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RENEWABLES 2023
GLOBAL STATUS REPORT

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FOREWORD

A lot has changed in a decade.

The past ten years have brought significant shifts in the renewable energy landscape. Renewables, once an emerging trend, have become a global necessity. Decision makers are finally acknowledging that a world fully energised by renewables is not only desirable but essential to bringing about prosperous economies, sustainable societies and equitable human development.

This report presents the first modules of the eight-piece Renewables 2023 Global Status Report (GSR) Collection. The Energy Demand modules on Buildings, Industry, Transport and Agriculture are a testament to the crucial role that energy-consuming sectors play in driving the transition to renewable energy. They underscore the importance of looking beyond the supply side and installed capacities, and recognising that accelerating the demand for renewables across these four sectors is critical. Without substantive progress on the demand side, it will be impossible to achieve the structural transformations needed to shift to a renewables-based energy system, economy and society.

With this report, REN21 continues to play a pivotal role in shaping the transition to sustainable energy sources and in bridging the gap between (renewable) energy supply and demand. The findings presented in the GSR Energy Demand modules represent an important step forward in understanding the full potential of renewables in meeting the world's energy needs, as well as the persisting barriers.

Renewables are the only energy sources compatible with the vision to "leave no one behind". Demand sectors are steadily discovering that clean, affordable, secure and accessible energy is key to leveraging for impact. For the first time, the world is using renewable energy solutions to overcome multiple global challenges simultaneously: economic instability, unprecedented energy crises, threats to peace and democracy, and the devastating socio-economic consequences of a global pandemic. We need to harness the political momentum to accelerate this transition.

We must build on each other to ensure that renewables are never left out from sustainable development conversations. We must make 2023 the year of renewables.

REN21, in its role as knowledge broker for the renewable energy sector, is ambitiously spearheading this global wave of change. Our goal is to amplify the voices of the multi-stakeholder community that we proudly represent. The GSR Energy Demand modules represent a collective effort of hundreds of collaborators who have worked meticulously to paint an accurate picture of renewables today.

I extend heartfelt thanks to the REN21 team, authors, special advisors and contributors who have brought their knowledge, time and dedication to producing this report. Your insights, passion and commitment have been instrumental in making the GSR Energy Demand modules a reality. I am confident that this report will serve as a valuable resource for policy makers, industry leaders and other stakeholders to inform decision making and drive the transition to a sustainable future for all a future powered by renewable energy.

Sincerely,

Rana Adib
Executive Director, REN21

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Reference Tables can be accessed through the GSR 2023 Energy Demand Data Pack at
→ **http://www.ren21.net/gsr2023-data-pack.**

REPORT CITATION

REN21. 2023.
Renewables 2023 Global Status Report collection, Renewables in Energy Demand
(Paris: REN21 Secretariat).
ISBN 978-3-948393-07-6

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Comments and questions are welcome and can be sent to **gsr@ren21.net**.

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RENEWABLES NOW

RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY

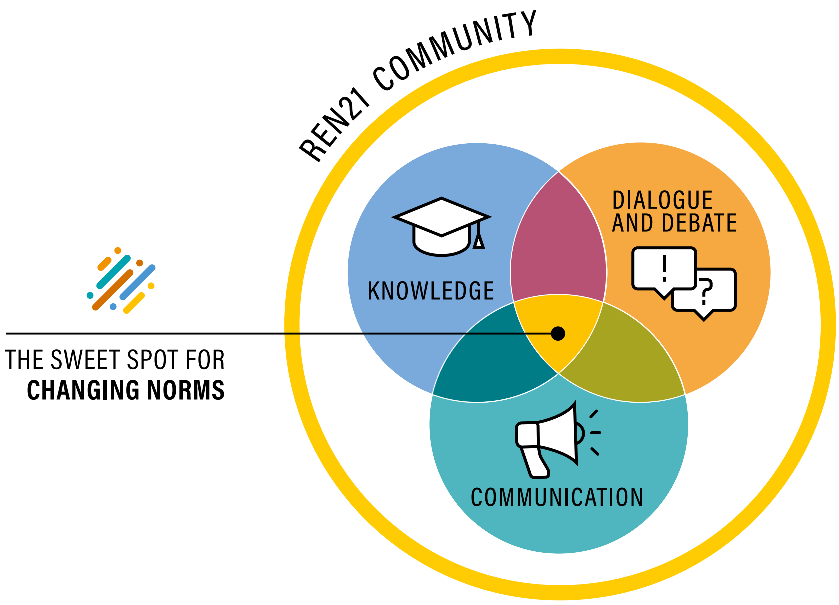
REN21 is the only global community of actors from science, governments, NGOs and industry **working collectively** to drive the rapid uptake of renewables – now!

REN21 works to build knowledge, shape dialogue and debate, and communicate these results to **inform decision makers** to strategically drive the deep transformations needed to make renewables the norm. We do this in close co-operation with the community, providing a platform for these stakeholders to engage and collaborate. REN21 also connects with non-energy players to grow the energy discourse, given the economic and social significance of energy.

The most successful organisms, such as an octopus, have a **decentralised intelligence** and "sensing" function. This increases responsiveness to a changing environment. REN21 incarnates this approach.

Our more than **4,000 community members** guide our co-operative work. They reflect the vast array of backgrounds and perspectives in society. As REN21's eyes and ears, they collect information, share intelligence and make the renewable voice heard.

REN21 takes all this information to better understand the current thinking around renewables and change norms. **Our publications** are probably the world's most comprehensive crowd-sourced reports on renewables. Each is a truly collaborative process of co-authoring, data collection and peer reviewing.



CROWD-SOURCED DATA AND KNOWLEDGE

REN21's data and knowledge collection method is built on a global multi-stakeholder community of experts. It is validated in a collaborative and transparent open peer-review process. It is made openly available to develop a shared language that shapes the sectoral, regional and global debate on the energy transition.

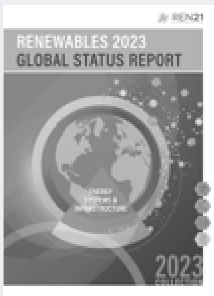
For more information, see the Methodological Notes section on data collection and validation.

RENEWABLES GLOBAL STATUS REPORT
2023 COLLECTION

Since 2005, REN21's Renewables Global Status Report (GSR) has spotlighted ongoing developments and emerging trends that shape the future of renewables. It is a collaborative effort involving hundreds of experts.

This year's edition (18th) has evolved in design and structure to reflect the fundamental changes in the global energy landscape. The new structure is in the form of a collection of five publications. In addition to presenting the trends in renewable energy supply, it also dives into the energy demand sectors, with dedicated modules on buildings, industry, transport and agriculture. It includes a publication on energy systems and infrastructure with renewables, as well as a publication on renewables for economic and social value creation, acknowledging the key role that energy plays across economies and societies. Collectively these five publications offer readers a systemic global overview of the current uptake of renewables.

This new structure makes the GSR a key tool in expanding the renewable energy discussion into key sectors and ecosystems, developing a shared language and driving a stronger integration of supply, demand, infrastructure, market and investment.



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UN environment programme

Supported by:

Federal Ministry for Economic Affairs and Climate Action

Federal Ministry for Economic Cooperation and Development

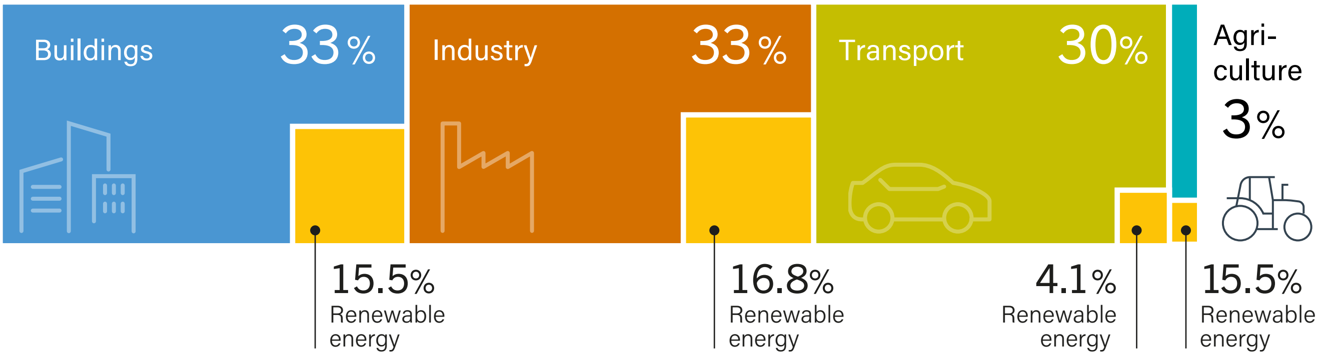
on the basis of a decision by the German Bundestag

This report was commissioned by REN21 and produced in collaboration with a global network of research partners. Financing was provided by the German Federal Ministry for Economic Cooperation and Development (BMZ), the German Federal Ministry for Economic Affaires and Climate Action (BMWK) and the UN Environment Programme. A large share of the research for this report was conducted on a voluntary basis.

FIGURE 1.

RENEWABLES IN **ENERGY DEMAND**

Total Final Energy Consumption and Total Modern Renewable Energy Consumption, by Sector, 2020



Total renewable energy demand grew **4.7%** per year on average between 2010 and 2020

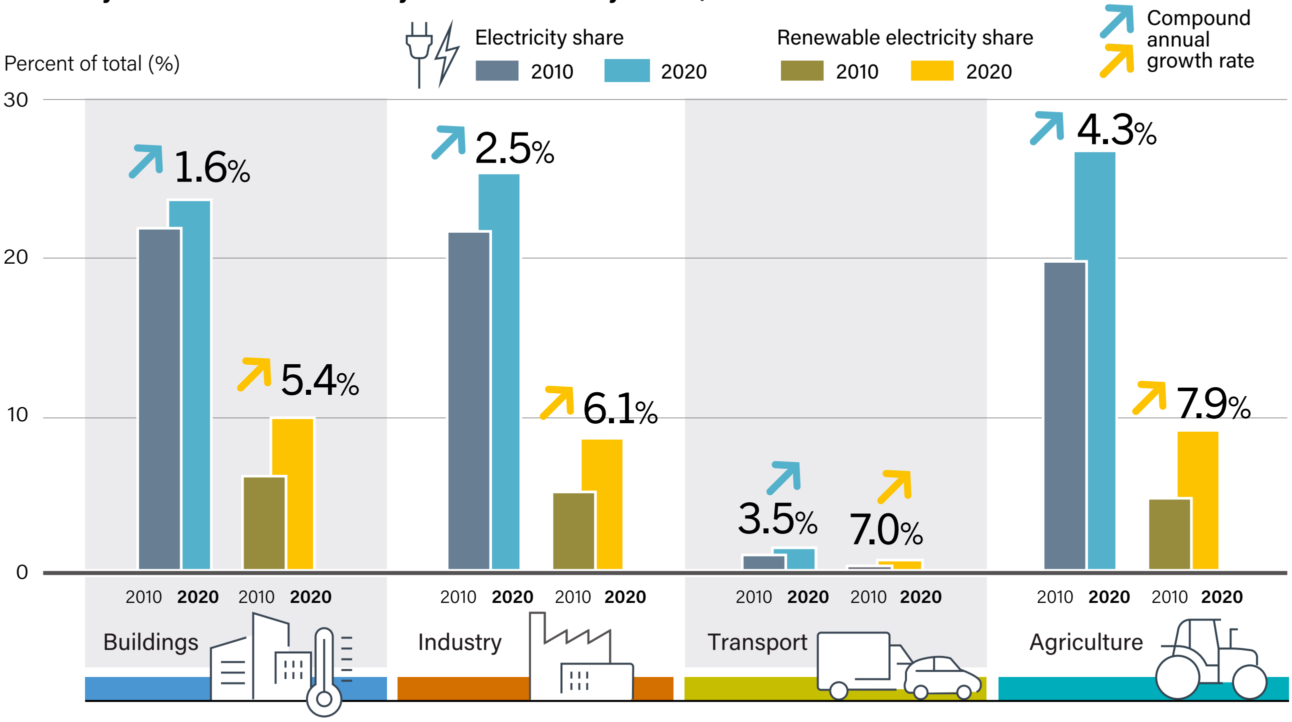
As of 2022, **94 countries** had either a renewable energy policy or target in at least one demand sector

As of 2022, **3 countries** had renewable energy targets or policies in **all** four demand sectors

Agriculture and transport have the fastest yearly growth rates of renewable energy adoption with more than **7%**

The share of renewable electricity in TFEC grew 3% in the last decade to reach **7%** in 2020

Electricity and Renewable Electricity Shares of TFEC by Sector, 2010 and 2020



Source: See endnote 1 in Renewable in Energy Demand: Global Trends.

Note: TFEC = Total Final Energy Consumption

RENEWABLES IN ENERGY DEMAND: GLOBAL TRENDS

Energy Crisis and Inflation

Starting in October 2021, the world experienced the impacts of a severe global energy crisis.[2] Rapid economic rebound following the slowing of the COVID-19 pandemic led to tighter markets, and the energy crisis was further exacerbated in February 2022 after the Russian Federation's invasion of Ukraine.[3] Throughout 2022, energy prices in Europe and elsewhere skyrocketed to their highest levels since 2008.[4] The International Energy Agency estimates that higher fossil fuel prices accounted for 90% of the increase in electricity prices in 2022, and that fossil gas prices alone accounted for more than half this rise.[5]

The **rise in energy prices had strong inflationary impacts** on all energy-consuming sectors – in some cases pushing families into poverty, forcing factories to cut production and slowing economic growth across sectors.[6] Because energy fuels all economic activity, it can affect the prices of goods from food to clothing to smartphones.[7] High inflation became a global phenomenon during 2022, even if the effects were less visible in some parts of the world, such as Asia.[8]

Energy prices reached their highest levels since 2008, impacting all energy-consuming sectors.

In many countries, governments sought alternative fossil fuel sources to restore disruptions to the energy supply or opted to heavily subsidise fossil fuels to shield consumers from price hikes; despite this, the uptake of renewables increased in all demand sectors.[9] Overall, 2022 was a year marked by energy crisis resulting in high inflation globally, but it also was a year of accelerated deployment of renewables as different sectors found renewable energy sources to be reliable, stable and affordable.

In direct response to rising inflation and energy costs, **two major policy packages** were introduced during the year: the European Commission's REPowerEU plan and the Inflation Reduction Act (IRA) in the United States.[10] Both packages aim to stimulate

economic growth via subsidy packages that target, among others, renewable energy production and use while boosting local industry.

The **REPowerEU** plan was designed to curtail the effects of energy market disruption caused by the war in Ukraine.[11] It tackles energy savings in all end-use sectors as well as diversification of the energy supply, while aiming to increase the production of renewable energy to 45% from the current 40%; the plan also includes an obligation to install rooftop solar on every **public building** by 2025.[12] The plan commits a total investment of USD 222 billion during 2023-2027 to phase out fossil fuel imports, including phasing out fossil gas in **industrial and domestic** uses and, over the long term, expanding renewable hydrogen in the steel industry.[13]

The **IRA** allocates USD 370 billion in new spending and tax credits and addresses all main energy demand sectors.[14] In **buildings and transport**, it provides tax credits for electric vehicles, energy-efficient appliances, rooftop solar, geothermal heating and home batteries, and for the **industry and agriculture** sectors it provides tax incentives for private investment in renewables.[15]

Also in 2022, **China** published its 14th Five-Year Plan, and the country is expected to contribute nearly half of all new renewable power capacity additions globally during 2022-2027.[16] In early 2023, **India** announced one of the world's most comprehensive plans for renewable hydrogen, including a USD 2.3 billion subsidy programme aimed at benefiting from cheap renewable energy prices to produce renewable hydrogen for industry and transport.[17]

Renewable energy

is the forefront of policy responses to the twin crises of rising energy costs and inflation.

Policy Trends

On the climate policy side, **climate commitments** expanded in 2022 and have targeted more ambitious efforts to decarbonise energy use in the end-use sectors, with progress varying across sectors and regions. During the year, 10 countries revised upwards their Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.[18] However, of the **193 countries** that have signed the agreement and submitted NDCs, only 25 have set targets for net-zero emissions.[19]

Climate policies need to translate into concrete enabling policies and mandates in all sectors. On the demand side, around **80 new renewable energy policies** (mostly in the form of fiscal/financial incentives) were announced in 2022, while regulatory policy announcements stagnated, bringing the total to 454 policies across sectors.[20] These announcements were made in 49 countries, with more than half of the countries in Europe, 8 in Latin America and the Caribbean, 7 in Asia, 4 in Africa, 2 in Oceania and only 1 each in North America and in the Middle East and North Africa.[21] This amounts to a total of **94 countries** that had either policies or targets in at least one end-use sector by year's end (→ *see Figure 1*); however, only **3 countries** (Spain, Portugal and Türkiye) had targets or policies in all four end-use sectors.[22]

In the **buildings**[i] sector (commercial, residential and public facilities), 52 countries had policies supporting the uptake of renewables as of the end of 2022.[23] Such policies include incentives for the installation of renewable technologies (such as rooftop solar, solar water heaters, biomass boilers and geothermal heat pumps) as well as mandates and targets banning the use of fossil fuels for heating in new and existing buildings. Policies were mostly in the form of fiscal/financial policies (45 countries), followed by regulatory policies (21 countries), although 14 countries had both regulatory and fiscal/financial policies for renewables in buildings.[24] (→ *See Figure 2.*)

In the **industry** sector, no new policies for renewables have been announced since 2019. By the end of 2022, 19 countries had policies that incentivise or mandate the use of renewables in industry.[25] Nine countries had renewable energy mandates enforcing the installation of renewables in specific industry sub-sectors, 12 countries had fiscal/financial incentives, and 2 countries (Spain and Türkiye) had both.[26]

A major policy announcement in 2022 was the European Union's (EU) **Carbon Border Adjustment Agreement (CBAM)**, which includes a carbon tax on imports to EU member countries.[27] The aim is to impose carbon taxes starting in 2026 on imports related to electricity, hydrogen, steel, cement, fertilisers and aluminium.[28] The CBAM will likely have adverse effects on Europe's trade partners and is expected to speed decarbonisation of the **industrial sector** globally.[29]

In **transport**, despite having the lowest share of renewable energy across demand sectors, 61 countries had renewable energy mandates or enabling policies as of the end of 2022.[30] Most of these were biofuel blending mandates (56 countries) and either electric vehicle targets or 100% bans on internal combustion engine vehicles (23 countries).[31] Only five countries – Chile, Denmark, New Zealand, Sweden and the United Kingdom – had both 100% renewable energy targets and 100% bans on internal combustion engine vehicles.[32] Meanwhile, 10 countries were pushed to reduce or suspend their **biofuel blending mandates** in 2022, mostly in Europe but also in Latin America and the Caribbean.[33]

In the **agriculture** sector, 14 countries had targets and policies for renewables as of the end of 2022, with 7 of these countries announcing them during the year.[34] All of the policies comprised either investments, subsidies, grants or tax deductions, mostly for solar-powered irrigation and agrivoltaics. No new or existing regulatory policies for renewables in agriculture were observed.[35]

i The number of countries with policies in buildings is not comparable to previous editions of the GSR because of a change in methodology. In previous editions, buildings included industries. In the GSR 2023, these are treated separately.

Market Developments and Trends

The risk of supply disruptions, as well as high fossil fuel price volatility, prompted more energy consumers worldwide to adopt on-site renewable energy systems and to switch to electrified technologies across the end-use sectors.[36]

In the **buildings** sector, 2022 was a record year for **heat pumps,** with installations increasing a record 10% over 2021.[37] This was most notable in Europe, with 38% growth in 2022, as households increasingly sought out efficient and reliable alternatives to fossil fuel heating.[38] **Rooftop solar** also became more affordable and attractive to end-users following the increases in fossil fuel prices.[39] (→ *See Snapshot: Europe, in the Buildings module.*)

Across Europe, **energy-intensive industries** were hit hardest by the energy crisis, with some industries cutting production and others considering relocation to reduce energy costs and boost security.[40] These same concerns drove a 21% increase in the number of **corporate power purchase agreements** (PPAs) in 2022, to surpass the installed capacity of utility PPAs by a record six times.[41] Renewable-powered industrial parks also became more attractive, as they allow hedging from energy price volatility and the risks of supply disruption.[42] (→ *See Snapshot: South Africa, in the Industry module.*)

Renewable energy shares in all demand sectors saw

record growth

in 2022 as energy users looked for affordable and secure energy sources.

