REN21

RENEWABLES 2024
GLOBAL STATUS REPORT

ENERGY DEMAND

2024

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FOREWORD

The transition to renewable energy in buildings, industry, transport, and agriculture is falling behind, with 12.7% of energy in these sectors coming from renewables. Despite the urgent need for targeted policies, progress is slow: by 2023, only 13 countries had comprehensive renewable energy policies across all key sectors.

This report, the second module in REN21's *Renewables 2024 Global Status Report* (GSR) collection, demonstrates the disconnect between energy supply and demand that is currently slowing the energy transition. The message is clear: accelerating renewables adoption in critical sectors like buildings, industry, transport, and agriculture is essential for emissions reduction and economic prosperity. Without significant demand-side advancements, a shift to a renewable-based energy system and economy remains out of reach.

Policy efforts, such as the U.S. Inflation Reduction Act and the EU's REPowerEU plan, have spurred renewable investments, but more needs to be done. Only 17 of the 69 countries with demand-side policies have set or renewed renewable energy targets for these sectors beyond 2024, and there are indications that governments may be tempted to water down measures in the face of economic and political pressure. Meanwhile, fossil fuels continue to receive subsidies, totalling USD 7 trillion in 2022.

At COP28, a landmark commitment was made to triple renewable energy capacity and double energy efficiency by 2030. Achieving this target requires immediate and comprehensive action to electrify operations across all sectors and feed them with renewable power. Governments have a key opportunity to implement ambitious policies to mandate renewables, developing the necessary infrastructure, and promoting energy efficiency. Supporting renewable heat and fuels, expected to meet around 50% of energy demand by 2050, is also crucial. Embracing renewable solutions is not just necessary; it is essential for a decarbonised, resilient and prosperous global energy system.

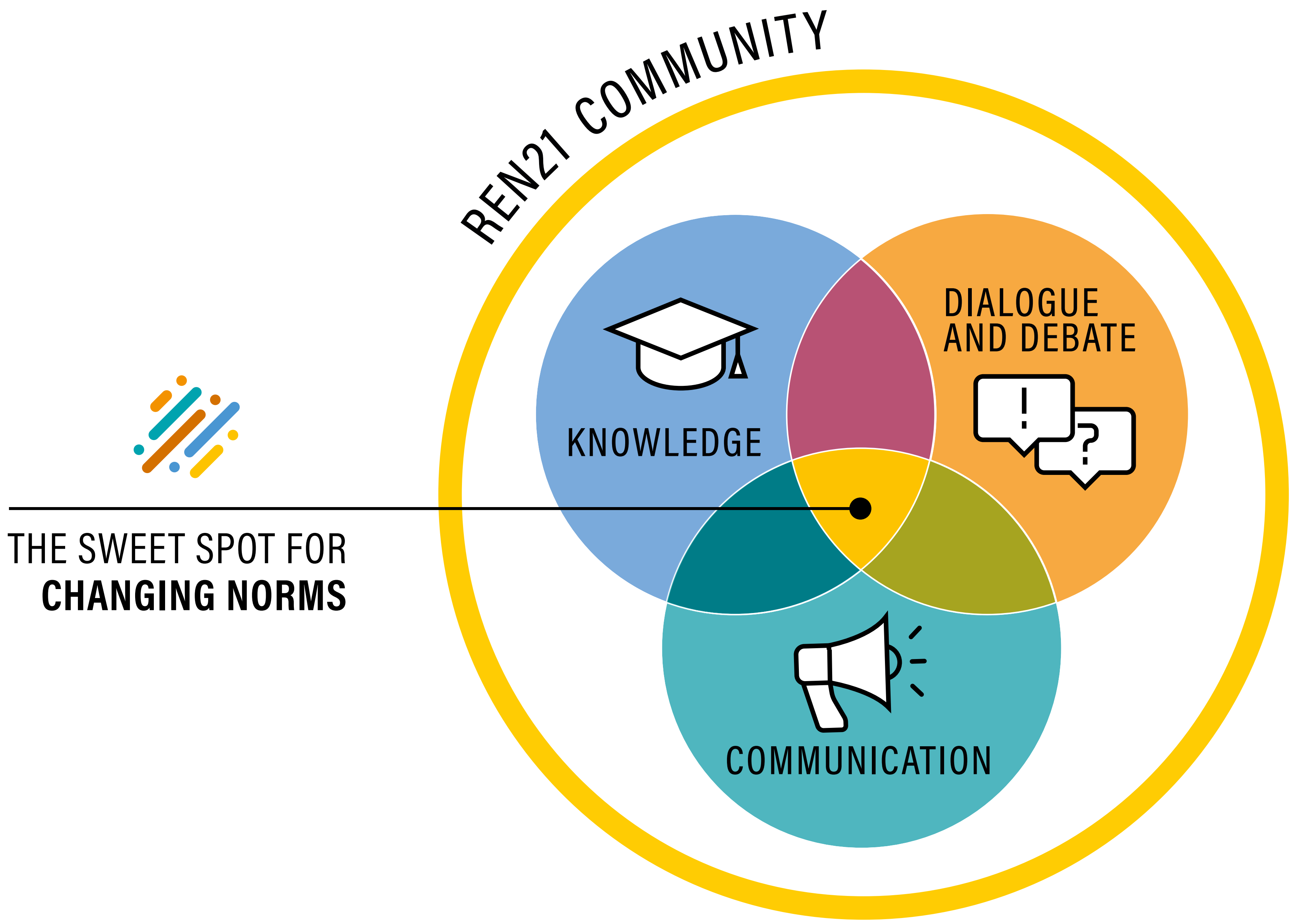
This crowd-sourced and peer-reviewed report, crafted by hundreds of dedicated contributors, offers evidence-based knowledge and data to propel a swift transition to renewable energy. The REN21 team, authors, special advisors and contributors have brought their expertise to this publication. I am confident this report will be an invaluable resource for policymakers, industry leaders and stakeholders, guiding their decisions and driving the global shift towards a sustainable energy future for all.

Sincerely,

Rana Adib
Executive Director, REN21

REN21
RENEWABLES NOW

RENEWABLE ENERGY POLICY NETWORK
FOR THE 21st CENTURY



REN21 is unique. It is the only global, **multi-stakeholder network** dedicated to renewables.

We create an **enabling environment to support renewable uptake**. Together, we build knowledge, shape dialogue and debate, and communicate this information to strategically drive the deep transformations needed to make renewables the norm.

Shifting to renewables is more than a fuel switch; it requires engaging with market players and society at large. **REN21 works in close cooperation with its community**, providing a platform for all stakeholders to engage and collaborate.

Through these collective efforts, REN21 builds bridges and amplifies positive and sustainable energy solutions. Our goal: enable decision-makers to **make the shift to renewable energy happen – now.**

20 YEARS OF REN21

This year marks two decades since the inception of REN21 – an opportunity to celebrate 20 years of instrumental contributions to the advancement, shaping and understanding of renewable energy worldwide.

Established in 2004, REN21 emerged from the collective vision of global pioneers who convened to call for accelerated commitments towards renewable energy adoption. For two decades, REN21 has been pivotal in elevating renewables to the forefront of global agendas for leaders and decision makers across all stakeholder groups, enabling knowledge exchange, dialogue and debate about the global transition to renewables.

The 20th-anniversary celebration of REN21 is also the occasion to acknowledge REN21's flagship knowledge product, the *Renewables Global Status Report*. Since the GSR's first release in 2005, REN21 has published 18 editions of the report, crafted annually with the most up-to-date insights, facts and stories from thousands of contributors spanning diverse regions and sectors. The GSR has been central to fulfilling REN21's mission, becoming a reference for many and positioning REN21 as the global trusted voice on renewables.

20 YEARS OF CROWD-SOURCED, CROWD-OWNED KNOWLEDGE AND DATA

REN21's data and knowledge collection method is unique, drawing upon the organisation's global multi-stakeholder community of experts. Contributors from across the globe are invited to submit data, insights and stories on annual developments in renewable energy technologies, market trends, policies and local perspectives, resulting in a comprehensive and diverse dataset.

REN21 performs rigorous data validation and fact-checking throughout the report's development, ensuring accuracy and reliability. Validation of the data is a collaborative and transparent process conducted through open peer reviews.

Collectively, hundreds of experts contribute to making the GSR one of the most authoritative and comprehensive publications in the field of renewables. Alongside its wealth of key facts and figures, the GSR is openly accessible, fostering a shared language that shapes the sectoral, regional and global debate on the energy transition.

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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) and the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

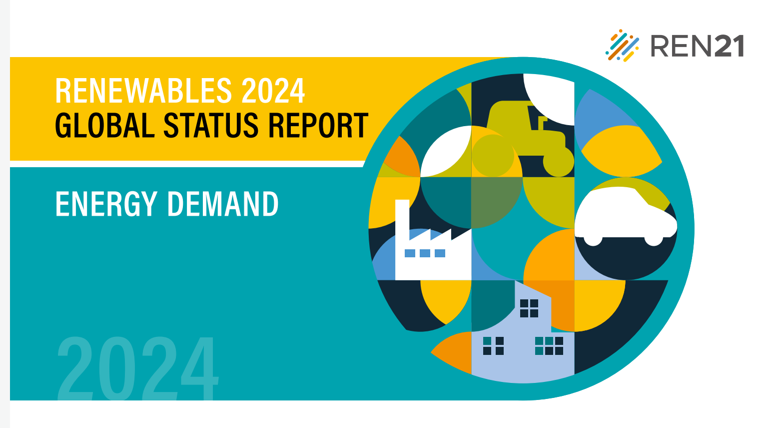
A large share of the research for this report was conducted on a voluntary basis.

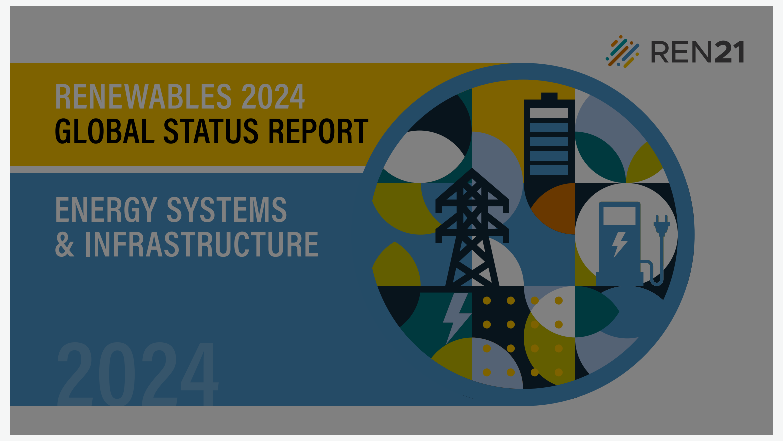
RENEWABLES GLOBAL STATUS REPORT
2024 COLLECTION

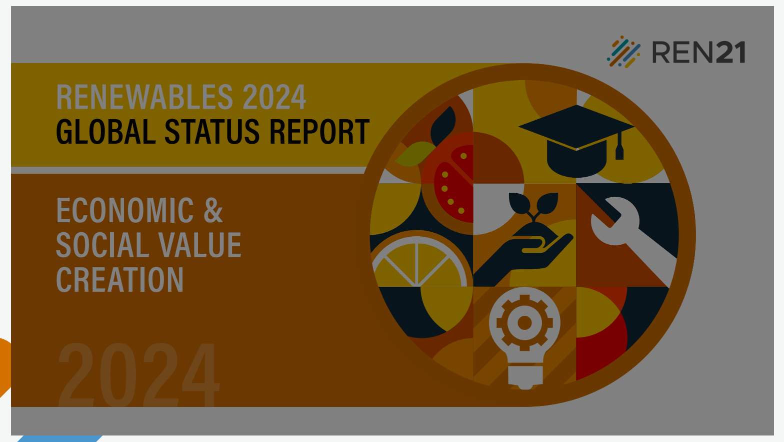
Since 2005, REN21's *Renewables Global Status Report* (GSR) has spotlighted ongoing developments and emerging trends that shape the future of renewables. It is a collaborative effort involving hundreds of experts. Structured as a collection of five publications, this year's 19th edition of the GSR reflects key trends in global energy.

In addition to diving into different energy demand sectors with dedicated modules on buildings, industry, transport and agriculture, the GSR also provides a global overview of the renewables landscape and presents developments in renewable energy supply. The collection further includes a publication on renewable energy systems and infrastructure as well as a publication on renewables for economic and social value creation, acknowledging the key benefits of renewables for economies and societies.

Collectively, these five publications offer readers a systemic global overview of the current uptake of renewables.







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ENERGY DEMAND

For further details and access to the report, references and endnotes, visit
www.ren21.net/gsr-2024

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

FIGURES

SNAPSHOTS

SIDEBARS

BOXES

LINKS TO MICROSITE

- → Energy Units and Conversion Factors
- → Data Collection and Validation
- → Methodological Notes
- → Glossary
- → List of Abbreviations

Reference Tables can be accessed through the GSR 2024 *Demand* Data Pack at
→ http://www.ren21.net/gsr2024-data-pack

GLOBAL TRENDS

Despite a notable decline in the prices of fossil fuels and other energy commodities in the first half of 2023, **wholesale electricity prices** remained high in many countries, negatively affecting energy-consuming sectors.[1] **Inflation** and **high interest rates** continued to hamper investment, particularly in emerging markets that face debt burdens and a **higher cost of capital**.[2] Meanwhile, massive **subsidies to fossil fuels** remain prevalent and have distorted the market, placing renewables at a disadvantage.[3]

Renewables nonetheless continued to prove attractive as an **affordable** and **secure** energy source in 2023, with investments rising to a record USD 623 billion and corporate power purchase agreements reaching a record 46 gigawatts (GW).[4] (→ *See Sidebar 1.*)

SIDEBAR 1. Corporate Power Purchase Agreements

Various financial mechanisms exist for private companies to support, invest in, and purchase renewable energy, such as power purchase agreements (PPAs), debt/equity financing, green bonds, renewable energy certificates (RECs), leasing and participation in joint ventures/partnerships. Corporate renewable energy procurement through PPAs is rising globally. In a corporate PPA, the company agrees to purchase renewable energy directly from a project developer, with terms negotiated between the buyer and seller.

In 2023, companies' PPA commitments represented 9.7% of total worldwide capacity additions, with a record 46 GW of solar and wind contracts signed, a 30% increase from 2022. PPA additions grew 12% in 2023, down from the 33% average growth between 2015 and 2023. (→ *See Figure 1.*)

Europe was the fastest growing region for corporate renewable energy PPAs in 2023, experiencing 74% growth for a total volume of 15.4 GW. Eight market segments in Europe have yearly contracted corporate renewable PPAs exceeding 500 megawatts (MW). The retail sector signed 72% more PPAs than in 2022, followed by food and drinks (up 61.9%), transport (up 57.2%) and automotive (up 45.5%). Solar photovoltaics (PV) dominated with 65% of the PPA volume in Europe in 2023, though contracts were also signed for onshore wind power (2.3 GW) and offshore wind power (2 GW).

The largest market for corporate renewable energy PPAs was the United States, with 37% (17.3 GW) of the total announced volume for 2023, down 16% from the country's record 20.6 GW in 2022. The heavy industry and information technology sectors were the biggest buyers globally. Amazon remained the largest corporate PPA buyer for the fourth consecutive year, followed by Meta, LyondellBasell and Google. BloombergNEF estimates that companies with targets for 100% renewable energy as part of the RE100 initiative will require an additional 105 GW of solar and wind power by 2030.

From the sellers' side, Engie sold the most PPAs in 2023 with 2.4 GW of deals, surpassing AES (1.9 GW), followed by Tata Power (1.2 GW), Lightsource BP (1 GW) and Eneco (0.9 GW).

Source: See endnote 4 for this module.

FIGURE 1.
Corporate Renewable Energy Power Purchase Agreements, Global Capacity and Annual Additions, 2015-2023

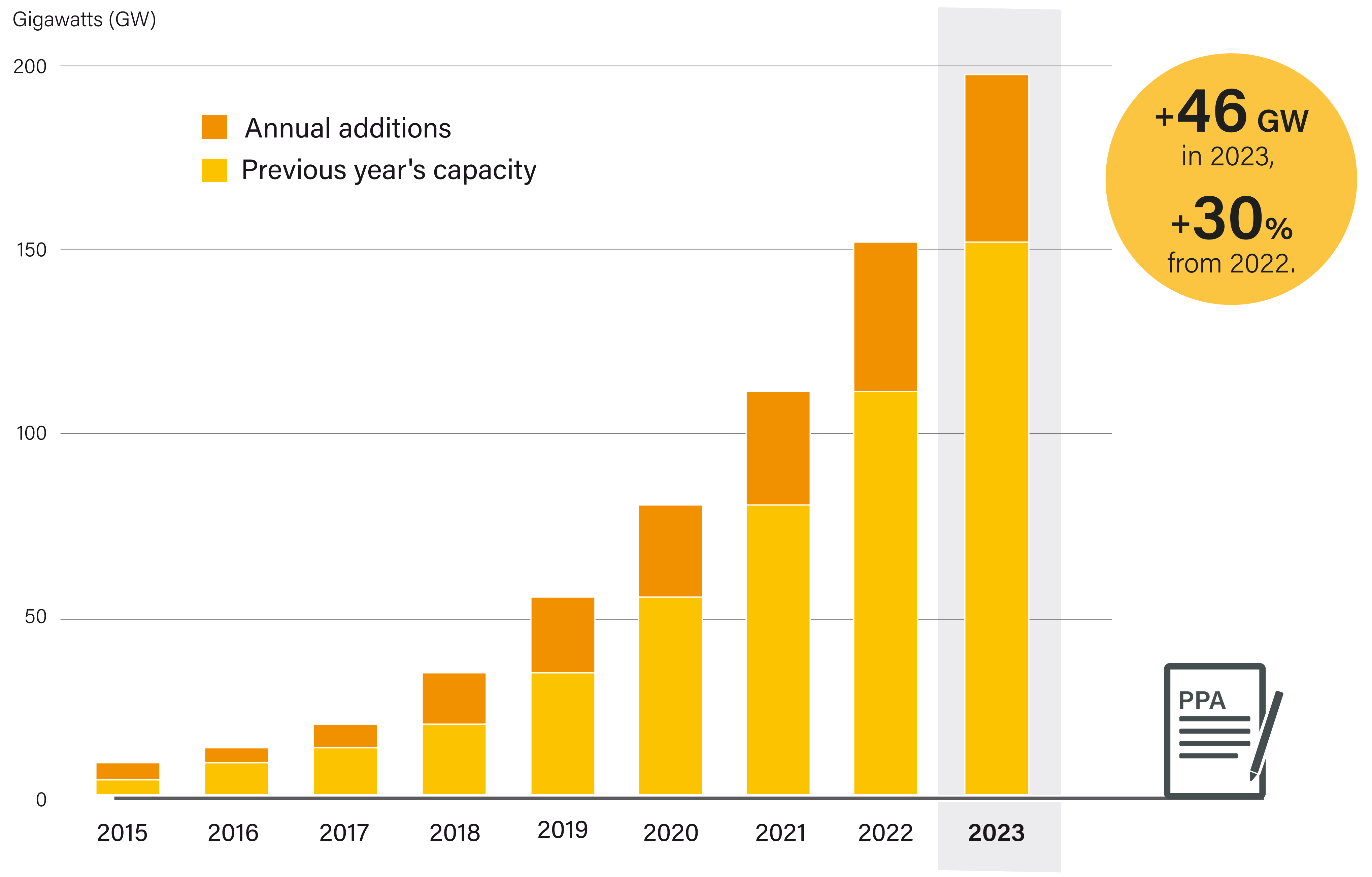
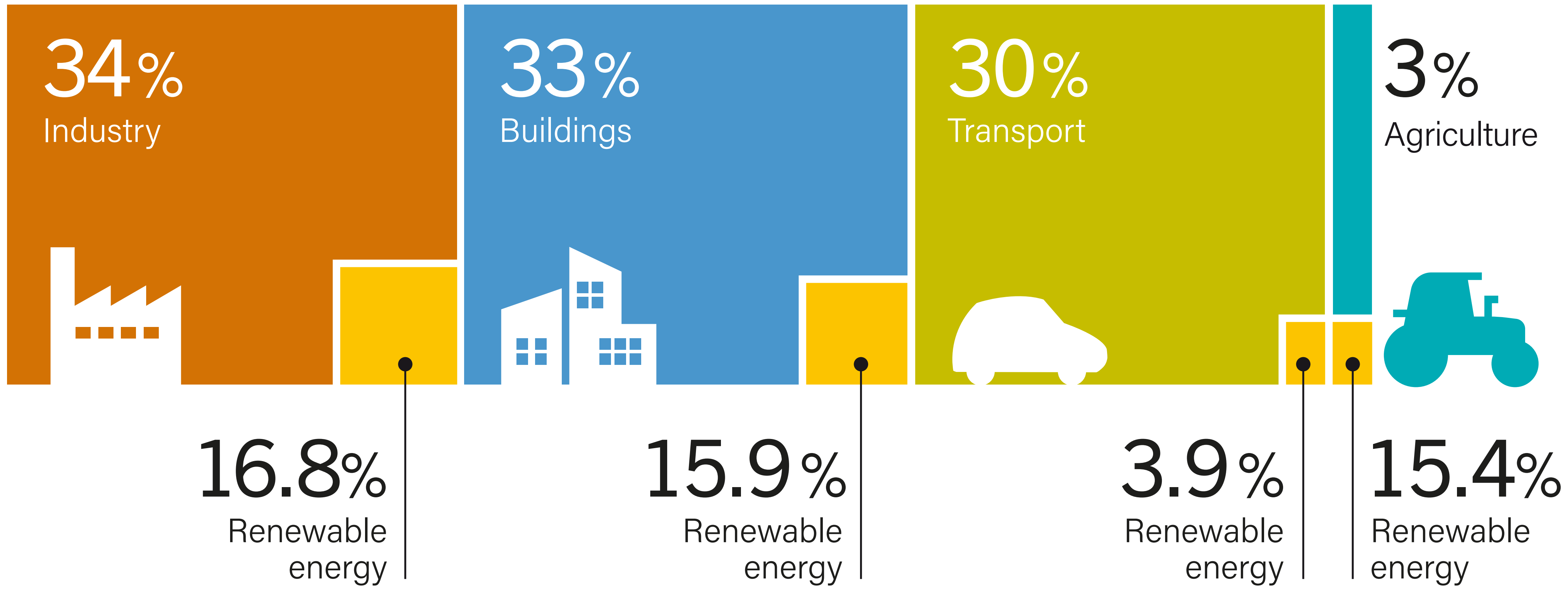


FIGURE 2.
Renewable Share of Total Final Energy Consumption, by Sector, 2021



Note: Total final energy consumption in the above figure does not account to military activty and energy use not elsewhere specified.

