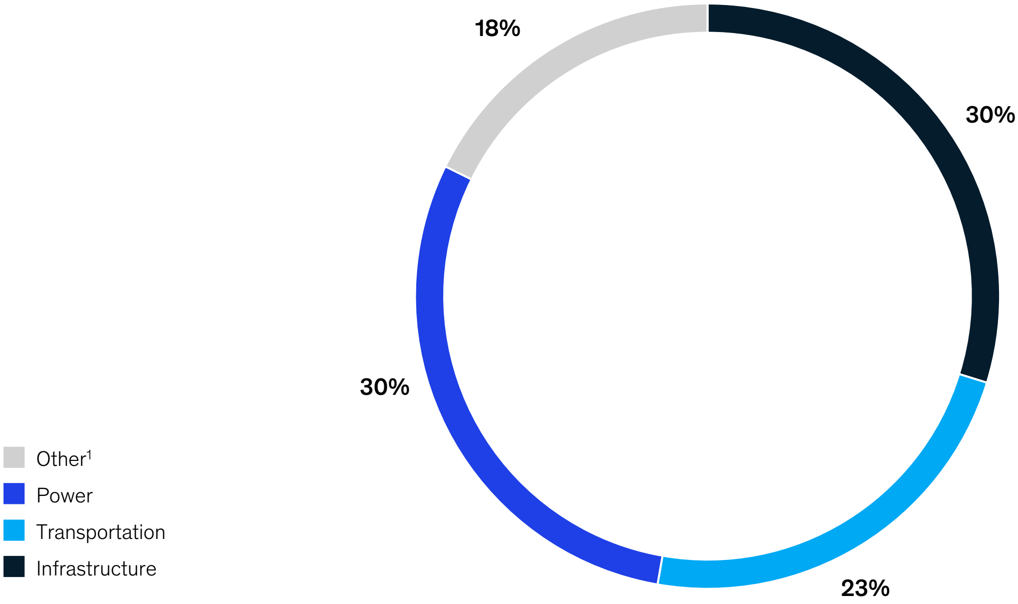
Additional CAPEX in Hungary, Net Zero Scenario, EUR bn



Total CAPEX required per sector 2021-50

%

100% = EUR 145-195 bn



NOTE: Numbers may not sum due to rounding.

1. Other including: Buildings, Industry and Agriculture

Source: McKinsey analysis

Chapter 6

Higher energy security

Importance of security of energy supply

In this chapter, we examine the impact that the transition to net zero could have on Hungary's energy security. Energy security is determined both by the volume and stability of a country's domestic energy sources, as well as its energy dependency (that is, the volume and stability of energy that it imports from external sources). Hungary and several other EU countries have been importers of substantial amount of energy from Russia, and the Russian-Ukrainian war has exposed a range of potential disruptions.

Hungary ranks among the most import dependent countries in the EU,[87] with about 70 percent[88] of primary energy sources imported, including 8 percent from other EU countries and 65 percent from elsewhere, mainly Russia.[89, 90]

Gas comprises the largest share of energy imports with 83 percent of total gas demand imported, and most of it comes from Russia.[91] To mitigate this level of exposure, Hungary has substantial gas storage capacity: as of 2022, capacity totaled 6.53 billion cubic meters,[92] or 63 percent[93] of annual demand. In addition, recently upgraded interconnectors allow for gas import from the Northwestern Route via Austria and Slovakia. These could serve as an alternative route to imports via Ukraine if the European supply sources transform in the future (e.g., potential growth of LNG's role).

Hungary imports 79 percent of the oil it uses for energy, significant share of which comes from Russia as well.[94] The pipeline infrastructure, is mainly based on eastern import. However, Hungary's western & southern pipelines (Austria, Croatia) would enable increased diversification. Furthermore, Hungary has substantial oil storage (the strategic reserve covers 90 days)[95] and the capacity of its Duna refinery provides further refinement flexibility.

Nuclear energy supply is almost exclusively generated by the Paks Nuclear Power Plant using fuel rods imported from Russia. Given the current cost of storage (nuclear fuel rods are cheaper to store than oil or gas), Hungary has enough nuclear fuel rods to cover two years[96] of the Paks plant's operation. Furthermore, fuel rods could be sourced from other sources within the two-year period above. Therefore, in theory, Hungary could diversify its fuel rod sourcing without supply disruption.