In the **transport** sector, energy costs increased for vehicle owners, freight operators and public transport services.[43] In Europe, the energy bills for most public transport operators doubled in 2022.[44] However, a few operators that had signed PPAs in previous years benefited from the stabilising effect that these agreements had on energy costs.[45]

As the electrification of road transport continued, 2022 was another record year for spending on **electric vehicles** and associated charging infrastructure, with investment in these areas rising 54%.[46] Most of this growth was in Asia, with India doubling its electric vehicle spending during the year.[47] Asia is home to 93 of the world's 100 most polluted cities and 6 of the top 10 countries most affected by climate risks, making electric vehicles an appealing option.[48] Several Asian countries have adopted bans on vehicles with internal combustion engines, including the Republic of Korea (target year 2025), India (2030), China and Japan (2035) and the Philippines (a new ban in 2022 with a target of 2040).[49]

In **agriculture**, the trend has been towards self-reliance and additional income generation, with agrivoltaics, geothermal and bioenergy taking growing shares of the sector's total final energy consumption.[50] In Africa, Asia, and the Caribbean, decentralised renewables have become a go-to solution in agriculture to boost energy access, reduce fuel costs and save energy.[51] Advancements range from technological developments in fishing vessels, gear and operations to the use of renewables in food production and for affordable cooling and refrigeration.[52] (→ *See Snapshot: India, in the Agriculture module.*) Solar water pumps have helped farmers boost productivity, with the Asia-Pacific region dominating this market.[53]

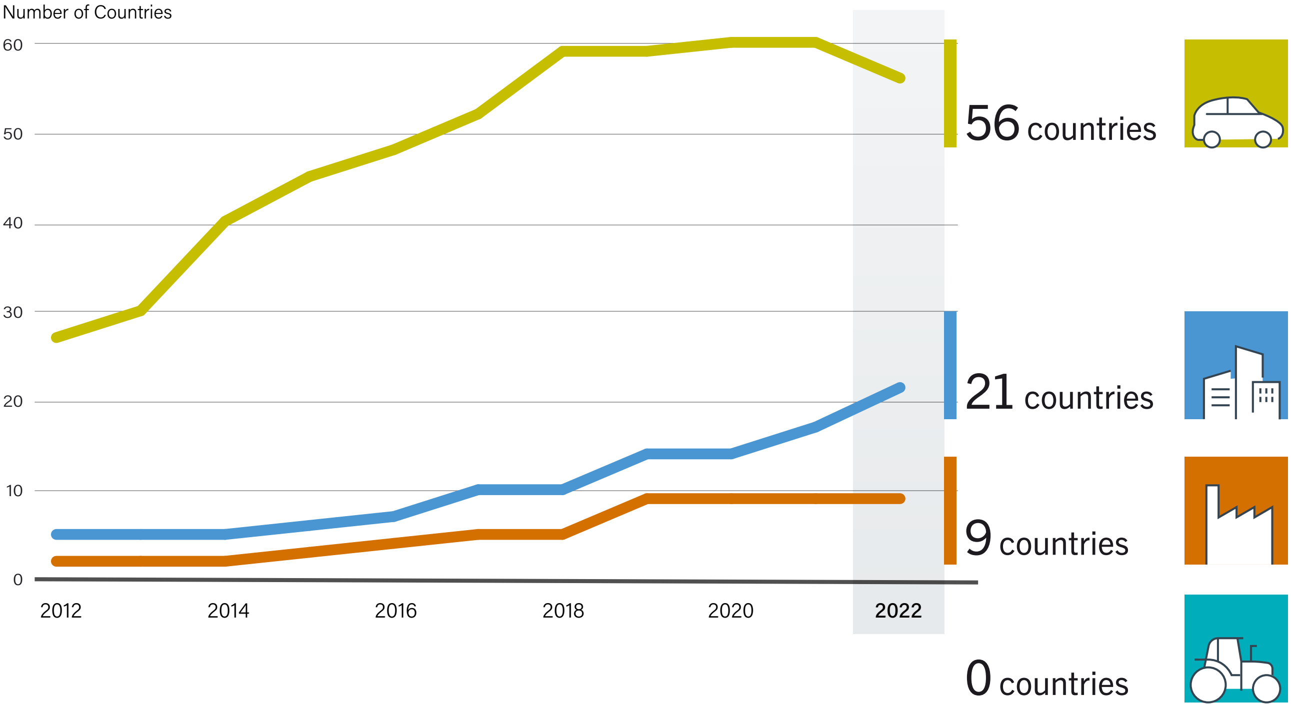
Electrification and Other Trends

Renewable energy shares increased in all four demand sectors in 2020, to reach 16.8% of energy consumption in industry, 15.5% each in buildings and agriculture, and 4.1% in transport.[54] However, overall energy use in these sectors has risen as well, with this growth still largely met by fossil fuels.[55] (→ *See Figure 1.*) While total final energy consumption grew 16% overall during 2010-2020, it grew 18% in the transport sector, followed by agriculture (16%), industry (9%) and buildings (8%).[56]

At the same time, the rising share of electricity in the total final energy consumption of end-use sectors has enabled the higher integration of renewables.[57] (→ *See Figure 1.*) The **electrification** of end-uses grew from a 15.3% share in 2010 to 17.7% in 2020.[58] Agriculture is the most electrified sector, at 26.7%, followed by industry (25.3%) and buildings (23.6%), with transport trailing well behind (only 1.4%). However, total electricity demand is still outpacing renewable electricity supply. In the last decade (2010-2020), 60% of the increase in electricity demand was met by modern renewables.[59]

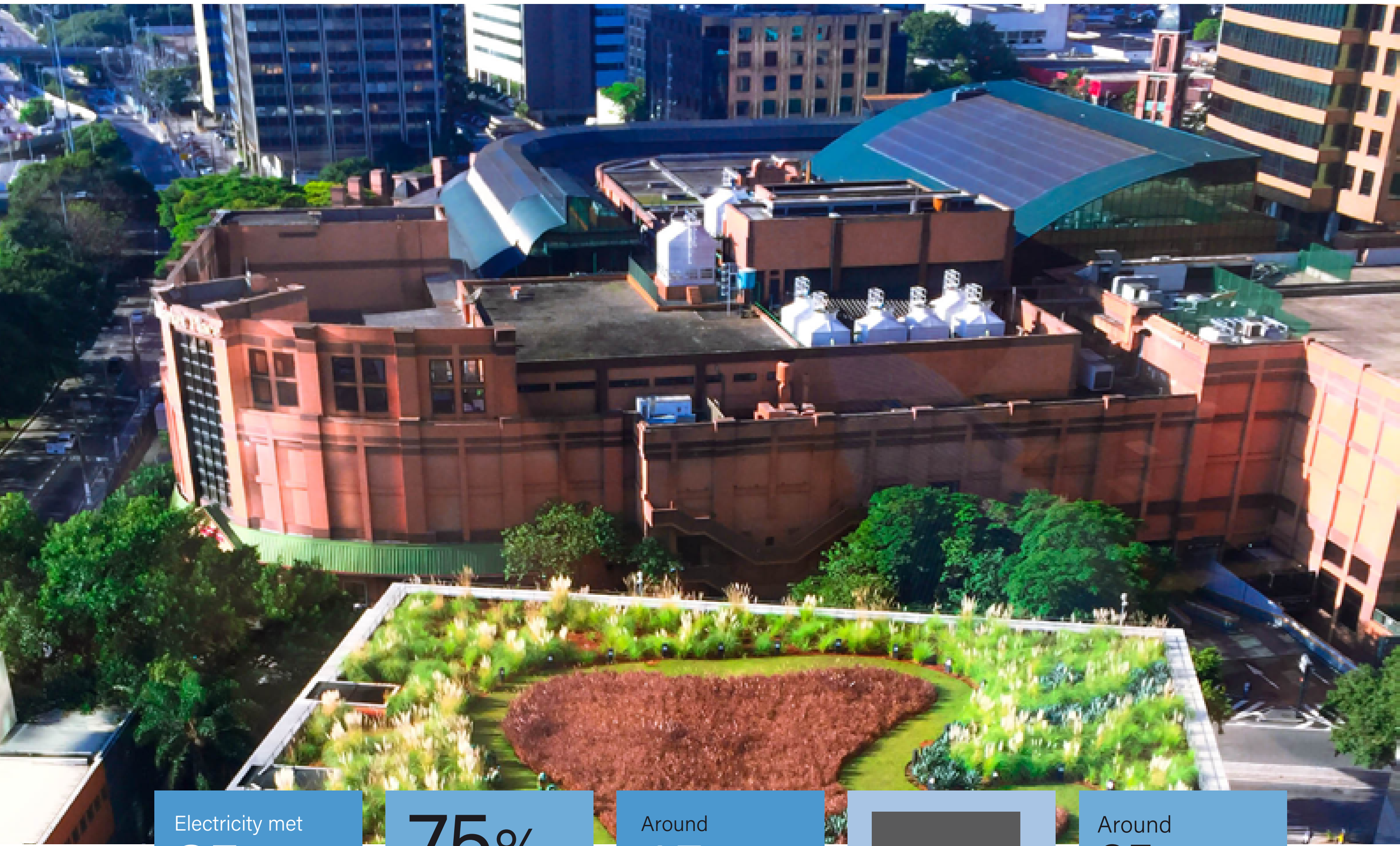
The rising intensity and frequency of **heatwaves** presents additional challenges to rapid electrification.[60] Both India and China suffered significant heatwaves in the summer of 2022 that led to spikes in electricity demand, resulting in weeks-long blackouts and forcing some industries to cut production.[61] **Cooling** is set to become a top driver of electricity demand in the coming years, especially in light of more-frequent heatwaves and rising household incomes in emerging economies.[62] Three countries – Barbados, Cambodia and Nigeria – published National Cooling Action Plans in 2022, bringing to 14 the total number of countries with such plans.[63]

FIGURE 2.
Number of Countries with Renewable Energy Regulatory Policies and Mandates, by Demand Sector, 2012-2022



Note: Poland announced a plan for a Social Contract for the Mining Industry in 2022, setting out a specific timetable for discontinuing hard coal mining at each production unit by the end of 2049. This policy is not in force yet and is included in the figure. The figure does not show all policy types in use. In many cases, countries have enacted additional fiscal incentives or public finance mechanisms to support renewables. A country is considered to have a policy (and is counted a single time) when it has at least one national-level policy in place. Policies for renewables in buildings apply for power, heating and cooling, or transport (for example, installing solar panels on parking structures or vehicle charging infrastructure in new buildings). Other policies for buildings include mandates for water heating or renewable energy technology installation. Building types for which policies apply are residential, commercial and public facilities. Fossil fuel bans in buildings are excluded from this figure. Policies for renewables in transport include biofuel mandates (biodiesel, ethanol, undspecified and advanced biofuels) for road transport, aviation, rail and shipping. For more information, see Reference Tables R1-R4 in the GSR 2023 Data Pack.

Source: See endnote 23 for this module.



Electricity met
35%
of energy needs in buildings in 2021

75%
of final energy consumed in buildings is used for space heating and hot water

Around
15% of
the energy used in the world's buildings comes from modern renewables

Renewable electricity
use in buildings grew from 6% to
10%
between 2010 and 2020

Around
25 million
households worldwide have distributed (rooftop) solar PV

BUILDINGS IN FOCUS

Module Overview | Policy | Investment | Market Developments | Challenges & Opportunities

MODULE OVERVIEW

Energy use in buildings accounted for around 30% of global final energy consumption in 2021, or around 132 exajoules (EJ).[1] As such, buildings contribute greatly to greenhouse gas emissions. Burning fossil fuels directly[i] for heat in buildings – including fossil gas in boilers, and oil and coal in furnaces – generated 8% of energy-related carbon dioxide (CO_2) emissions in 2021.[2] Meanwhile, indirectly producing the electricity and heat used to provide hot water and thermal comfort, and to power appliances and other devices in buildings, contributed 19% of emissions.[3] Together, these direct and indirect emissions grew 2% between 2019 and 2021.[4] Energy use in buildings also results in local air pollution, with the residential sector releasing more than a third of all emissions of particulate matter 2.5.[5]

The use of renewable electricity in buildings is provided mainly through the power grid, but a growing number of buildings are powered using on-site systems, including rooftop solar photovoltaics (PV). Renewable heat for space and water heating and for cooking can be provided by on-site renewable energy systems such as solar thermal or by district energy networks or renewable electricity.

Around 75% of the final energy consumed in buildings, and the associated emissions, are related to space and water heating.[6] The remaining 25% is electricity used to power appliances, lighting and other electricity-based services (excluding heating and cooling).[7]

In 2021, the demand for space cooling increased 6.5% over 2020 levels, representing the largest growth in demand among end-uses.[8] Electricity use grew from 30% of the total energy use in buildings in 2011 to 35% in 2021.[9]

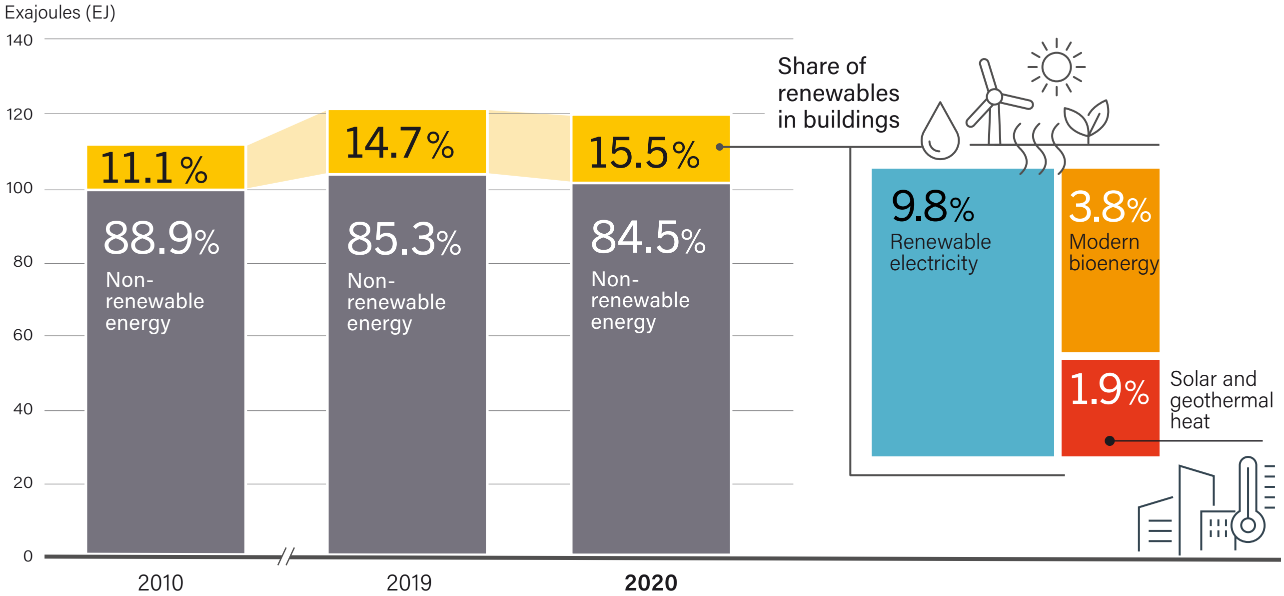
> In 2020, renewables provided around
> **15.5 %**
> of the energy used in buildings.

Modern renewables provided around 15.5% of the energy used in the world's buildings in 2020, up from 11.1% in 2010.[10] (→ *See Figure 3.*) However, the share of renewables in buildings has grown more slowly than the renewable energy share overall. For example, the share of renewables in total electricity generation worldwide increased at an annual rate of 0.8% between 2010 and 2021 (rising from 19.5% to 28.2%), yet the share of renewables used in buildings increased only 0.4% annually.[11]

Energy consumption in buildings varies greatly around the world, including among the top ten energy-consuming countries.[12] (→ *See Figure 4.*) In 2021, energy consumption in buildings rebounded above 2019 levels, following a drop in 2020 related to COVID-19 restrictions.[13] The countries with the highest renewable shares in buildings in 2021 were Brazil (where

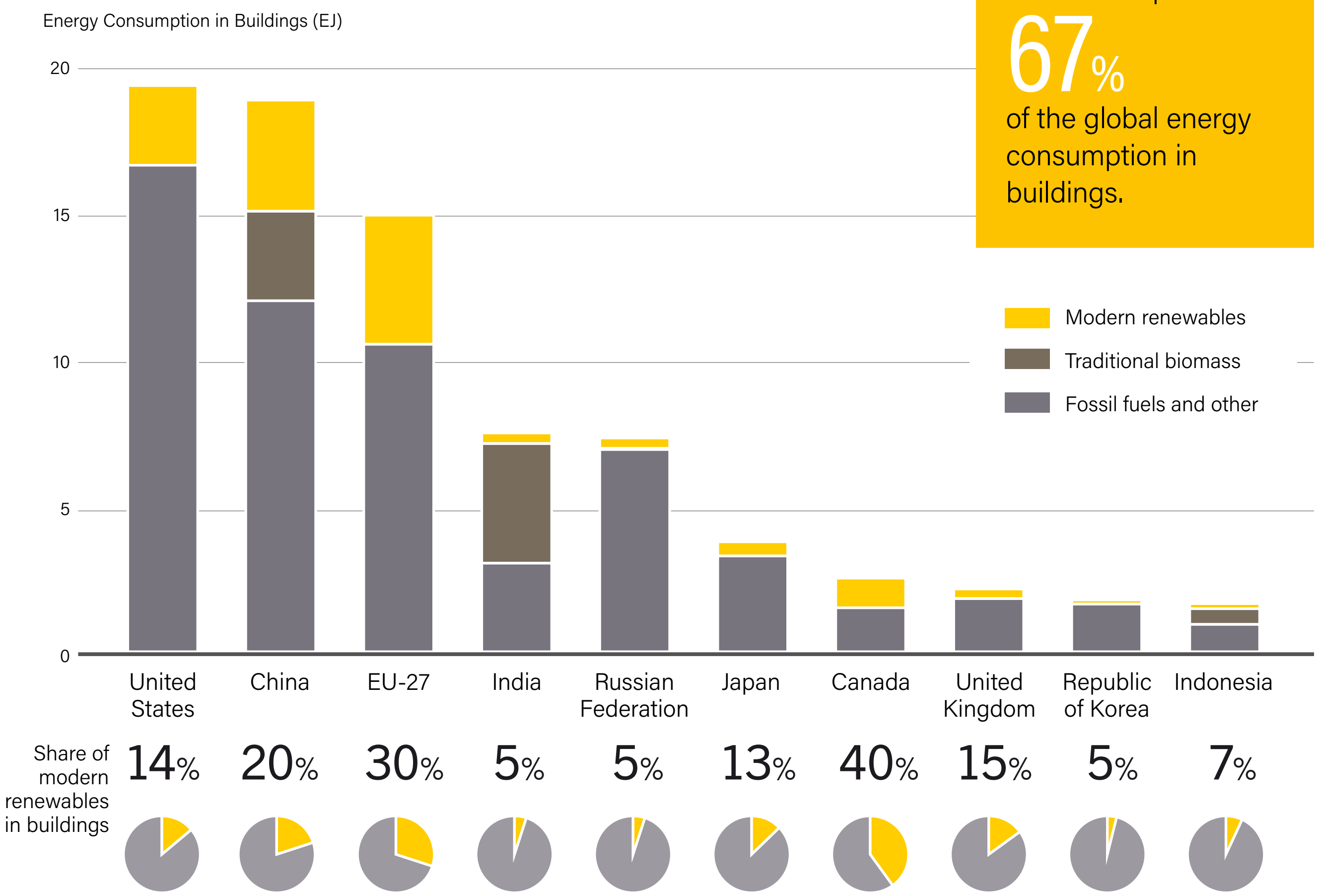
i This module focuses on the direct use of energy in building operations, excluding energy used in the building construction industry and in the power and heat sector that supplies energy to buildings.

FIGURE 3.
Renewable Share of Total Final Energy Consumption in Buildings, 2010, 2019 and 2020



Source: See endnote 10 for this module.

FIGURE 4.
Energy Consumption in Buildings by Major Country/Region, 2020



Source: IEA. See endnote 12 for this module.

bioenergy is used for heating and cooking, and hydropower supplies large shares of electricity) and Canada (which relies heavily on electricity for heating and also has a high share of hydropower).[14] France, Italy and Germany also had above-average renewable shares in buildings, due mainly to reliance on biomass for heat and, to a lesser extent, on (renewable) electricity.[15] The lowest shares of renewables in buildings (less than 5% each) in the top ten consuming countries were in India, the Russian Federation and the Republic of Korea.[16]

Not all buildings or occupants have reliable access to energy. As of 2020, around 733 million people worldwide still lacked access to electricity, mainly in Sub-Saharan Africa and Southeast Asia.[17] Meanwhile, around 2.4 billion people were without access to clean fuels or modern cooking technologies.[18] To provide heat or cook meals, many households in developing and emerging countries continue to burn wood, charcoal or processed oil in simple, inefficient devices, contributing to indoor air pollution. In the wake of the COVID-19 pandemic and the recent rise in energy prices, the number of people without access to energy has likely increased, leading residents in countries such as Brazil to resort to fuelwood instead of cleaner-burning alternatives for heating and cooking.[19]

In general, increasing the uptake of renewables for **heating and cooling** applications in buildings is more challenging than deploying renewables for electricity.[20] In 2021, fossil fuels contributed nearly two-thirds of the energy used to heat buildings, a share only slightly lower than in 2011.[21] (→ *See Figure 5.*) A key barrier to the expansion of renewables has been the rise in the direct use of fossil gas for heating, which grew 17% from 2011 to 2021, due largely to its affordability and to a supply boom in the United States; by 2021, fossil gas contributed more than 40% of the total energy used to heat buildings globally.[22]

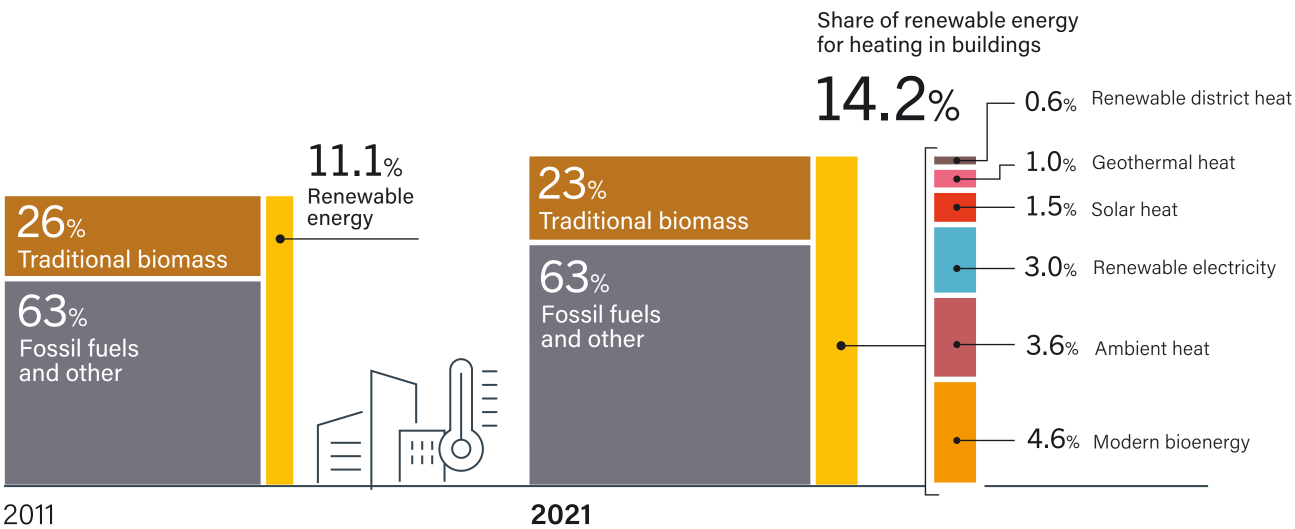
The direct use of modern bioenergy to heat buildings – for example, through solid biomass pellets or briquettes, or gaseous fuels such as biogas and biomethane – is the largest end-use of renewables in buildings. Heat from bioenergy also can be produced centrally – such as at a combined heat-and-power plant – and distributed through a district heating network. The use of bioenergy for heating remained relatively stable during 2011-2021, although it was expected to increase in 2022 because of a fossil gas shortfall.[23] Modern bioenergy accounts for slightly less than half (42%) of the total energy consumption for heating and cooling that is derived from modern renewable sources.[24]

Electricity is supplying a growing share of heat in the world's buildings, estimated at 14% of total heating needs in 2021.[25] As renewables contribute a larger share of the world's electricity overall, the contribution of renewable electric heating has risen in turn. When electricity is used to power heat pumps (for either heating or cooling), these devices harness ambient energy – typically from the outside air, but also from ground and water sources. Global use of ambient energy from heat pumps grew 26% between 2011 and 2021, providing around 4% of heating in buildings in 2021.[26]

Solar and geothermal heat supply a small but rising share of buildings' heating needs. Overall, district heating meets 7% of heating needs in buildings, with renewables contributing a growing share of district heat.[27] Total heat consumption from district systems increased 12% between 2011 and 2021, while the renewable share of heat in district systems grew 68%.[28]

Improving the **energy efficiency** of building envelopes can help renewables meet a higher share of heating loads. More rapid progress can be made if each unit of heat from renewable energy

FIGURE 5.
Energy Consumption for Heating in Buildings, by Source, 2011 and 2021



Source: See endnote 21 for this module.

does not need to directly replace the same unit of heat from fossil fuels. Despite efforts to improve efficiency, energy demand in buildings has continued to rise – up 4% in 2021 following the pandemic-related slowdown, and up 2% overall between 2019 and 2021.[29]

Investment in energy efficiency[i] grew 15% in 2021 to USD 211 billion, suggesting that consumers may be turning their attention towards reducing energy demand.[30] Governments have sought to legislate improved efficiency as well. (→ *See Investment section.*) By 2021, more than 80% of the final energy use from air conditioners occurred in countries that had adopted minimum energy performance standards, up from two-thirds in 2010.[31]

As more households and businesses turned to renewables in 2022, a **key driver** was favourable economics. High fossil fuel prices, spurred in part by the Russian invasion of Ukraine (→ *see Snapshot: Europe*), made technologies such as rooftop solar PV and heat pumps more cost effective.[32] In 2022, record demand for renewables saved the European Union (EU) billions of euros in fossil gas imports that likely would have driven household energy prices even higher.[33] The overall declines in the costs of solar and wind power – notwithstanding slight increases in 2022 due to higher commodity prices – have further driven investment in renewable power plants (now the least-cost option in many countries) and in household renewable energy solutions.[34]

Government policy also was a key driver of renewables in buildings in 2022. Government targets and regulation, as well as growing policy support to reduce energy costs, have bolstered consumer interest in renewables, particularly distributed solar PV.[35] Concerns about **climate change and local air pollution** have similarly encouraged consumers to adopt renewable technologies.