Source: See endnote 7 for this module.

The **post-crisis recovery packages of 2022** sparked a surge in renewable energy deployment; however, **progress has since stalled**, and more ambitious structural and integrated reforms are needed to maintain the momentum.[5] In 2023, there were indications that policy **measures supporting the uptake of renewables may be revoked or weakened** in the face of multi-faceted economic and political pressures.[6]

By demand sector, the share of renewables in total final energy consumption (TFEC) ranged from as high as 16.8% in industry to as low as 3.9% in transport in 2021 (latest data available).[7] (→ *See Figure 2*.) These disparities reflect not only the differing characteristics of sectors, but also a lack of integrated policies aimed at increasing the renewable energy share both within and across sectors.

Further action is needed to speed the electrification of end-use sectors (→ *see Sidebar 2*.) and to transition to renewable heat and fuels.[8]

Disparities in renewable deployment across the sectors highlights the need for **integrated policies.**

SIDEBAR 2. Electrification of End-Use Sectors

Electrification of demand sectors allows major energy consumers to tap into the rising share of renewables in the power supply.

Agriculture maintained the highest electrification rate among all sectors in 2021 (latest data available), reaching 27%, up from 20.1% in 2011. (→ *See Figure 3.*) This was enabled by cost savings, technological advancements and improved performance of electric machinery.

In **transport**, electric vehicles accounted for 18% of all car sales in 2023, with 35% year-on-year growth. At least 18 countries announced new policies during the year supporting the uptake of electric vehicles. In **buildings**, heat pump installations increased 10% in 2023, mostly in Europe. However, electrification of buildings increased only 2 percentage points, and of transport just 0.2 percentage points, between 2011 and 2021. (→ *See Figure 3.*) **Industry** electrification has been limited due to the challenges of high-temperature processes such as steelmaking or cement production, with wide variation among industrial sub-sectors.

FIGURE 3. Electricity and Renewable Shares of Total Final Energy Consumption, by Sector, 2021

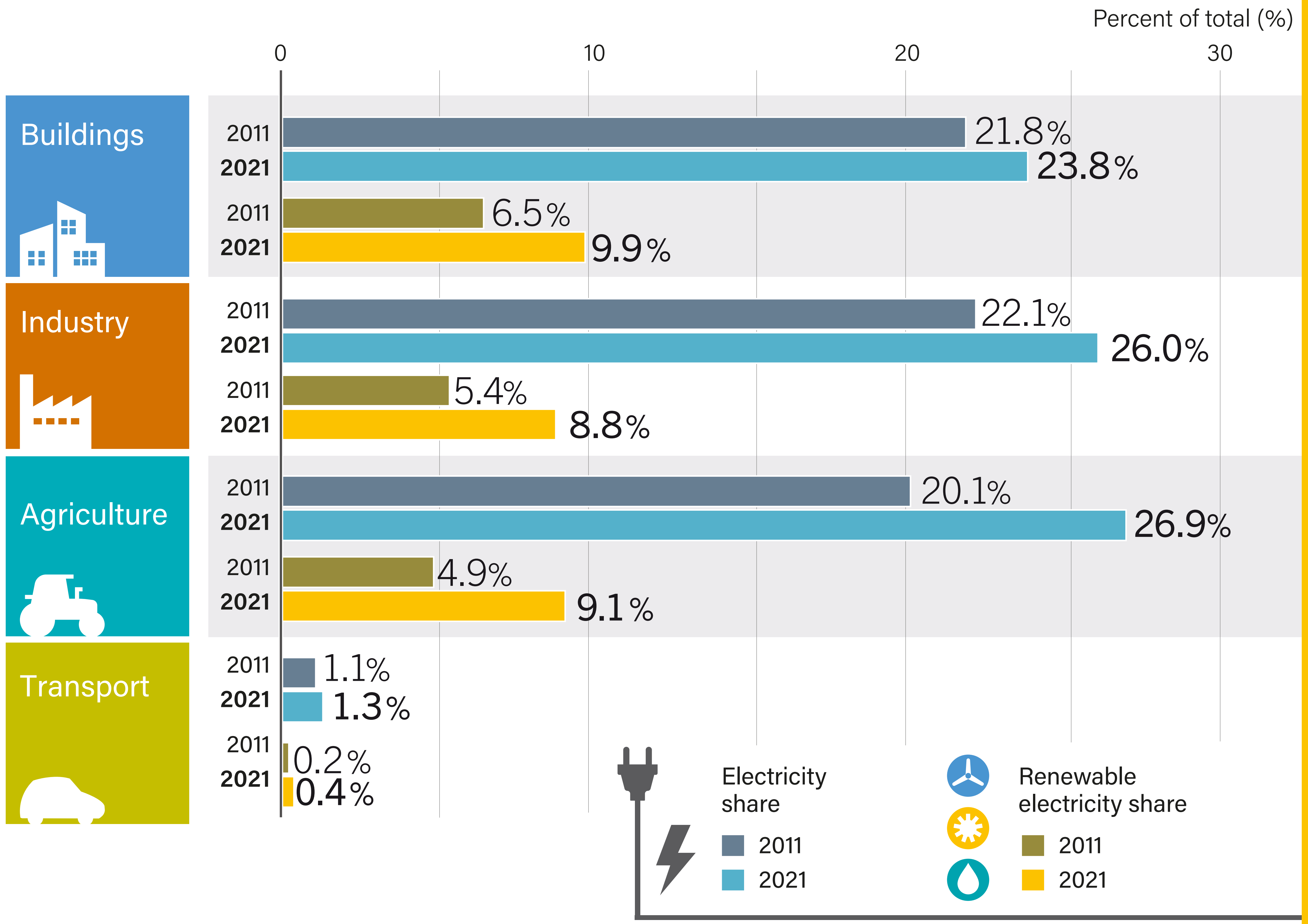
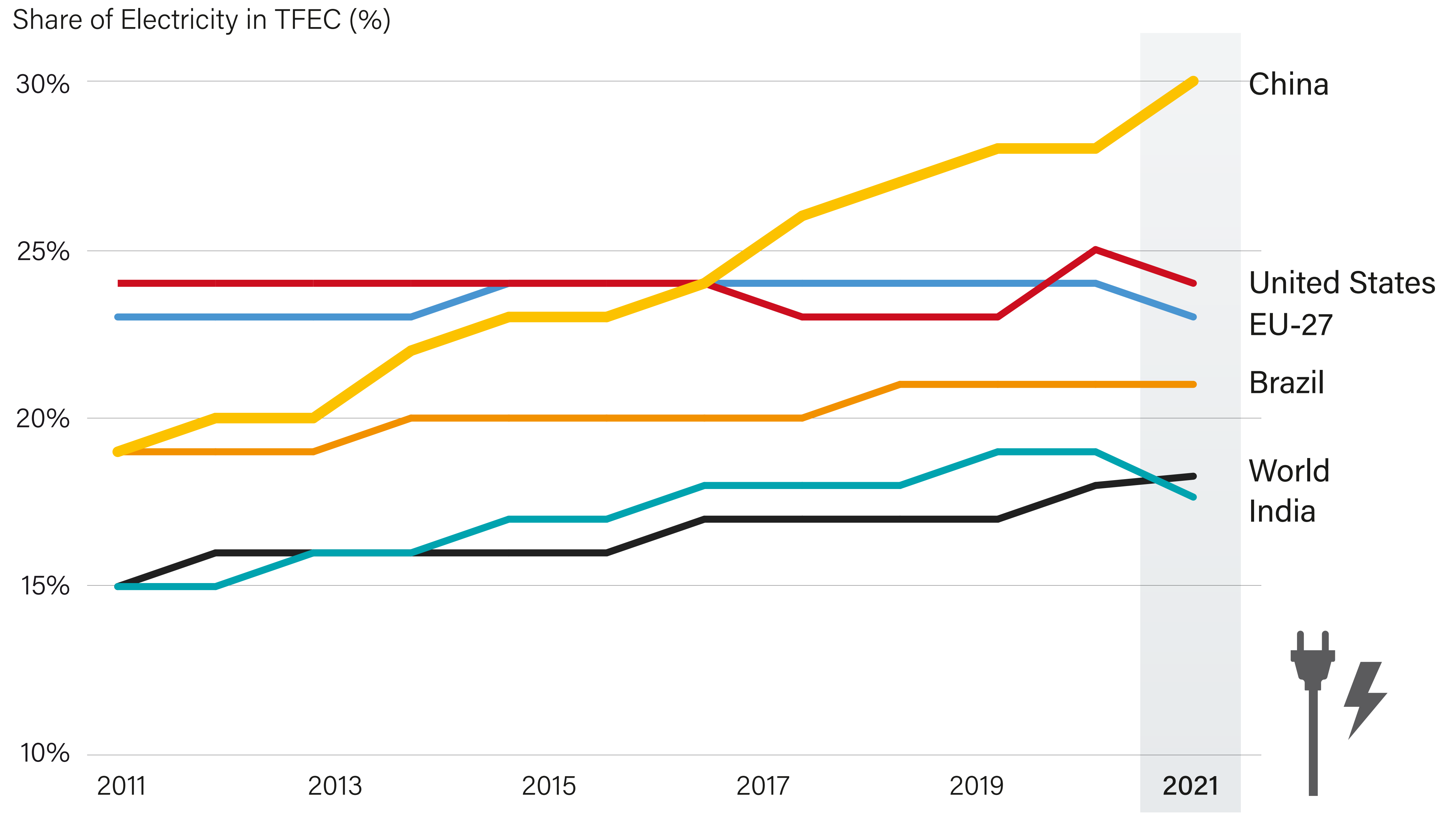


FIGURE 4.
Share of Electricity in Total Final Energy Consumption by Major Country/Region, 2011-2021



Electrification has stalled in most regions except China, where it grew 10 percentage points between 2011 and 2021. (→ *See Figure 4.*) The shares of electricity in total final energy consumption in the United States and the European Union (EU) remained stagnant In 2021, at around 23.7% and 23.4%, respectively. China saw the largest growth in electrification rates between 2011 and 2021 in buildings (up 12 percentage points), transport (up 1.1 percentage points) and industry (up 10.2 percentage points). The United States led in buildings electrification during this period, with a 12.2 percentage points increase.

Source: See endnote 8 for this module.

POLICY TRENDS

As of 2023, only **13 countries** had in place renewable energy **policies for all four demand sectors** (power, buildings, industry and transport).[9] A further 20 countries had policies for three demand sectors, and 84 countries had no demand-sector policies in place.[10] (→ *See Figure 5.*) Of the 69 countries that set renewable energy targets for end-use sectors between 2010 and 2020, only 17 had renewed or set new targets beyond 2024.[11]

Countries announced around **21 new renewable energy regulatory policies** in demand sectors in 2023, bringing the total number to 111.[12] Transport has seen regulatory action in 64 countries, followed by buildings (30), industry (12) and agriculture (5).[13] (→ See Figure 6.) Various fiscal and financial incentives – including grants, rebates, and tax reductions or exemptions – have been implemented to boost the adoption of renewables across different sectors.[14]

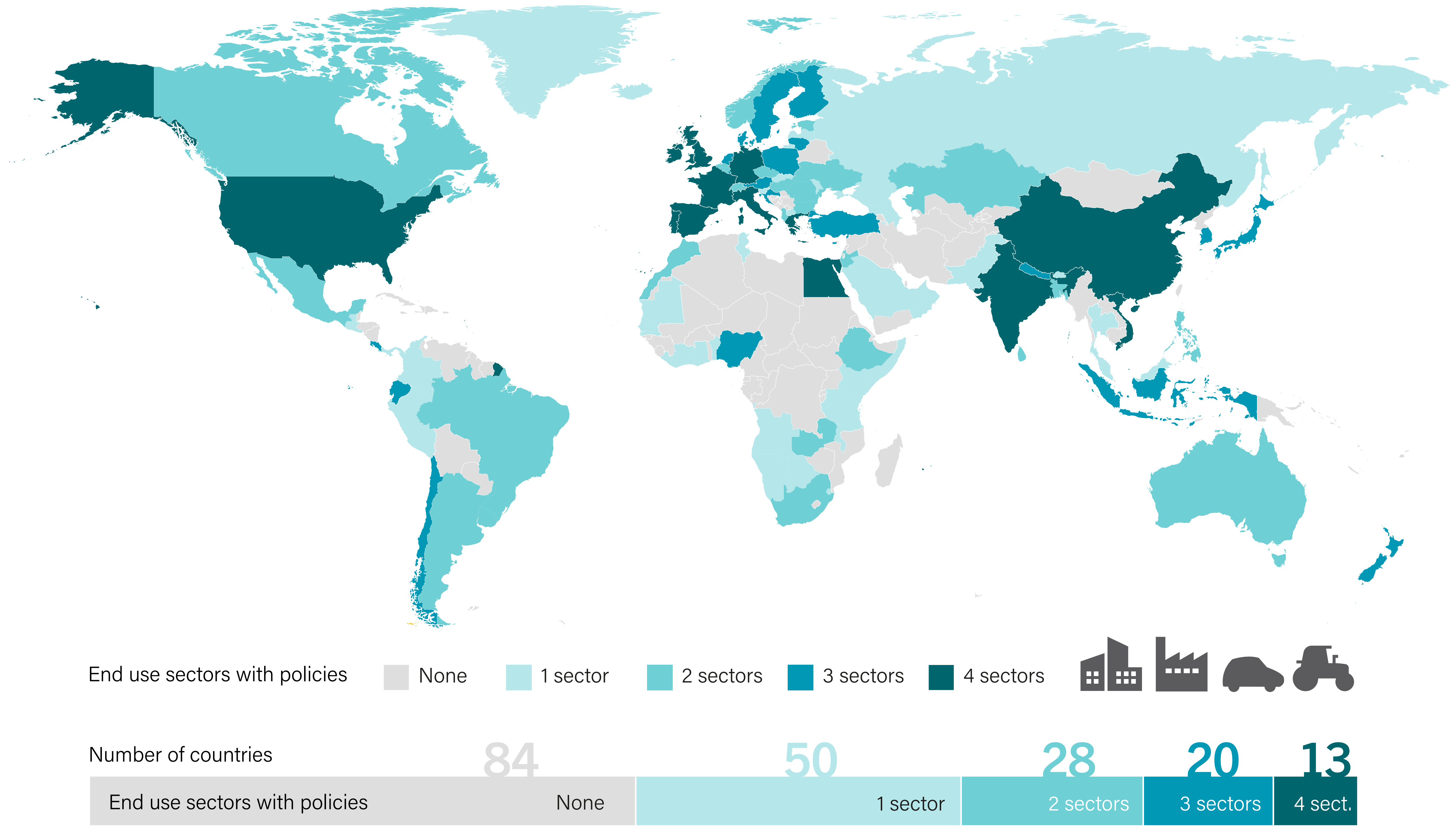
In 2023, progress on renewable energy use in **buildings** continued to be driven by net metering, incentives for rooftop solar, and targets for energy use and retrofitting.[15] Building energy codes have become increasingly widespread globally. As of 2023, the number of building codes worldwide totalled 81 for residential structures and 77 for non-residential structures, with 80% of the codes being mandatory.[16]

In **industry**, nine countries introduced or updated fiscal and financial policies supporting the uptake of renewables during 2023, and three countries introduced regulatory incentives or mandates.[17] Countries also continued to craft broader national renewable energy strategies relevant to industry, such as the United Kingdom's plan for net zero emissions and the EU's Carbon Border Adjustment Mechanism.[18] Most new policies in industry target renewable hydrogen, particularly in heavy industry.[19]

At least 49 countries had specific renewable energy targets for **transport** as of 2023.[20] Ten countries introduced or revised biofuel blending mandates (with some reducing their mandates).[21] At least 18 countries announced new electric vehicle policies, with a range of financial incentives such as subsidies, grants and tax benefits aiming to encourage adoption of the vehicles and related infrastructure.[22] Renewable hydrogen policies and green shipping corridors continued to emerge, whereas efforts to integrate renewables into aviation, rail, and shipping advanced only slowly, with a few new mandates for sustainable aviation fuel, sustainable marine fuels and hydrogen-powered rail development.[23]

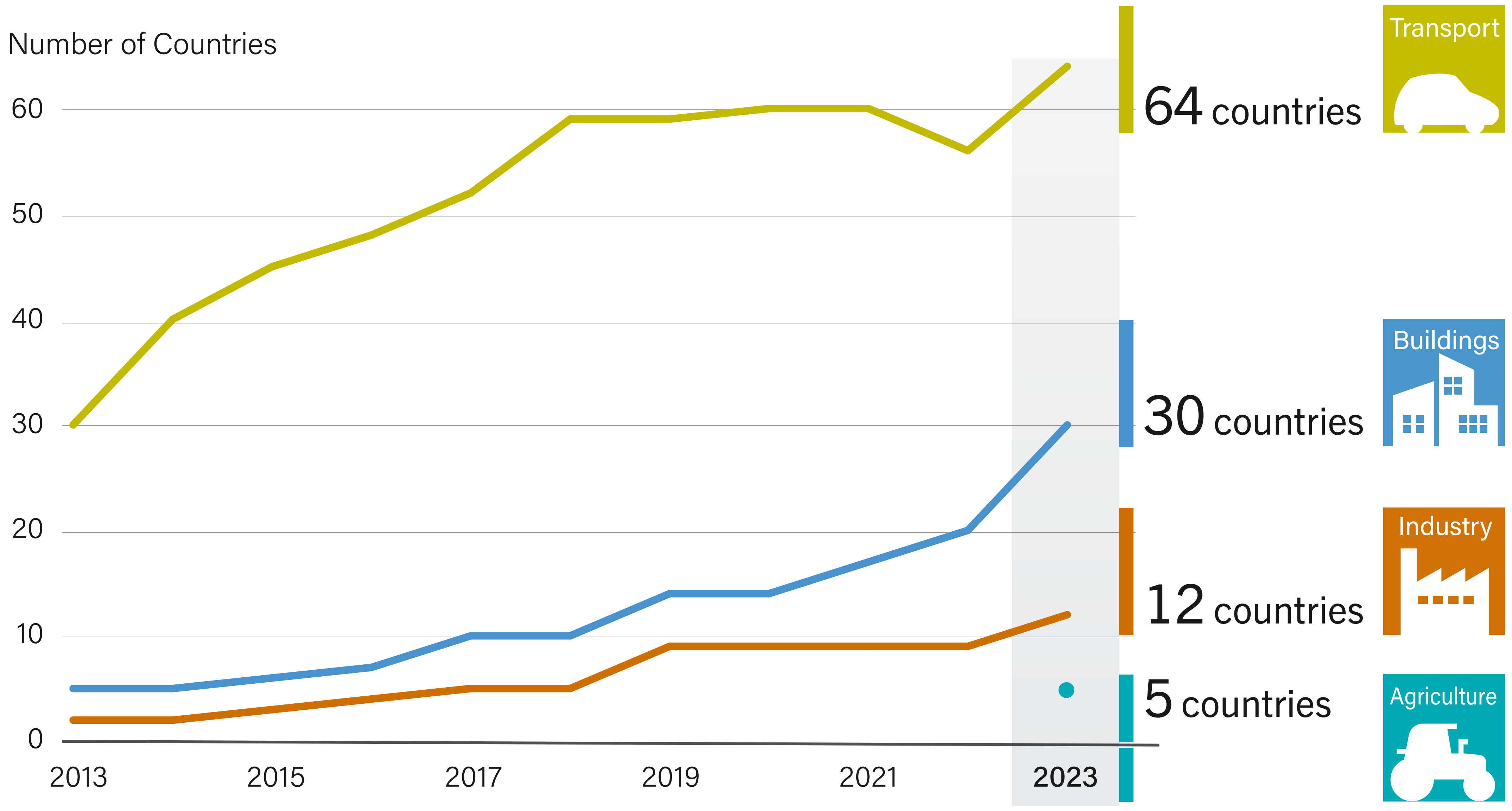
Policies related to energy use in **agriculture** often lack coherence and can send mixed signals: for example, subsidies or tax reductions for agricultural diesel have led to reluctance among farmers to consider renewable energy investments.[24] A major advancement in 2023 was the EU's Common Agricultural Policy, which targets 1.5 GW of renewable energy capacity on farms by 2027, with a focus on biogas and solar power.[25]

FIGURE 5.
Countries with Renewable Energy Policies for End-Use Sectors, as of 2023



Source: See endnote 10 for this module.