Hungary relies on domestic sources for other energy supplies (e.g., sun & wind power, other energy sources such as biomass and waste, which pose limited risk to security.)[97]

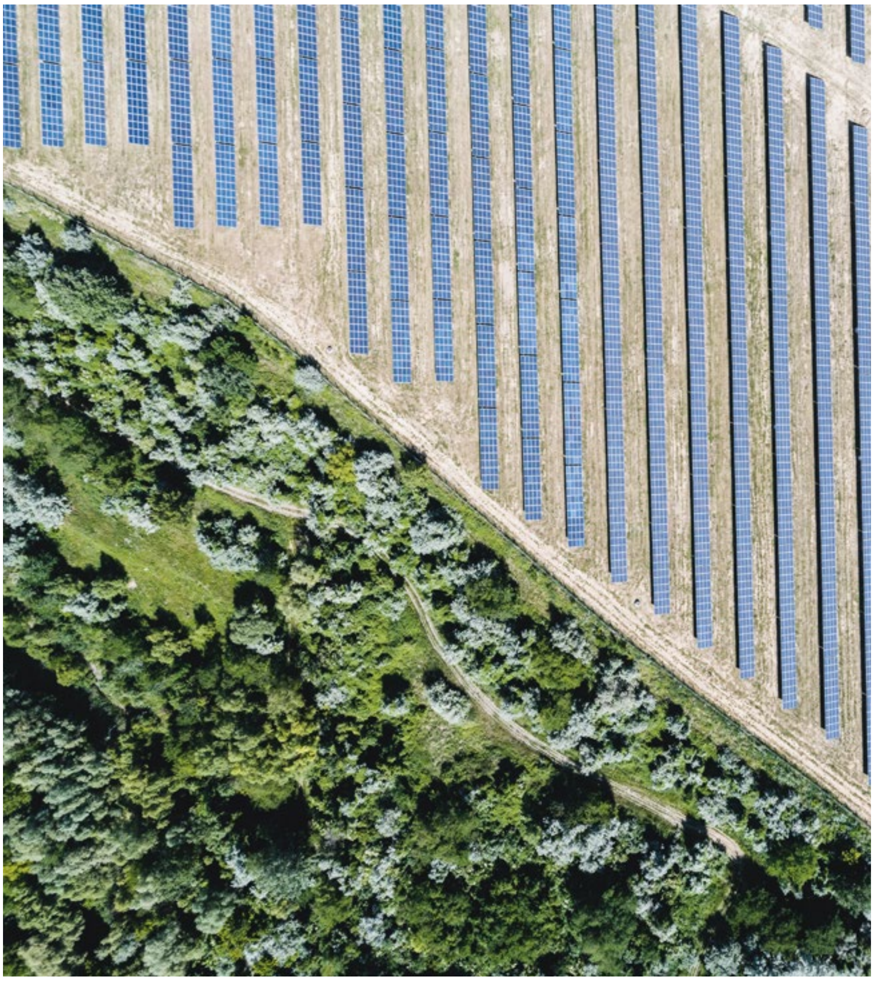
As of 2020, 27 percent of Hungary's energy is generated from primary energy supply that is produced within the country, 8 percent in other EU countries and 65 percent from other countries (esp. Russia)

Impact of net zero transition

The analysis indicates that the transition to net zero could significantly improve Hungary's energy security by decreasing demand for oil and gas and increasing the supply of renewable resources. Specifically, the share of primary energy sources produced domestically will increase from 27 percent to 34 percent by 2030, reducing the need for imported energy. Allowing for diversified imports, non-EU imports would decline from 65 percent to 46 percent.