Spurred by these drivers, more countries have sought to increase the uptake of renewables in heating and cooling for buildings. In 2021, Chile and the United Kingdom released national heating strategies, and in 2022 Ireland released a national heat study targeting a net zero heating sector and laying out the options available to reach it.[36] The Netherlands also announced plans to phase out fossil gas from its heating supply.[37] In an effort to include equity considerations in policy design, some measures seek to ensure that low-income households benefit the most from revised heating policies and avoid bearing the cost burden, particularly during times of high energy prices.[38]

POLICY

Policy action to boost the uptake of renewable heating and cooling in buildings typically takes the form of either national target-setting – such as pursuing a defined share of renewable heating and cooling by a certain date – or specific support policies, such as financial incentives or regulatory policies. By the end of 2022, 80 national and sub-national jurisdictions had in place renewable energy regulatory (43 jurisdictions) or fiscal/financial (57 jurisdictions) policies for buildings. 19 jurisdictions had both.

Globally, only a few overarching **targets** exist for the use of renewables in buildings, and/or for renewables to supply a rising share of heating and cooling needs. The EU's Renewable Energy Directive sets an indicative target for Member States to increase the share of renewables in heating and cooling (of which buildings is a large share) by 1.1% annually by 2030, or 1.3% when waste heat is involved.[39] In late 2022, the European Parliament suggested raising this share to 2.5%.[40]

An increasing number of countries have technology-based targets for renewables in buildings. In addition to the EU's regional heat pump target, several individual European countries, such as Germany, Ireland, and the United Kingdom, have announced national targets for annual heat pump installations that are up to 10 times greater than the annual installations completed in 2021.[41] In April 2022, China's Building Energy Efficiency and Green Building Development Plan entered into force, targeting more than 50 gigawatts (GW) of solar PV on buildings and geothermal heat coverage of 100 million square metres.[42]

The spread of **net zero emission pledges** around the world has the potential to accelerate the uptake of renewables in buildings. However, recent pledges have not necessarily been transformed into actionable policy, nor have they resulted in a decrease in fossil fuel investment in the countries making them.[43]

Many countries have provided **financial incentives** for renewables in buildings. The most common form of support is subsidies, but incentives also include tax credits, rebates and loans. During 2022, 17 national and sub-national jurisdictions – mainly in Europe but also in Australia, India, Japan and the United States – introduced new financial support policies for renewables in buildings, bringing the total number of countries and sub-national jurisdictions offering such support to 57.[44]

In Europe, France removed financial support for fossil gas boilers and increased its funding for renewable heating solutions by EUR 1,000 (USD 1,067) per application.[45] Germany earmarked EUR 3 billion (USD 3.2 billion) to expand its district heating and cooling sector and transition it to renewables, funding up to 40% of the cost of new grids that rely on at least 75% renewable energy.[46] Spain made available around EUR 660 million (USD 705 million) for installing renewable heating and cooling systems and energy storage systems in residential buildings, as well as EUR 100 million (USD 107 million) for renewable district heating and cooling networks – Spain's first explicit subsidy for that technology.[47]

i Because most energy efficiency investments in buildings are components of larger projects, they are difficult to extract from the overall project cost. Energy efficiency investments lead to a decrease in energy use compared to a baseline and are thereby incremental in nature. A lack of clear definitions, standards and benchmarks for assessing the energy efficiency performance of buildings makes tracking these investments challenging. See endnote 30 for this module.

SNAPSHOT

EUROPE

Strategies to Phase Out Russian Fossil Gas in European Buildings via Renewables

The Russian Federation's invasion of Ukraine in early 2022 and the coinciding European energy crisis turned the region's attention to the role of fossil gas. The EU has depended heavily on Russian gas imports, which supplied around 40% of regional gas demand in 2021 (155 out of the 389 billion cubic metres consumed). These imports dropped dramatically in 2022: in July and August, the EU imported nearly 70% less Russian gas than during the same period in 2021.

Fossil gas contributes nearly 40% of the energy used for space heating in European buildings and accounts for around 33% of the region's total energy use. In response to the events in Ukraine, in May 2022 the European Commission announced the REPowerEU plan to "rapidly reduce our dependence on Russian fossil fuels by fast-forwarding the clean transition". The plan targets reducing the EU's fossil gas use by 124 billion cubic metres by 2030.

To achieve this goal, REPowerEU recommends increasing the EU-wide renewable energy target to 45% of total final energy consumption by 2030 (up from 38%) and boosting the energy savings target to 13% (up from 9%). It also includes measures that could further swap fossil gas demand in buildings for renewables: doubling the deployment rate of heat pumps, doubling the deployment of solar PV (more than 320 GW, by 2025) and proposing a solar rooftop obligation for some types of buildings. Although REPowerEU is not law, it has fed into ongoing negotiations between the European Parliament and Council updating some key directives.

Another key policy plank for phasing out fossil gas is the Energy Performance in Buildings Directive (EPBD), the EU's main lever for renovating and decarbonising buildings. The policies proposed in the EPBD are intended to double the annual renovation rate of buildings. However, there are concerns that the proposed changes to the EPBD may fall short of the depth and rate required to reach the EU's 2030 climate targets.

Source: See endnote 32 for this module.

The United Kingdom launched a programme that provides GBP 450 million (USD 543 million), or up to GBP 5,000 (USD 6,029) per installation, to replace fossil heating systems with heat pumps.[48] Denmark also increased its available subsidies for heat pumps and solar thermal.[49] The European Bank for Reconstruction and Development provided EUR 65 million (USD 69 million) to build solar district heating systems in Pristina, Kosovo.[50]

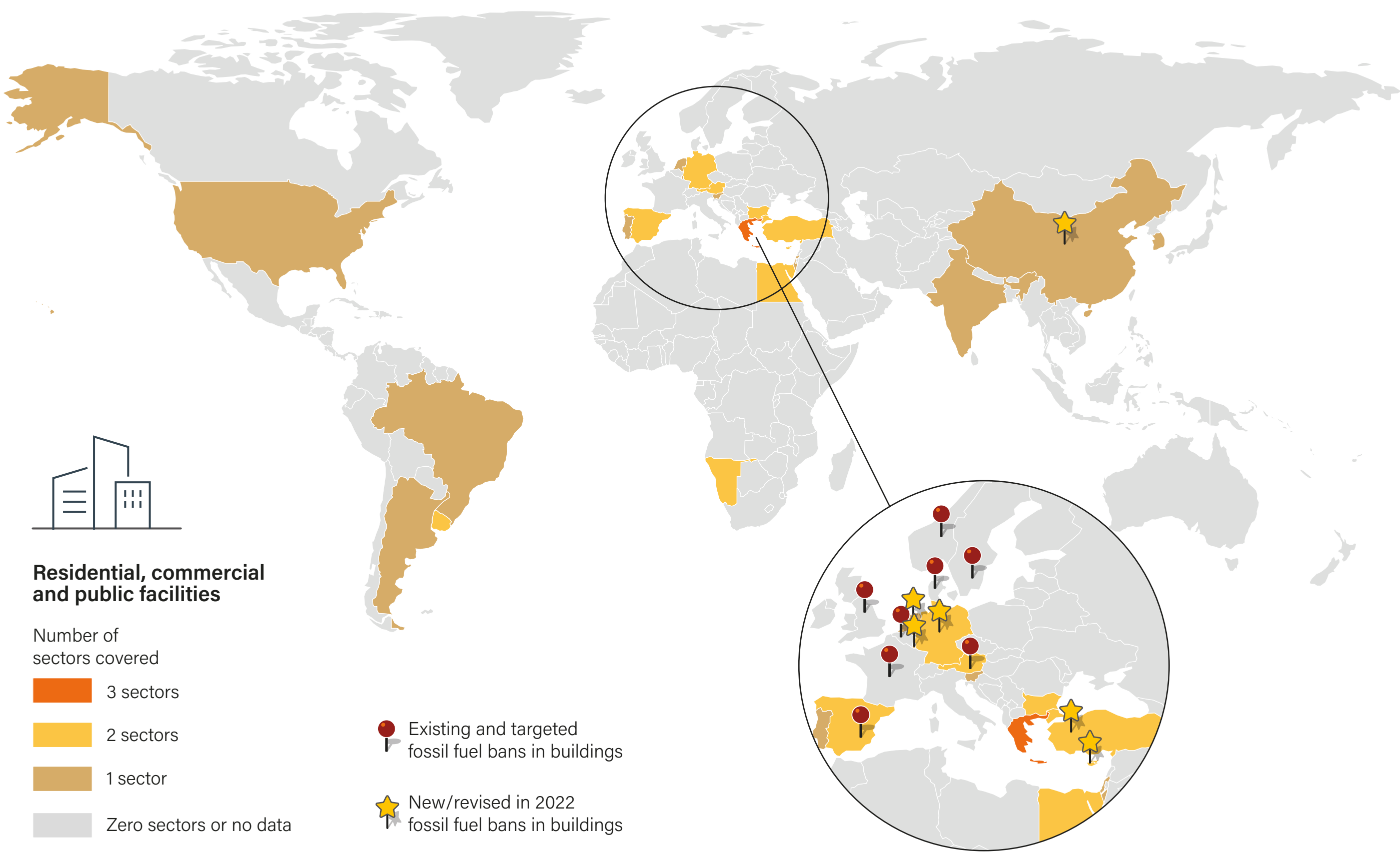
In the United States, the Inflation Reduction Act of 2022 allocated USD 4.5 billion in rebates for electric appliances (including heat pumps), USD 4.3 billion for home energy efficiency rebates and a 30% investment tax credit for purchases of ground-source heat pumps and of residential and commercial solar.[51] Uttar Pradesh, India announced rebates to farmers and citizens of up to 100% for distributed solar deployment.[52]

In some cases, the financial incentives vary based on household income, providing extra benefits for low-income homeowners. Within the US Inflation Reduction Act, the High Efficiency Electric Home Rebate Act offers point-of-sale rebates for electrification projects – including purchases of heat pumps – and low-income households can be reimbursed for 100% of the project costs (up to USD 14,000).[53] In Poland, subsidies for renewable heating solutions vary based on household income.[54] France's MaPrimeRénov programme provides funding for renewable heat installations and energy efficiency measures, with amounts increasing for lower-income households.[55]

Regulations can have a great impact on how renewable energy is used in buildings. Regulatory policies include those that mandate clean technology deployment, restrict the use of fossil fuels, and set standards for building performance or mandatory electrification. At least 21 national (and 22 sub-national) jurisdictions had such regulations by the end of 2022.[56] (→ *See Figure 6.*)

China introduced its first binding national energy efficiency standard that promotes the use of renewables in buildings, aiming for an 8% share by 2025 – up from around 4% in 2020, excluding biomass.[57] (→ *See Snapshot: China.*) The country's 2022 Work Plan on Energy Saving and Environment Protection in Government and Public Buildings requires installing heat pumps to meet the heating needs of 2 million square metres of public and government buildings.[58]

FIGURE 6.
Regulatory Policies in Buildings, by Building Type, as of End-2022



Notes: In 2021, 67 countries had mandatory building energy codes at the national level. This number has not been updated in 2022.

Policies also exist for Industrial buildings. By the end of 2022, nine countries (China, Indonesia, Japan, Morocco, New Zealand, Philippines, the Slovak Republic, Spain and Türkiye) had regulatory policies for industrial buildings. For more information, see the Industry in Focus module.

Source: See endnote 56 for this module.

SNAPSHOT

CHINA

Decarbonising Buildings With Renewables

Energy use in buildings is responsible for 21% of China's energy-related CO_2 emissions. Indirect emissions from the burning of fossil fuels to produce electricity and heat make up most of this, but on-site fuel combustion is responsible for around 600 megatonnes of CO_2 emissions per year, or around 6% of China's energy-related emissions.

China faces various challenges in decarbonising its buildings, including a lack of public awareness and of a sufficient workforce to install and maintain renewable heating and cooling technologies. Additionally, China's Renewable Energy Law does not recognise the ambient heat provided by heat pumps as a "renewable" resource. Energy tariffs also do not encourage electrification, as coal and gas retain an economic advantage.

As China's population has urbanised, great differences remain between rural and urban areas. In rural areas, coal-fired stoves supply around 42% of heating in households. In urban settings, however, district energy networks supply more than 85% of space heating. These are based largely on fossil fuels, with around 72% of district heating alone provided by coal, in the form of coal boilers and combined heat-and-power plants.

In 2017, China launched a campaign to phase out coal and gas in its predominantly rural northern provinces. The goal was to use "clean sources" to supply 70% of the region's heating needs by 2021 (a share of 65% was achieved by 2020, based on the latest data available) and to install heat pumps to cover 500 million square metres. China provided up to CNY 1 billion (USD 140 million) to each of 62 pilot cities to replace coal boilers with cleaner alternatives, and some jurisdictions, such as Beijing, set mandatory solar thermal ordinances.

Going forward, China's 14th Five-Year Building Energy Efficiency and Green Building Development Plan aims to rapidly increase the deployment of renewables in buildings. As the country's first binding national energy efficiency standard, the plan applies to all new buildings. It targets at least 350 million square metres of energy-saving renovation and stipulates that on-site renewables provide 8% of the energy demand in urban buildings. The law provides a strong incentive for electrification, especially of new buildings, by requiring that the share of electricity in buildings' energy demand should exceed 55% by 2025. China also plans to install 50 GW of solar PV on all new public buildings and factories by 2025 and to install heat pumps for 2 million square metres of public and government buildings.

Source: See endnote 57 for this module.

Germany's coalition agreement laid out an obligation, expected to apply in January 2024, that all new heating systems must run on 65% renewable energy, effectively ruling out the use of stand-alone oil furnaces and gas boilers.[59] The Netherlands, which in 2018 prohibited the connection of new buildings to the gas grid, announced additional measures in 2022 to make heat pumps mandatory for all new buildings as of 2022 and to ban all fossil heating by 2026.[60]

As of February 2023, at least 100 US jurisdictions (covering 11 states) had introduced binding ordinances for **zero-emission buildings**.[61] Although most measures target new construction, some also include renovations and equipment replacement, as in cities in California, Utah and Washington state.[62] Overall, around 31 million people in the United States live in a jurisdiction with a building electrification policy.[63] California has banned the sale of fossil gas heating systems by 2030, and a programme in New York state provides more than USD 500 million for electrifying space and water heating.[64] However, backlash to such measures has resulted in more than 20 US states – covering around 30% of the country's gas demand in buildings – prohibiting efforts to ban fossil gas use.[65]

Obligations to install **rooftop solar PV** on buildings also have proliferated. The REPowerEU proposal includes an obligation to install rooftop solar on every public building by 2025.[66] In 2022, the US state of California introduced a solar-plus-storage mandate that all new buildings that are required to install solar must also have a battery storage system.[67] The state also rolled out a new community solar subscription model.[68] However, California has struggled to reform its net metering policies, after dropping a proposal to charge owners of rooftop PV a monthly fee.[69] Likewise, Nova Scotia, Canada scrapped a plan to charge a monthly fee to building owners who sell solar electricity back to the grid.[70]

Building energy codes are another regulatory lever to increase the penetration of renewables. By reducing the energy intensity of buildings, such codes can enable higher shares of renewable energy use. Additionally, building energy codes increasingly mandate the deployment of renewables. However, as of 2022 only 80 countries had building energy codes (up from 79 in 2021), most of which were voluntary.[71] As of late 2022, only 40% of countries had mandatory building energy codes.[72] China's new buildings law, which includes the country's first binding national energy efficiency standard, sets new construction standards for green buildings that apply to all new buildings; it also targets at least 250 million square metres of energy-saving renovation.[73]

South Africa has mandated that all new buildings be designed and constructed to be net zero energy by 2030; Kenya has a similar mandate for 2035 and Nigeria for 2050.[74] India's 2022 energy conservation act applies its mandatory building energy code to residential buildings.[75] Japan initiated a programme that gradually increases mandatory performance standards for buildings.[76] In the United States, the California Building Energy Code, updated in 2022, includes requirements to install demand response technologies for heating systems to enable their automated control.[77]

INVESTMENT

Data on investment in renewables specifically in the buildings sector are limited, both for power and for heat. However, assuming that the buildings sector consumed around half of all power generated worldwide in 2022, then roughly USD 244.8 billion of the global new investment in renewable power capacity that year would have gone to buildings.[78]

Influenced in large part by the Russian Federation's invasion of Ukraine and by the transition away from Russian gas, European investment in heat pumps rose sharply in 2022, particularly in Austria, Finland, Germany, Italy, the Netherlands and Poland.[79] Globally, heat pump investments increased 9.6% during the year, to USD 64.3 billion, with the strongest market growth in Europe, Japan and the United States.[80] Many US consumers were drawn to heat pumps to alleviate higher utility bills related to inflation.[81]

Investments also occurred in renewable-fed district heating systems for buildings. In Groningen, the Netherlands, a "special purpose vehicle" comprising the project developer, an investor and a turnkey provider of the solar field invested EUR 23 million (USD 25 million) in the world's fourth largest solar district heating plant.[82] In Markham, Canada, a CAD 270 million (USD 199 million) investment was dedicated to expanding the city's low-carbon district energy system.[83] Germany announced a EUR 3 billion (USD 3.2 billion) programme to finance the construction of heating networks supplied by at least 75% renewable or waste heat, as well as the decarbonisation of existing networks, to further reduce CO_2 emissions and the country's dependence on Russian energy.[84]

Although markets for solar thermal technologies (including solar water and space heating in buildings) remained broadly stable during 2021-2022, rising inflation and interest rates affected investments in some regions.[85] In Europe, some energy utilities and energy-intensive industries faced higher energy costs, which led many companies to put on hold new investment decisions.[86]

Investment in energy efficiency in buildings surged in 2021 but was expected to slow in 2022 due to higher construction, material and financing costs as well as lower spending in emerging and developing markets.[87] European countries, the United States and China have dominated energy efficiency investment in recent years, reflecting the recovery of construction investment in Western Europe and ongoing construction growth in China, Germany and the United States.[88] Energy efficiency investment in Southeast Asia and Africa has struggled due to pandemic-related disruptions to construction as well as limited public programmes for investment.[89]

As of late 2022,
only 40% of countries
had mandatory building energy codes.

MARKET DEVELOPMENTS

Markets for renewable energy technologies in buildings have been on the upswing, due largely to favourable economics, supportive government policy and the need to address climate change. The use of on-site and community-generated renewable electricity, as well as markets for renewable heating and cooling technologies (especially heat pumps), grew strongly during 2021 and 2022.

Distributed solar PV supplied electricity to around 25 million households worldwide in 2021.[90] Distributed solar accounted for nearly half of the global solar market that year, its highest share since 2012.[91] (Centralised solar PV generation overtook distributed generation in 2015 and has since accounted for the majority of PV installations worldwide, at 56%, a share that has remained roughly stable.[92]) Of the estimated 78 GW of distributed solar PV installed in 2021, around 60% was residential and 40% commercial.[93]

Europe had the highest regional share of distributed solar PV in 2021, but China, with its overall market lead, was the world's top installer.[94] China also was one of the few top markets to install more distributed solar PV (29 GW) than centralised solar PV (26 GW), joined by Germany (3.75 GW versus 2 GW), Australia (3.2 GW versus 1.7 GW) and Japan (3.6 GW versus 3.0 GW).[95] Countries that installed more utility-scale plants than distributed capacity included the United States (20 GW centralised versus 6.6 GW distributed) and India (11.6 GW versus 2 GW).[96] Rooftop solar also picked up in nascent markets such as Israel and Jordan.[97]

Global technology companies have launched several projects to use waste heat from data centres for district heating and other purposes. For example, the waste heat from an Amazon data centre in Dublin (Ireland) is heating local homes and offices; Microsoft launched a similar project in Helsinki (Finland) in early 2022; and an Interxion data centre aims to provide heat to a hospital in Vienna (Austria).[98]

Heating for space and water is the largest energy use in buildings and the one most heavily based on fossil fuels. In 2022, markets for many renewable heating and cooling technologies grew in response to the energy crisis.