FIGURE 6.
Number of Countries with Renewable Energy Regulatory Policies, by Demand Sector, 2013-2023



Source: See endnote 13 for this module.

In 2023,
investment
in EVs and charging infrastructure surpassed investment in renewables.

MARKET DEVELOPMENTS AND INVESTMENT TRENDS

In **buildings** and **industry**, concerns about volatile energy prices and supply disruptions have highlighted the role of renewables as reliable and affordable alternatives to fossil fuels. In 2023, significant investments were made in solar thermal technologies for buildings and industry, while heat pumps continued to attract funding (despite a 4% decline in investment, to USD 63.1 billion).[26]

Bioenergy has remained the leading source of renewable heat in **buildings**, although renewable electricity is the fastest growing heat solution.[27] Rooftop solar PV systems continued to see strong growth in 2023, while heat pump installations increased 10% (with a 38% increase in Europe alone).[28]

Industry relies heavily on heat, which accounts for around three-quarters of the sector's energy use.[29] Renewable energy projects for heavy industry have focused on electric arc furnaces, hydrogen and bioenergy.[30] Light industries are deploying industrial-scale heat pumps and solar thermal systems.[31] Bioenergy use in industry is on the rise, increasing 46% between 2011 and 2021.[32]

Progress in the **transport** sector was driven mainly by electric vehicles and related charging infrastructure, which have become key recipients of energy transition financing, with investment reaching USD 634 billion in 2023.[33] Biofuels continued to be the dominant renewable fuel in transport, supplying 90% of the sector's renewable energy use in 2021 (biofuel consumption increased 3% in 2021 but remained slightly below pre-pandemic levels).[34]

The share of renewable energy adoption in **agriculture** increased from 10.2% in 2010 to 15.4% in 2021, driven by cost reductions and food preservation benefits.[35] Solar PV led the way, with agrivoltaics gaining traction in Europe and India.[36] PV-powered mini-grids and water pumps boosted rural electrification and irrigation in countries across the globe.[37] Geothermal energy and micro-hydropower also saw increased use, particularly in the United States.[38]

RENEWABLES IN INDUSTRY[i]

Industry is the largest energy consuming sector and the sector with the highest share of renewables. Renewable heat, fuels and electricity are all playing key roles in industrial decarbonisation efforts.

34% of energy consumption in 2021 was in the industrial sector

16.8% of energy consumption in industry came from renewables in 2021

12 countries had regulatory policies supporting renewable energy uptake specifically in industry in 2023, three more than in 2022

i Energy use in industry includes energy used for mining, construction, manufacturing of machinery, pesticides and fertilisers and food packaging, processing and transport.

KEY FACTS

- Despite a 5% absolute increase in renewable energy use in 2021, the **share of renewables in industrial energy consumption remained relatively steady** in 2020 and 2021 as overall energy use also increased.
- The share of direct **energy use for heat** in industry was **74% in 2021**, of which 12.1% was renewable energy.
- Due to the **diverse processes and temperature requirements** of industrial sub-sectors, the share of renewables in energy use varies from 7% in the chemical and petrochemical industry to 44% in paper, pulp and printing.
- **Renewable hydrogen policies for heavy industry** expanded in 2023, especially in the Europe, with the EU's New Renewable Energy Directive stating that at least 42% of the hydrogen in industry should come from renewable fuels of non-biological origin by 2030.

MODULE OVERVIEW

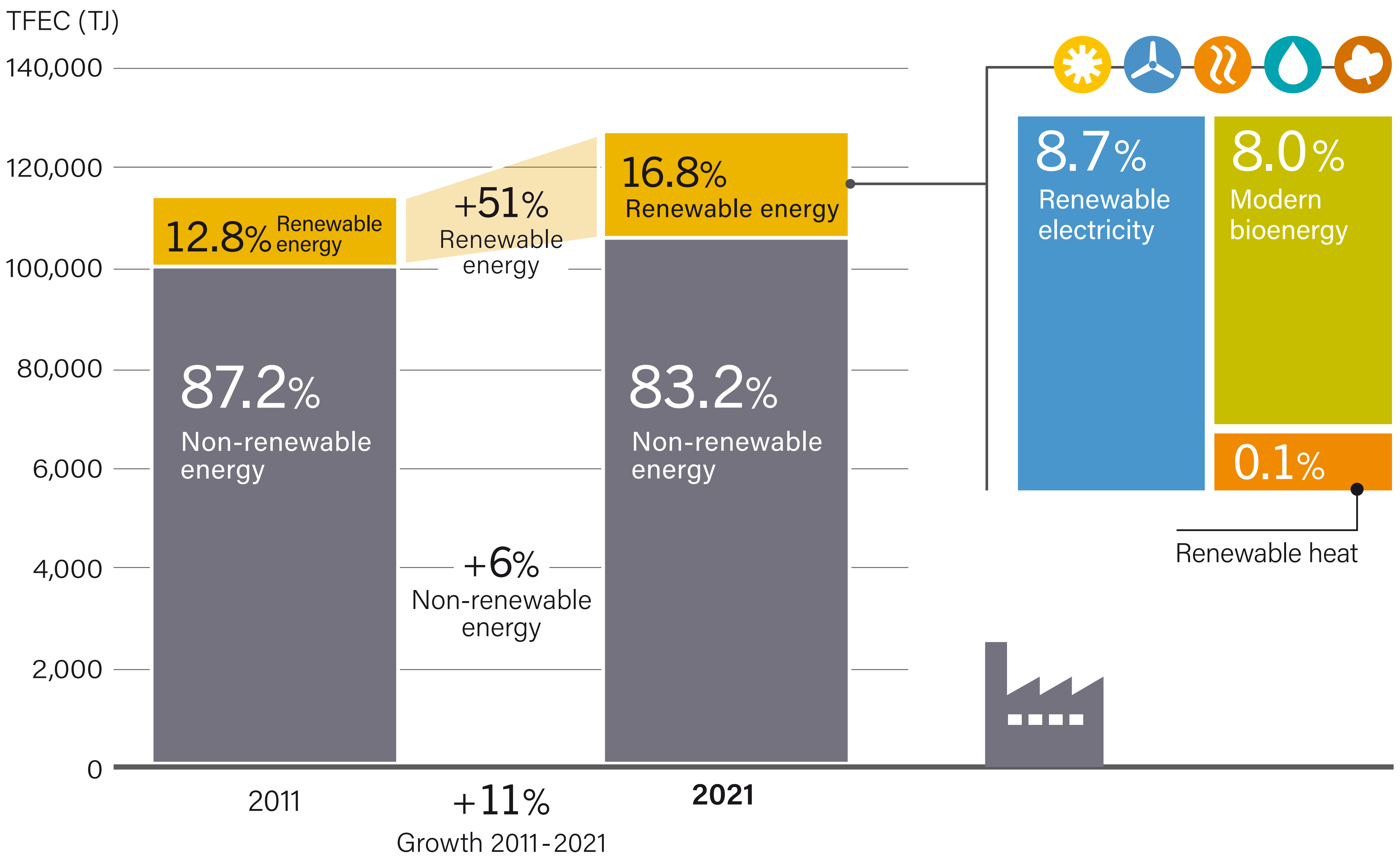
Industry is the largest energy-consuming sector, accounting for 34% of the energy consumption in end-use sectors in 2022.[1] Energy demand in industry stagnated in 2022 after increasing rapidly in 2021 to surpass the pre-pandemic level by 5%.[2] Two key industries – iron and steel (17.2%) and chemicals (16.7%) – together accounted for more than one-third (34%) of the industrial energy demand in 2021, followed by non-metallic minerals (13.2%, including cement and concrete), food and tobacco (6.4%), non-ferrous metals (5.5%), pulp and paper (5.2%) and mining (2.7%).[3]

Industrial enterprises generated 28% of global GDP in 2022 and 23% of total employment.[4] Globally, industrial production underwent significant disruptions that year as a result of the Russian Federation's invasion of Ukraine and a slowdown of the construction sector in China.[5] Industrial activity produced around 9.37 gigatonnes of CO_2 in 2023, up 4.3% from 2022.[6] Around 71% of direct[i] industrial CO_2 emissions came from three sectors: cement and concrete, iron and steel, and chemicals and petrochemicals.[7]

CO_2 emissions from industry show a contrast between high- and low-income regions.[8] In the European Union (EU), industrial production slowed in 2023 due to high energy prices and interest rates, weak domestic demand and strong international competition.[9] Industrial CO_2 emissions fell by 34 million tonnes in the EU and 26 million tonnes in the United States.[10] In contrast, CO_2 emissions from the sector rose by 32 million tonnes in China, 44 million tonnes in India and 39 million tonnes in Indonesia in 2023.[11]

Since 2010, the energy mix of the industry sector has remained relatively stable, with a heavy reliance on fossil fuels. The share of fossil fuel use in industry declined slightly from 87.2% in 2011 to 82.7% in 2021 (→ *see Figure 7*), due mainly to the ongoing electrification of industrial heat combined with the rise of renewable electricity use, which more than doubled during the decade.[12] The renewable energy share in industry in 2021 was 16.8%, split nearly evenly between modern bioenergy and renewable electricity.[13] Despite a 5% absolute increase in renewable energy use in 2021, the share of renewables in industrial energy consumption remained steady in 2020 and 2021 because overall energy use also rose.[14]

FIGURE 7.
Renewable Energy Share in Final Energy Consumption in Industry, 2011 and 2021



Source: See endnote 12 for this module.

i Emissions from energy combustion and industrial processes excluding flaring.

The share of **electricity** in the industrial sector reached 26% in 2021, up from 22% in 2011.[15] Electricity can provide heating across a wide range of temperature levels, including through heat pumps for low-temperature applications and electric arc furnaces for high-temperature applications (such as steel making). Electrical heat also can be provided through resistance, infrared, induction, microwave and plasma heating.[16] Electricity is used to power a range of industrial processes, including alumina electrolysis for aluminium production, and electrowinning[i] which produces copper and nickel.[17]

The share of **energy use for heat** applications in the industrial sector was 74% in 2021, down from 78% in 2011.[18] Renewable energy represented 12.1% of the direct use of process heat in 2021.[19] The majority of this was modern bioheat (89%), followed by renewable electricity (10%) and direct solar thermal and geothermal heat (less than 1%).[20] Bioenergy use is most common in biomass-based industries that generate energy from their own waste. In the pulp and paper industry, bioenergy (mainly black liquor from pulping) contributed 40% of the total final energy consumption in 2022.[21] Additional ways to replace fossil fuels for process heat include alternative renewable fuels such as renewable-based hydrogen, which is gaining momentum in steel, ammonia and glass making (→ *see Market Developments section*). Other renewable heat sources, such as geothermal and solar thermal, are used in the food and chemicals industries.

i Electrochemical process used to extract metal ions from water-based solutions.

POLICY AND TARGETS

Geopolitical considerations are increasingly influencing industrial policies across the globe, reflecting the complex interplay between national security, economic development and environmental sustainability.[22] The diverse nature of industries presents a challenge in crafting renewable energy policies that accommodate the needs and characteristics across different sectors.

Energy-related policies in industry have been driven by the need to decarbonise and have focused mainly on energy efficiency rather than renewable energy requirements.[23] Policy makers also have explored the use of hydrogen in heavy industry sectors (such as the steel and cement industries) and have pushed for the electrification of industrial processes where possible. Some countries, such as Germany and Poland, continued to subsidise the energy costs of diverse industries in the wake of energy price increases in 2023.[24]

Renewable energy targets for heat in the industry sector continued to gain momentum. The EU's New Renewable Energy Directive includes a provision to increase the use of renewables in the total final energy consumption of industry by 1.6% annually.[25] As EU Member States continued to update their National Energy and Climate Plans, they set targets for renewable energy shares in heating and cooling for industry by 2030, including in Latvia (64%), Slovenia (30%) and Italy (27%).[26] Spain set a target to increase the renewable energy share in industry by 5.1% annually.[27]

As of 2023, a total of 10 countries had **fiscal and financial policies** supporting renewable energy uptake in industry, with 9 countries introducing new or updated policies during the year.[28] To accelerate decarbonisation, Germany announced funding for energy-intensive industries through carbon "contracts for difference", which will cover the additional costs for decarbonising industrial production, including through renewable energy technologies.[29] Estonia is providing grants to manufacturers to improve the security of their energy supply, including through the purchase and installation of thermal energy storage systems and connections to district heating systems.[30]

Countries continued to publish **national strategies or roadmaps** for renewables in the industrial sector. The United Kingdom released its Net Zero Growth Plan, which includes strategies to deliver on commitments to net zero emissions through investments in renewables in industry.[31] In the EU, the Carbon Border Adjustment Mechanism enacted in late 2023, which puts a carbon price on certain products sold in the region, has already spurred industries worldwide to decarbonise their production.[32] (→ *See Sidebar 3.*) Japan amended its Energy Conservation Act to require large energy consumers to submit plans for transitioning to non-fossil fuel sources by 2030.[33] In early 2024, Brazil launched its new industrial policy, Nova Industria Brasil, with a pillar focused on decarbonising the industrial sector through the deployment of renewables.[34]

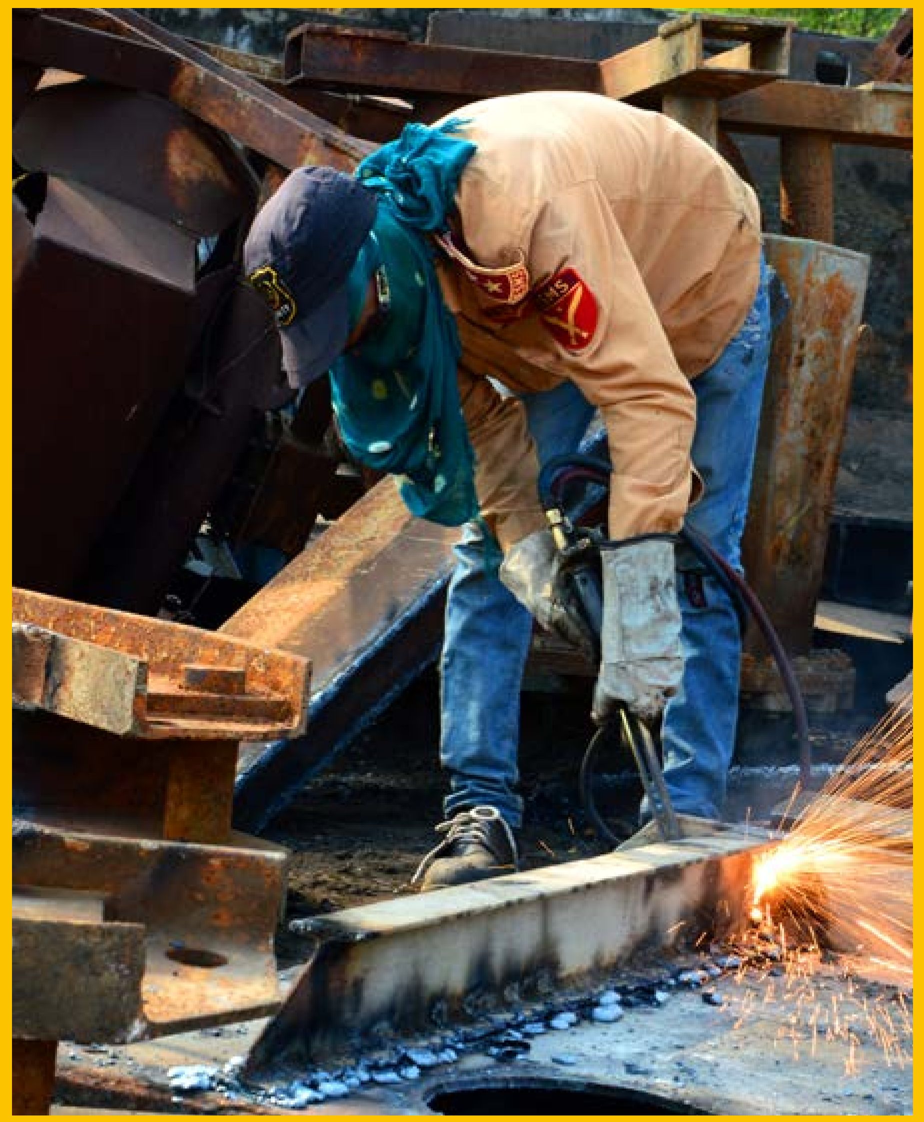
SIDEBAR 3. The Effects of Europe's Carbon Border Adjustment Mechanism on Global Industry

The EU's Carbon Border Adjustment Mechanism (CBAM) started its transition (reporting-only) period in October 2023 and will enter into full force in January 2026. Under the CBAM, the region is placing a CO_2 tax (equal to the EU's carbon price) on imports of certain manufactured goods from non-EU countries – including cement, fertilisers, electricity, iron and steel, aluminium and hydrogen. The mechanism is intended to ensure the competitiveness of EU and other exporters that engage in "cleaner" practices, and thereby to incentivise manufacturers to increase their use of renewable energy.

The CBAM will have a direct impact on the competitiveness of countries that are large exporters of these goods to the EU. For example, India and Zimbabwe are both leading exporters of iron and steel to Europe (with 23.5% and 91.7% of these countries' exports going to the EU, respectively) and could be highly affected. Ukraine could be one of the countries most affected by the CBAM, as the EU is the destination for 34% of Ukraine's iron and steel exports, 36% of its fertilisers, 100% of its electricity exports and 90% of its cement.

The CBAM is intended to prevent the offshoring of greenhouse gas emissions to non-EU countries. The EU wants to ensure that investments in emissions reduction efforts by European steel making companies will not be undercut by low-cost competitors that use dirtier energy sources. The EU's decision could prompt countries to enforce similar measures, and on a wider variety of products. In December 2023, the United Kingdom announced that it would introduce its own carbon import tax by 2027.

Source: See endnote 32 for this module.



Renewable hydrogen policies for the industry sector increased in 2023. The steel, cement and chemicals industries – deemed "hard-to-abate" due to their high emissions and energy intensity – are exploring the use of renewable hydrogen as a potential pathway to decarbonisation. The EU's New Renewable Energy Directive states that at least 42% of the hydrogen used in industry should come from renewable fuels of non-biological origin by 2030, and 60% by 2035.[35] The EU Clean Hydrogen Partnership issued a call for proposals to stimulate the use of renewable hydrogen in energy-intensive industries and other hard-to-abate sectors.[36] Estonia allocated subsidies for renewable hydrogen use in the chemical industry.[37] In the United States and as part of the Inflation Reduction Act (IRA), tax credits of up to USD 3 per kilogram of hydrogen are offered to projects with low life-cycle greenhouse gas emissions.[38] The US Department of Energy's Clean Energy Hubs is set to invest USD 7 billion aiming to catalyse a total of USD 50 billion in hydrogen investment.[39]

Energy efficiency measures in the industry sector are sometimes paired with renewable energy solutions to enhance the overall efficiency. Hungary extended its grant programmes to cover up to 15% of the investment in energy efficiency for energy-intensive small and medium-sized manufacturers.[40] Austria enacted a new financial package that includes provisions for decarbonising energy-intensive industries.[41] Under the New Energy Efficiency Directive, the EU has nearly doubled the energy savings obligations for Member States, driving energy savings in end-use sectors such as industry.[42]

INVESTMENT AND FINANCE

Data on renewable energy investment in industry remain limited. Many of the efforts to decarbonise the sector have concentrated on energy efficiency and on carbon capture, utilisation and storage. Although no comprehensive datasets are available summarising investment in renewables in industry, examples of specific investments exist. They include investments in solar thermal heating, geothermal heat, and biomass technologies for industrial uses in the agro-food, pulp and paper, mining and steel industries.