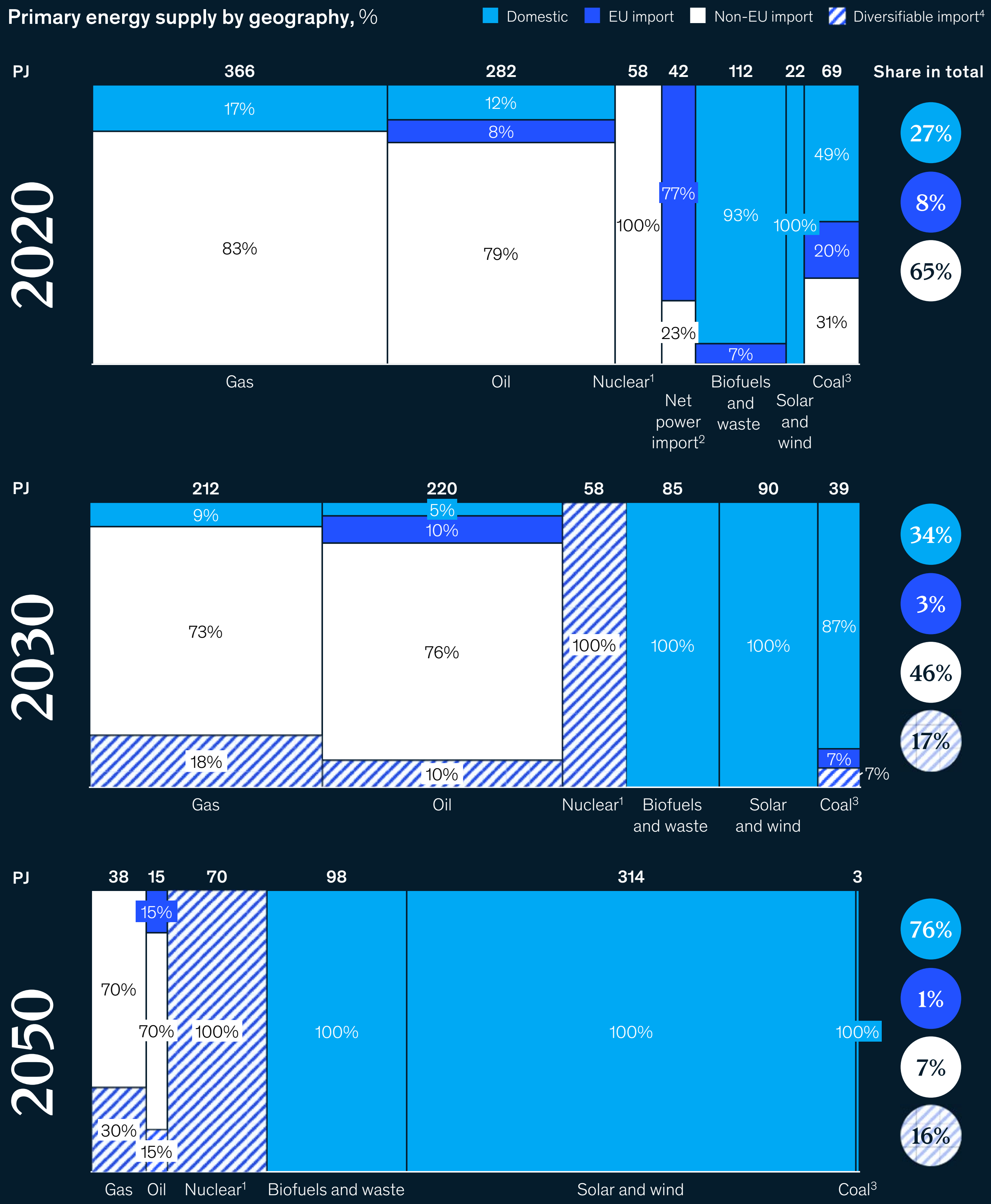
Our analysis suggests that demand for oil and gas will decline by 22 percent and 42 percent by 2030 and 90 percent and 95 percent by 2050, respectively, thereby reducing reliance on imports from Russia. At the same time, Hungary should evaluate its options to increase access towards alternative markets (e.g., LNG import from seaports).

Uptake of local renewable energy sources will enhance Hungary's energy security both by increasing the domestic supply and by enabling the production of hydrogen, which can be stored, exported, and flexibly used (e.g., hydrogen-fired peak power plants). However, it should be noted that even if Hungary becomes a net energy exporter, it will need to increase cross-border power flows with other EU countries to balance the variability of renewable resources. This, in turn, will require major investments in power interconnectors.



Hungary's primary energy dependence will be significantly improved by the Net Zero transition

Primary energy supply by geography, %



NOTE: Numbers may not sum due to rounding.

1. Corresponds to generated electricity, fuel rods are imported
2. Difference between energy demand and domestic supply
3. Hard Coal, Brown Coal, Steam coal, Anthracite, other bituminous coal, Coke oven coke, Coal tar, BKB
4. Could be imported from various sources, both EU and non-EU countries