The use of **bioenergy** to provide heating services is the largest renewable energy end-use in buildings. Much of this comes from the traditional use of biomass[i], which increased from 24.3 EJ in 2019 to 24.5 EJ in 2021.[99] Europe consumes more than three-quarters of the world's biomass pellets, many of them imported from the United States and Canada.[100] Sales of biomass stoves surged in Europe during 2022, notably in Germany, and wood pellets in Europe and the United States faced a supply crunch as more households turned to biomass heat.[101] China also is an emerging market for biomass heat.[102]

Solar heat provided around 10.5% of modern renewable heating consumption in 2021.[103] In 2021, the global market for solar collectors grew 3% to reach a cumulative 522 gigawatts-thermal, continuing its rebound from a 2019 low.[104] China's solar heat market, the world's largest, grew modestly during 2021, and strong growth also occurred in Brazil, Greece, India, Italy, Poland and the United States.[105] In Africa, a solar thermal project in Namibia provides water heating to at least 58 social housing residences, and southern African countries such as Botswana, Lesotho, Namibia, South Africa and Zimbabwe have published roadmaps on the potential to increase solar thermal uptake.[106] The European solar thermal industry struggled in 2022 due to the aftershocks of the COVID-19 pandemic and the war in Ukraine.[107]

Solar heat increasingly provides space heating through large-scale installations and district heating networks. In 2021, 44 new large-scale solar heat systems came online – mainly in China and Europe but also in Mexico (3 systems) – and growth continued in 2022 with the start of construction of a solar district heating plant in the Netherlands, among other projects.[108] The use of hybrid solar PV-thermal (PVT) panels grew 13% in 2021, with more than 6,000 systems brought online for a total capacity of 751 megawatts-thermal (MWth).[109]

i The traditional use of biomass includes the burning of woody biomass or charcoal, as well as dung and other agricultural residues, in simple and inefficient devices to provide energy for residential cooking and heating in developing and emerging economies.

Wood pellets in Europe and the United States faced a supply crunch in 2022 as more households turned to biomass heat.

Direct use of **geothermal heat** also provides space and water heating services. Around 39% of geothermal direct use is for space heating.[110] In total, the global installed geothermal heating capacity grew around 9% annually from 2014 to 2019.[111] The world leaders in geothermal direct use for heating and cooling are China, the United States, Sweden, Türkiye and Japan; on a per capita basis, the leaders are Iceland, Sweden, Finland and Norway.[112]

During 2022, China launched geothermal heating services covering millions of households in more than 60 cities and counties.[113] In the United States, construction started on New York City's largest district heating and cooling system; work progressed on projects in Massachusetts and Texas; and the Department of Energy announced a USD 13 million fund to develop geothermal district heat.[114] In total, the United States has 23 geothermal district heating systems, with the first installed in 1892.[115] Canada allotted CAD 1.3 million (USD 960,000) to develop geothermal heat projects in Nova Scotia.[116]

In Europe, 13 new geothermal district heating and cooling projects were brought online in 2021, providing more than 154 MWth of new capacity.[117] Three-quarters of this growth was in France, Poland and Iceland.[118] During 2022, more than 20 projects were in development, including in these three countries.[119] The first geothermal district heating plant in Vienna (Austria) also was given the green light.[120]

Policies that support building electrification continued to boost markets for electric heat technologies, notably **electric heat pumps**. Heat pump markets set growth records in many countries in 2022, including in the EU and the United States.[121] Year-on-year growth over the first half of the year exceeded 10% in six countries: Italy (up 114%), the Netherlands (100%), Poland (96%), Finland (80%), Germany (25%) and Norway (11%).[122] The US market grew 7.3% in the first half of 2022 compared to the same period in 2021.[123]

Influenced by the war in Ukraine and by REPowerEU, several heat pump manufacturers announced or made significant investments in production facilities during the year. Viessmann plans to spend EUR 1 billion (USD 1,067 million) over three years; Daikin announced a EUR 1.2 billion (USD 1,281 million) investment in heat pump manufacturing to 2025 in Europe, aiming to triple its manufacturing capacity; and Bosch, Panasonic and many other manufacturers made similar announcements.[124]

District heating networks met a rising share of heating demand in buildings in 2022. The use of renewable energy in district heating grew from 0.4 EJ in 2011 to 0.6 EJ in 2021.[125] Overall, the share of renewables in district heating systems grew from 4.1% to an estimated 5.6% during the decade.[126] Most district heating activity is in Europe, although much of this entails converting existing networks to renewable sources (biomass, solar and geothermal heat, and large-scale heat pumps), rather than building new networks.[127] More projects are integrating waste heat into district networks, such as in the Netherlands and Sweden.[128] In a novel example in Finland, ambient heat from the Baltic Sea is fed into a district heat network to heat homes in place of coal and fossil gas.[129]

Markets for **cooling** technologies are changing quickly. Globally, 1.2 billion people are at risk due to lack of access to cooling, and demand for air conditioning and other cooling services has been the fastest growing energy use in buildings.[130] The average efficiency of cooling appliances has been increasing, helping to mitigate the growth in electricity demand from cooling.[131] However, the most efficient models have not necessarily had the highest uptake.[132] Examples of renewable cooling applications in 2022 included the drilling of the first wells for a geothermal cooling system in India and plans for geothermal cooling in Bali, Indonesia.[133]

CHALLENGES AND OPPORTUNITIES
for the Uptake of Renewables in Buildings

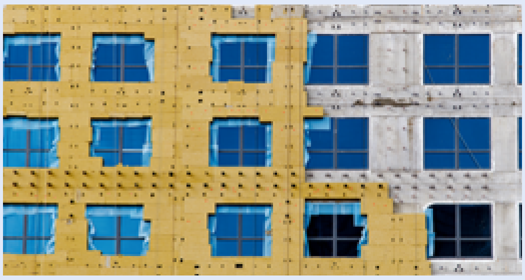
CHALLENGES

- Because many heating systems are stand-alone units (*e.g.*, individual fossil gas boilers or oil furnaces), replacing them would require **significant investment, time and workforce,** especially in the case of multi-dwelling housing such as large apartment buildings.
- Implementing renewable-based district heating systems requires **high upfront investment**, which is often not feasible for residents without government support and incentives.

- The **number of engineers and installers** currently available to replace household energy systems with new systems is insufficient to meet the workforce levels needed to achieve climate goals.
- Modern "**clean cooking**" still depends largely on the use of traditional bioenergy and fossil gas fuels, and applications of electrified technologies are limited mostly to developed countries.
- Incumbent **fossil fuel companies** continue to **invest heavily in public relations campaigns** designed to slow the transition to renewables in buildings.

OPPORTUNITIES

- The use of renewables in buildings would help **reduce heating and other energy costs** – especially for low-income households – and limit the vulnerability of households to fossil fuel price swings.
- Greater **electrification** of buildings would contribute to **demand response and system flexibility**, helping to achieve higher levels of renewable energy integration.
- In regions with high levels of new construction, designing efficient and renewable heating systems (and buildings) would help to **avoid costly renovations or upgrades at a later stage**.
- In regions with high shares of existing building stock, there is an **opportunity to greatly improve the efficiency** of these buildings and to lower energy bills for consumers.



- Leapfrogging via renewables is a way to **provide energy access** to those currently without access to modern energy sources.
- **New business models** (such as heat-as-a-service) provide an opportunity for consumers to avoid upfront expenses associated with changing their heating systems.

Industry had the highest share of renewables in final energy use in 2020, at

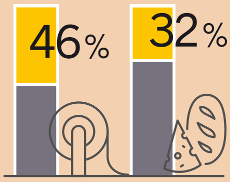
16.8%

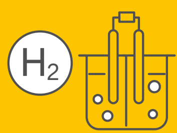
Modern biomass represented

8.2%

of industry TFEC

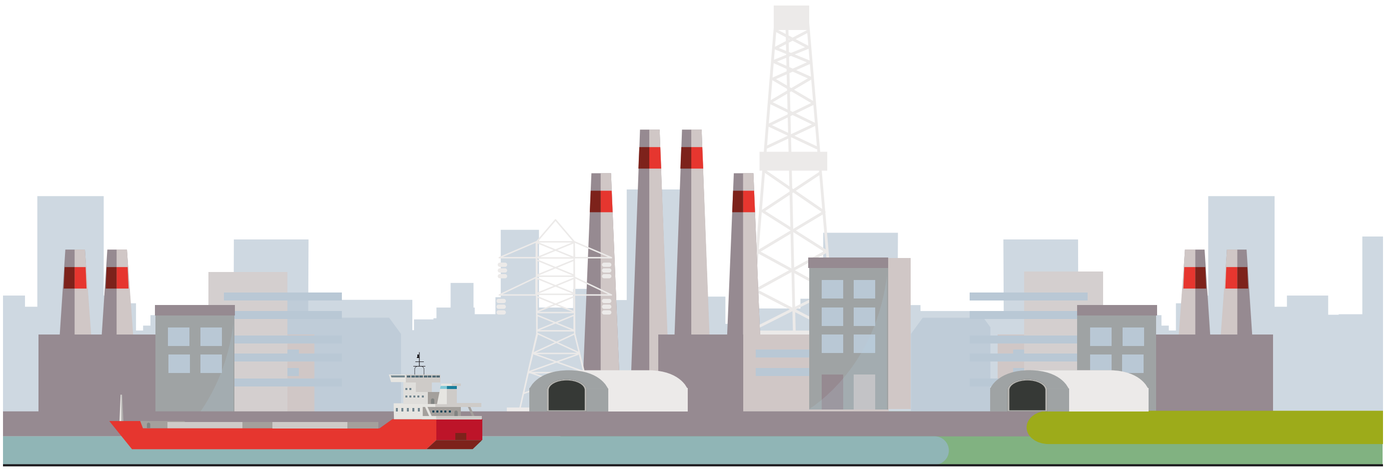
Pulp & paper and **food & tobacco** had the highest shares of modern renewables in 2020





Seven countries had industry roadmaps or recovery plans for **renewable hydrogen** by end-2022

19 countries had renewable energy mandates or fiscal/financial policies for industry by end-2022



Note: TFEC = Total final energy consumption.

INDUSTRY IN FOCUS

Module Overview | Policy | Investment | Market Developments | Challenges & Opportunities

MODULE OVERVIEW

Industrial enterprises generate around a quarter of the world's gross domestic product and employment.[1] Industry is also the largest energy-consuming sector, accounting for 33% of global total final energy consumption in 2021.[2] Despite the impacts of the COVID-19 pandemic, energy use in industry grew 9% between 2010 and 2020, due mainly to rising demand for industrial goods, particularly in energy-intensive sectors.[3] Two key industries – iron and steel and chemicals – together accounted for nearly a third (32%) of industrial energy demand in 2020, while food and tobacco, pulp and paper, and mining consumed around 5% each.[4] Industrial activity produced around 9.4 gigatonnes of carbon dioxide (CO_2) in 2021, or roughly a quarter of global emissions.[5] Around 70% of emissions came from three sectors: cement and concrete, iron and steel, and chemicals and petrochemicals.[6]

Since 2010, the energy mix of the industry sector has remained relatively stable, with a heavy reliance on fossil fuels. However, the share of fossil fuel use fell from 87% in 2010 to 83% in 2020, (→ *see Figure 7*) due mainly to the ongoing electrification of industrial heat coupled with renewable electricity use, which grew 80% during the decade.[7] The direct use of renewables for process heat accounted for less than 9% of industrial energy use in 2020, with modern bioenergy supplying most of this (8%) followed by solar and geothermal heat (less than 0.1%).[8] Bioenergy use is most common in biomass-based industries that generate energy from their own waste: for example, in the pulp and paper industry 43% of the total final energy consumption in 2021 was bioenergy (mainly black liquor from pulping).[9]

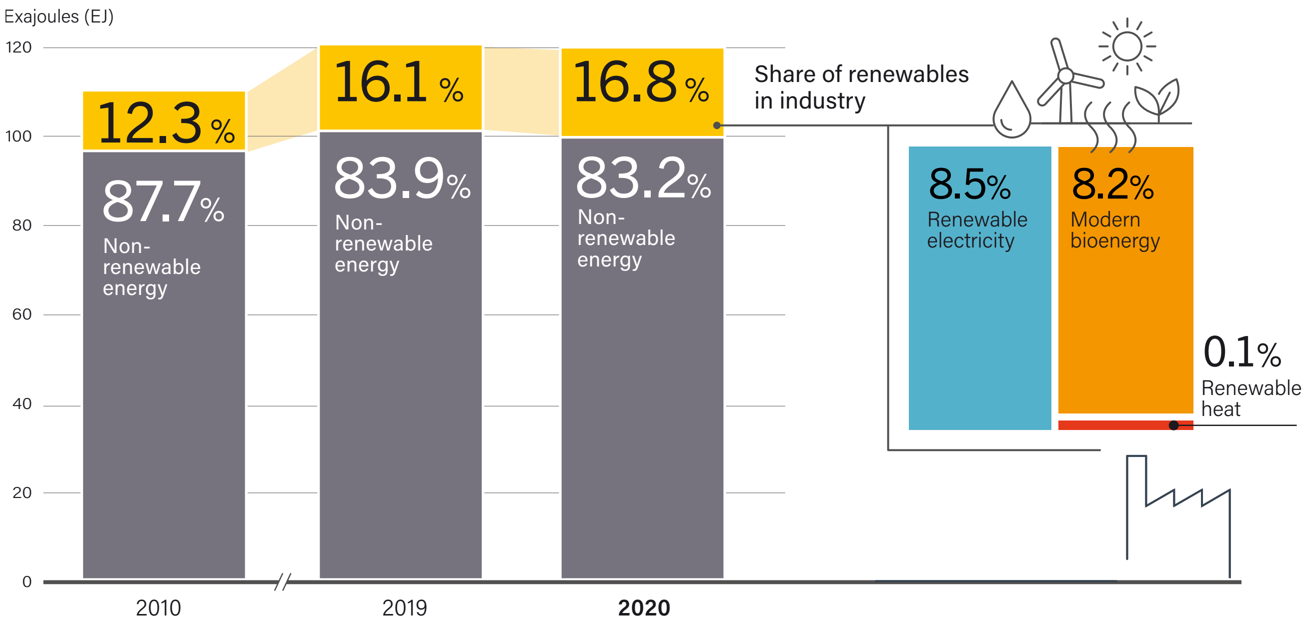
Following the Russian Federation's invasion of Ukraine in early 2022, energy prices in Europe and elsewhere skyrocketed.[10] In this context, companies have increased their interest in energy efficiency and the use of renewables as a way to cut energy costs and increase the security of supply.[11] In developing countries and for industries located in remote areas, such as mining, the need for secure, reliable and affordable energy is a key driver of the uptake of renewables.

In 2020, the direct use of renewables for process heat accounted for

less than 9%

of industrial energy use.

FIGURE 7.
Renewable Share of Total Final Energy Consumption in Industry, 2010, 2019 and 2020



Note: Modern bioenergy includes heat supplied by district energy networks.
Source: See endnote 7 for this module.

More companies are announcing net zero commitments[i], both to maintain a positive corporate image and in response to rising pressure from regulators, such as through the European Union (EU) Taxonomy, the United Kingdom's mandatory climate disclosures and the US Biden administration's comprehensive climate plan.[12] Although most companies still lack concrete and credible action strategies, some industrial firms have committed to shifting to 100% renewables and to reducing the energy demand of their production processes via heat recovery and materials recycling.[13]

In the cement sector, solutions have included reducing the clinker-to-cement ratio[ii] and using waste as an alternative fuel[iii]; other industries are using heat pumps to capture and reuse waste heat.[14] In 2022, the French manufacturer Saint Gobain was able to produce the world's first zero-carbon glass by using biogas and 100% recycled glass.[15] Renewable hydrogen, created using renewable electricity, also advanced during 2021-2022 and is considered key to decarbonising energy-intensive sectors.[16]

i As of June 2022, more than one-third of the world's largest publicly traded companies had targets for net zero carbon emissions, up 60% since December 2020. However, 65% of corporate targets do not yet meet minimum procedural reporting standards. See endnote 12 for this module.

ii Because clinker production is the most energy-intensive and CO_2-emitting step of the cement-making process, reductions in the clinker-to-cement ratio (through the use of clinker substitutes) reduce energy use and process CO_2 emissions.

iii Only a portion of waste used as an alternative fuel in the cement industry is considered renewable.

POLICY

Policies related to industry typically have not included renewable energy requirements, reflecting the very diverse energy needs of industrial sectors (for heating, electricity, etc.); however, some progress has been made on energy efficiency and energy management. Policies supporting renewable heat often mention industrial uses, and many carbon pricing mechanisms encourage the use of renewables in large industry sectors. Renewable hydrogen also has gained policy attention. Other factors driving industrial policies and regulations related to renewables include the ongoing energy crisis, concerns about energy security, growing net zero commitments by countries and companies, and the emergence of the hydrogen economy.[17] However, a lack of robust national-level data has hindered the mapping of energy needs in the industry sector and the design of effective policies on renewables.

In 2022, no new jurisdictions adopted regulatory policies for renewables in industry, and only one country, Poland, announced plans for a new renewable energy mandate for industry, for the mining sector.[18] In addition, the EU's REPowerEU plan (yet to be approved as of the time of writing) set a target of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of hydrogen imports by 2030 for heavy industries, and also includes a target for renewable energy use in industry.[19] This brings the total number of countries with road maps that include hydrogen in the industry sector to 10, five of which (Australia, Brazil, South Africa, Spain and Sweden) are for renewable hydrogen.[20]

The REPowerEU plan also mentions the electrification of industrial processes and the use of alternative bio-based or renewable inputs, along with energy efficiency, waste valorisation and circular use of materials.[21] In addition, it aims to expand the EU's manufacturing capacity for clean energy technology, including through industrial alliances such as the Solar industrial Alliance to push the solar panel manufacturing sector, and the Biomethane Industrial Partnership.[22]

Financial incentives remain the most common policy support for promoting the use renewables in industry, with 12 countries having such policies by the end of 2022. Overall, no new policies for renewables in industry have been announced since 2019. As of the end of 2022, a total of 19 countries had renewable energy mandates and/or fiscal/financial policies for industry; only 9 countries had renewable energy mandates that enforce the installation of renewables, and 2 countries (Spain and Türkiye) had both regulatory and fiscal/financial incentives.[23]

The most common financing framework for renewables in the industry sector is direct contracting through power purchase agreements (PPAs) or environmental attribute certificates. However, national utilities have been reluctant to support industry's transition to independent electricity sources, and in countries where the grid is unreliable, fossil fuel back-up systems remain the norm.[24] The lack of enabling policies for renewable energy captive markets has pushed the private sector to be innovative with business models, such as lease-to-own solar parks.[25]

> The Inflation Reduction Act is a key US policy for industry that allots **USD 370 billion** to energy and climate change.

The momentum towards net zero carbon emissions continues to drive policies. As of November 2022, a total of 140 countries, representing 90% of global emissions, had committed to net zero pathways; this was up from 130 countries representing 70% of emissions in May 2021.[26] As governments and industries look to renewables as a potential solution for mitigating emissions, countries have begun bridging the silos between renewable energy policies and industry policies.

A key US policy advancement in the industry sector in 2022 was the adoption of the Inflation Reduction Act, which allots USD 370 billion (out of a total USD 433 billion) to energy and climate change, putting the United States on track to reach its 2050 emission reduction target.[27] The law highlights domestic manufacturing of both renewable energy technologies and electric vehicles and infrastructure.[28] For energy-intensive industries such as steel and cement, two aspects of the law are noteworthy: 1) clean electricity tax credits are technology-neutral and include energy storage and green hydrogen starting in 2025, and 2) the credits will be in place for at least a decade, giving industrial users ample time and confidence to develop renewable supply options for their own energy needs.[29]

South Africa's Just Energy Transition Investment Plan 2023-2027 mentions decarbonising the industry sector through increased investment in renewable power.[30] It also highlights renewable hydrogen as a way to decarbonise hard-to-abate sectors (such as transport, petrochemicals, iron and steel, and cement) as well as the automotive industry and Special Development Zones (industrial parks).[31]

During the United Nations climate talks in Egypt in November 2022, several policy announcements supported the uptake of renewables in industry; for example, India introduced a mandatory green hydrogen purchase obligation for industrial users.[32] The previous month, at the Group of Twenty (G20) meetings in Indonesia, the International Renewable Energy Agency and industry leaders established the Alliance for Industry Decarbonization to encourage wider industry adoption of renewables.[33]

In the area of renewable hydrogen, Egypt announced a new National Hydrogen Strategy in 2022 that includes building the infrastructure to support industrial users of both conventional and renewable hydrogen.[34] Also during the year, South Africa published its Hydrogen Society Roadmap, which focuses on renewable hydrogen, including large projects aimed at industrial users, such as the Boegoebaai Green Hydrogen development in the Northern Cape.[35] However, most industry leaders globally continue to consider both fossil-based and renewable hydrogen in the push towards net zero emissions.[36]

So far, only a few policies have focused on the use of land for industrial renewable energy projects. This includes, for example, developing industrial clusters where diverse industries share energy generation processes; industrial parks or special economic zones; and industry community renewable energy.[37] Chile launched a plan in 2022 to facilitate renewable hydrogen concessions on public lands to meet the needs of the mining industry.[38]

INVESTMENT

Although no comprehensive datasets cover investment in renewables in the industry sector, several examples exist of key industrial investments in solar thermal, geothermal heat and renewable hydrogen technologies.

The chemical manufacturing, mining, and pulp and paper industries, in particular, have invested in solar industrial heat.[39] Projects over the past decade included a solar-powered steam boiler for chemical evaporation and distillation in Tianjin, China; a solar thermal project to dry pigments in Vellore, India; and the use of a solar thermal collector to heat water for cleaning processes in Maharashtra, India.[40] In the mining industry, the Hellenic Copper Mine in Cyprus invested in a solar thermal system to heat a process medium, and a mine in Durango, Mexico invested in a system to heat make-up water.[41] In Kingsey Falls, Canada, a concentrating solar power plant was built to provide hot water for industrial processes in the pulp and paper industry.[42]

In Germany, recent investments have supported the expansion of geothermal heat for paper drying in the pulp and paper industry, with support from the EU and the state of North Rhine Westphalia.[43] In New Zealand, an AUD 15 million (USD 10.2 million) investment, funded in part by the Government Investment in Decarbonising Industry Fund, aims to establish the world's first tissue machine running a fully geothermal steam drying process.[44]

Since 2020, a surge of announcements have been made reporting investment in net zero technologies in the steel industry, some of which include the use of renewables.[45] Investing in decarbonised steel neither lowers costs nor increases product quality, so the primary motivation often is the opportunity to capture incipient markets for "green steel" and to avoid stranded assets in anticipation of more stringent climate policies.[46] In 2021, the Swedish company H2 Green Steel allocated an initial USD 3 billion for a plant that will use renewable hydrogen for steel production starting in 2024.[47] In addition, the new Financing Steel Decarbonization instrument aims to mobilise private finance for low-carbon technologies to decarbonise steel, including through renewables and renewable hydrogen.[48]

Although many industries, such as the pulp and paper and cement industries, use biomass to generate heat, few specific data are available on industrial investments in biomass projects.[49]

Eco-industrial parks are becoming more attractive for investors as they offer better cost competitiveness and risk resiliency.