In the **food and tobacco industry**, several noteworthy investments were made in solar thermal systems for process heat in 2023. In Spain, Europe's largest industrial heat plant – a 30 megawatts-thermal (MW_{th}) parabolic trough solar thermal plant, with a total investment of USD 22.5 million (EUR 21 million) – was inaugurated in Seville in September.[43] The plant is the result of a 20-year heat purchase agreement between the Dutch beer company Heineken and the French energy giant Engie and was financed through a public-private partnership with the European Regional Development Fund, which provided a subsidy of USD 14.3 million (EUR 13.4 million).[44]

France's largest solar thermal plant for industrial processes, with a total investment of USD 6.4 million (EUR 6 million), was inaugurated in late 2023 with a 55% subsidy from the environment agency ADEME and additional financing from the Public Interest Group Objectif Meuse and the Grand Est Region Climaxio programme.[45] The plant will provide the dairy company Lactalis Ingredients with heat for a drying tower.[46]

Also in the food industry, São Martinho in Brazil invested USD 50 million (BRL 250 million) to build its first biomethane plant, which will use the vinasse residue produced at an adjacent sugarcane facility to produce biogas that will be used to replace fossil diesel in the company's trucking fleet.[47]

In the **pulp and paper industry**, a paper and packaging manufacturer in Belgium commissioned a new concentrated solar thermal system combined with a thermal storage unit in Turnhout – the largest such facility in Europe – financed by Campina Energy, with support from the EU's Horizon programme and the Green Heat scheme.[48] In New Zealand, the Government Investment in Decarbonising Industry Fund contributed part of the USD 9.8 million (AUD 15 million) in total funding to help the tissue manufacturer Sorbent purchase geothermal steam from a local supplier for use in paper drying.[49] In Kenya, early steps were taken to develop a geothermal field that will supply energy for industrial uses such as fertilisers, iron and steel, plastics, and pulp and paper.[50]

In the **mining industry**, Saudi Arabia's leading mining company, Ma'aden, announced plans to begin building the first gigawatt-scale solar heat plant in early 2024, which will provide steam for refining bauxite ore at an alumina refinery in the city of Ras al Khair.[51] In the United States, the mining company Rio Tinto partnered with Neste to transition all of the heavy machinery at its mine in Boron, California from fossil diesel to renewable diesel, although information on the total investment was unavailable.[52]

The company also announced that it would replace its entire fossil diesel consumption at its Kennecott copper operation in Salt Lake City with renewable diesel starting in 2024.[53] In Chile, the Chilean power utility Gasco is investing USD 71 million in industrial solar heat plants, in the framework of a 20-year heat purchase agreement to cover more that 80% of the heat demand of two copper mines, Minera Escondida and Spence, the remaining heat will be delivered by electric boilers powered by renewable electricity.[54]

In several sub-Saharan African countries, as of 2023, a number of mines had announced plans to transition towards solar PV-powered microgrids to enhance energy security and reduce costs.[55] (→ *See Snapshot: sub-Saharan Africa.*)

In the **steel industry**, a surge of investments in net zero technologies, which may include renewable energy use, have been announced in recent years.[56] The Swedish company H2 Green Steel allocated an initial USD 3 billion for a new plant, set to begin production in 2024, that will use renewable hydrogen.[57] In 2023, several wind-powered hydrogen projects were postponed. In Canada the World Energy GH2 project was delayed due to lagging hydrogen infrastructure, and projects in Europe were delayed due to regulatory restrictions.[58] With a focus on India's steel industry, an innovative financing instrument titled Financing Steel Decarbonization was developed in 2022 to mobilise private finance for low-carbon technologies for decarbonising steel, which includes using renewables to meet the electricity requirements of steel production facilities, or to produce renewable hydrogen.[59] Because investing in decarbonised steel neither lowers costs nor increases product quality, it is often motivated by the opportunity to capture incipient green steel markets and to avoid stranded assets in anticipation of more stringent climate policies.[60]

Additional investment in renewables occurred outside of these primary industries targeted for decarbonisation. In Cuernavaca, Mexico, Unilever announced a USD 446,000 (EUR 417,000) industrial solar steam project to support the manufacture of personal hygiene products, with construction to begin in 2024.[61] In the United Kingdom, the clean-tech company Sonichem secured USD 1.49 (EUR 1.4 million) to convert low-value forestry by-products (such as sugars, cellulose and lignin) to renewable biochemicals.[62]

SNAPSHOT SUB-SAHARAN AFRICA

HARNESSING SOLAR POWER TO TRANSITION THE REGION'S MINING SECTOR

The mining sector is a leading economic driver in Sub-Saharan Africa, valued at more than USD 108 billion in 2023. For the region's 15 most mineral-rich countries, the sector accounted for 10% of GDP on average in 2021. In most of these countries, mining is the main source of foreign direct investment, accounting for up to half of all exports. However, it is also the most energy-intensive sector, consuming half of Sub-Saharan Africa's total electricity in 2022 (and even higher shares in countries such as Guinea, Mozambique and Sierra Leone).

In many Sub-Saharan African countries, the electricity sector faces challenges due to fluctuating world oil prices and persistent droughts, resulting in insufficient generation capacity, rising energy tariffs and unreliable service. Rising energy prices greatly impact mining projects because energy accounts for a significant portion of mining projects' budgets, reaching 10-35% of mining expenses in the region in 2023. Furthermore, power shortages and disruptions impact the mining sector, which requires continuous energy supply for efficient operations, in several detrimental ways, including damaged equipment, reduced output and large financial losses.

Some mines in Sub-Saharan Africa are located in remote areas and must rely on diesel-generated power rather than being connected to national or regional electricity grids. This presents challenges due to volatile global diesel prices and the high cost of transporting this energy to remote locations.

As an alternative, mines are increasingly implementing hybrid microgrids, which combine solar PV with energy storage and operate independently from the state grid. This reduces their reliance on fossil fuels and limits their use of generators running on diesel or heavy fuel oil to supplying only back-up power. This reflects a larger trend across Sub-Saharan Africa of installing solar PV microgrids to reduce reliance on unstable national and regional grids and to avoid the high cost of diesel.

In 2023, the Tasiast gold mine in Mauritania installed a 34 MW solar PV plant with an 18 MW battery system to supply 20% of total power needs. The project is operated by the Canadian-based mining company Kinross, while the renewable energy producer Voltalia collaborated with ABB for the systems integration and value chain support.

Over the lifespan of the mine, the system will avoid an estimated 530,000 tonnes of greenhouse gas emissions and save 180 million litres of fuel.

Since 2018, the Essakane gold mine in Burkina Faso has been powered by Africa's largest solar PV hybrid power plant, a 15 MW system comprising some 130,000 PV panels developed by the Finnish company, Wärtsilä. By optimising solar PV power, the mine has reduced its annual fuel consumption by 6 million litres and its CO_2 emissions by 18,500 tonnes per year.

In 2023, NextSource Materials announced the commissioning of a 2.69 MW solar plant at the Molo mine in Madagascar. The plant, which covers 1.3 hectares and comprises 4,902 PV panels, is accompanied by a 1.37 MWh battery and supported by a 3.1 MW back-up diesel generator. This hybrid set-up is designed to meet 100% of the mine's power needs during peak hours, with the solar PV supplying 35% of the overall electricity demand. The project will boost the mine's energy security by providing uninterrupted power, while cutting carbon emissions by 2,275 tonnes annually and contributing to national climate goals.

As of 2023, mining companies in South Africa had plans to spend a collective USD 3.8 billion on several major solar PV installations, with an estimated maximum total capacity of 3,900 MW. These installations include Sibanye-Stillwater's combined 175 MW of solar plants across multiple platinum mining sites, Anglo American Platinum's 100 MW project at its Mogalakwena mine, Gold Fields' 50 MW plant at South Deep Khanyisa gold mine, Harmony Gold's phased roll-out of 167 MW of solar plants (including three 10 MW plants) and Impala Platinum's 10 MW project at the Marula Platinum mine. As of 2023, only the solar plant at South Deep Khanyisa was operational, and all other projects were under construction, with planned completion dates during 2024-2025.

Source: See endnote 55 for this module.

MARKET DEVELOPMENTS

Heat dominates energy consumption in industry. It is used for washing, cooking, sterilising, drying, preheating boiler feed water and other uses and is essential in refining raw materials, smelting metals and producing chemicals.[63] The share of heat in industrial energy use varies by sub-sector, ranging from 32% in machinery production, to 41% in transport equipment manufacturing, to 85% in glass and cement industries and the share of electrification and renewable energy share varies broadly across sub-sectors.[64] (→ *See Figure 8.*)

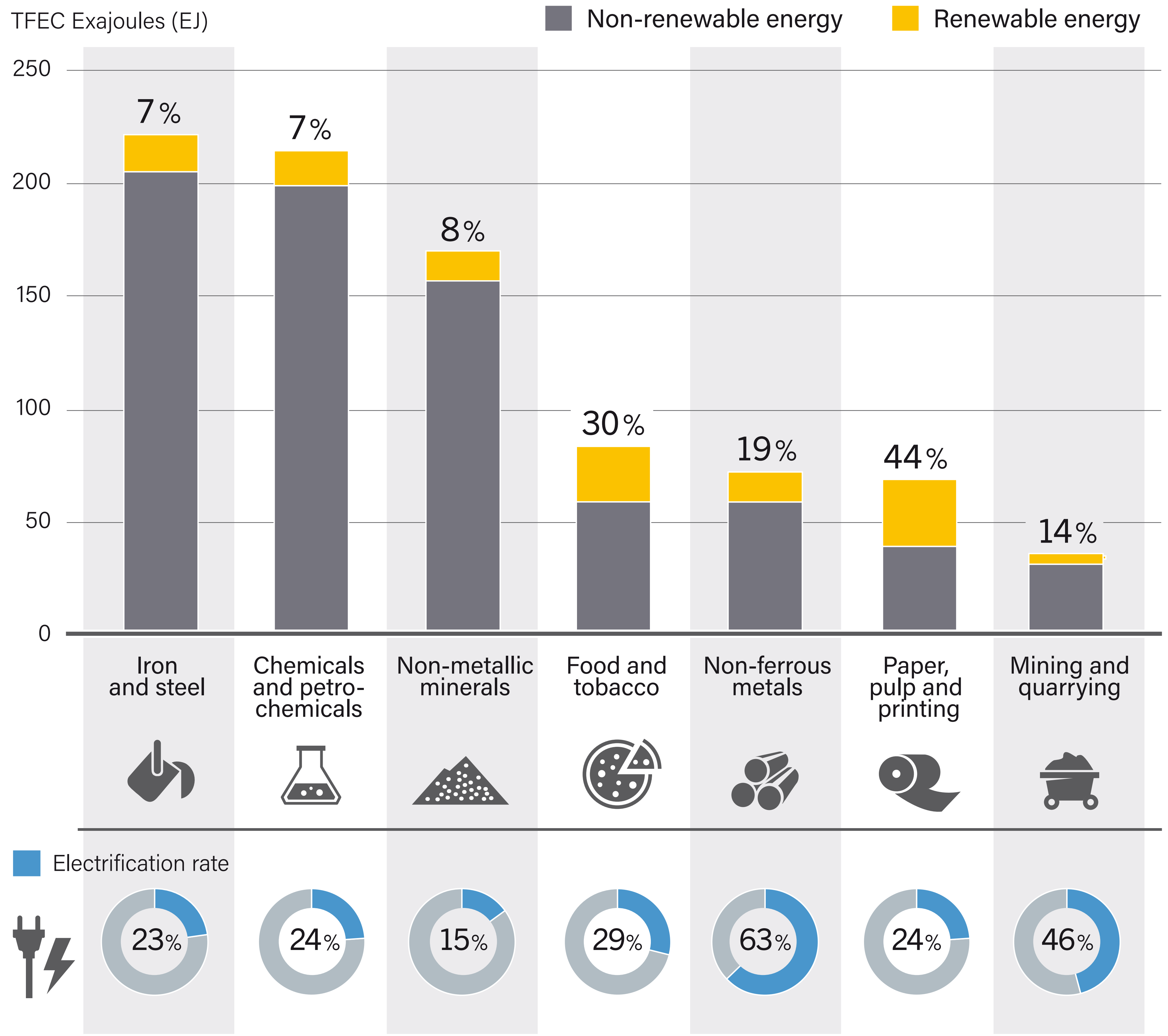
As of 2021, only 12.1% of heat consumption in the industry sector was renewable, and solutions are emerging to increase this share across specific sub-sectors, depending on the required process temperature.[65] Process heat over 750°C remains dependent on fossil fuels, but in some cases resistance, infrared, induction, microwave and plasma heating can provide electric-based solutions up to 1500°C, with renewable hydrogen and biomass also positioned as strong alternatives.[66] Electrothermal energy storage (ETES)[i] technologies have commercially available solutions for heat processes that require temperatures up to 400°C.[67] For processes below 200°C, **direct electrification** through renewable electricity has gained momentum, with heat pump technology evolving to provide medium-temperature heat.[68] Heat purchase agreements (HPAs) also are on the rise, especially in industries with low and medium temperature requirements (→ *see Investment: Food industry and Mining*).

The use of **modern bioenergy** in industry increased by 46% between 2011 and 2021, rising from 8 exajoules (EJ) to 10.1 EJ.[69] However, the share of bioenergy use relative to total final energy consumption in industry increased only slightly during the decade, from 7% to 8%.[70]

Solar thermal can be an efficient means of providing zero-carbon heat and a cost-effective alternative to the electrification of heat. Although it has been used mainly for low-temperature applications, new solar thermal designs serve applications with temperature requirements of up to 400°C.[71] High initial capital costs, long lead times, and low client awareness have led to limited uptake, even in sectors with significant technical and economic potential, such as textiles and food.[72] However, in 2023 the Dutch packaging and materials manufacturer Avery Dennison commissioned Europe's largest concentrated solar thermal platform and storage unit, with a peak energy yield of 2.7 gigawatt-hours (GWh) of thermal power.[73] By the end of 2023, at least 1,209 solar heat for industrial processes (SHIP) installations, totalling more than 951 MW_{th}, were supplying process heat to factories worldwide.[74] At least 116 projects came online in 2023 alone.[75] Projects are getting bigger, and the proportion of systems with temperatures above 100°C is increasing rapidly.[76]

High-temperature geothermal energy can be used directly to generate electricity, heat, or both. Direct geothermal use accounted for less than 1% of the total thermal energy use in industry in 2021, mainly in food processing, packaging and transport, and mining.[77] Barriers to wider adoption include resource availability and high upfront costs.[78]

FIGURE 8.
Renewable Energy Share and Electrification Rate by Industry Sub-Sector, 2021



Source: See endnote 64 for this module.

i ETES technologies use electricity to produce heat and then store it in a heat storage medium such as Bricks. The systems can charge when electricity is cheapest or when there is excess renewable electricity production.

Electrification via renewables continued to develop in 2023. Industries have invested in on-site renewable electricity plants or are using power purchase agreements (PPAs) to procure renewable electricity for their operations. However, the cost of electrified operations is not equal across the globe. Electricity prices for energy-intensive industries in the EU were almost double those in China and the United States in 2023, potentially increasing the attractiveness of on-site renewable energy production for European industries.[79]

Heat pumps, although not technically a renewable energy technology, are an energy-efficient alternative to traditional heating and cooling systems and a key technology for electrifying industry and increasing the renewable share of industrial energy use.[80] Energy security risks and fluctuating fossil fuel prices, along with a growing focus on efficiency, is driving market uptake among the three main industrial users of heat pumps: pulp and paper, food and beverage, and chemicals.[81] Large-scale heat pumps are a rapidly expanding solution for meeting industrial heat demand.[82]

Renewable hydrogen has been discussed mainly in the context of decarbonising energy-intensive processes, in particular in the petrochemical and steel industries. Despite growing momentum for renewable hydrogen in 2023, development remained limited due to high production costs, lack of demand-side subsidies, lack of offtake agreements, high risk perception from the finance sector, lack of consistent green hydrogen standards and the need for related infrastructure.[83]

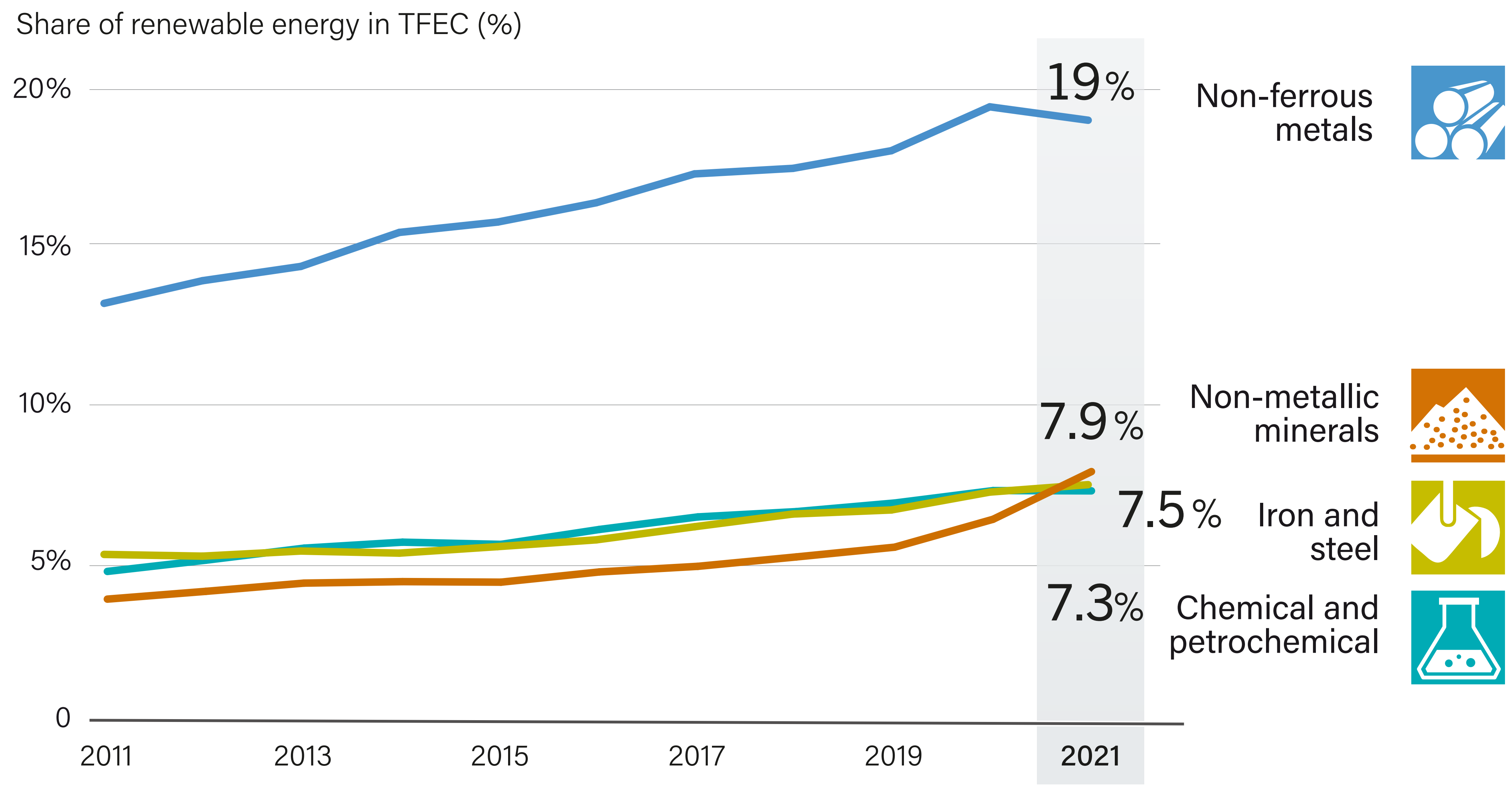
Globally, the number of **eco-industrial parks** that pool renewable energy generation, use, and sometimes research and development has grown rapidly, with the aim of creating resource-efficient industrial parks that are more competitive, risk resilient and attractive for investment. In 2023, in the framework of the World Economic Forum's (WEF) "Transitioning industrial clusters towards net zero" initiative, Dunkerke in **France** launched the DKarbonation project, which aims to create a zero-emission industrial cluster by 2050, including for steel, aluminium, cement, gas, low-carbon hydrogen and battery production.[84] **China**'s Tianjin Economic and Technological Development Area (TEDA), which joined the WEF initiative in 2023, has introduced resource recycling in the automotive and electronics industries.[85] The industrial park also implemented energy and environmental infrastructure projects – such as geothermal, reclaimed water plants and waste heat utilisation development – to improve the park's system efficiency and circularity.[86]

Due to 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.[87]

FOCUS ON HEAVY INDUSTRY

Heavy industries are the most energy-intensive users in the industry sector. Four main sub-sectors account for more than 47% of industrial energy use: iron and steel, non-ferrous metals, chemicals and petrochemicals, and non-metallic minerals.[88] The renewable energy share in heavy industry continues to be lower than the average industrial sector, with renewables representing 8.7% of energy consumption in the aforementioned sectors in 2021 as compared to 16.8% across all industries[89] (→ *See Figure 9.*)

FIGURE 9.
Share of Renewable Energy in TFEC by Heavy Industry Sub-Sector, 2011 to 2021



Source: See endnote 89 for this module.