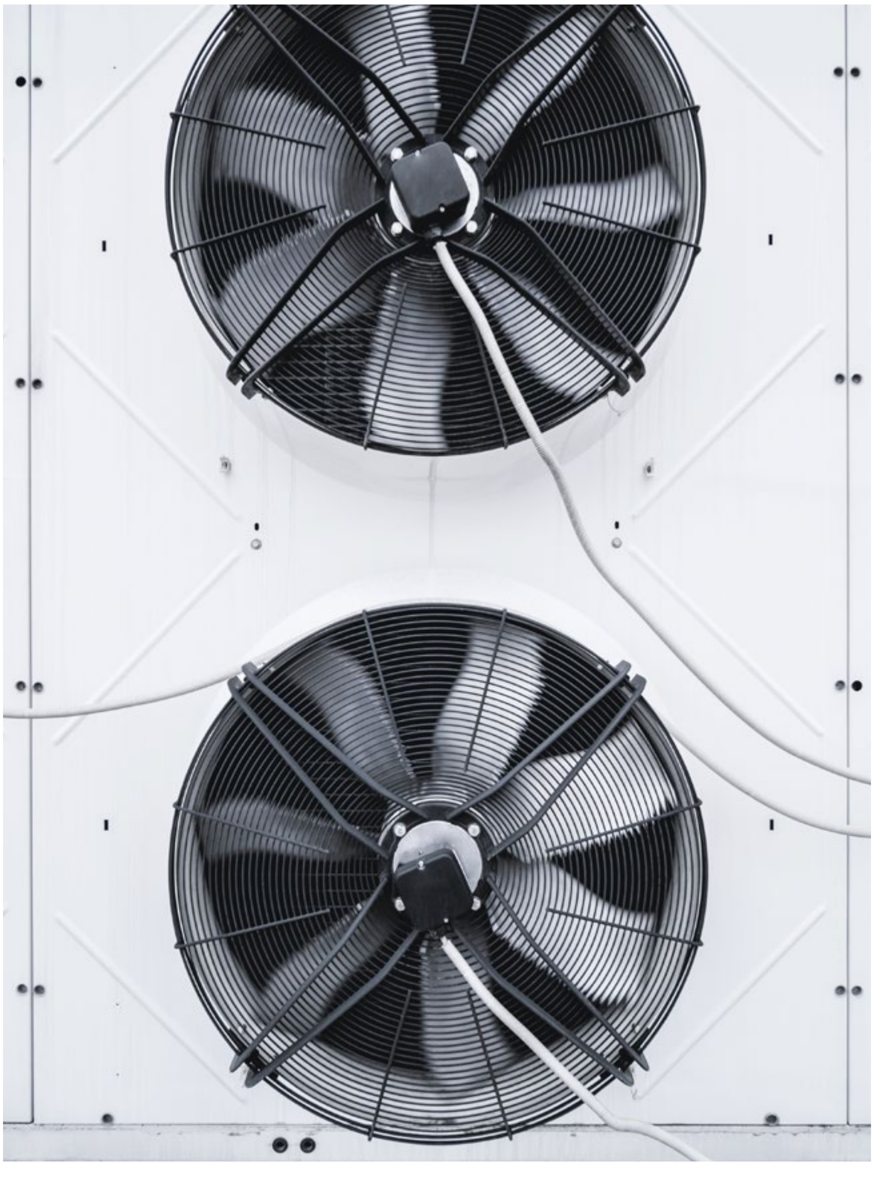
Source: IEA Energy Information, MAVIR Data of the Hungarian Electricity System; McKinsey team analysis

Tactical steps beyond net zero

While Hungary's transition to net zero will enhance its energy security, our analysis suggests it will remain highly exposed to potential disruptions in supply from non-EU countries until the early 2030s. Beyond the substantial oil and gas storage capacity that could cushion short-term disruption, there are some additional measures that could further bolster Hungary's energy security during the transition.

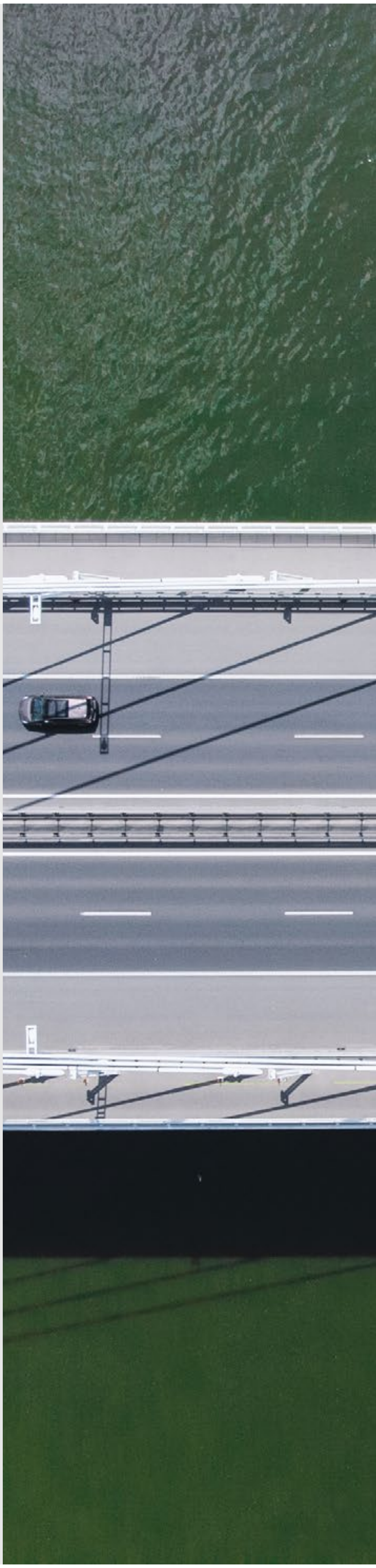
For example, to reduce dependence on natural gas imports, Hungary could accelerate the uptake of heat pumps and improvements to buildings insulation to reduce reliance on gas-based heating; it could increase the use of green hydrogen in fertilizer production; and it could adapt gas-fired power plants to enable inclusion of hydrogen in the mix, thereby reducing the need for natural gas.