MARKET DEVELOPMENTS

Most of the energy used in industry (around 75%) is for process heat, with the rest going to electrical operations (such as cooling and powering motors) and non-process activities (such as lighting).[50]

A key trend is **electrification via renewables**, which is generally easier to achieve for industrial processes that require low- or medium-temperature heat (below 400 degrees Celsius, °C). Renewable electrification occurs mainly in the food and beverage, transport equipment, machinery, and pulp and paper industries, although it has great potential in chemicals, pharmaceuticals and textiles, notably through the installation of heat pumps.[51] Industries with higher temperature requirements for process heat – such as cement, chemicals, and iron and steel – are harder to electrify; however, the use of electric arc furnaces in steelmaking now represents around 25% of global production.[52]

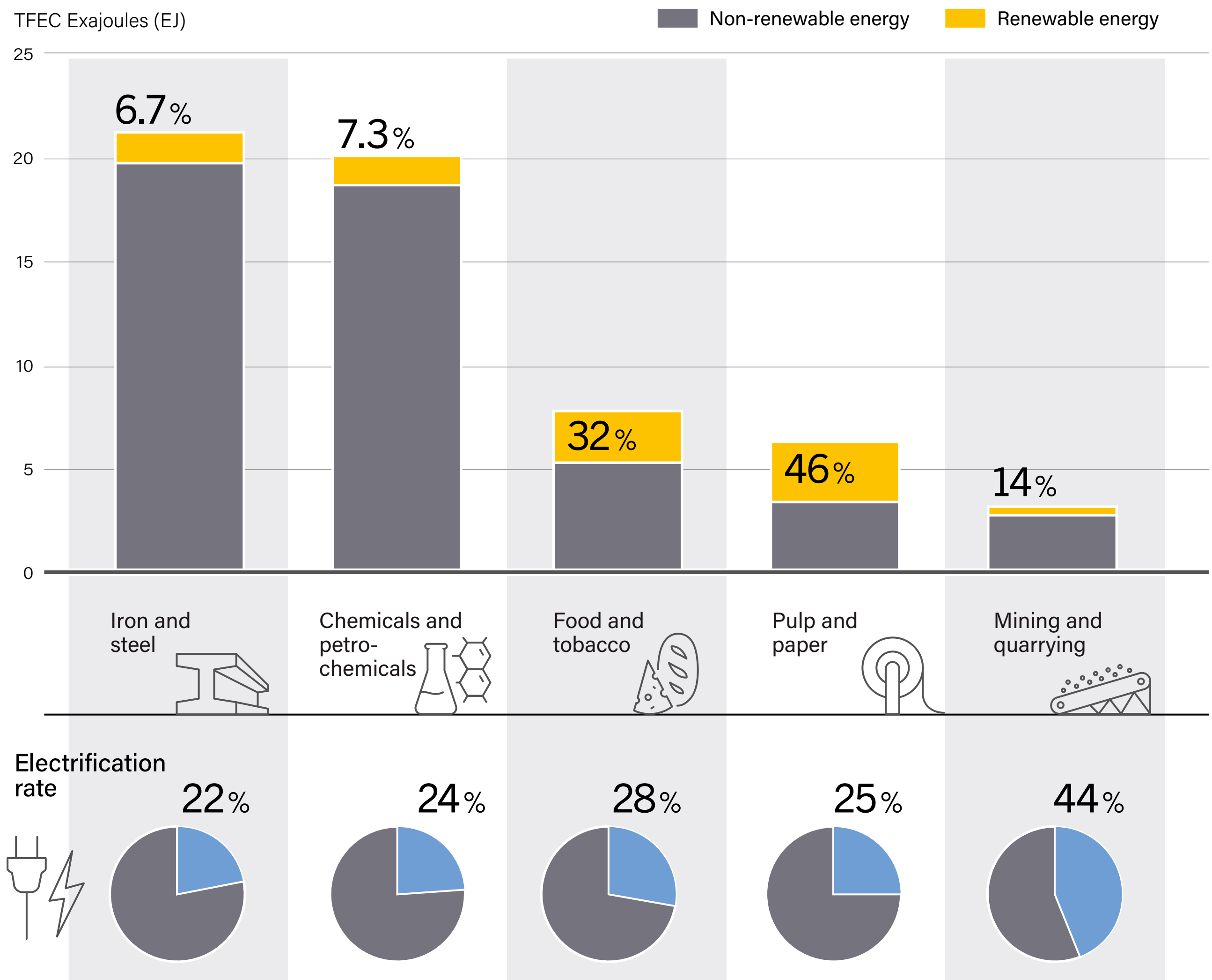
In parallel, many industries that already use high shares of electricity in their operations are switching to renewable electricity supply. Steel and cement companies, driven by net zero commitments, are increasingly using PPAs to procure renewable power for their operations.[53] In 2022, the steel manufacturer ArcelorMittal invested in wind and solar plants in Argentina and India, and German steelmakers such as the GMH Group and Salzgitter signed PPAs with renewable providers to power their electric arc furnaces.[54] Cement manufacturers that signed renewable PPAs included Cemex in Spain, Suez Cement in Egypt, Opterra in Germany and Lafarge in Hungary.[55] In the chemical sector, the global manufacturer BASF committed to PPAs at various European and US locations.[56] In addition, mining companies have developed decentralised renewable energy projects in Australia, Madagascar and Mali that provide reliable and affordable energy for both mine sites and local communities.[57]

Globally, the number of **eco-industrial parks** has grown rapidly, with the aim of creating resource-efficient industrial parks that are more competitive, risk-resilient and attractive for investment.[58] By integrating processes within a cluster – such as generating low-cost renewable power and heat on-site – industries can share energy and material streams.[59] Vietnam's Decree 35 relies on policies and incentives to boost the eco-transition of local industrial parks to attract global manufacturers.[60] In 2022, four industrial clusters in Belgium, the Netherlands and the US states of Ohio and Texas joined the World Economic Forum's "Transitioning Industrial Clusters Towards Net Zero" initiative.[61] Eco-industrial parks also are being developed in Colombia, Egypt, Indonesia, Peru, South Africa, Ukraine and Vietnam, with support from the United Nations Industrial Development Organization (UNIDO).[62] (→ *See Snapshot: South Africa.*)

Because of a lack of financing, the adoption of renewable electricity by small and medium-sized industries represents a largely untapped solution area for low-carbon industrialisation, particularly in developing countries.[63] (→ *See Snapshot: Pakistan.*) However, in some countries smaller-scale businesses have been able to access co-financing for energy efficiency and self-consumption of renewables. Chile expanded its pilot programme "Put your energy to your SME" in 2021, and France's new climate action loan supports the energy transition of small and medium-sized businesses.[64]

In general, the uptake of renewables and electrification in industry varies greatly depending on the specific sub-sector and on the processes and technologies being used.[65] (→ *See Figure 8.*)

FIGURE 8.
Renewable Energy Share and Electrification Rates in Selected Industry Sub-Sectors, 2020



Source: See endnote 65 for this module.

SNAPSHOT

SOUTH AFRICA

Clustering Development to Meet Energy Demand and Decarbonisation Commitments

Mpumalanga province in eastern South Africa is using a cluster development model to encourage the growth of renewable energy manufacturing. The regional economy depends heavily on coal exploitation, accounting for around 80% of South Africa's coal production and hosting most of the country's coal-fired power plants and coal mining activities. Mpumalanga also is rich in wind and solar resources[i], with a combined grid capacity of 6,520 megawatts (MW). These assets make the province an ideal location for large-scale renewable energy projects that take advantage of former coal mining sites and the existing transmission infrastructure.

In May 2022, the Mpumalanga Department of Economic Development and Tourism, in collaboration with GreenCape, UKPACT and Germany's technical co-operation agency GIZ, launched the Mpumalanga Green Cluster Agency, an independent entity that seeks to overcome investment barriers and unlock new economic opportunities, including in renewables. The Green Cluster aligns with recent policies and legislation aimed at decarbonising South Africa's economy, such as the national Renewable Energy Masterplan, which envisions opportunities to develop renewable manufacturing value in key regions like Mpumalanga.

In July 2022, South Africa removed the 100 MW cap on self-generation of electricity without a licence. As a result, energy-intensive users such as industrial and mining companies can now generate or buy electricity from independent power producers on a larger scale. Mining companies already have committed to developing 4 gigawatts (GW) of renewables nationally, and as of July they had registered 73 self-generation projects totalling 295 MW. In Mpumalanga, the market is expected to grow to around 2 GW by 2030.

Additionally, South Africa's state-owned utility Eskom is set to decommission up to 11 GW of coal-fired generation by 2030. This presents an opportunity to re-purpose and re-power coal plants and adjacent land. Eskom issued tenders in April 2022 to lease land for renewable energy projects, and in June the utility announced that it had selected 18 companies to lease 4,000 hectares to develop renewable projects totalling 1.8 GW.

i Wind speeds in the province are between 4 and 7 metres per second at 100 metres above ground level, which is sufficient for commercially viable wind farms. The long-term average global horizontal irradiation in Mpumalanga ranges between 1,752 and 2,044 kilowatts per square metre annually (only around 16% lower than in the Northern Cape).

Source: See endnote 62 for this module.

The use of **modern solid bioenergy** in industry increased 46% between 2011 and 2021, rising from 8.2 exajoules (EJ) to 12.0 EJ.[66] However, the share of this bioenergy use relative to total final energy consumption increased by only 15%.[67] Driven by net zero commitments, various pulp and paper companies adopted bioenergy during 2022. For example, South Africa's Sappi replaced coal boilers with biomass, Finno-Swedish Stora Enso announced the replacement of fuel oil with renewable pitch oil, and Finland's Metsä invested in biomass electricity generation to help achieve its 2030 fossil-free energy target.[68]

Examples of biogas use in industry are found mainly in the food sector, where several leading manufacturers operate anaerobic digestion facilities to generate heat and electricity for factories.[69] In 2022, Danone (France) committed to increase its use of biogas (as well as solar and biomass) as part of its decarbonisation plan, and in 2021 both Unilever (UK) and Starbucks (US) joined the US Biogas Alliance.[70]

The use of biomass as an industry feedstock remains limited. In 2021, global production of biomass-based plastic accounted for less than 1% of global plastic production.[71] Bio-based chemicals such as methanol[i] could be used as key substitutes for oil in decarbonising the chemical industry.[72]

Solar thermal can be an efficient means of providing zero-carbon heat and a cost-effective alternative to the electrification of heat. Although solar thermal has been used mainly for low-temperature applications, new designs serve applications with temperature requirements of up to 400°C.[73] However, high initial capital costs and low deployment rates have limited uptake, even in sectors with significant technical and economic potential, such as textiles and food.[74] As of 2022, there were an estimated 136 solar heat projects in industry, most of them in the food and beverage sector, including large-scale projects at malting plants in Croatia, France and Spain.[75] A recent technical development is the commercialisation of a versatile solar hot water solution capable of generating high operating temperatures, including for industrial heating processes.[76]

High-temperature geothermal energy can be used to generate electricity or a combination of heat and power.[77] Direct geothermal use accounted for only 1.6% of the total thermal energy use in industry in 2019, mainly in mining and food manufacturing.[78] Barriers to wider application include resource availability and high upfront costs.[79] The International Geothermal Association has sought to scale direct industrial applications in the agri-food sector in South America and the Caribbean.[80] In Europe, the oil, gas and chemicals company OMV started two geothermal projects in 2022: one in Austria using heat as a direct carrier and one in Germany for electricity generation.[81] In the United States, a research programme aims to replace diesel fuel with geothermal to power mining operations, particularly in remote areas.[82] Meanwhile, start-ups in the United Kingdom are developing technologies to extract lithium using geothermal waters, to replace the energy-intensive extraction practice of heating seawater brine to high temperatures; two pilot sites were expected by spring 2023.[83]

Heat pumps are an energy-efficient alternative to traditional heating and cooling systems and a key technology for electrifying industry.[84] The growing focus on efficiency, combined with the recent rise in fossil gas prices (especially in Europe), could drive market uptake among the three main industrial users of heat pumps: the pulp and paper, food and beverage, and chemicals sectors.[85] However, technical barriers and high initial costs continue to impede more generalised use.[86]

As of 2022, commercial trials of heat pumps operating at 160°C were ongoing, with prototypes also available for heat pumps to achieve 200°C.[87] In the context of the EU-funded PUSH2HEAT project, launched in October 2022, technologies for processes of 90°C to 160°C will be demonstrated at four industrial sites in the food, paper and chemicals sub-sectors, with the aim of increasing the deployment of heat pump technologies for heat upgrade.[88] On the demand side, interest is rising in heat pumps that have additional performance and energy-saving features, such as re-using low-temperature waste heat (for example, from refrigeration processes).[89]

Renewable hydrogen is being discussed mainly in the context of decarbonising energy-intensive processes, in particular in petrochemicals and steelmaking. Despite growing momentum for renewable hydrogen, applications remain limited due to high production costs and the need for related infrastructure.[90] In 2022, two Important Projects of Common European Interest were approved in the context of REPowerEU, aiming to integrate green hydrogen into industrial steel, cement and glass processes.[91] Producing high-value-added products such as renewable ammonia (or steel) for domestic production or for export to the EU is seen as a way to sustainably industrialise countries and boost renewable hydrogen uptake in Africa, particularly in South Africa and other members of the Africa Green Hydrogen Alliance (Egypt, Kenya, Mauritania, Morocco and Namibia).[92]

i Methanol is a key chemical product, contributing to 10% of total greenhouse gas emissions from chemicals. It is produced mainly from oil today but also can be produced from biomass feedstocks, including forestry and agricultural waste and by-products; biogas from landfills, sewage and municipal solid waste; and black liquor from the pulp and paper industry.

SNAPSHOT

PAKISTAN

Making Progress in Decarbonising Industry with Renewables

Pakistan, which experienced devastating floods in 2022, faces an urgent need to decarbonise its industry sector and mitigate the risks of climate change. The country aims to halve its emissions by 2030 while also expanding energy access. A quarter of the population, mainly in rural areas, still lacks access to electricity.

In 2022, several renewable energy initiatives were undertaken to promote economic development while developing local industry. For example, the Nationally Appropriate Mitigation Actions (NAMA) facility provided funding and advisory support to help small and medium-sized businesses invest in energy efficiency and renewables in the textile industry, which is Pakistan's largest industrial employer and contributes around 6% of national greenhouse gas emissions. In the sugar industry, the EU supported a programme to help sugar mills produce their own electricity from sugarcane bagasse and feed surplus power to the grid.

In addition, UNIDO has provided small businesses and micro-enterprises in Pakistan with interest-free loans to procure and install renewables. Under this scheme, the country added 1.3 MW of solar photovoltaics (PV) in 2022, generating 1,825 megawatt-hours of electricity per year. The solar power enabled businesses to improve their productivity and increase incomes 25% on average, while reducing their vulnerability to power outages and eliminating more than 827 tonnes of CO_2 emissions annually. In addition, the UK government, through the Climate Finance Accelerator, announced a programme to install 150 MW of distributed solar PV at commercial and industrial sites under a pay-as-you-go model.

Source: See endnote 63 for this chapter.

Steelmaking using renewable hydrogen has experienced strong momentum globally, with more than 70 projects under development and 10 new projects announced in 2022.[93] Major European manufacturers such as ArcelorMittal and ThyssenKrupp have developed at least 19 pilot and large-scale projects in Europe, including in France, Germany, the Netherlands, Spain and Sweden.[94] In China, which produces over half the world's steel, hydrogen-based projects are being developed in Hebei, Guangdong and Inner Mongolia.[95] Tangshan city announced a plan in 2022 to become a hydrogen production hub and to support local steelmakers in using hydrogen-based direct-reduced iron (DRI).[96] Most of the hydrogen will be produced using coke oven gas, but solar power plants will also be built to produce renewable hydrogen.[97] Overall, however, hydrogen-run DRI plants remain limited.[98] A key factor impeding the conversion to DRI plants in Asia is the relatively young age of the conventional equipment in steel plants, which makes it financially difficult to justify their conversion.[99]

The production of ammonia – a key product in the fertiliser and chemical industries – using renewable hydrogen is still in the early stages of development and commercialisation, and further efforts are needed to improve its cost efficiency and scalability.[100] Around 54 projects exist currently, notably in Australia, Mauritania and Oman, although projects also have been announced in Latin America, particularly in Chile, which is rich in wind and solar energy.[101] The first renewable hydrogen-based ammonia plant became operational in 2021 in Spain, while the first gigawatt-scale renewable ammonia plant is being built in Saudi Arabia and set to begin operations in 2025.[102] In 2022, the Zero Carbon Certification Scheme pre-certified Yara International's green ammonia plant in Western Australia in recognition of the company's commitment to using energy from on-site solar PV.[103]

CHALLENGES AND OPPORTUNITIES

for the Uptake of Renewables in Industry

CHALLENGES

→ Although several **renewable heat technologies** for low-to-medium temperature processes are on the market, fossil fuel-based heating technologies generally remain more cost effective, hindering the adoption of renewable solutions.

→ Renewable technologies for decarbonising **high-temperature industrial processes** remain limited, and further technological development is needed.

→ Many industry sectors are **capital intensive**, with long-lived capital assets. Switching to renewable technologies is expensive due to the long lifetimes of industrial equipment and plants.

→ **Tailoring policy** to the needs and characteristics of different industries is challenging, as the **heterogeneity among sub-sectors**, including in energy use and intensity, impedes having a comprehensive policy.

OPPORTUNITIES

→ **The potential for using industrial heat pumps in low-temperature heat applications is high**; this has the advantage of both reducing costs through energy efficiency and providing low-carbon energy.

→ **Renewable hydrogen can be used in many energy-intensive industries**, where it is challenging to use 100% renewable technologies.

→ **Small and medium-sized businesses** have significant untapped **potential for uptake of renewables**, while simultaneously increasing their competitiveness through cost savings and improved sustainability practices.

→ Investments in decarbonised steel, which may include the use of renewables, are driven by the wish to capture opportunities in incipient green steel markets and **to avoid stranded assets in anticipation of more stringent climate policies.**

6 countries and sub-national jurisdictions announced or up-dated renewable targets for transport in 2022

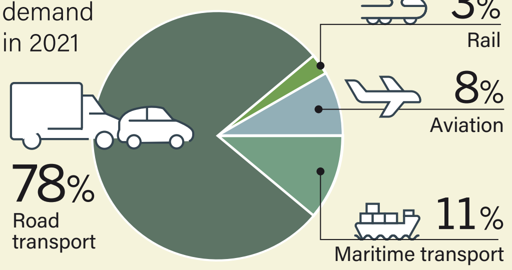
In 2022, total investment in electric transport was equivalent to **80%** of the total investment in renewable energy

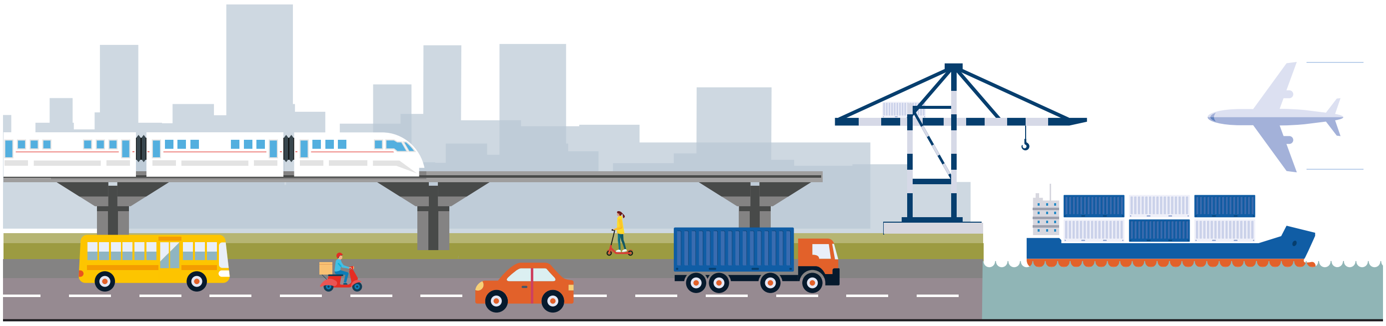
Transport is the fastest growing energy-consuming sector, at an average rate of **2%** per year

10 countries and sub-national jurisdictions **reduced or suspended** their biofuel blending mandates in 2022

Investment in electric vehicles and charging infrastructure was up **54%** in 2022

Breakdown of transport demand in 2021





TRANSPORT IN FOCUS

Module Overview | Policy | Investment | Market Developments | Challenges & Opportunities

MODULE OVERVIEW

Over the past century, global economic growth has been tightly linked with the transport sector, coinciding with the surge and expansion of globalisation. Modern transport has enabled exponential growth in the connections between producers and consumers, and between people and opportunities. In 2021, the transport sector contributed an estimated 7% of the global gross domestic product – some USD 6.8 trillion – and employed 5.6% of the workforce, or 193 million people.[1]

The transport sector consumed 113.4 exajoules (EJ) of energy in 2021, representing around a third of the total energy demand for end-uses.[2] Transport energy demand increased 7.8% during the year but was still 6.6% below pre-pandemic levels.[3] This was due mostly to a 7.7% decline in transport-related oil consumption between 2019 and 2021, even as demand rose for electricity, biofuels and fossil gas.[4]

Road transport consumed the vast majority of transport-related energy (nearly 78%) in 2021, followed by marine transport (11%) and aviation (8%), whereas rail transport consumed far less (3%).[5] Energy use in road transport is dominated by passenger travel, primarily in light-duty vehicles. Passenger aviation represented nearly 7% of the transport sector's total energy consumption in 2021, five times more than air transport for freight.[6] In the railway sector, however, freight transport consumed four times more energy than passenger rail.[7]

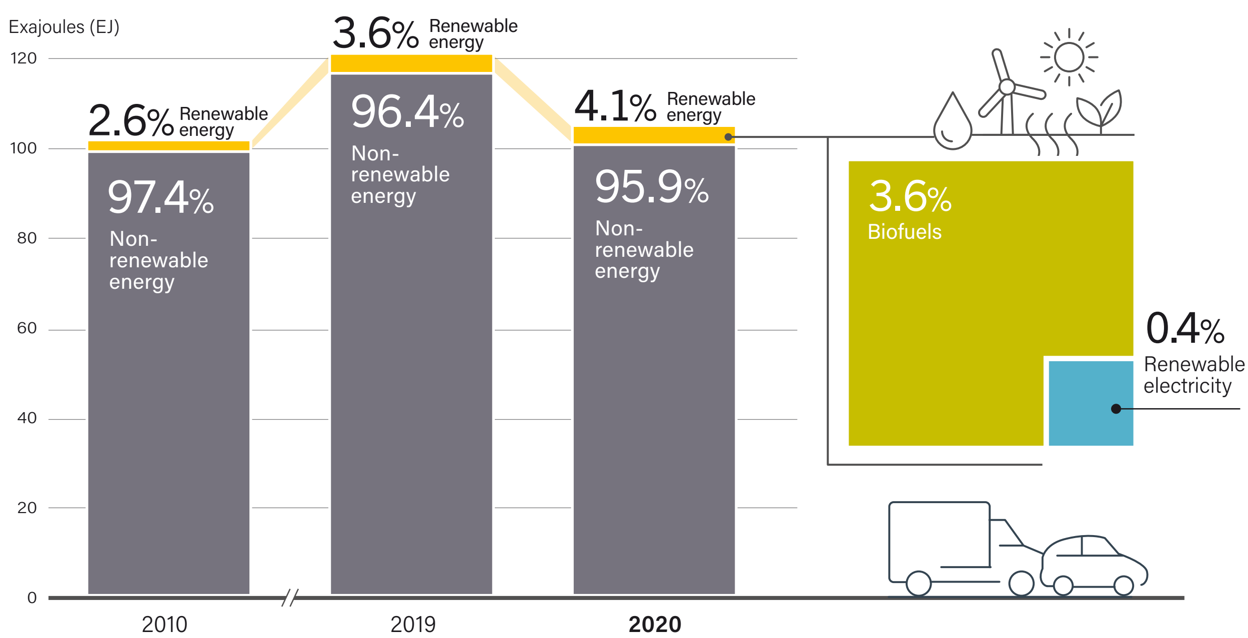
Transport has the lowest penetration of renewable energy among the main end-use sectors (buildings, industry and agriculture).