Iron and Steel and Non-Ferrous Metals

Values in 2021	**Iron and steel**	**Non-ferrous metals**
Share of sub-sector in industry TFEC	17.2%	5.5%
Share of electricity in sub-sectoral TFEC	23%	63%
Share of renewable energy in sub-sectoral TFEC	7%	19%
Share of bioenergy in renewable energy in sub-sectoral TFEC	9%	0%

Source: See endnote 89 for this module.

Chemicals and Petrochemicals

Values in 2021	**Chemicals and Petrochemicals**
Share of sub-sector in industry TFEC	16.7%
Share of electricity in sub-sectoral TFEC	24%
Share of renewable energy in sub-sectoral TFEC	7%
Share of bioenergy in renewable energy in sub-sectoral TFEC	3%

Source: See endnote 100 for this module.

Traditionally, the iron and steel industry has relied heavily on blast furnaces that use a high-carbon form of coal known as coke. Increasingly, **electric arc furnaces** are being adopted that enable the direct use of renewable electricity, mainly to produce secondary steel made from recycled or scrap steel.[90] So far, secondary steel has not been able to satisfy high-grade or specialty requirements, and the volume is insufficient to meet global steel demand.[91] Direct reduced iron, produced with **renewable hydrogen** and linked with renewable-powered electric furnaces, is a solution to renewables in primary steelmaking.[92] Of the steelmaking capacity added since 2021, 43% is based on electric arc furnace technology and 57% uses coal-based blast furnace-basic oxygen furnaces.[93]

In Europe, the price of carbon under the EU Emission Trading Scheme (EU-ETS) has made investment in "green" steelmaking increasingly attractive.[94] In Belgium, the wind turbine manufacturer Vestas partnered with steel manufacturer ArcelorMittal in early 2024 to produce a turbine tower based on low-emission steel, using 100% steel scrap melted in an electric furnace powered by 100% wind energy.[95]

In the United States, the steel industry has been buying more renewable energy. In 2022, Ohio-based Cleveland Cliffs, North America's largest producer of flat-rolled steel, agreed to a 15-year PPA with EDP Renewables to consume electricity generated by a 180 MW wind farm in Indiana.[96] The firm also has made progress in lowering its emissions through energy efficiency improvements: in 2020, it opened a "direct reduction" plant, which reduces the temperature requirements and the amount of coke needed in blast furnaces.[97]

In India, steel manufacturer Tata Steel trialled the use of hydrogen in blast furnaces for steel making in 2023, using a hydrogen injection of up to 40%, which confirms the potential of green hydrogen use for for steel production.[98] Globally, 14 green steel projects were announced during the year, 8 of which involve renewable hydrogen.[99]

The chemical industry faces the dual challenge of phasing out fossil fuel use both as an energy source and for non-energy purposes, such as the use of carbon feedstock to produce organic chemicals.[101]

In **process heat**, renewable electricity (through heat pumps for low-temperature heat), solar thermal heat (boosted by heat pumps) and renewable hydrogen (for higher-temperature processes) are well positioned to provide a stable and secure energy supply.[102] In Belgium, the plastics manufacturer INEOS Inovyn signed a 15-year PPA to purchase renewable electricity produced on-site via a 60 MW solar PV installation financed and owned by Green4Power.[103] In Germany, the chemical manufacturer

BASF plans to use an industrial heat pump for steam production with a capacity of 129 MW at what is set to be the world's largest chemical plant.[104] For **chemical feedstocks**, renewable hydrogen can replace fossil-based hydrogen in the production of ammonia and other products, such as methanol, when combined with modern biomass.[105] In 2023, LEGO, the world's largest toy company, and Novo Nordisk, a leading health-care company, agreed on a project to replace fossil fuel use in plastic production, using e-methanol produced by renewable electricity.[106]

The chemical industry also is well suited to efficiently use a wide range of residual and waste **biomass**, or biomass that is currently burned for energy.[107] In Thailand, Braskem and SCG Chemicals signed a joint venture to advance the use of ethanol from sugar cane for plastic production.[108] In the United States, New Energy Blue announced a long-term supply agreement with Dow to create bio-based ethylene from renewable agricultural residues for plastic production.[109]

Non-Metallic Minerals

Values in 2021	Non-Metallic Minerals
Share of sub-sector in industry TFEC	13.2%
Share of electricity in sub-sectoral TFEC	15%
Share of renewable energy in sub-sectoral TFEC	8%
Share of bioenergy in renewable energy in sub-sectoral TFEC	44%

Source: See endnote 110 for this module.

Cement and concrete are the second most-used substance in the world (after water) and also the second largest source of direct CO_2 emissions from industry.[111] Fossil fuels remain the dominant energy source (90% in 2022) for production processes that require temperatures of up to 1500°C, followed by bioenergy and renewable waste (4%) and non-renewable waste (4%).[112] Emissions in this industry come mainly from chemical reactions in the cement production process (50%), with 40% coming from burning fossil fuels and the rest from electricity use for machinery operation, mining and transport of raw materials.[113] Cement production fell 5% in 2022, due mainly to a slowdown in China, and stayed at that level in 2023.[114]

In 2023, several cement manufacturers installed solar plants. ARGOS, present in several Latin American countries, inaugurated a 20 MW solar PV plant in Honduras.[115] In Kenya, Bamburi Cement Plc signed a land lease agreement for a 20 MW solar PV plant, and HOLCIM was set to generate 75% of its on-site electricity consumption with a 25 MW solar PV plant.[116] In Spain, the cement manufacturer Cemex, in partnership with the Swiss-based concentrated solar company Synhelion, achieved industrial production of clinker (the most energy-intensive part of cement manufacturing) in Madrid using only solar heat.[117]

Fossil fuels provide
90%
of energy consumption in cement and concrete production, which requires temperatures of up to 1,500°C.

Electricity use accounts for around 5% of the greenhouse gas emissions from cement making, and various efforts emerged in 2023 to decarbonise this electricity use through renewables.[118] In the Philippines, Filinvest-Engie Renewable Energy Enterprise (FREE) announced a 25-year PPA for 13 MW of solar power to supply the Cemex manufacturing plant.[119] **Electrification of kilns** is a further avenue for integrating renewables in cement production. Coolbrook, a Finnish company, developed a RotoDynamic Heater in 2023 that can be retrofitted to existing plants to provide electric process heat for high-temperature industrial applications.[120] Another option for electrifying cement making is **thermal "batteries"**. In Thailand, Siam Cement Group has the capacity as of mid-2023 to produce 2.4 GWh annually of heat "batteries", which use an insulated refractory brick to store renewable electricity in the form of high-temperature heat.[121] Over 30 companies are providing high-temperature thermal storage for industrial applications.[122]

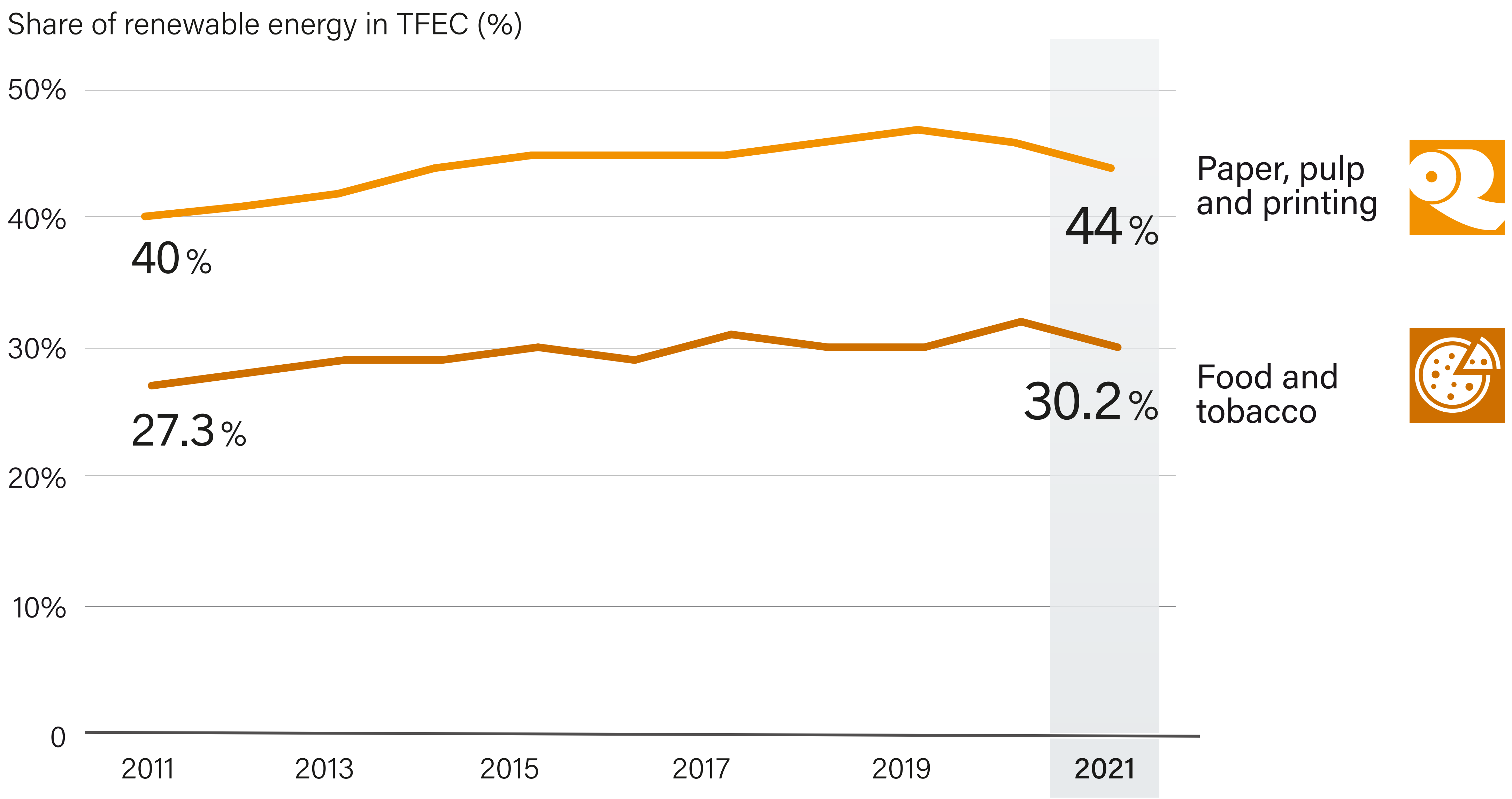
FOCUS ON LIGHT INDUSTRY

The lower temperature requirements of light industry enable easier integration of renewables. However, manufacturing sites are more diverse and widely spread, which makes the scale-up of technologies more complex.[129] The highest energy consumers among light industries are paper, pulp, and printing, as well as food and tobacco, which use a combined 11.6% share of the total energy consumption in industry.[130] The share of renewable energy in these sectors, has remained relatively stable in the last decade[131] (→ *See Figure 10.*)

For **glass production**, up to 85% of the energy requirement is for heating raw materials in a furnace with a constant temperature of around 1500°C.[123] The industry relies on fossil gas for three-quarters of its total energy use, as a stable energy source, and a supply disruption would cause irreversible damage to glass production infrastructure.[124] Alternatives to fossil gas include fully electric resistance heaters and oxy-hybrid furnaces that combine electricity, hydrogen and oxygen to reach the needed temperatures.[125]

In early 2023, the French company Saint-Gobain became the world's first glass manufacturer to pilot the use of more than 30% hydrogen in energy (60% in volume) to produce flat glass, which would open the possibility of using renewable hydrogen in glass production.[126] In Luxembourg, Plug Power developed 5 MW electrolysers that will enable Ardagh Glass to produce renewable hydrogen to replace fossil gas use.[127] However, concerns about changes in the glass quality when using high shares of hydrogen remain, highlighting the need for further research and development.[128]

FIGURE 10.
Share of Renewable Energy in TFEC by Light Industry Sub-Sector, 2011 to 2021



Source: See endnote 131 for this Module.

Bioenergy represents over **90%** of renewable energy consumed in the food and paper industries.

Paper, Pulp and Printing

Values in 2021	Paper, Pulp and Printing
Share of sub-sector in industry TFEC	5.2%
Share of electricity in sub-sectoral TFEC	24%
Share of renewable energy in sub-sectoral TFEC	44%
Share of bioenergy in renewable energy in sub-sectoral TFEC	83%

Source: See endnote 131 for this module.

The pulp and paper industry relies heavily on its own waste to produce large amounts of heat and electricity.[132] More than two-thirds of the energy used in paper making is in the form of heat for drying pulp and paper, with bioenergy providing more than half.[133] To cover the heat requirements beyond what waste provides, renewable-powered large heat pumps that repurpose residual heat are being explored as an alternative to fossil fuels, and to fossil gas in particular.[134]

In 2023, the Italian company Turboden announced the development of a large heat pump specifically for the pulp and paper industry that can generate mid-temperature steam of more than 200°C.[135] In Spain, ACCIONA Energía signed a 10-year PPA to supply renewable electricity to tissue paper manufacturer Sofidel, providing more than 90 GWh per year.[136] In Finland, Doosan Škoda Power and Metsä Fibre commissioned a 270 MW steam turbine that will help replace fossil fuels with renewable bioenergy for paper production.[137]

Food and tobacco

Values in 2021	Food and Tobacco
Share of sub-sector in industry TFEC	6.4%
Share of electricity in sub-sectoral TFEC	29%
Share of renewable energy in sub-sectoral TFEC	30%
Share of bioenergy in renewable energy in sub-sectoral TFEC	71%

Source: See endnote 138 for this module.

The food and tobacco industries require process heat temperatures mainly between 60°C and 200°C, with most food and beverage processing occurring below 130°C (for pasteurisation, cleaning and drying).[139] In this context, several renewable energy technologies have the potential to quickly replace fossil fuels.

Solar thermal heating is another existing solution that is well adapted to low and medium-temperature processes (→ *see Industry Investment Section*).

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. In Germany, sugar manufacturer Pfeifer & Langen transitioned from coal-fired boilers to biomass, which will enable the company to use discards from the sugar process for heat production.[140]

Technologies for electrifying low-process heat are increasingly common, particularly heat pumps powered by **renewable electricity**.[141] In Israel, developer Tigi Solar deployed a 780 kilowatt (kW) heat pump for the food industry firm Of Galil Ltd., using waste heat as input.[142] The Mars chocolate factory in Veghel, the Netherlands installed a 1,400 kW heat pump that harvests waste heat to maintain molten chocolate and syrup storage.[143] To increase its energy self-sufficiency, Madi, a meat processing company in Bosnia and Herzegovina, deployed solar PV panels that will provide 1,147 megawatt-hours of electricity annually to cover the plant's operations.[144]

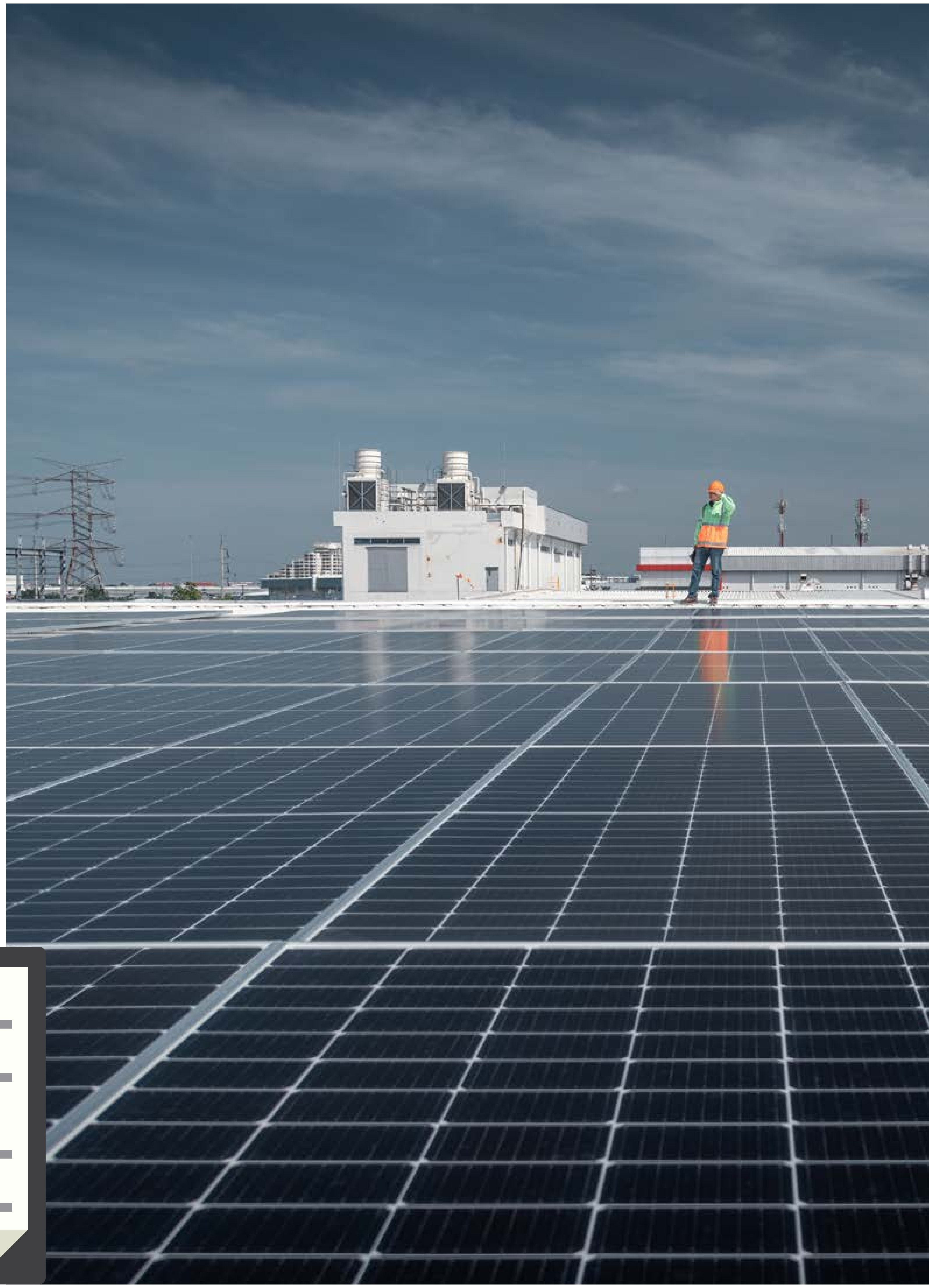
> The food and tobacco and paper and pulp industries heavily rely on their **own waste** for electricity generation and for heating processes of up to 200°C.

CHALLENGES

- The **diverse nature** of industries presents a challenge in crafting renewable energy policies that accommodate the needs and characteristics across different sub-sectors.
- **Heating needs vary widely** across sectors from around 100°C for drying in paper and food industries to over 1,500°C for cement kilns or iron furnaces.
- Several industries such as the glass industry require an **uninterrupted heat supply**, which is currently mainly covered using fossil gas.
- **Electricity prices** for energy-intensive industries in the EU were almost double those in China and the United States in 2023.
- **Solar heat for industrial processes** remains a challenging sector because of low awareness, projects requiring significant lead time and long payback periods.
- **Renewable hydrogen** development in industry remained limited due to high production costs, lack of demand-side subsidies, lack of offtake agreements, high risk perception from the finance sector, lack of consistent green hydrogen standards and the need for related infrastructure.
- **Data** on renewable energy investment in industry remain limited.

OPPORTUNITIES

- The EU's **Carbon Border Adjustment Mechanism** (CBAM), set in motion in 2023, covers the worldwide exports of cement, fertilisers, electricity, iron and steel, aluminium and hydrogen, potentially leading to higher use of renewables in industry to comply with EU standards.
- Increasing **electrification** of industrial sectors opens the opportunity to increase the use of renewable electricity.
  - For processes below 200°C, large-scale **heat pumps** are advancing to the capacity needed to achieve higher temperatures.
  - In high-temperature industrial applications, **electric arc furnaces** powered by renewable electricity can replace coke-reliant blast furnaces.
- **Heat purchase agreements** are on the rise, especially in industries with low and medium temperature requirements.
- Total installed capacity additions of **solar heat for industrial processes** tripled in 2023. At the same time, projects are getting bigger and the proportion of systems with temperatures above 100°C is increasing rapidly.
- In the chemical industry, **renewable hydrogen** can replace fossil-based hydrogen as feedstock to produce ammonia and other products, such as methanol, when combined with modern biomass.



RENEWABLES IN BUILDINGS

The buildings sector is a significant energy consumer, and the adoption of renewable energy sources like solar panels and energy-efficient systems are contributing to the reduction of carbon emissions.

30% of total energy consumed is in the buildings sector.

15.9% of energy used in the buildings sector comes from renewables.

30 countries had regulatory policies for the use of renewables in buildings by the end of 2023.