Hungary could also consider diversifying its energy suppliers, such as by exploring alternative gas supply routes from Northern and Western sources and by increasing co-investments in LNG terminals and power and gas interconnectors to enable further import sources.



Chapter 7

Charting a way forward



Climate change presents a daunting challenge for Hungary and the rest of the world – but the findings presented in this report give reason to be optimistic about a carbon-neutral future. Using existing technologies and proven methodologies, Hungary has a viable and cost-optimal route to achieving carbon neutrality by 2050. Moreover, the transition to net zero affords Hungary unique opportunities to develop its economy.

But time is short. Hungary's ability to harness new opportunities and achieve net zero depends on the conscious and collective efforts of businesses, banks, and consumers, as well as an enabling policy, regulatory, and financial ecosystem.

Recognizing that Hungary's ability to achieve net zero by 2050 depends in part on technologies not yet available for mass adoption, there are immediate actions that stakeholders can take now to lower carbon emissions and accelerate sustainable growth.

Renewable energy sources such as wind and solar power are ripe for harvesting, for example. The faster Hungary can boost its renewables capacity, the quicker it will be able to produce green hydrogen for use in industry and heavy-duty transport, as well as for export. Similarly, accelerating uptake of battery-powered electric vehicles will decarbonize the transport sector while also presenting new business opportunities. Increasing adoption of easily accessed, energy-efficient insulation and heat pumps in the buildings sector will reduce reliance on natural gas imports and thereby bolster energy security. Scaling up the use of methane capture technologies beyond maintaining the carbon absorption capability of the country's forests will enable Hungary to offset the emissions from waste and agriculture that cannot be fully eliminated.

To succeed, stakeholders across economic sectors need support from the financial, regulatory, and consumer spheres. EU incentives to facilitate decarbonization across economic sectors can be a first step. National and municipal governments can also formulate policy frameworks and financial supports like grants and subsidies to accelerate emissions reductions. Hungarian banks and financial institutions can advance financial schemes to support carbon-neutral economic activity and research and development (i.e., 'green capital'). Finally, consumers can proactively divert resources towards more sustainable products and services. While there are encouraging signs of movement towards a carbon-neutral economy, the urgency of climate

The transition to climate neutrality may open up new opportunities for Hungary

Appendix

List of Acronyms

AVAC:	Automated Vacuum Collection System
BF:	Blast Furnace
BEV:	Battery-Powered Electric Vehicle
BECCS:	Bioenergy with Carbon Capture and Storage
BOF:	Blast Oxygen Furnace
CAGR:	Compound Annual Growth Rate
CAPEX:	Capital Expenditures
CCS:	Carbon Capture and Storage
CCUS:	Carbon Capture, Utilization, and Storage
CO_2:	Carbon Dioxide
CO_2e:	Carbon Dioxide Equivalent
DACS:	Direct Air Capture and Storage
DC:	Direct Current
DRI:	Direct Reduced Iron
EAF:	Electric Arc Furnace
EU:	European Union
EC:	European Commission
EV:	Electric Vehicle
EVCI:	Electric Vehicle Charging Infrastructure
FCEV:	Fuel Cell Electric Vehicle
GDP:	Gross Domestic Product
GHG:	Greenhouse Gases
GW:	Gigawatt
kW:	Kilowatt
KMS:	Kilometers
ICE:	Internal Combustion Engine
IPCC:	United Nations Intergovernmental Panel on Climate Change
LULUCF:	Land Use, Land-Use Change, and Forestry
MT:	Megaton
MT CO_2e:	Megaton Carbon Dioxide Equivalent
MW:	Megawatt
PV:	Photovoltaic
RE:	Renewable Energy
UN:	United Nations

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Endnotes

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