The transport sector contributes

USD 6.8 trillion

of global GDP and employs 5.6% of the workforce.

FIGURE 9.
Renewable Share of Total Final Energy Consumption in Transport, 2010, 2019 and 2020



Source: See endnote 8 for this module.

In 2020, the transport sector continued to rely heavily on fossil fuels, dominated by oil (90%) and also including fossil gas (nearly 5%).[8] (→ *See Figure 9.*) Renewables accounted for only 4.1% of the sector's total energy consumption, comprising 3.6% biofuels and 0.4% renewable electricity.[9]

Although the demand for biofuels in transport fell in 2020, due mainly to the COVID-19 pandemic, it increased again in 2021 (by 7.8%) to surpass pre-pandemic levels by 2.5%.[10] The use of renewable electricity in transport also grew, rising 7.1% in 2021 and exceeding pre-pandemic levels by 11.9%.[11]

Transport continues to contribute greatly to greenhouse gas emissions.[12] Between 2009 and the start of the COVID-19 pandemic (2019), emissions from aviation and road transport were growing at average annual rates of around 4% and 2%, respectively.[13] By 2021, emissions from road transport nearly resumed their 2019 level, while aviation emissions were still 31.7% below the pre-pandemic peak.[14]

Overall, the transport sector released 7.7 gigatonnes (Gt) of carbon dioxide (CO_2) emissions in 2021, or around 20% of the global total.[15] Transport-related emissions were up 7.8% relative to 2020 but still 7.2 percentage points below pre-pandemic levels.[16] Road transport alone released more than three-quarters of transport emissions in 2021 (76.6%, or 5.9 Gt of CO_2), followed by marine transport (11%) and aviation (9.2%).[17]

Passenger road transport, aviation and trucks are the least-efficient modes of transport, using around 2,000 kilojoules of energy per passenger-kilometre or tonne-kilometre carried.[18] During 2000-2019, the energy intensity of freight road transport increased 11%, indicating reduced efficiency, whereas the energy intensity of cars and airplanes declined, reflecting improvements in efficiency.[19]

A common lens for addressing efficiency in transport is the "avoid-shift-improve" framework, which focuses on boosting the efficiency of: 1) the transport sector as a whole (by "avoiding" traveling where possible), 2) individual trips (by "shifting" transport modes) and 3) vehicles (by "improving" technologies).[20] For example, as the demand for energy grows, public policy and land management strategies can help reduce the need for motorised transport, especially in urban areas.[21] In addition, incentives and investments can shift users towards less energy-intensive modes such as cycling, walking and rail.[22] Finally, improving vehicle technologies and increasing the share of renewables is critical to reducing both energy use and emissions, thus enabling large efficiency gains.

POLICY

Policies to encourage the use of renewable energy in the transport sector include targets, incentives and mandates aimed at increasing the use of biofuels and at boosting vehicle electrification through the integration of renewables. The global momentum towards net zero emission pathways also has driven policy change in the transport sector, although with a stronger focus on decarbonisation than on the penetration of renewables.[23]

During 2022, no new national targets for renewable energy shares were adopted in the transport sector, however, a few countries revised their targets. Two countries raised their targets for the share of renewables in transport by 2030: Portugal from 20% to 29%, and the Netherlands from 14% to 28%.[24] In contrast, Italy revised its target downward from 22% to 16%.[25] At the city level, Curitiba (Brazil) set a target to power 100% of passenger transport with renewables by 2050.[26] In the United States, King County (Washington state) committed to achieving a zero-emission public transport fleet by 2040.[27]

Road Transport

The global energy crisis resulting from the war in Ukraine, as well as high fuel prices at the pump, have motivated policy makers to enact more low-carbon policies for road transport.[28] Although biofuels have been a key focus for decades, the number of new biofuel policies has flattened in recent years. Meanwhile, policies targeting the electrification of road transport have received growing interest. However, incentives for electric vehicles do not necessarily lead to greater renewable energy uptake unless they are aligned specifically with efforts to increase renewables in the electricity mix.

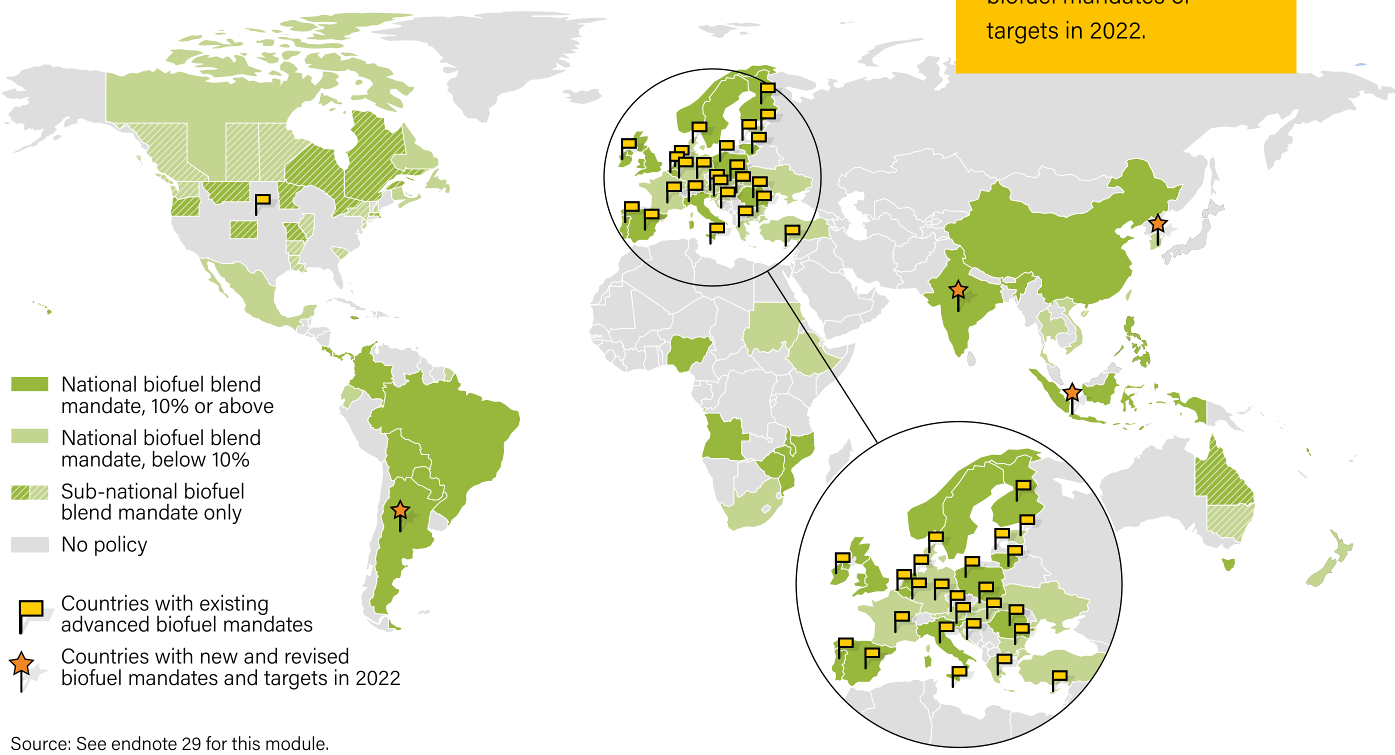
Biofuel blending mandates remain the most common policy for advancing renewable fuels in transport. As of the end of 2022, a total of 56 countries and 30 sub-national jurisdictions had in place biofuel blending mandates (→ *see Figure 10*); this was down from 65 countries in 2021, due to temporary suspensions of mandates in some countries.[29]

Some countries updated their policies. Four countries – Argentina, India, Indonesia and the Republic of Korea – increased their biofuel mandates or targets in 2022. To reduce reliance on oil imports, India amended its national biofuel policy by increasing the ethanol blend in petrol to 20% by 2025-2026 (five years ahead of schedule) and allowing for additional feedstocks in biofuel production.[30] The Republic of Korea raised its biofuel blend mandate for road transport from 3% to 3.5%, and in the United States the Environmental Protection Agency proposed updating the national renewable fuel policy to mandate higher volumes.[31]

During 2022, 10 national and sub-national jurisdictions either temporarily reduced their biofuel blending mandates (Brazil, Colombia, Finland, Mexico and Thailand) or suspended them (Czech Republic, Latvia, Peru, Zimbabwe and the US state of New Mexico).[32] In some cases, countries scaled back their mandates

4 countries (Argentina, India, Indonesia and the Republic of Korea) **increased** their biofuel mandates or targets in 2022.

FIGURE 10.
National and Sub-National Renewable Biofuel Mandates and Targets, as of End-2022



Source: See endnote 29 for this module.

because of rising prices for vegetable oil. Brazil's National Energy Policy Council opted to extend the existing mandate of 10% for a longer time period, rather than increasing it.[33]

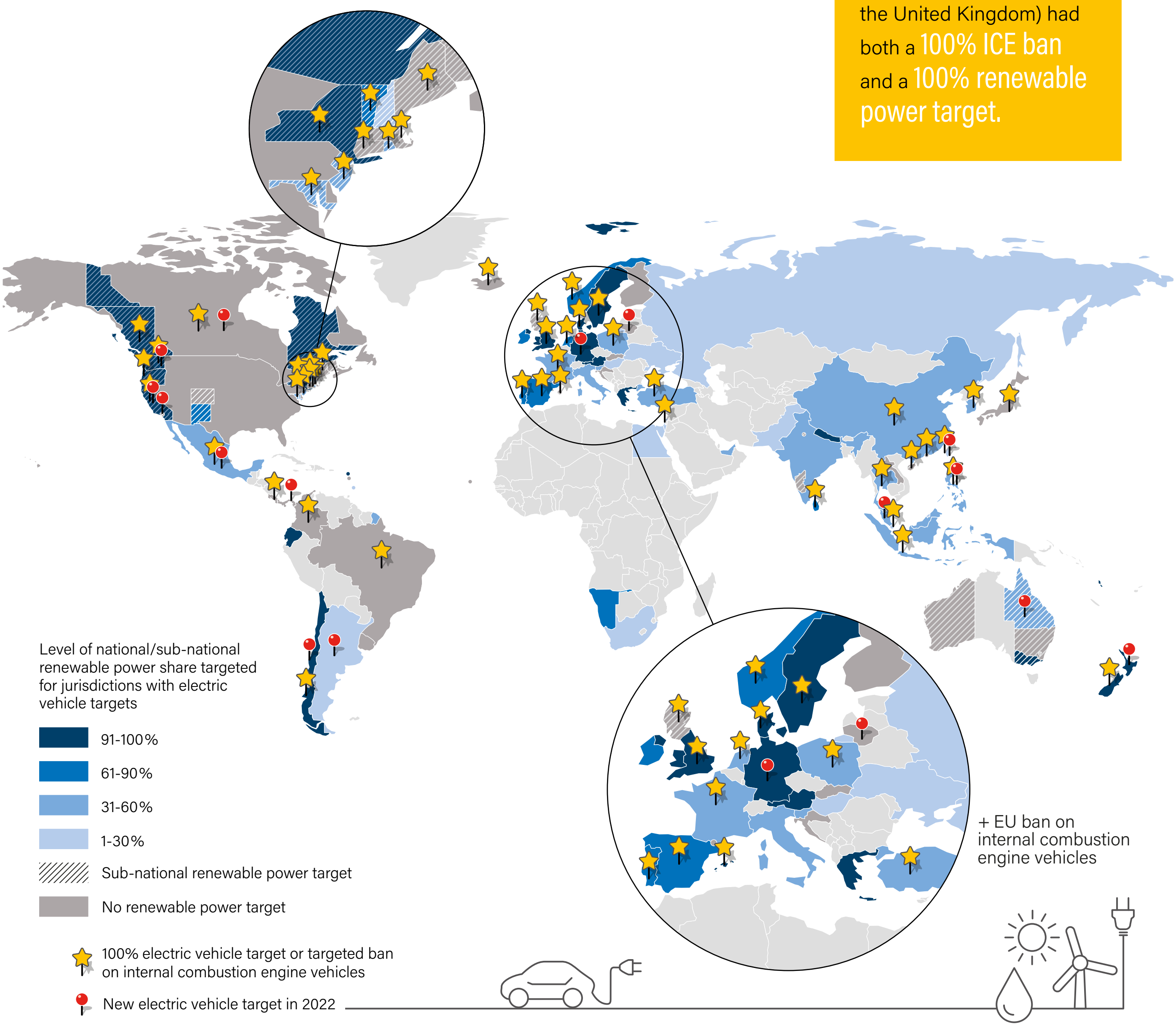
Momentum for the electrification of vehicles is growing, with support policies ranging from tax incentives and stimulus packages to specific targets for **electric vehicles**. By the end of 2022, a total of 23 national and 17 sub-national jurisdictions had 100% bans on internal combustion engine vehicles.[34] (→ *See Figure 11.*)

Early in the year, Thailand rolled out a set of exemptions or reductions of import duty and excise tax, as well as conditional subsidies, for imported electric vehicles; these measures build on the target set in 2021 to produce domestically 250,000 electric vehicles, 3,000 electric public buses, and 53,000 electric motorcycles by 2025, and 1.2 million electric vehicles by 2036.[35] In the Philippines, the Electric Vehicle Industry Development Act entered into law, offering fiscal incentives for the manufacture of electric vehicles.[36] The US Environmental Protection Agency amended its renewable fuel policy to include, for the first time, a pathway for electric vehicle manufacturers.[37]

As support for COVID-19 stimulus packages continued in 2022, some countries provided ongoing incentives for electric vehicle purchases. France and Germany, among others, now offer consumers an environmental bonus for buying an electric vehicle, often financed through a tax collected on the sale of internal combustion engine vehicles.[38] A few countries revised

5 countries (Chile, Denmark, New Zealand, Sweden and the United Kingdom) had both a **100% ICE ban** and a **100% renewable power target.**

FIGURE 11.
Targets for Renewable Power and Electric Vehicles, as of End-2022



Source: See endnote 34 for this module.

down their vehicle electrification targets. For example, Germany adjusted its initial target of having 15 million exclusively battery electric vehicles on the road by 2030, so that it also includes plug-in hybrids.[39]

Policies for charging infrastructure also gained attention during the year. The US Department of Transportation proposed standards for a National Electric Vehicle Charging Network that includes using renewable electricity for charging.[40] In France, new legislation makes it mandatory for parking lots that have 80 spots or more to install solar photovoltaic (PV) systems for electric vehicle charging within three to five years.[41]

Hydrogen production for road transport is seen as suitable for use in heavy-duty vehicles that drive long distances. India launched a Green Hydrogen and Green Ammonia Policy in February 2022 and also announced a National Hydrogen Mission, with specific mention of the transport sector.[42]

Bans on internal combustion engine vehicles provide indirect policy support for renewables. In 2022, 17 new and revised electric vehicle targets and policies were announced, covering 16 countries and 1 sub-national jurisdiction (the US state of Minnesota), with 6 of the countries (Canada, Chile, Chinese Taipei, Mexico, New Zealand and the Philippines) announcing 100% bans on internal combustion engine vehicles by a specified year.[43] Chile and New Zealand also have targets for 100% renewable power (across all sectors).[44] The European Union (EU) approved a ban on the sale of all new petrol and diesel cars from 2035.[45]

Aviation, Rail and Shipping

Despite growing efforts to incorporate renewables into aviation, rail and shipping – such as by using biofuels in aviation and developing electric and hydrogen-powered trains – policies supporting these initiatives remain nascent and face significant challenges. The use of renewables also has been limited by the heavy reliance on fossil fuels in these sectors. In some cases, policies have impeded the development of low-carbon alternatives: for example, the EU continues to provide tax exemptions for kerosene fuel used in aviation.[46]

In 2022, there was growing emphasis on policies supporting sustainable aviation fuel, or SAF, defined as fuels produced from sustainable feedstocks that have similar properties to conventional aviation fuel. With more countries and airlines committing to net zero emissions, SAF is increasingly seen as the way forward for decarbonising aviation.[47]

The EU and the United States have led the way in SAF policies. In December 2022, the EU's the ReFuelEU Aviation package of legislative proposals includes a blending mandate for aviation fuel suppliers starting in 2025.[48] The United States adopted legislation in August that includes a two-year blender tax credit and a two-year production tax credit for SAF, along with a grant programme of USD 290 million.[49] Subsequently, the US Department of Energy issued the SAF grand challenge roadmap, which details the country's strategy to reach its SAF targets.[50]

Denmark announced plans to make all domestic **flights fossil fuel-free** by 2030 and is considering a range of technological options to achieve this, including synthetic paraffin, battery-electric and fuel cell-electric aircraft.[51] In a similar push to reduce emissions, France banned all short-haul flights if there is an existing rail alternative of less than 2.5 hours' duration.[52] Concurrently, the French national railway company signed a 25-year power purchase agreement (PPA) to secure enough solar PV power to cover 3.6% of its annual energy use; this brings to seven the total number of solar PPAs the company has signed in recent years.[53] The rail company is aiming for a 40-50% renewable energy mix by 2026.[54]

In the shipping sector, several **green shipping corridors** – where zero-emission solutions are in place along key maritime trade routes – were announced in 2022. These include the Los Angeles-Long Beach-Singapore Green and Digital Shipping Corridor, the Republic of Korea-US Green Corridor, the Rotterdam-Singapore Green Corridor and, notably, the Shanghai-Los Angeles corridor.[55] (→ *See Snapshot: US-China.*) These are among several worldwide initiatives and commitments made in the shipping industry following the signing of the Clydebank Declaration (on the establishment of green shipping corridors) at the United Nations climate conference in Glasgow, Scotland in 2021.[56]

SNAPSHOT

US-CHINA

World's First Trans-Pacific Green Shipping Corridor Between Los Angeles and Shanghai

In 2022, the Port of Los Angeles in the United States and the Port of Shanghai in China announced a strategic partnership to create a green transport corridor to reduce emissions from one of the world's busiest container shipping routes. The alliance aims to phase in low-carbon fuels in order to achieve zero-carbon container ships by 2030. It was facilitated by the C40 Cities Climate Leadership Group and involves authorities from both cities as well as industry partners, including shipping companies and a network of cargo owners.

This alliance represents a step forward in promoting long-term decarbonisation solutions for shipping. The shipping sector is responsible for up to 3% of global greenhouse gas emissions, and emissions from the sector are expected to double by 2050. In 2020, an estimated 21% of the total of 31.2 million containers moved by ship across the Pacific Ocean travelled along the Trans-Pacific corridor. Introducing low- and zero-carbon fuel ships on this busy transport route can potentially reduce a large share of the sector's emissions.

In addition to phasing in low- and ultra-low-carbon fuel ships in the 2020s and operating the first zero-carbon container ships by 2030, the Los Angeles and Shanghai Green Shipping Corridor Association aims to develop best management practices to improve the efficiency of all ships that use the corridor and to reduce emissions from the port operations supply chain to improve air quality.

Source: See endnote 55 for this module.

INVESTMENT

Global investment in **biofuels**[i] reached an all-time high in 2021 then fell slightly in 2022, to USD 5.84 billion.[57] Biofuel investment has been hampered by rising prices and declining demand, due in part to disruptions related to the COVID-19 pandemic, rising energy efficiency, surging electric vehicle sales, behavioural change and suspensions in biofuel mandates.[58] However, investor interest has increased in Brazil, a leading biofuel-producing country, due to higher ethanol prices and the possibility of merging or acquiring struggling smaller companies to harness the country's idle capacity.[59]

i Data are from BloombergNEF and include all biofuel projects (bioethanol, biodiesel, renewable diesel and sustainable aviation fuel) with an annual production capacity of 1 million litres or more.