KEY FACTS

- The share of r**enewables in building energy demand increased** to 15.9% in 2021 up from 11.3% in 2011. Renewable energy provided 11.5% of the **heat consumed in buildings, showing an increase** of 0.5%.
- The **share of electricity in total final energy demand in buildings has risen** from 30% in 2010 to 35% in 2022.
- Estonia, Ireland, and Poland have launched various subsidy schemes to **encourage the adoption of renewable energy heating systems, including heat pumps.**

MODULE OVERVIEW

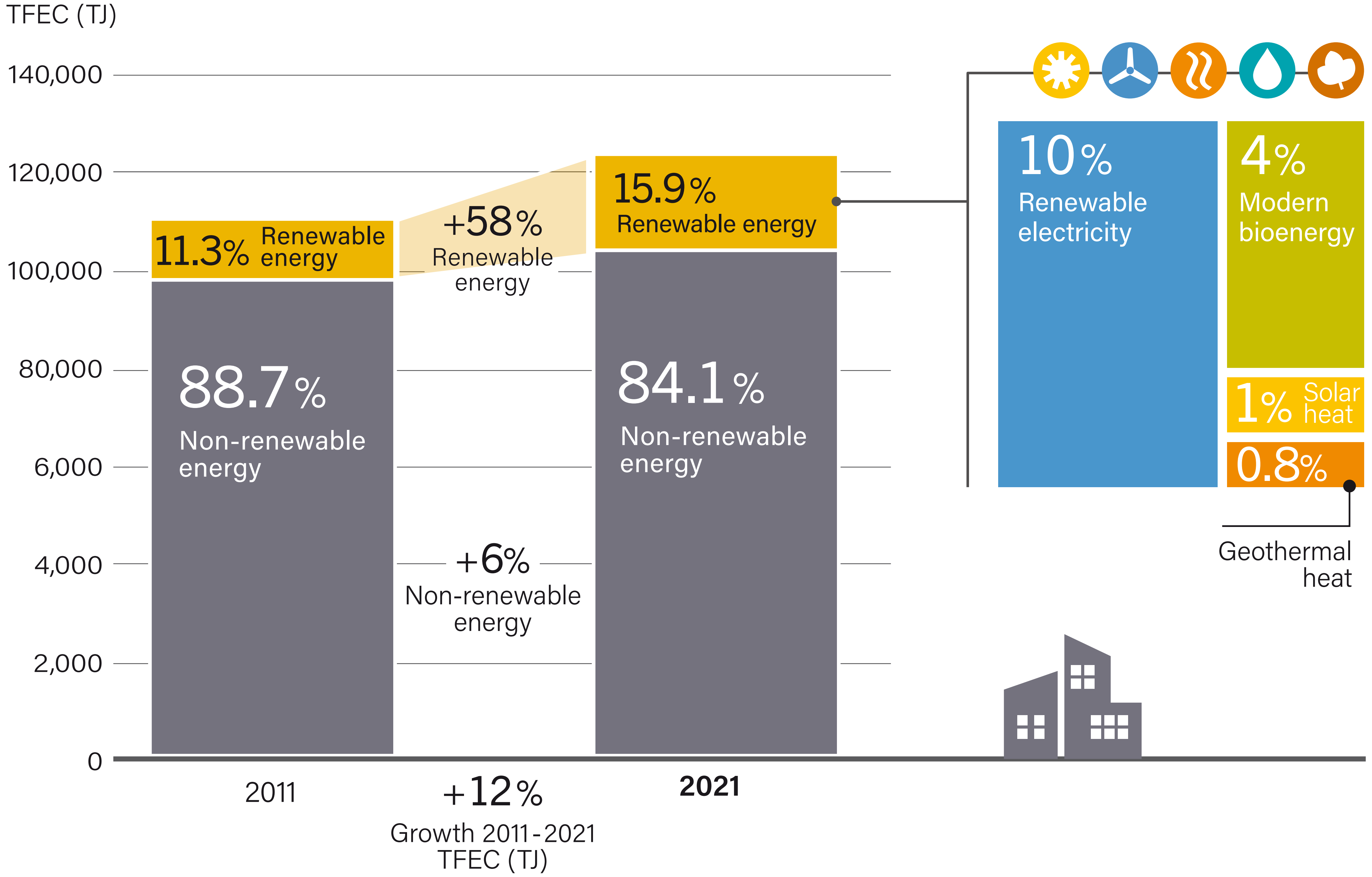
Buildings account for around one-third of global energy demand and carbon emissions, with direct energy consumption[i] in buildings representing 30% of global final energy consumption in 2022.[1] As of 2021, around 15.9% of the energy demand in buildings was met by modern renewable sources[ii] (→ *see Figure 11*), up from 11.3% in 2011.[2] Renewable energy share of heat consumed in buildings stood at 11.5% in 2021, an increase of 0.5%.[3]

Energy consumption in buildings varies greatly around the world, including among the top energy-consuming countries.[4] (→ *See Figure 12.*) Energy is consumed in buildings mainly for space and water heating, space cooling, cooking, lighting, and powering of appliances and electronics[iii]. This use takes various forms, such as electricity, fuels and direct thermal renewable energy.

Thermal applications accounted for around three-quarters of the final energy consumption in buildings in 2021, with the remaining quarter being electricity used to power appliances[i].[5] The share of electricity in the total final energy demand of buildings has increased from 30% in 2010 to 35% in 2022, in parallel with a shift towards renewables.[6] Space cooling is the largest growth sector among energy end-uses in buildings, rising more than 5% in 2022.[7]

The share of **electricity** in the total final energy demand of buildings has increased from 30% in 2010 to 35% in 2022.

FIGURE 11.
Renewable Share of Total Final Energy Consumption in Buildings, 2011 and 2021



Source: See endnote 2 for this module.

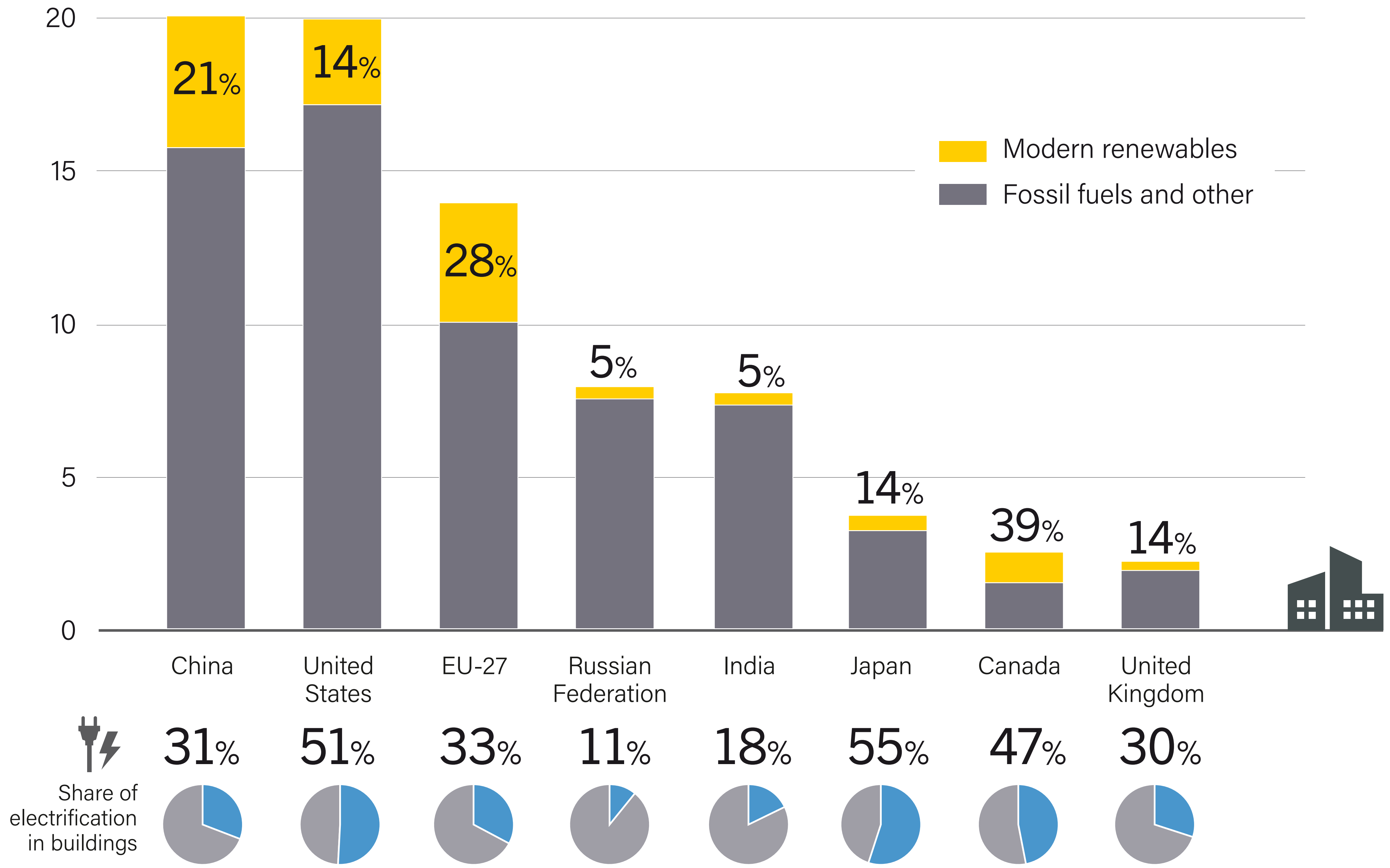
i Around one-third of the primary energy supply is dissipated through conversion inefficiencies, losses, and various processes, notably in electricity generation. The section does not cover the embodied energy in building materials and construction.

ii This excludes the traditional use of biomass – that is, 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.

iii The two main energy end-uses in buildings are thermal and electrical. Thermal end-uses refer to space heating and cooling, water heating and cooking (including the electricity used to provide heating and cooling).

iv Appliances include lighting and other electricity-based services (cooking appliances, electronics and charging devices), excluding those used for heating and cooling.

FIGURE 12.
Energy Consumption in Buildings by Major Country/Region, 2021

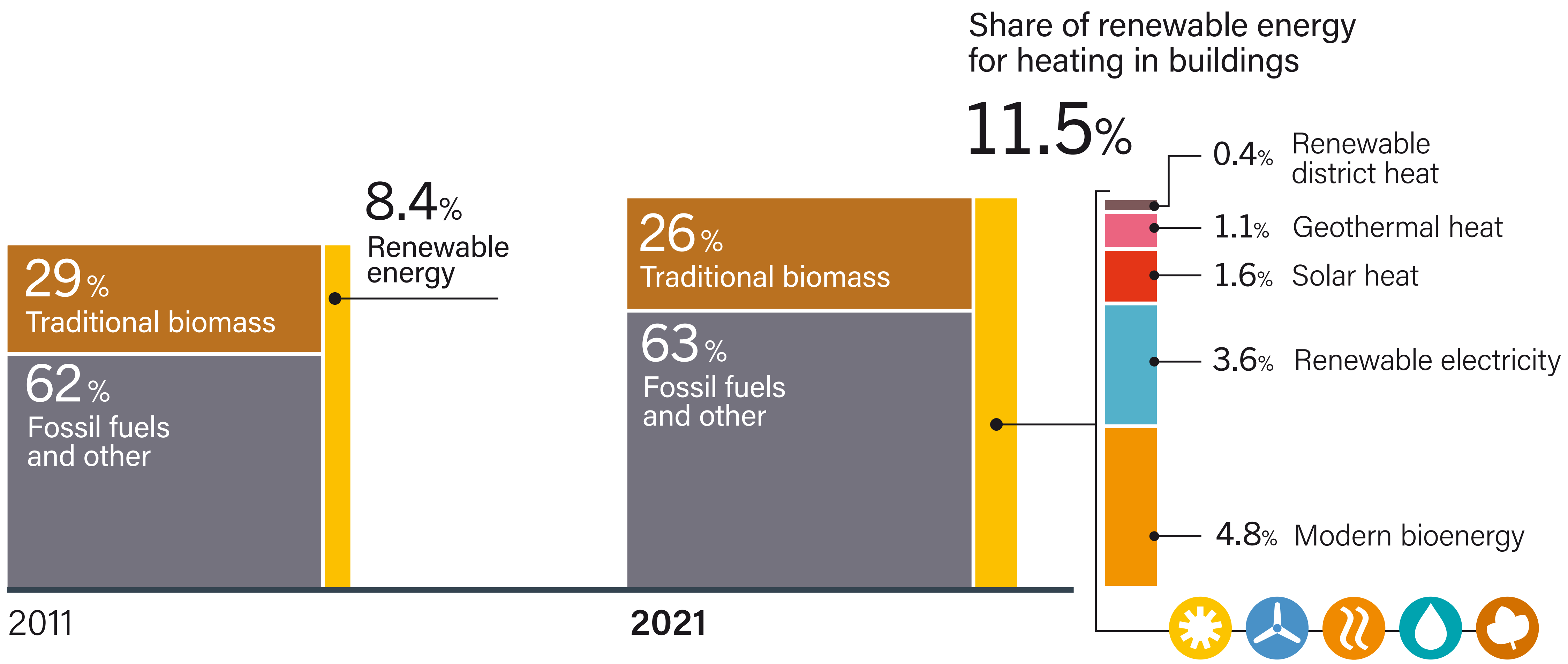


Source: See endnote 4 for this module.

The deployment of heat pumps (→ *see Box 1*), electric boilers and other electric heating systems has helped drive a shift towards renewable electricity to heat buildings.[8] (→ *See Figure 13.*) This has boosted the use of renewables in the heat sector in China, the European Union (EU), and the United States, although the transition has been gradual.[9]

Improvements in the efficiency of building envelopes and of end-uses within buildings are helping to improve the economics of renewable energy applications, supporting the deployment of adjacent technologies such as heat pumps. Solar PV, wind power, and other renewable energy technologies are increasingly competitive with fossil fuels owing to falling technology costs, increased efficiency, and the impetus for strengthening energy security and independence.[10] Innovations in generation technologies and energy storage continue to enhance efficiency and reliability while also bringing down costs, making renewables suitable for a wide range of applications in the built environment.[11]

FIGURE 13.
Energy Consumption for Heating in Buildings, by Source, 2011 and 2021



Source: See endnote 8 for this module.

BOX 1. Heat Pumps

Heat pumps are highly efficient devices, using three to five times less electricity than traditional heaters and boilers to produce the same heat output. Although heat pumps accounted for less than 15% of the electricity used to heat buildings globally in 2022, deployment is increasing rapidly. From 2023 to 2028, heat pumps are expected to account for one-third of the increase in global electricity consumption and and nearly one-quarter of the rise in renewable electricity use. Heat pumps achieve high efficiencies not only by using electricity, but also by harnessing ambient heat, thereby driving a global increase in renewable heat use in buildings.

Existing heat pump installations are found mainly in new buildings and single-family homes, whereas deployment has lagged in multi-storey apartment buildings and commercial spaces. Retrofitting existing buildings and building district-scale energy systems is essential for unlocking progress toward decarbonisation.

In 2023, XX countries announced new policies for heat pumps. Estonia launched a subsidy scheme for building retrofits that covers renewables for heating – which includes covering the replacement of furnaces, gas or electrical heating by renewable energy heating systems or district heating as well as rooftop solar (PV and thermal). Ireland extended its grants for renewable heat to cover heat pump installations, and Poland expanded its clean air programme to include grants for replacing solid fuel heating sources with heat pumps. The Slovak Republic is providing grants totalling USD 169 million (EUR 156 million) to support up to half of the system and installation cost for solar thermal collectors, solar PV systems and heat pumps.

Source: See endnote 8 for this module.

POLICY AND TARGETS

Policy action to boost the uptake of renewable heating and cooling in buildings typically includes national targets (such as pursuing a defined share of renewable heating and cooling by a certain date) or specific support policies, such as financial incentives or regulations.[12] At the international level, the Buildings Breakthrough Initiative was launched in 2023 to catalyse action on the decarbonisation of buildings.[13] (→ *See Box 2.*)

In 2023, 5 countries (mainly in the EU) adopted new or updated **renewable energy targets** in the buildings sector, bringing the total number of countries with such targets to 16.[14] The EU's new Renewable Energy Directive includes an indicative target for at least 49% of energy consumption in buildings to come from renewable sources by 2030.[15] Portugal set a target for 97-98% renewables in the total final energy consumption of the buildings sector by 2050 (depending on the building type), with interim 2030 targets of 57% for residential buildings and 78% for non-residential buildings.[16] Latvia and Slovenia set targets for 68% and 66% renewables in buildings, respectively.[17]

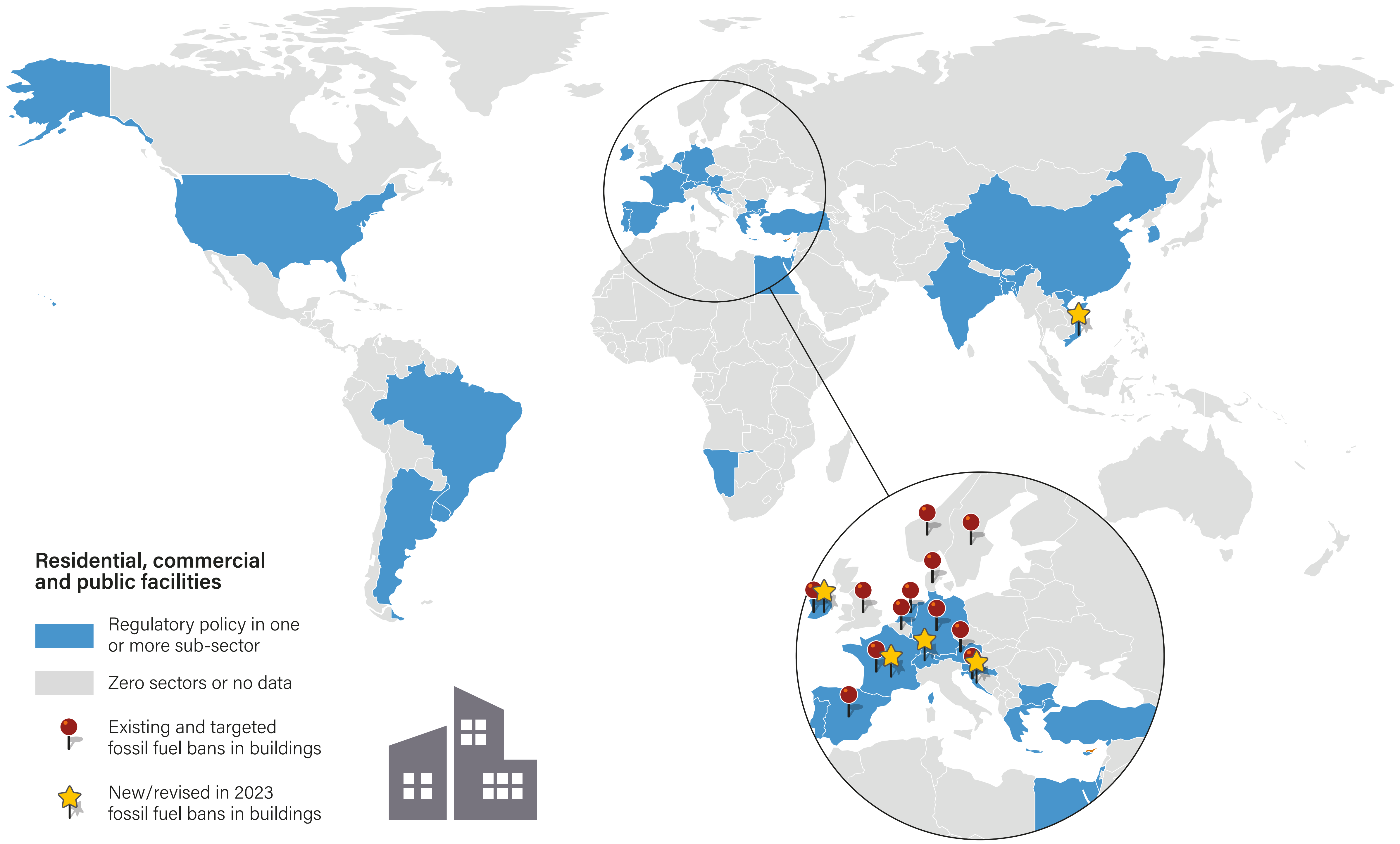
In China, the government has set a target of 8% renewables in the total energy consumption of urban buildings by 2025.[18] In 2023, the Chinese National Energy Administration issued a call for rural counties to participate in an energy transition programme that sets a target of 30% renewables in the total final energy consumption of rural buildings.[19]

BOX 2. The Buildings Breakthrough Initiative

Launched in December 2023 at the United Nations Climate Change Conference in Dubai (COP 28), the Buildings Breakthrough initiative aims to achieve near-zero emissions and climate resilience in the buildings sector by 2030. The initiative focuses on expanding access to sustainable solutions and clean technologies globally and is led by France, Morocco, and the United Nations Environment Programme, with co-ordination by the Global Alliance for Buildings and Construction. As of February 2024, 28 countries had committed to the initiative, which emphasises the need for accelerated action, stakeholder co-ordination, harmonised standards, procurement commitments, funding for net-zero construction, knowledge sharing, and alignment of research with policy goals.

Source: See endnote 13 for this module.

FIGURE 14.
Regulatory Policies in Buildings, by Building Type, as of End-2022



Source: See endnote 23 for this module.

With regard to **renewable energy targets for heating**, the EU aims to increase the share of renewables used in heating and cooling by 0.8% annually to 2026 and 1.1% annually to 2030.[20] In 2023, several EU Member States submitted draft updates of their energy and climate plans, adopting new 2030 targets for the renewable share of heating in the buildings sector – including Latvia (68%), Cyprus (47.9%), Slovenia (66%) and Italy (42.5%).[21] A few countries have targeted the uptake of renewables in district heating, including Denmark (85% by 2030) and Croatia (1.3% annual increase to 2030).[22]

Heat roadmaps are increasingly being developed to analyse current energy sources, infrastructure, and emissions, and to chart a course to decarbonisation through renewables. These plans aim to guide policy development, foster collaboration and encourage investments.[23] Key strategies in heat roadmaps include promoting the uptake of renewables, such as geothermal, solar thermal and biomass; promoting efficiency; encouraging the deployment of heat pumps; using waste heat; building and improving district heating networks; and developing smart grids that can flexibly combine heat and power infrastructure.[24] The Heat Roadmap Europe initiative has developed strategies for 14 countries[i],[25]

By the end of 2023, at least 30 countries had **regulatory policies** for the use of renewables in buildings.[26] (→ *See Figure 14.*) These include policies that set building performance standards, mandate clean technology deployment or electrification, and restrict the use of fossil fuels.

Fiscal and financial incentives have remained popular policies to advance renewable energy uptake in the buildings sector. These can include tax incentives – such as credits and deductions for the installation of renewable energy technologies – as well as grants, rebates, and direct subsidies, which lower the upfront costs and increase the attractiveness of renewable energy projects. As of 2023, 18 countries had fiscal and financial incentives in place for the deployment of renewables in the buildings sector.[27] For example, Japan launched a new mortgage scheme in 2023, Flat35, to provide lower interest rates for sustainable homes.[28]

District heating continued to receive policy attention. District heating policies can lead to the increased adoption of renewables – including geothermal, solar thermal and biogas – in heating systems.[29] The United Kingdom issued an Energy Security Bill that includes regulations and zoning for heat networks, with a focus on decarbonising the existing network through the use of renewables.[30] The country awarded USD 488 million (GBP 388 million) for a Green Heat Network fund, which disbursed its first allocations in early 2023.[31] Denmark put in place subsidies totalling USD 3.5 million (DKK 24 million) for decarbonising district heating.[32] The EU is funding a USD 1.3 billion (EUR 1.2 billion) scheme in the Czech Republic to promote green district heating, with an emphasis on renewables.[33] Although no new district cooling policies were enacted in 2023, such policies have been in place for a few years, including in the Persian Gulf countries and Southeast Asia.[34]

i The initiative has produced detailed reports for countries including Austria, Belgium, the Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, Sweden and the United Kingdom. These roadmaps are based on scenario analyses and offer insights into the potential for energy efficiency improvements and the adoption of district energy systems, among other solutions.

Policies for increasing **on-site and distributed renewable energy generation** in buildings also continued to develop, especially for rooftop solar systems (PV and thermal). Türkiye introduced new incentives for rooftop solar power, including net metering for homeowners.[35] Greece is providing grants for households to purchase and install rooftop PV systems at up to 76% of the cost.[36] Bulgaria launched a household solar rebate scheme for PV and thermal systems, totalling USD 133 million (BGN 240 million).[37] India announced a new rooftop PV subsidy scheme for 10 million households and extended its previous solar subsidy scheme to 2026.[38] Kenya updated its draft regulations for solar water heaters, making it mandatory to install the units on all residential and commercial buildings, schools and health centres.[39]

Building energy codes and net zero energy codes typically include provisions for the uptake of renewables in buildings. As of 2023, the number of building codes globally totalled 81 for residential structures and 77 for non-residential structures, with 80% of the codes being mandatory.[40] However, building codes can be challenging to implement due to complex regulations and ineffective enforcement (whether due to lack of capacity or corruption).[41] Around one-third of existing codes have not been updated since 2015 and may fall short of current best practices and standards.[42] Nonetheless, in 2022, a 3.5% improvement in the energy intensity of buildings per square metre was attributed to better building codes and fabric[i] performance.[43]

In 2023, Türkiye introduced regulations targeting a minimum 5% renewable energy share for all new buildings above 2,000 square metres.[44] Under the Inflation Reduction Act, the United States announced an additional USD 530 million in technical assistance competitive grants for the adoption and implementation of the latest energy codes and standards, including zero energy codes that promote decarbonisation in buildings.[45] Since January 2023, Denmark's new building regulation has mandated an annual cap on greenhouse gas emissions per unit area for new construction.[46] Germany has implemented policies to ensure that new buildings meet standards for nearly zero-energy buildings (NZEBs), focusing on high energy performance and significant use of renewables.[47] France is aligning with EU directives to transition new buildings to NZEBs, with earlier adoption required for public buildings than for private ones; this includes integrating energy performance and the use of renewables into building regulations.[48]

In Canada, the federal government has committed to developing a model building code on net zero emissions by 2024.[49] At the sub-national level, the province of Nova Scotia announced stronger energy requirements in its updated building energy codes for the residential sector, and the city of Victoria mandates that all new buildings comply with the new Zero Carbon Building Code.[50] The Canada Green Building Council leads in promoting net zero energy buildings through specific certification programmes.[51]

Energy efficiency policies in the buildings sector complement renewable energy policies by helping to reduce overall energy use. The more efficiently that energy services are delivered, the faster renewables can become an effective and significant contributor to buildings' final energy consumption.[52] Energy efficiency policies are widely used globally and can focus both on the building envelope itself and on the appliances used in the building.

By the end of 2023, at least 30 countries had **regulatory policies** for the use of renewables in buildings.

i The building fabric is the components and materials that the building itself is made of, such as the walls, floors, roof, windows and doors.

In 2023, Ireland allocated grants for home insulation for households living in energy poverty[i,53] France established a green fund for the clean energy transition that supports energy efficiency measures in public buildings.[54] Bosnia and Herzegovina released an energy efficiency strategy that earmarks USD 7 million (BAM 12.6 million) for public sector buildings, and Croatia allocated USD 43 million (EUR 40 million) for energy efficiency renovations of public buildings.[55] The EU Energy Performance of Buildings Directive mandates zero-emission standards for new buildings by 2030, with an emphasis on deep renovations, sustainable materials and the integration of renewables.[56]

Minimum energy performance standards (MEPS) for appliances were in place in more than 110 countries as of 2023.[57] These covered around 90% of the global demand for space cooling and refrigeration and around half the global demand for space and water heating.[58] The United States strengthened its MEPS for central air conditioners and heat pumps.[59]

In 2023, the United Kingdom and Ireland adopted policies supporting a **shift away from fossil fuel use for heating** in buildings.[60] Germany enacted legislation mandating that all new heating systems use at least 65% renewable energy starting in January 2024, and that all fossil fuel heating systems be replaced by 2045.[61]

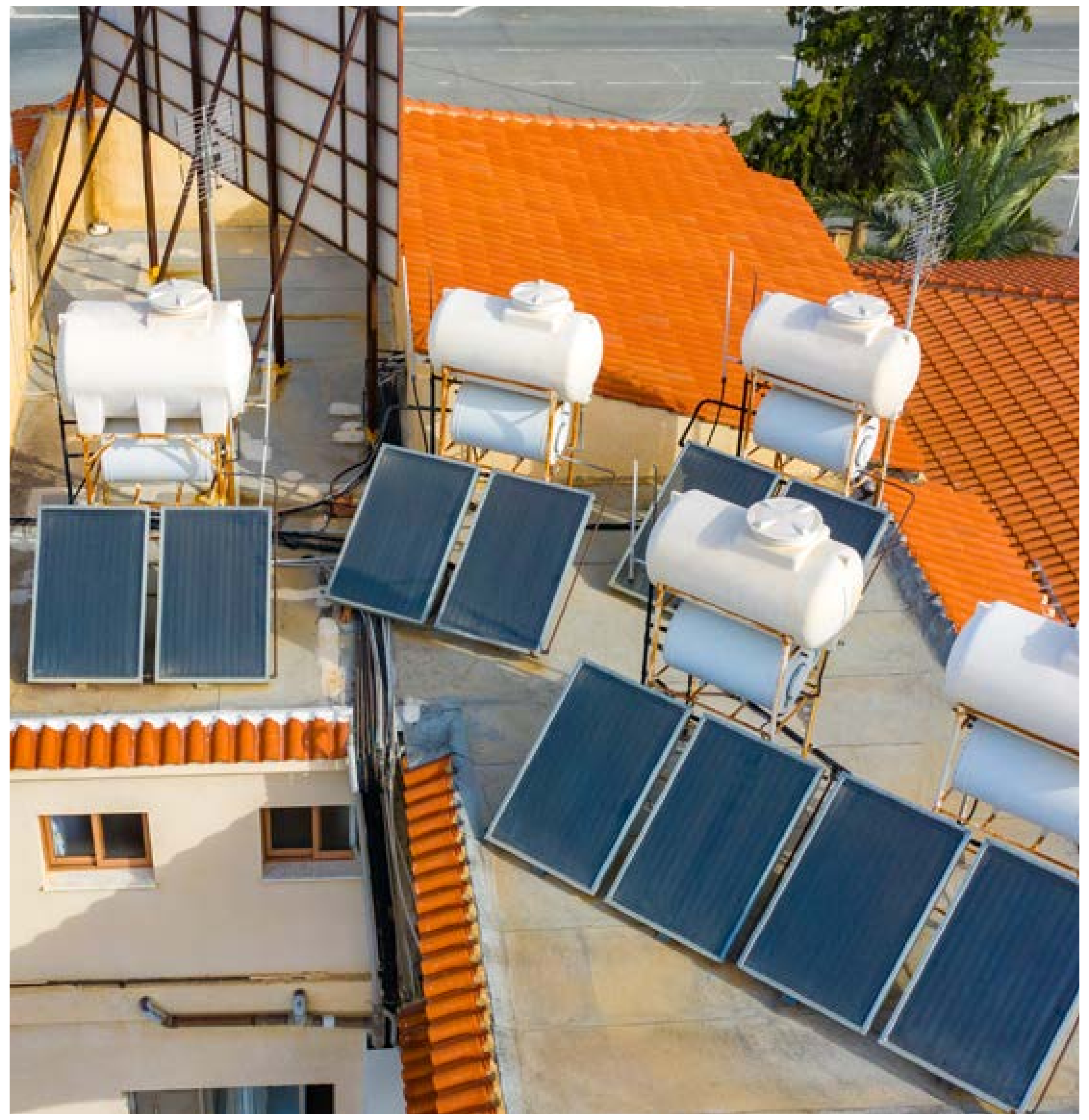
Switzerland's new 2050 Heat Strategy focuses on eliminating all fossil fuel use to heat buildings and replacing it with renewables by 2050.[62] Austria banned gas boilers in new buildings.[63] France banned oil and coal heaters starting in 2022, and gas boilers starting in 2024, although it later backpedalled on gas boilers – again allowing them, but removing related subsidies.[64] At the sub-national level, New York became the first US state to ban gas stoves and furnaces for most new buildings.[65]

INVESTMENT AND FINANCE

Data on **investment in renewables** specifically for the buildings sector remain limited, both for power and for heat. Global investment in **solar thermal heating**[ii] totalled an estimated USD 19.1 billion in 2021.[66] More than two-thirds of this occurred in China (around 69%, or roughly USD 13.2 billion), followed by Europe (11.6%, or roughly USD 2.3 billion).[67]

Investments in **energy efficiency** in buildings[iii] rose 14% in 2022 to reach USD 285 billion,[68] though preliminary indications suggest that growth will slow in 2023 due to inflation in project costs and to rising interest rates.[69] The increased spending was the result of policy-driven investment in the United States as well as a continued effort, led by Europe, to respond to the energy crisis triggered by the Russian invasion of Ukraine.[70]

Europe led energy efficiency investments in 2022, with increased spending in Germany (USD 51 billion) and Italy (USD 57 billion); however, other countries in the region (such as France and the United Kingdom) experienced declines due to slowdowns in the construction sector.[71] Spending in the United States, which ranked second globally in energy efficiency investment, exceeded USD 33 billion in 2022, supported mainly through public funding from Department of Energy efficiency programmes (such as federal EnergySTAR residential tax credits) coupled with utility demand-side management.[72] In China, investment in real estate development fell 10% in 2022, impacting energy efficiency investment in the country.[73]



i Energy poverty is defined as the lack of access to modern and efficient energy services, including clean technologies and fuels for cooking and electricity, which are crucial for a healthy and sustainable quality of life.

ii Solar thermal heating investment numbers are calculated based on the collector areas/systems installed in the respective year and on the average costs of the system.

iii 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 in buildings makes tracking energy efficiency investments challenging. See endnote 72 for this module.

MARKET DEVELOPMENTS

ENERGY DEMAND BY REGION

In 2023, the G20 countries with the highest shares of renewable energy use in buildings were Iceland (where more than 90% of space heating is from geothermal), Brazil (where hydropower supplies a high share of electricity, and bioenergy is used for heating and cooking) and Canada (which relies heavily on electric heat and hydropower).[74] The lowest shares of renewables in buildings (less than 5% each) in the G20 countries were in Indonesia, the Russian Federation, the Republic of Korea, Saudi Arabia and South Africa.[75]

In **Europe**, France, Italy and Germany had above-average renewable energy shares in buildings, due largely to the use of biomass for heat.[76] In Germany, biomass (solid, liquid and gaseous) remained the leading energy source for heating and cooling, providing 78% of renewable heat in 2022.[77] In France, solid biomass[i] supplied 62% of renewable heat and cooling in 2022, while heat pumps accounted for around 27%.[ii][78]

In **Asia**, China's large population and energy demand continued to drive renewable heat development in the buildings sector in 2023, including significant deployments of electric heating equipment, solar thermal and geothermal energy.[79]

In **Africa**, South Africa, along with Egypt, Kenya, Morocco, and Nigeria, have been at the forefront of integrating renewables such as solar, wind, and geothermal into their national energy mixes, with several projects aimed specifically at improving energy efficiency and renewable energy use in buildings.[80]

In **North America**, policies such as the US Inflation Reduction Act helped set new records for solar PV deployment in 2023, with a large increase in residential installations.[81]

In **Latin America and the Caribbean**, notable focus was given to geothermal energy in the Caribbean, with countries such as Dominica and Saint Lucia making significant investments to explore and develop geothermal resources, with the aim of achieving energy self-sufficiency.[82]

Among developments in **Oceania**, Australia revised its National Construction Code to include updated efficiency standards for new buildings and major renovations, in a key shift towards energy-efficient buildings.[83] The revision supports the expansion of the home energy rating scheme to include the energy used by appliances, not just the home's thermal shell.[84] Australia's emphasis on improving energy productivity in residential buildings is part of a broader strategy under the National Energy Productivity Plan, which aims for a 40% improvement by 2030 and includes initiatives to increase the efficiency of appliances and building materials through labelling and standards.[85]

New Zealand's energy strategy, still under development as of 2023, focuses greatly on leveraging the country's high share of renewable electricity for building applications. This includes increasing electricity use for heating to expand the penetration of renewables for thermal needs and further reduce the carbon footprint of residential and commercial buildings.[86]

In the **Middle East and North Africa** region, countries including Bahrain, Kuwait, Oman, Saudi Arabia and the United Arab Emirates have embraced net zero emission targets, some of them specific to buildings.[87]

TRENDS BY SECTOR AND TECHNOLOGY

Power

In 2023, consumers continued to adopt distributed solar PV systems in response to higher grid electricity prices and favourable policy support.[88] Rooftop solar PV has become mainstream in many countries, driven by innovative business models such as net metering and net billing that combine self-consumption and feed-in tariffs for prosumers[iii].[89] Rooftop solar systems accounted for around 45% of solar PV additions in 2023, with up to 446 gigawatts (GW) of capacity being commissioned.[90] Notable growth occurred in Brazil, Italy and Spain.[91] In Germany, the city of Hamburg set a pioneering standard for climate protection in the buildings sector by mandating solar PV systems on all new buildings and advancing similar requirements for existing buildings undergoing roof renovations.[92] (→ *See Snapshot: Hamburg.*)

Building-integrated PV (BIPV) and rooftop wind turbines have the potential to complement traditional solar electric panels to power buildings in the urban environment; however, these remain niche uses, and data on these markets are limited.[93]

i Of this solid biomass, 63% comes from domestic wood consumption. This category also includes "renewable municipal waste".

ii Note that not all heat pump output is powered by renewable electricity, as the French grid is only partially renewable (28%).

iii A prosumer is an individual, household or small business that not only consumes energy but also produces it. Prosumers may play an active role in energy storage and demand-side management.

SNAPSHOT HAMBURG

HAMBURG PIONEERING RENEWABLE ENERGY LEGISLATION WITH MANDATORY SOLAR PANELS ON BUILDINGS

Hamburg, a German city and federal state, is pioneering renewable energy legislation in the buildings sector, including by mandating the installation of solar panels on new buildings from 2023 and on roof renovations from 2024. The amendment of Hamburg's Climate Protection Act reinforces the city's commitment to promoting renewable energy and tackling carbon emissions, targeting a 70% reduction by 2030 compared with 1990 levels and climate-neutrality by 2045.

Two-thirds of electricity demand in buildings could be met by solar power and energy storage, with a potential capacity of 9.4 GW. This would require a deployment area of approximately 60 km^2 (8% of Hamburg's relatively small territory). While roofs only cover around 10% of Hamburg's land area, at least 80% of the potential solar power supply would come from rooftops, with the remaining 20% deployed in agriculture (agrivoltaics) and on car parks. The largest potential is found in single-family houses, followed by multi-family houses and commercial and industrial buildings. A small-scale solar PV system (up to 10 kW) generally costs between €1,500 and €1,700 per kW, implying a payback period of under 20 years.

At the national level, the German government aims to boost the portion of renewable electricity to 80% of total consumption by 2030, as outlined in the revised Renewable Energy Sources Act of 2023.

The recently implemented Solar Package I, adopted in April 2024, sets a target of 215 GW of solar capacity in Germany by 2030, while new regulations will simplify and expedite the installation of balcony PV systems, increasing accessibility and affordability. The package introduces a 'shared building supply' model, streamlining the supply of solar power within residential buildings and reducing bureaucratic barriers.

Source: See endnote 96 for this module.

Heat

Bioenergy continues to be the largest source of renewable heat in buildings globally.[94] However, the fastest growing renewable heat source in the sector in 2023 was renewable electricity.[95]

Solar thermal systems are a prominent source of hot water for individual buildings and contributed around 6% of renewable heat in 2022.[96] An estimated 250 million dwellings were using solar thermal technologies for water heating as of 2020.[97] Large-scale solar thermal deployments have also increased. in 2022, an estimated 571 large-scale solar thermal plants were operational (mostly to provide district heating), with a combined capacity of 2.2 gigawatts-thermal.[98] China continued to lead in global solar thermal developments in 2023.