A growing number of refineries that produce **renewable diesel,** also known as hydrotreated vegetable oil or HVO, received investment in recent years, particularly in the US states of California and Oregon.[60] In 2022, Phillips 66 announced a USD 850 million investment to convert its crude oil refinery in Rodeo, California to one that processes renewable diesel, biofuels and SAF.[61] Two state-level policies – the California Low Carbon Fuel Standard and Oregon's Clean Fuel Program – have fuelled this US growth.[62] Also in 2022, Brazil Biofuels announced a BRL 2.2 billion (USD 410 million) investment in a biorefinery that will use palm oil harvested in the Amazon region[i] to produce HVO, with support from the Banco Nacional de Desenbvolvimento Economico e Social (BNDES).[63]

Global investment in **electric vehicles** and related charging infrastructure surged 53.6% in 2022 to reach USD 466.1 billion. The largest investment was in China, totaling USD 234 billion, followed by the United States with USD 57 billion.[64] (→ *See Figure 12.*) This rapid growth reflects a mix of policy support for electrification in core auto markets, improvements in battery technologies, the expansion of charging infrastructure and new compelling vehicle models from automakers.[65] The investment surge occurred despite a sharp increase in the prices of electric vehicle batteries due to higher raw material and component costs and soaring inflation.[66]

Investment in SAF, although in the early stages, also attracted growing attention, driven by net zero commitments and related policy support for the aviation industry. Neste, one of the world's largest SAF producers, issued its first seven-year green bond in 2021, allocating EUR 16 million (USD 17 million) for a refinery in Rotterdam (Netherlands) and EUR 278 million (USD 297 million) for one in Singapore.[67] In 2022, Saudi Arabia's Alfanar Group announced that it would invest USD 1.3 billion in a project in Teesside (United Kingdom) that would eventually produce 180 million litres of SAF.[68] Airlines also are investing in more novel technologies and feedstocks[ii], either on their own or as a part of an airline alliance.[69]

Investment in biofuels

fell slightly in 2022 to USD 5.84 billion, after reaching an all-time high in 2021.

Finance for **electric aircraft** is also on the rise, although it is comparatively nascent. In 2021, United Airlines announced the purchase of 100 electric planes.[70] In 2022, Air Canada announced the purchase of 30 electric aircraft, plus a USD 5 million equity stake in the manufacturer Heart Aerospace.[71]

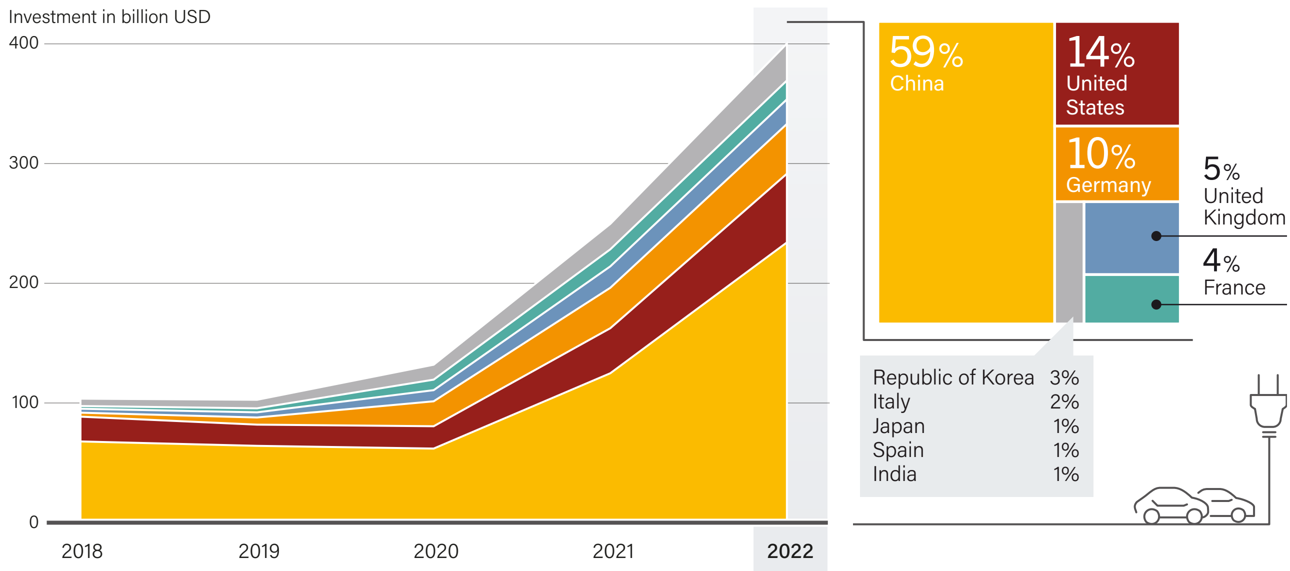
In the **rail sector**, investments in renewables have focused mainly on electric-based systems. In 2022, the Austrian Federal Railway (ÖBB) announced a EUR 1 billion (USD 1.07 billion) investment in hydropower, wind power and solar PV projects to supplement its existing renewable energy systems.[72]

Although some efforts are under way to push renewable options in the shipping sector (for example, wind-powered vessels), investment has been hampered by the lock-in of investment in existing, fossil fuel-based shipping fleets.[73]

i This project conforms with the Brazilian law stating that palm oil can only be cultivated in areas that were deforested before 2007; however, environmentalists have criticised the investment and describe oil palm as a proven predatory crop that leads to enormous biodiversity loss. See endnote 63 for this module.

ii Gasification Fischer-Tropsch and other processes that use biomass, landfill waste and ethanol-to-jet are emerging as alternatives.

FIGURE 12.
Investment in Electric Vehicles by Major Country, 2018-2022



Source: See endnote 64 for this module.

MARKET DEVELOPMENTS

The transport sector moves an estimated 60 trillion passenger-kilometres of people and nearly 150 trillion tonne-kilometres of freight annually.[74] These volumes are expected to more than double by 2050.[75] Asia (in particular China) is the main driver of transport demand for both passengers and freight, followed by North America and Europe.[76] Transport demand in sub-Saharan Africa is expected to increase sharply, with passenger-kilometres rising from around 2 trillion in 2015 to 10 trillion in 2050, and freight tonne-kilometres rising from around 1 trillion in 2015 to more than 3 trillion in 2050.[77]

Transport accounted for around 29% of global energy use in 2020, and in most countries it is either the first or second largest energy-consuming sector.[78] The Asia-Pacific region and North America together accounted for more than half of all transport energy use in 2022.[79] The United States consumed an estimated 23.3 EJ, followed by China (15.2 EJ) and India (4.4 EJ).[80] The Asia-Pacific region experienced the highest average annual growth in transport energy demand between 2011 and 2019, at 4.7%, driven largely by India and China (where growth exceeded 6%).[81] Africa and Latin America and the Caribbean had the lowest demand, although Africa witnessed the second highest growth, at 3.7%.[82]

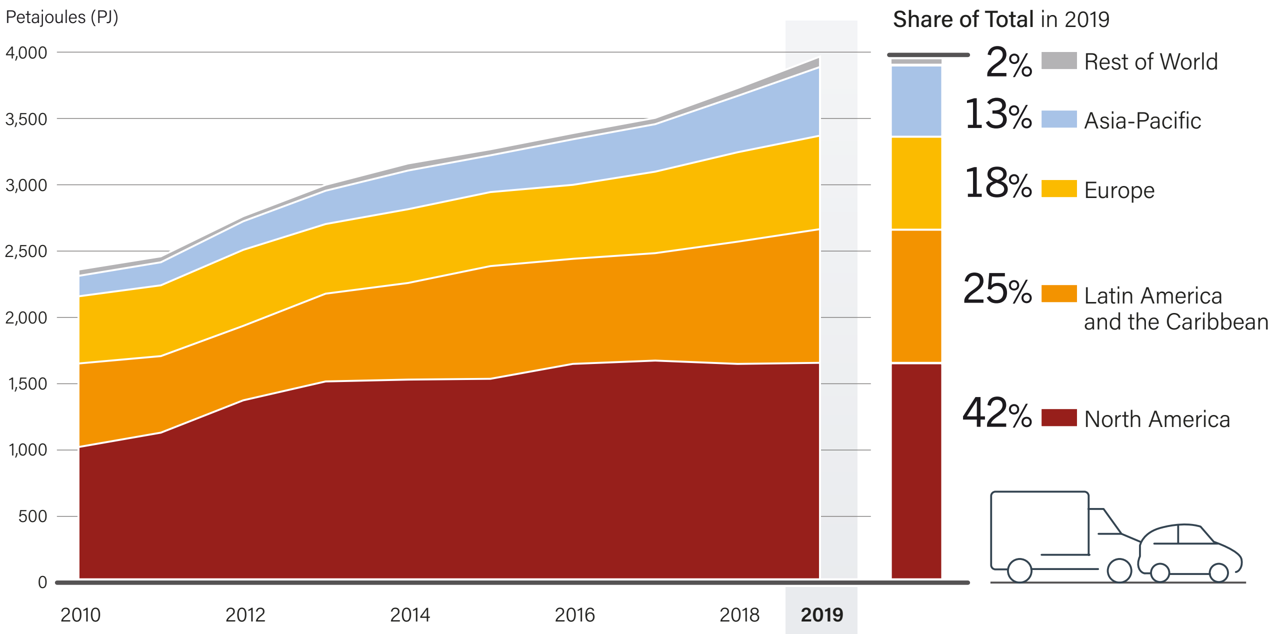
The Asia-Pacific region also has the fastest growing use of renewables in transport, with demand increasing 13.9% annually on average between 2010 and 2019.[83] (→ *See Figure 13.*) In 2019, the leading countries in Asia were Indonesia (around 0.17 EJ of renewables) and China (around 0.12 EJ).[84] The United States, the largest consumer of renewables for transport, represented around 40% of global demand, or 1.6 EJ.[85] The second largest consumer was Brazil, with 0.9 EJ, while in Europe, three countries – France, Germany and Spain – together accounted for 44% of the regional consumption.[86]

Road transport contributes nearly a fifth of global CO_2 emissions, with automobiles, vans and two- and three-wheelers together accounting for 68% of that share.[87] By using existing data on the production, sale and use of these light-duty vehicles, it is possible to approximate the evolution of energy use in transport and the overall targets to be pursued.

Globally, nearly 60 million new cars were sold in 2022.[88] The Asia-Pacific region led the market with a 61% share, followed by Europe at 25%.[89] By country, China sold the largest share of new cars worldwide (38%, or more than 21 million) in 2021 (latest data available), followed by Japan, the United States, India and Germany, at between 4% and 6% each.[90]

The highest rates of vehicle ownership are in the United States, New Zealand, Canada, Australia, Japan and European countries, at between 600 and 900 vehicles per 1,000 inhabitants, suggesting that as countries develop, vehicle ownership worldwide will only

FIGURE 13.
Renewables in Transport, by Region, 2010-2019



Source: See endnote 83 for this module.

Asia-Pacific has the fastest growing use of renewables in transport, with a 13.9 % annual increase between 2010 and 2019.

continue to rise.[91] This points to the need to target more policy and investment at delivering accessible, good-quality public transport infrastructure and services to help decouple economic growth and vehicle ownership and reduce emissions.

Biofuels account for around 90% of the renewable energy use in transport, with average annual growth of 5% between 2010 and 2020.[92] Biofuel consumption fell 4% in 2020 but is expected to grow significantly in the coming decade (potentially four-fold, by some estimates).[93] Much of this rise will likely be driven by blending mandates and regulations that increase the share of biofuels in blends.

Transport fuels produced from advanced biomass feedstocks provide a short-term option towards decarbonising aviation and maritime transport as well as heavy-duty trucks and public buses.[94] (→ *See Snapshot: Spain.*) The EU's ReFuelEU Aviation initiative proposes raising the required share of SAF used in flights departing from the EU to 2% in 2025 and 63% in 2050, which could accelerate changes globally.[95] More ambitious targets could be set in the future, following successful test flights in 2022 of commercial aircraft running entirely on SAF, resulting in life-cycle emission reductions of 80%.[96]

Renewable electricity accounts for 10% of the renewable energy used in transport, with average annual growth of 7% between 2010 and 2020.[97] Overall electricity demand in the sector grew at an average rate of 3.6% per year.[98] In 2020, despite the slowdown in electricity use in transport (down 3% compared to 2019), the demand for renewable electricity in the sector grew 5.4%.[99]

Electric cars accounted for 15-18% of all new automobiles sold in 2022, reflecting the steep sales growth in recent years.[100] China alone registered around half of the estimated 10 million electric vehicles sold globally in 2022.[101] In just a five-year period, electric car sales grew 10-fold in China and 18-fold in the Republic of Korea.[102] In Europe, around 17% of all automobile sales were electric in 2022, with this share reaching 86% in Norway.[103] In Germany, the electric car fleet grew nearly 30-fold between 2016 and 2021, at an average annual rate of 109%.[104]

Although electric vehicle sales have focused mainly on light-duty passenger vehicles, annual sales of **electric buses** are projected to triple by 2025, and electric trucks to grow 13-fold, to reach a combined 468,000 units.[105] By the end of 2022, the number of **electric two- and three-wheelers** exceeded an estimated 250 million worldwide, dominated by the Asian market; China alone has around 195 million electric two-wheelers, while in India nearly 40% of three-wheelers are electric.[106] These increases are driven mostly by battery electric vehicles, whereas plug-in hybrids have shown only modest growth.[107]

Concerns about costs, range, prolonged charging times and a lack of dense charging networks have all hampered greater adoption of electric vehicles.[108] This is especially true for electric trucks, which are crucial to cutting transport emissions because trucks are the least-efficient transport mode in energy use per tonne-kilometre.[109] In the medium term, promising advancements include greater government investment in charging networks, as well as technology innovations that point to much faster charging times.[110] Prototype vehicle-integrated solar PV modules are being tested to improve electric vehicle ranges by 800 kilometres per year and electric trucks ranges by 10,000 kilometres per year.[111]

In another industry development, the European ISO 15118-20 standard for vehicle-to-grid technology was published in 2022, supporting communication between electric vehicle batteries and the power grid. Such communication will enable efficiency gains in charging operations as well as the use of electric vehicles as distributed energy sources that supply power to the electricity grid, contributing to grid stability.[112]

In 2021, the stock of hydrogen-powered **fuel cell electric vehicles** was still very small, at 51,600 units, with 82% of these being automobiles and the rest being trucks and buses.[113] Although fuel cell electric vehicles are less efficient than battery electric vehicles, they are a plausible option for cutting emissions from heavy road transport in the medium term.[114] Advancements in fuel cell technology have enabled ranges of up to 1,500 kilometres and faster tank fill-up, and efforts are progressing to green the production of hydrogen and make it more efficient.[115] China has led the way, with buses and trucks comprising most of its hydrogen fleet, and a network of 146 charging stations in 2021.[116]

Globally, however, less than 1% of the hydrogen that is currently supplied across sectors is low-emission – produced mainly from bioenergy and from fossil fuels using carbon capture, utilisation and storage technology.[117] To meet future demand, the hydrogen obtained from these two sources, and especially zero-emission hydrogen, must increase significantly, alongside efforts to produce renewable hydrogen through electrolysis. This will require adding up to an estimated 700 gigawatts of electrolyser capacity by 2030.[118] If achievable, the shift to renewable hydrogen could play an important role in reducing emissions in maritime transport and aviation in the coming decade.[119]

SNAPSHOT

SPAIN

Transitioning from Polluting Compressed Fossil Gas to Biogas

In 2022, Madrid City Council in Spain announced a project to power city buses with biomethane generated by the Valdemingómez Technology Park, one of the largest waste treatment plants in Europe. Since the 2000s, Madrid Municipal Transport Company (EMT) has used compressed natural gas (CNG) buses to replace its diesel units. Although CNG improves urban air quality by reducing nitrogen oxide pollutants, it does not reduce CO_2 emissions. The use of biomethane, a biofuel obtained from organic waste transformed through anaerobic digestion processes, contributes to reduced emissions while performing similarly to fossil gas.

During 2023, the Valdemingómez Technology Park will supply at least 6 gigawatt-hours (GWh) of biomethane to a fleet of 20 CNG buses for the C1 circular line, one of the network's busiest. In 2021, the C1 line covered more than 1 million kilometres and transported around 4.4 million passengers. The Park was recently renovated to increase its biomethane production capacity to 180 GWh per year, equivalent to the fossil gas consumption of 20,000 Spanish homes or 500 EMT buses. The plant's waste treatment services represent an estimated reduction of more than 43,500 tonnes of CO_2-equivalent emissions annually.

The initiative is made possible through an agreement between EMT and the Valdemingómez Technology Park, with the participation of private groups such as PreZero (the company in charge of the biogas treatment plant at the Park) and the trading company Axpo. The project has secured EUR 285,000 (USD 305,000) in grant financing from the Madrid Business Forum, a public-private platform for business development. The initiative is part of the Madrid City Council's Circular Mobility Project and EMT's Strategic Plan, and is also aligned with the Madrid 360 Environmental Sustainability Strategy, which aims to reduce the city's emissions through programmes such as sustainable mobility.

Source: See endnote 94 for this module.

CHALLENGES AND OPPORTUNITIES
for the Uptake of Renewables in Transport

CHALLENGES

- Current renewable energy production **is not keeping pace** with the rapid growth in energy demand for transport, especially in emerging regions.
- Despite the sharp rise in electric vehicle sales worldwide, **most of the electricity** used to power battery electric vehicles and to produce hydrogen for fuel cell vehicles still **comes from fossil fuels**.
- The increased use of **battery electric vehicles** remains tainted by concerns about **human rights** abuses and the sustainability of **mining for raw materials**, while interest in **crop-based biofuels** is marred by the potential **competition with other land uses**.[120]
- **Solutions are still lacking** to substantially decarbonise the **long-haul truck, aviation and maritime** transport industries.
- **Fuel subsidies** remain one of the biggest barriers to the uptake of renewables in transport, and ongoing **tax exemptions** for kerosene are hindering the development of alternative fuels in aviation.

OPPORTUNITIES

- The **rising price of oil and its intrinsic volatility** – along with government efforts to boost energy independence – can encourage a dramatic increase in renewable energy generation.
- Rising fossil fuel prices and **declining prices for electric alternatives** could further incentivise consumers to shift to electric vehicles.
- Because the **electric vehicle market** is increasingly **consumer-driven** and less dependent on regulation, these vehicles could be a **financially viable** option in countries where public sector support is limited or non-existent.[121]
- Concerns about the **sustainability of mining** and **hydrogen production** for electrified transport could incentivise industry and government to **increase recycling and develop circularity-based business models**.[122]
- Broader acknowledgement of developing countries' limited resources to address **climate change** is driving international organisations and donors to **increase funding** for energy transition projects, including potentially **renewables-based transport projects**.[123]

Most of the electricity used to power electric vehicles and to produce hydrogen fuel cells still comes from **fossil fuels.**

14 countries had renewable energy targets or policies **for agriculture** in 2022

By end-2022, around 15 countries were using **geothermal greenhouse heating** to grow vegetables, fruits and flowers

The **EU** launched a tender in 2022 for the incorporation of renewables in agriculture and forestry

The use of biogas in agriculture **doubled** during 2010-20, while the use of liquid biofuels grew **9.4 times**

7 countries had financial incentives for the use of renewables for irrigation as of end-2022

AGRICULTURE IN FOCUS

Module Overview | Policy | Investment | Market Developments | Challenges & Opportunities

MODULE OVERVIEW

Agriculture, forestry, fisheries and aquaculture[i] contributed around 4.3% of the world's gross domestic product in 2021.[1] The agriculture sector[ii] employed just over a quarter (26.6%) of the total global working population that year.[2] The highest shares of agricultural employment were in Africa (51.8%) and South Asia (41.5%), followed by Southeast Asia and the Pacific (27.8%), North Africa (23.7%), East Asia (22.2%) and Central and West Asia (20%).[3] Employment in agriculture was below 15% in each of the remaining world regions: Latin America and the Caribbean (14.5%), the Arab States (9.5%), Eastern Europe (8.2%), Northern, Southern and Western Europe (3.1%) and North America (1.6%).[4]

In 2020, agriculture and forestry accounted for around 3% of the world's total final energy consumption, and fisheries represented around 0.07%.[5] Of the total energy use in agriculture, around 73.3% was in the form of heat.[6] Meanwhile, fishing is one of the world's most energy-intensive food production methods, relying almost entirely on fossil fuels.[7] In 2022, the annual fuel consumption of the European Union's (EU) fishing fleet alone was nearly 2 billion litres.[8]

Energy use in agriculture, fisheries and aquaculture contributed around 1 gigatonne of carbon dioxide (CO_2)-equivalent emissions in 2020, including direct emissions from burning fossil fuels and indirect emissions from electricity generation.[9] Nearly 94% of these total emissions were CO_2, and nearly half were from electricity use.[10] Emissions from these sectors have increased over the past two decades.[11]

i When this module presents combined figures for more than one of these sub-sectors, this was either the only information available, or the most accurate. "Agriculture" includes on-farm crop and livestock production and on-site small-scale processing activities. Energy use in agriculture includes fuels to operate machinery and tractors. Energy use in "agriculture" does not include energy used for manufacturing of machinery, pesticides, or fertilisers, nor does it include energy used for food packaging, processing or transport. Forestry does not include the manufacture of wood and wood products and the pulp and paper industry. Energy used for fisheries includes all forms of energy used onboard fishing vessels, including the fuels to operate the vessels. These fuels are not included in the GSR 2023 Transport module.

ii Percentage of total working global population in agriculture as defined by the International Labour Organization, which may differ from the definition of agriculture (agriculture, forestry, fisheries and aquaculture) as presented in the GSR 2023.

The share of renewable energy used in the agriculture sector grew from 10.2% in 2010 to 15.4% in 2020.[12] (→ *See Figure 14.*) Of the renewable share in 2020, 59% was renewable electricity, 7% was solar thermal and geothermal heat, and 34% was modern bioenergy.[13] The use of modern bioenergy in agriculture has remained nearly flat, rising from 5.2% in 2010 to 5.4% in 2020.[14] Within the bioenergy segment, the share of solid biofuels fell sharply, from 94.3% to 78.7%, while the share of biogas increased from 4.06% to nearly 8% and the share of liquid biofuels surged from 1.6% to 13.4%.[15] Overall, the renewable electricity share in agriculture increased from 4.7% to 9.0% of the sector's total final energy consumption, and the use of solar and geothermal heat rose from 0.2% to 1%. [16]

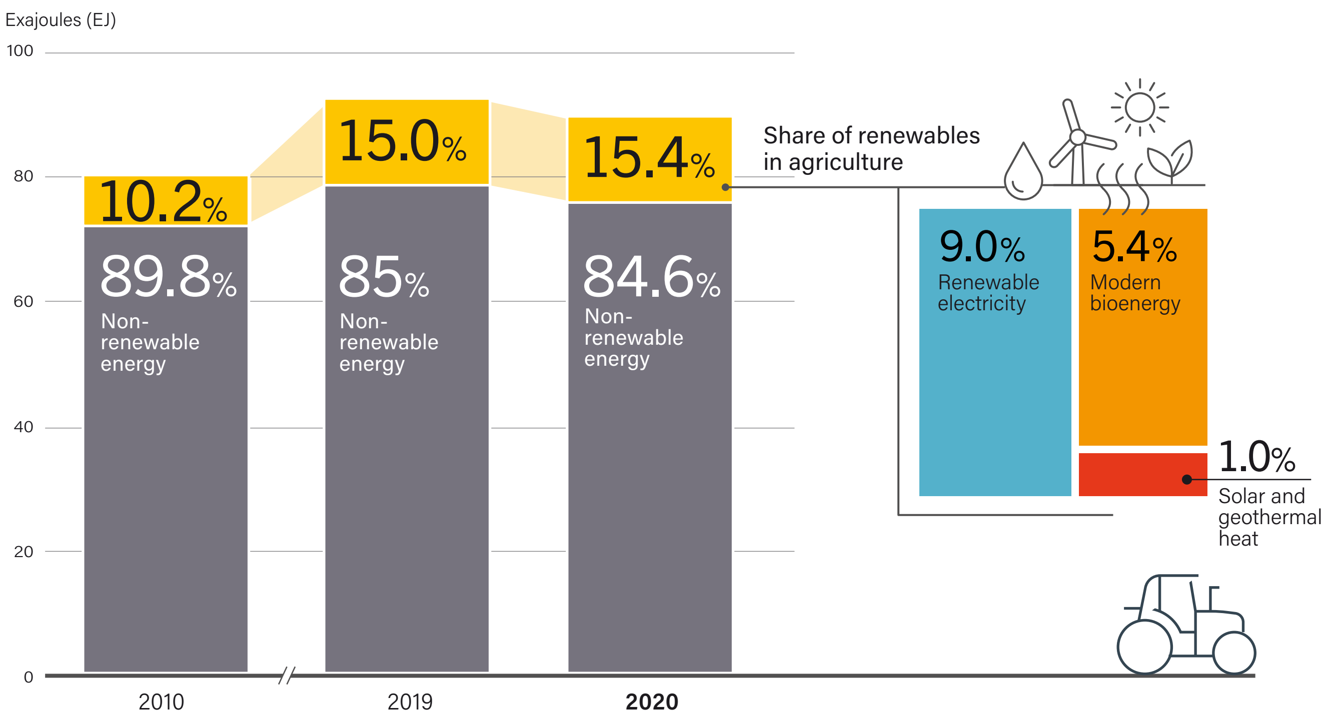
Key drivers of technological developments in the agriculture and fishery sectors have included the desires to reduce fuel costs and save energy, as well as to increase access to energy for farmers and fishers.[17] In the fisheries sector, technological developments in vessels, gear and operations – such as the use of LED lighting for night fishing – have brought cost savings to fishers in Asia, Southern Africa and the Caribbean, among other places.[18] Additional key topics of discussion in 2022 included the need to decouple food production from fossil fuels and the need to scale up investment in renewables in the agri-food sector to reach last-mile farmers and support their energy transition.[19]

In rural areas, the lack of access to a reliable power grid has driven farmers to embrace renewable alternatives.[20] Off-grid renewable cooling technologies have helped reduce massive post-harvest losses of agricultural products, allowing farmers to expand their market reach and gain power in price negotiations, as they are less constrained by time.[21] Renewable technologies also allow rural populations to adopt time-saving revenue-generating solutions, such as small-scale solar milling in place of large-scale diesel-powered mills.[22] Through the use of geothermal heating for greenhouses – for example, in Iceland – farmers can grow produce locally, helping to avoid domestic reliance on costly imports.[23]

These drivers, many of them economic, have led farmers, fishers, multilateral organisations and donors to take greater interest in energy efficiency and renewable energy technologies for agriculture and to support their deployment across the globe.

> The agriculture sector contributes to
> **USD 4.2 trillion**
> of global GDP and employs
> **26%** of the workforce.

FIGURE 14.
Renewable Share of Total Final Energy Consumption in Agriculture, 2010, 2019 and 2020



Source: See endnote 12 for this module.

POLICY

Agricultural and renewable energy policies often operate in silos and can sometimes be in conflict.[24] Policies related to renewables in agriculture target a wide range of technologies, including renewable electricity generation for agricultural processes, solar water pumping, renewable fuels to run agricultural equipment, renewable heat for food processing and solar thermal energy to heat greenhouses. Net zero pathways and the push for decarbonisation have driven how policies are designed in the agri-energy space, along with energy efficiency measures, especially in food processing and the cold chain.[25] Water availability also is essential in the design of evidence-based policies (policies based on and informed by rigorously established evidence for the agri-water-food nexus).[26]

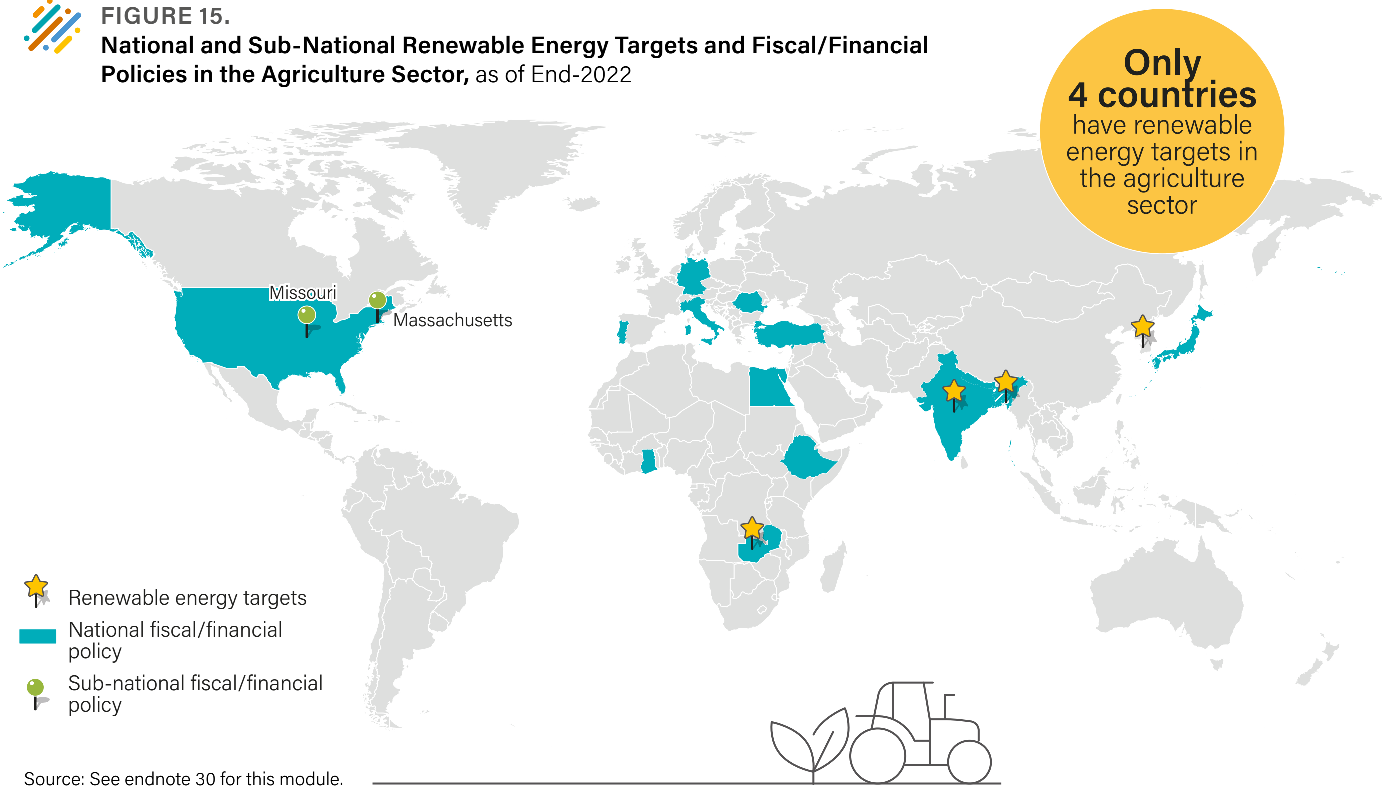
Overall, policies aimed at the uptake of renewables in agriculture have increased.[27] In some cases, governments have used renewable energy mandates and targets to require that a certain share of energy used in the sector be generated from renewables. In 2022, India announced a target for zero diesel use in agriculture by 2024, with the goal of replacing diesel generators for pumping and food processing, as well as other diesel uses, with renewables.[28] As of the end of 2022, four countries – Bangladesh, India, the Republic of Korea and Zambia – had targets for renewables in agriculture.[29]

The most popular policies for renewables in the agriculture sector are financial incentives such as subsidies and tax credits, in addition to funding programmes. By the end of 2022, a total of 25 national and sub-national jurisdictions had renewable energy policies for agriculture, led by efforts in the United States, India and Bangladesh.[30] (→ *See Figure 15.*) This total included 14 national and 2 sub-national jurisdictions (the US states of Massachusetts and Missouri) with fiscal and financial policies for the use of renewables in agriculture, as well as 7 national and 2 sub-national jurisdictions (the Indian states of Maharashtra and Punjab) with other related enabling policies and programmes.[31]

India has been a leader in the development of renewable energy policies tailored to the agricultural sector. The government's PM-KUSUM scheme, launched in 2019 and extended to March 2026, has encouraged farmers to switch from fossil fuel-based irrigation systems to grid-connected solar pumps by offering a performance-based incentive for exporting pump-generated electricity to the grid.[32] In November 2022, India also announced that it would extend its National Bioenergy Programme to 2026 and include a biogas programme, a waste-to-energy programme that covers industrial waste, and a biomass programme to support co-generation in industries and the manufacturing of briquettes and pellets.[33] In addition, India released a draft framework for distributed renewable energy applications, including addressing the energy needs of the agri-food chain.[34]

Greece revised its grid distribution to allocate up to 30% of its grid availability to net metering for farmers.[35] Türkiye revised its 2019-2023 strategic plan to ease the rules for small-scale solar systems, including exempting solar irrigation projects from a permitting requirement for systems under 125 square metres.[36] In Nigeria, the Rural Electrification Agency's Energising Agriculture Program promotes renewables for irrigation and also links mini-grids and agricultural production.[37]

FIGURE 15.
National and Sub-National Renewable Energy Targets and Fiscal/Financial Policies in the Agriculture Sector, as of End-2022



Source: See endnote 30 for this module.

The debate over competing land uses for agriculture and solar generation has eased as countries increasingly develop regulatory frameworks for agrivoltaics[i],[38] In 2022, Italy launched a USD 1.5 billion scheme for agrivoltaics using funding from the EU Recovery and Resilience Facility.[39] Both Italy and France also released new standards for agrivoltaics, and an Italian court ruled that regional authorities could not deny permits to solar projects on agricultural land without considering the potential for agrivoltaics.[40] The United States allocated a USD 8 million grant for the development of agrivoltaics.[41]

Germany has modified its regulations to encompass agrivoltaics and the use of renewables in agriculture.[42] In January 2022, it passed amendments to no longer exclude agrivoltaics from EU subsidies, given that at least 85% of the land area used for agrivoltaics can be cultivated.[43] Amendments to the German Renewable Energy Source Act also recognise dual land-use solar projects, including agrivoltaics and floating photovoltaics (PV), and support the construction of solar sites to restore degraded moorlands used for agriculture.[44] Starting in 2022, innovation tenders under the Act included provisions for agrivoltaics.[45]

In contrast, the United Kingdom has backed down from agrivoltaics by planning to reclassify the majority of agricultural land so that solar energy development is no longer allowed, with the view that such activity impedes food production objectives.[46]

INVESTMENT

In general, data on renewable energy investments in the agriculture sector are limited. This includes not only global investment data, but also local-level data on energy flows across agri-food value chains, as well as granular data on spending for farms and non-farm enterprises.[47]

For small and medium-sized actors in agri-food chains, affordability is a significant barrier to the uptake of renewables due to the capital-intensive structure of most renewable energy investments and to the seasonality of farmer incomes.[48] A variety of programmes provide financing for renewable installations in the agriculture sector.[49] In 2022, the impact investment fund Acumen launched the five-year, USD 25 million Powering Livelihoods Using Solar (PEII+) initiative to provide micro-entrepreneurs and smallholder farmers in India and Africa with solar-powered appliances such as mills and irrigation pumps.[50] PEG Africa, a pay-as-you-go operator in Côte d'Ivoire, Ghana, Mali, and Senegal, also offers financing for solar pumps.[51] In Romania, the National Rural Development Programme, launched in 2021, offers funding to support biomass fuels and the use of renewables in agricultural processing.[52]

In the United Kingdom, programmes that provide dedicated funding for renewables in agriculture include the Renewable Energy Investment Scheme, the Countryside Productivity Scheme, the Renewable Heat Incentive and the Energy Crops Scheme.[53] In the United States, the Renewable Energy for America Program offers renewable energy grants of between USD 2,500 and USD 1 million, as well as loans to agricultural producers and rural small businesses for investments in renewables.[54]

Farmers and agricultural suppliers are investing in solar thermal and other renewable energy projects, in part to alleviate the effects of rising fossil fuel prices and supply shocks.[55] In Guanajuato, Mexico, a MXN 9.5 million (USD 0.5 million) parabolic trough

Greece
revised its grid distribution to allocate up to 30% of its grid availability to net metering for farmers.

i Agrivoltaics entails the use of agricultural land simultaneously for crop production or grazing and for electricity generation from solar PV, thus increasing land-use efficiency. Among other benefits, agrivoltaics can reduce the need for irrigation by retaining moisture in soils and protecting soils from hail, frost and drought. See endnote 38 for this module.

solar system began providing steam for food processing in 2021 through an innovative financing model in which the client pays monthly per tonne of steam used, thereby avoiding the upfront cost of the system.[56] In Argentina, where fossil gas prices are highly subsidised, multinational corporations motivated by strict CO_2 reduction targets are providing around USD 10 million in financing to support four concentrating solar heat projects, to be used mainly for drying cereals.[57]

In Europe, solar technologies supply heat to the agricultural production value chain. In 2021, a EUR 6 million (USD 6.4 million) solar heat plant was inaugurated in France to provide renewable heat for the drying of grains to produce malt.[58] In Croatia, EUR 7.5 million (USD 8 million) was invested in an industrial solar heat system to pre-heat air used for drying malt, with more than half of the funding coming from the European Commission's Innovation Fund.[59] In Spain, solar technology providers offer heat purchase agreements, which the global beer producer Heineken utilised at its site in Seville.[60]

Investments in agrivoltaics also have increased, building on demonstration projects started in 2004.[61] In New South Wales, Australia, the Clean Energy Finance Corporation provided AUD 5 million (USD 3.5 million) to finance a 350 megawatt (MW) solar PV park on cattle and sheep grazing land.[62]

Investments in geothermal systems have supported diverse applications including greenhouse and soil heating, aquaculture, food drying and milk pasteurisation.[63] In Türkiye, during 2021-2022, USD 10 million was invested in geothermal energy to support a drying facility and soil-less greenhouses in the west, and USD 190,000 was awarded to build geothermal greenhouses in the city of Eskisehir.[64]

MARKET DEVELOPMENTS

Globally, the agriculture, fisheries and aquaculture sectors have adopted a wide range of energy efficiency and renewable energy technologies, including solar PV and solar thermal, geothermal, hydropower and bioenergy.

Solar PV applications offer some of the most developed off-grid solutions for productive uses of energy, from both a technical and a business perspective.[65] **Solar water pumps for irrigation** have huge potential for smallholder operations, and most farmers that have adopted them report an increase in productivity.[66] In 2021, solar pumping capacity totalled 654 MW, led by India (588 MW) and Bangladesh (48 MW) followed by Rwanda (3.3 MW) and Yemen (2.3 MW).[67] In Niger, a project launched in October 2021 is helping farmers install a total of 4.6 MW of solar water pumping capacity to improve irrigation systems.[68]

Development partners and donors have supported **renewable cooling technologies** for the cold chain to keep produce fresh, helping to reduce post-harvest losses and expand the market reach of farmers.[69] In Sub-Saharan Africa and South Asia, farmers in India, Kenya, Nigeria and Rwanda have started using large-scale, solar-powered cold rooms, which help make cooling more affordable.[70] (→ *See Snapshot: India.*) Expanding access to solar water pumps and cold storage technologies could improve the livelihoods of around 22 million smallholder farmers across India and sub-Saharan Africa.[71] The use of **solar thermal** for cooling, refrigeration and food drying in agriculture has remained limited.[72]

Electricity generated from **agrivoltaics** has been used to directly power irrigation pumps and refrigeration as well as processing equipment for agricultural products.[73] The global installed agrivoltaic power capacity surged from around 5 MW peak in 2012 to more than 14 GW peak in 2021, supported in part by national funding programmes in Japan (since 2013), China (since 2014), France (since 2017), the United States (since 2018) and most recently the Republic of Korea.[74] Pilot projects are ongoing to determine the optimal use of the electricity generated.[75]

In fisheries and aquaculture, solar PV systems are being used to charge vessel motors, power aquaculture equipment (such as feeders, pumps, aerators and security lighting) and run processing, ice-making, refrigeration and cold storage appliances, including during transport and retail.[76] German and Vietnamese partners have developed an **aquaculture photovoltaics** (aqua-PV) project to install PV panels above shrimp farming ponds in Vietnam, using the electricity generated on-site to power the aquaculture systems.[77] The aim is to assess the technical and economic feasibility of the concept after studies showed that aqua-PV nearly doubles land-use efficiency.[78] In Norway, two new commercial-scale **floating solar PV** projects are generating electricity to power fish farms off the coast.[79]

Geothermal energy allows farmers to grow crops in difficult environments and to increase food availability and yields through greenhouse and soil heating, food drying, sterilisation, refrigeration, milk pasteurisation and irrigation.[80] By the end of 2022, around

SNAPSHOT

INDIA

Solar-powered Cold Storage to Reduce Food Waste

Food waste has been a major issue in India due to the lack of cold storage and food processing facilities. As of 2022, an estimated 40% of the food produced in the country was wasted. Rural farmers often are forced to sell perishable items as quickly as possible before they become overripe. Extreme weather caused by climate change is putting farmers in an even more difficult situation.

A solar cold storage project implemented by the Science, Technology & Innovation Council in India's Mizoram state has benefited farmers in the village of Kawnzar. The project uses solar PV and ice battery technology to convert water into ice within six hours. The cold storage allows farmers to stock up to 10 tonnes of food, enabling them to store their harvest for longer time periods instead of being forced to sell it cheaply or discard it. The USD 27,100 project, funded by India's Department of Science & Technology, has helped increase the incomes of small-scale farmers while also supporting the adoption of renewables in the agriculture sector. The project falls in line with the country's target to install 500 gigawatts (GW) of renewable energy capacity by 2030.

Similar cold storage systems have been installed throughout India by different companies, including Ecozen, Inficold and Oorja Development Solutions. This activity is expected to scale up further, and solar energy also is being used in food processing such as drying perishable goods, thereby improving the lives of local farmers.

Source: See endnote 70 for this module.

31 countries – including Iceland and the Netherlands as well as emerging economies such as Algeria and Tunisia – were using geothermal greenhouse heating to grow vegetables and fruits as well as flowers, houseplants and tree seedlings.[81] In addition, some 21 countries use geothermal energy to heat water in aquaculture ponds and to support fish drying.[82] In 2019, around 2% of the geothermal energy used globally was for aquaculture.[83]

In agriculture and aquaculture, farmers use **hydropower** mainly at the micro scale as an alternative to diesel to power agro-processing activities.[84] In Sierra Leone, a 250 kilowatt hydro-based mini-grid provides electricity to run a palm oil pressing plant, and in Nepal micro-hydropower plants power local mills, replacing labour-intensive manual processing and allowing other income-generating activities.[85] Micro-hydropower systems also are used to provide clean electricity for aquaculture.[86]

Bioenergy accounts for 5.4% of the total energy consumption in agriculture, where it is used to produce heat and electricity for farm use, processing and storage.[87] Between 2010 and 2020, the use of biogas in agriculture doubled, while the use of liquid biofuels grew 9.4 times.[88] In Vietnam, thousands of biogas digesters transform livestock manure into biogas to power income-generating food production activities.[89] In Africa, farmers have adopted biogas digesters in Burkina Faso, Ethiopia, Kenya, Rwanda, Senegal, Tanzania and Uganda, among other countries.[90]

Improving the **energy efficiency** of food cold chains – including through the use of fridge insulation, efficient compressors and better controllers – has helped reduce energy use.[91] Additionally, some companies have developed and introduced models for "cooling-as-a-service".[92] In Africa, a project launched in The Gambia in 2022 aims to provide vulnerable fishing communities with fuel-efficient biomass ovens for fish smoking, to help reduce air pollution and its health impacts among fishers.[93] In some fisheries, intermediate fuel oils[i] are being substituted for marine diesel oil to reduce fuel costs.[94]

21 countries
use geothermal energy to heat water in aquaculture ponds and to support fish drying.

i These fuel oils are classified and named according to their viscosity and typically reduce fuel consumption costs. The most common oils used for inboard fishing vessel engines are IFO 180 and IFO 380. See endnote 94 for this module.

CHALLENGES AND OPPORTUNITIES
for the Uptake of Renewables in Agriculture

CHALLENGES

- **The lack of robust data on energy uses** in agriculture and fisheries, especially for small-scale actors, makes it difficult to track progress in renewable energy adoption and to understand the policy gaps that need to be filled.[95]
- The seasonal nature of agricultural income, coupled with the capital-intensive structure of most renewable energy investments, makes **affordability a challenge for small and medium-sized actors** in agri-food chains.[96]
- Agricultural policies and energy policies tend to operate in silos, and **policy frameworks and incentives** to encourage the adoption of renewables in agriculture **remain limited and insufficient.**

OPPORTUNITIES

- **Farmers can increase their incomes** by adding value through the use of renewable technologies in their production processes.
- The use of renewables offers the opportunity to **reduce reliance on fossil** fuels and protect farmers from price volatility and supply shocks.
- Opportunities exist to **improve co-ordination among government ministries and other stakeholders** in setting policies and collecting data.

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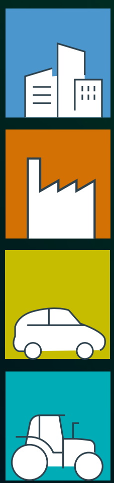

RENEWABLES IN ENERGY DEMAND

ISBN 978-3-948393-07-6

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