In 2022, China was responsible for nearly 90% of global direct **geothermal heat** consumption, with the EU accounting for most of the rest.[99] Other leaders in geothermal direct use for heating and cooling were the United States, Sweden, Türkiye and Japan; on a per capita basis, the top countries were Iceland, Sweden, Finland and Norway.[100]

District heating systems, which provide heat for residential and commercial buildings from a centralised location, have large potential to meet building heat demands efficiently.[101] They can effectively integrate renewables – such as geothermal, solar thermal and bioenergy – and can incorporate thermal storage to bring flexibility to the entire energy system.[102] As of 2023, most of the world's district heating (around 90%) continued to rely on fossil fuels, particularly in China and the Russian Federation.[103] In the EU, countries such as France, Austria, and Germany still rely on fossil-based cogeneration, while Iceland meets nearly all its heating demand in buildings through geothermal district heating systems.[104]

In Germany, nine solar district heating systems were under construction or in advanced planning stages as of early 2024.[105] These included the country's largest solar district heating plant, which is expected to supply 2% of the network's total annual heat requirements (up to 20% in summer) and is slated for commissioning in Leipzig in 2025.[106] In the Netherlands, a large-scale solar thermal plant neared completion in Groningen in 2023 and will connect to the local district heating grid.[107] Three companies – Solarfields, K3 and TVP Solar – came together to found a special purpose vehicle for the project, ultimately reducing the risk for financial institutions associated with the required USD 25 million (EUR 23 million) in capital expenditure.[108] Solar district heating plants in Kosovo and Serbia were also in planning stages.[109]

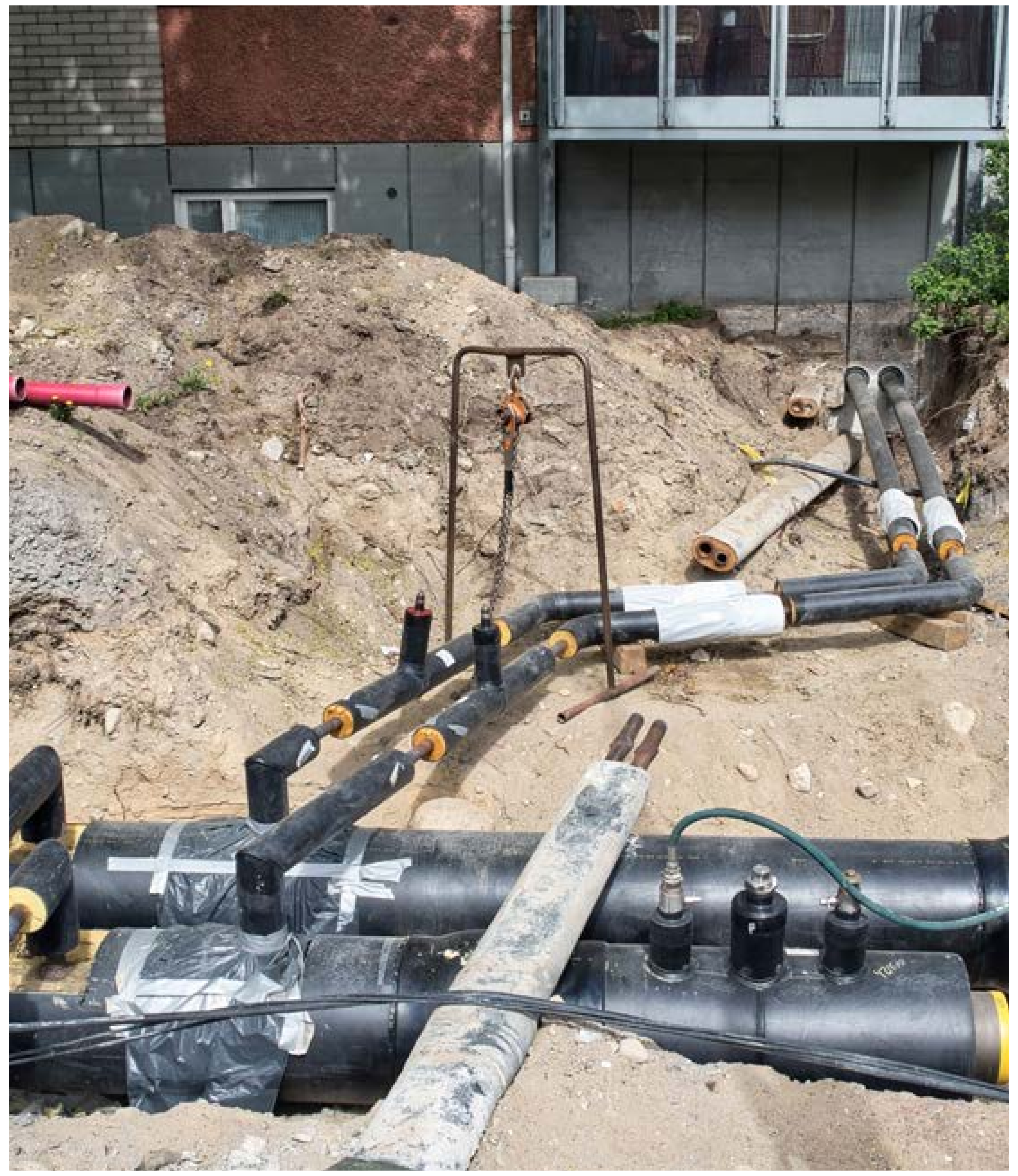
Cooling

Renewables are increasingly being used to cool buildings. Renewable energy, heat pumps, novel air conditioning technologies and passive building designs are increasingly being used to efficiently cool buildings and reduce energy consumption. Nascent solar thermal cooling systems can use natural refrigerants such as water and ammonia, offering a way to meet rapidly growing demand for air conditioners.[110]

In Southeast Asia, as incomes rise and populations grow, the demand for air conditioning has boomed, and the region has set ambitious milestones for upgrading cooling technologies.[111] Cambodia – where heat stress leads to an annual loss in the gross domestic product (GDP) of at least USD 1.12 billion – has increased its attention to cooling needs; in 2023, it launched a new National Cooling Action Plan focused on five areas: building space cooling, the food and healthcare cold chains, mobile air conditioning and process cooling.[112] South Africa launched its National Cooling Action Plan in early 2023, showing a pro-active approach to enhancing energy efficiency and reducing emissions from space cooling.[113]

District cooling can provide substantial energy savings by reducing reliance on air conditioners or fans. Although markets for district cooling are growing in many regions, data are not systematically collected on investments that incorporate renewables into such systems.[114] In the health-care sector, renewables are enhancing health services in hospitals in rural Africa by providing sustainable cooling, heating, and clean water solutions through solar-powered technologies, greatly improving health outcomes and advancing sustainable development goals.[115] (→ *See Snapshot: Africa.*)

As of 2023, most of the **world's district heating** (around 90%) continued to rely on fossil fuels, particularly in China and the Russian Federation.



SNAPSHOT AFRICA

COOLING RURAL HOSPITALS IN AFRICA THROUGH SOLAR PV: THE SOPHIA PROJECT

Rural communities in Africa often lack access to health care, clean water and infrastructure, exacerbating ruralurban health disparities across the continent. Unreliable electricity and water supply makes it challenging to maintain proper cooling and heating, essential for adequate storage of medicine and blood plasma. Demand for cooling and refrigeration in Africa is expected to grow significantly until 2030 owing to population growth, rising living standards and increasing temperatures. Access to cooling is key to achieving various Sustainable Development Goals (SDGs) by 2030, including those concerning health and well-being (SDG3) and poverty (SDG1).

The Sustainable Off-grid Solutions for Pharmacies and Hospitals in Africa (SophiA) project, funded by the European Commission, aims to improve cooling and heating systems in remote hospitals in African countries. This four-year initiative (2020-2024) brings together 13 African and European partners to develop cooling facilities and technologies for water processing and electricity generation, thereby elevating working conditions and treatment standards in remote hospitals. The first facility was installed at the Léo Hospital in Burkina Faso in May 2024, with three more planned in Uganda, Cameroon and Malawi.

The cooling systems are built into a 40-foot container and powered by integrated solar panels (24-27 kW capacity). Two containers have been developed: the Solar Cooling Container addresses cooling requirements across three different temperature ranges and the Solar Water Container produces clean and cooled drinking water, sterilized water and hot steam for the autoclaves and sustainable cooking.

The cooling container uses natural refrigerants[i] (ethane, CO_2, and propane) to provide storage at three temperature levels: -30°C for blood plasma, -70°C for vaccines and sensitive drugs, and +5°C for medicines and food. Each container has a dedicated water-ice thermal energy storage based on refrigerant condensation that can store up to 1,500 kg of ice – enough to provide two full days of refrigeration. During the day, electricity generated by the PV panels feeds into this thermal storage system, while surplus electricity is used to power devices outside the container, such as washing machines, autoclaves and clean cooking facilities. Around 90% of the containers' electricity demand is met by solar PV, and the system also includes a 70-kW battery and a diesel generator to ensure uninterrupted supply and provide flexibility. At night, the energy-intensive propane processor is switched off to reduce reliance on batteries.

The systems are manufactured in South Africa and local companies are involved in installation. Skills are being developed with local universities and communities based on a train-the-trainer model.

The cooling systems developed by SophiA could be deployed to serve a range of functions in decentralised systems and remote areas, including providing relief in first aid situations, preserving food and supporting natural disaster response. These technologies can also be used to clean water and cooling to households.

Overall, the SophiA project signifies a major step in advancing healthcare infrastructure and renewable energy in remote areas in Africa, while fostering sustainable development pathways through low-carbon and climate-resilient trajectories, leapfrogging fossil fuels and high global warming potential refrigerant technologies.

Source: See endnote 115 for this module.

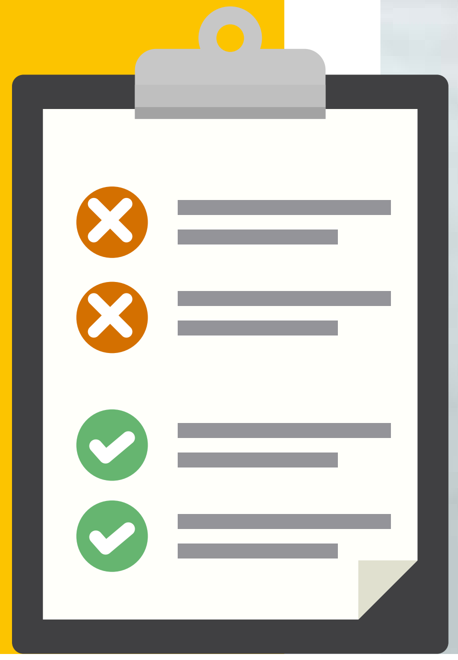
i Natural refrigerants, used in refrigerant systems, are substances that occur directly in nature, such as carbon dioxide and hydrocarbons like propane, and have a low global warming potential while being cost-effective.

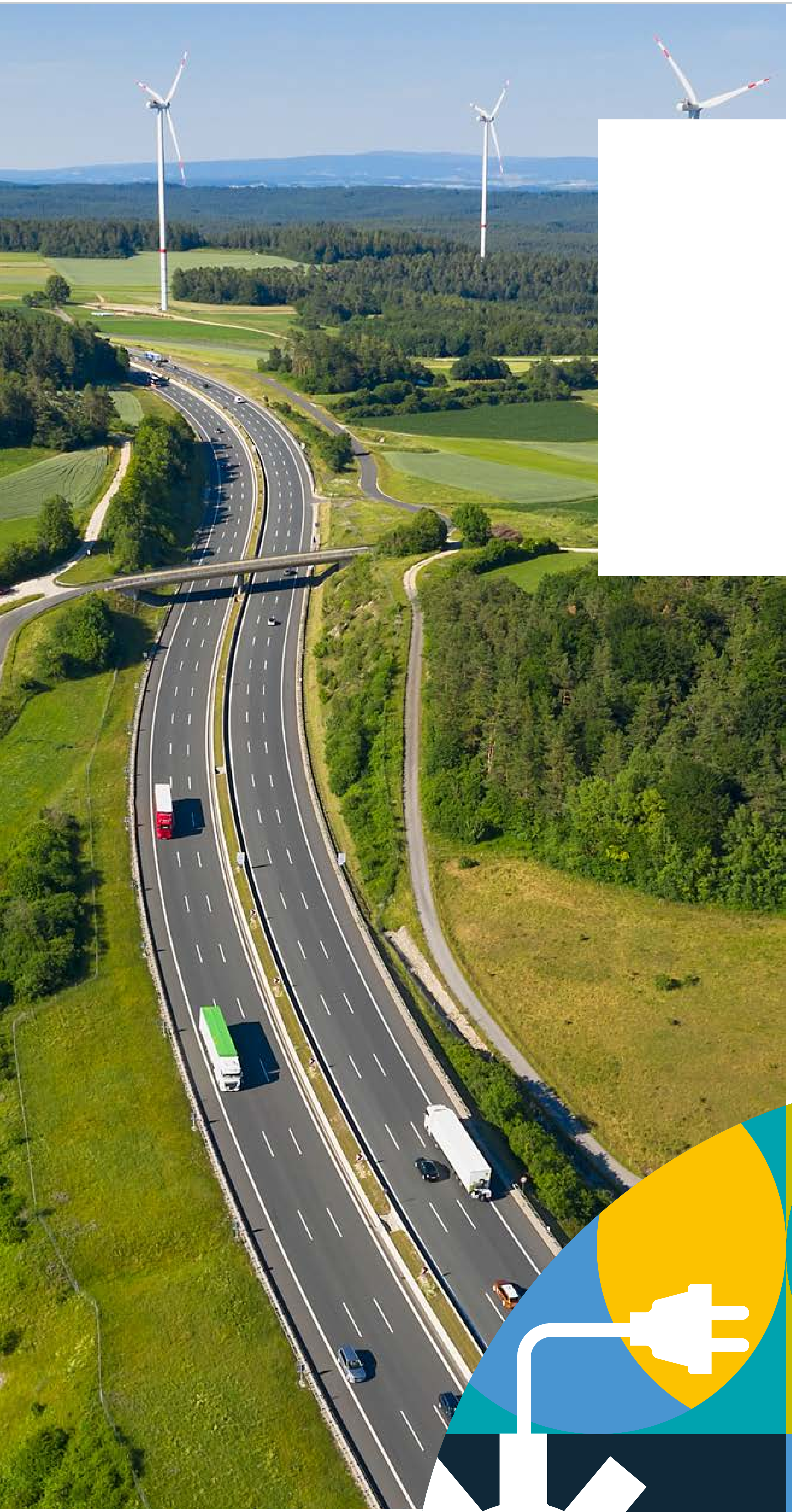
CHALLENGES

- **High initial costs:** Despite the long-term savings, the initial costs associated with retrofitting buildings with renewable energy systems or constructing new buildings with these systems remain a significant barrier for many stakeholders.
- **Regulatory and policy hurdles:** While many countries have supportive policies, others still face regulatory hurdles that slow 'the adoption of renewables in buildings. Inconsistencies in regulations across regions and insufficient governmental support can impede progress.
- **Slow growth in renewable heating:** While renewable electricity has seen rapid integration in buildings, renewable thermal technologies such as bioenergy, solar thermal and geothermal have grown more slowly.

OPPORTUNITIES

- **Government incentives and policy support:** Enhanced government policies, such as subsidies and tax incentives, have greatly bolstered the adoption of renewable technologies in the buildings sector. Policies are also incorporating specific requirements for the integration of renewables and energy efficiency into new building codes and standards.
- **Growing market for net zero buildings:** The market demand for net zero energy buildings is strong and growing, driven by both environmental concerns and long-term economic benefits. This trend is supported by significant increases in certifications and interest in high-performance buildings.
- **Global collaborations and agreements:** International initiatives, such as the Buildings Breakthrough Initiative launched at COP 28, aim to make near-zero emissions and climate-resilient buildings the norm by 2030, highlighting a strong commitment to global standards and practices.





RENEWABLES IN TRANSPORT

Despite vehicle electrification progress and increasing policy attention to renewables, transport is the sector with the highest share of fossil fuel in final energy consumtion.

634 billion USD had been invested globally in electric vehicles and charging infrastructure as of 2023

22 countries announced new or revised targets for the share of renewables in transport in 2023

18 countries announced new policies supporting electric vehicle uptake in 2023

KEY FACTS

- The **volume of freight** transported globally already surpassed pre-pandemic levels by 2021, and passenger transport volumes were expected to return to pre-pandemic levels in 2023.
- **Biofuel mandates** remain an important instrument to promote renewables in transport, and 64 countries had them in place in 2023. Many countries raised their mandates during the year, although some reduced them in response to ongoing inflation.
- The strong focus on **vehicle electrification** continued, with many countries supporting this transition through policy instruments – mostly fiscal and financial incentives, but also support for local manufacturing and direct investments in charging infrastructure and public vehicles.

MODULE OVERVIEW

Transport represented 30.2% of total final energy consumption globally in 2021.[1] Energy use in transport increased 7.31% that year, returning to a growth rate higher than before the COVID-19 pandemic in 2020, when transport activity plummeted; however, transport energy use in 2021 was still below pre-pandemic levels.[2]

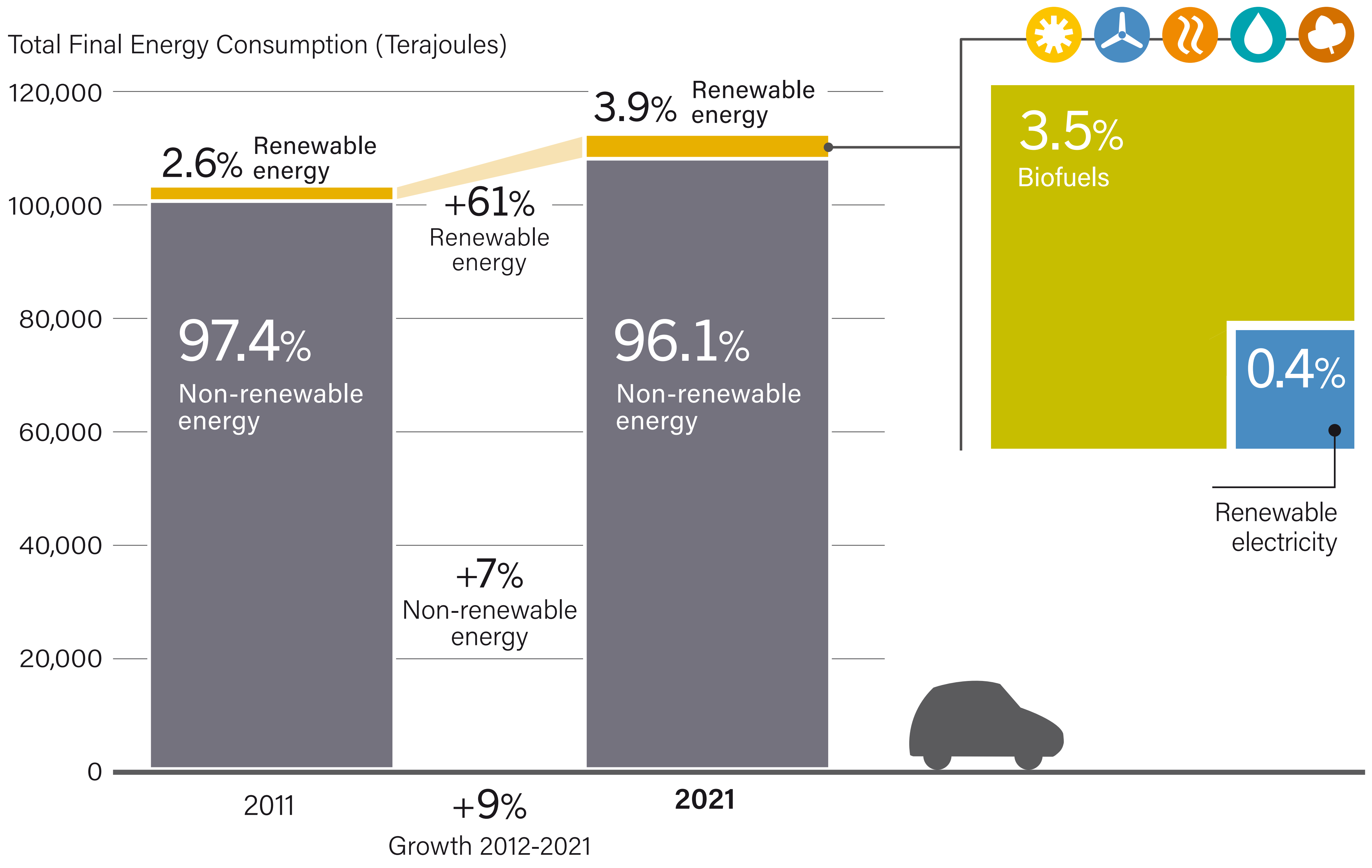
Global transport energy consumption dropped 13.2% in 2020, due mostly to sharp declines in fossil fuel consumption.[3] In contrast, biofuel use in the sector fell only 4.4% that year, and renewable electricity use[i] grew 4.5%, owing to rising shares of renewables in power generation and to increasing use of electricity.[4]

In 2021, renewables accounted for 3.9% of total transport energy consumption, with the bulk of this being biofuels (3.5%) and the rest renewable electricity (0.4%).[5] (→ *See Figure 15.*) Absolute use of renewables in transport increased 3% globally in 2021, with biofuels rebounding to near-2019 levels and renewable electricity growing moderately at 1.4%.[6] However, this could not compensate for the overall growth in energy use in the sector, which led the share of renewables in transport to decline from 4.1% in 2020 to 3.9% in 2021.[7]

Road transport continued to dominate energy consumption in transport in 2021, representing 77.2% of the total energy used, (→ *See Figure 16.*) with 4.6% of this coming from renewable sources, mainly biofuels.[8] Marine transport was the second largest consumer, accounting for 9.7% of total energy use in the sector, almost all of it from fossil fuels.[9] Both sub-sectors reduced their share in energy use by 0.3 percentage points in 2021, while aviation increased its share by 0.5 percentage points.[10] In 2021, aviation used 8.2% of total final energy consumption in transport and had no significant contribution from renewables.[11] Only rail transport[ii], which consumed 2.1% of total energy in the transport sector, had a significant share of renewable energy at 15%, with 91% of this from renewable electricity.[12]

Transport has the lowest share of renewables among end-use sectors, at only **3.9%.**

FIGURE 15.
Renewable Share of Total Final Energy Consumption in Transport, 2011 and 2021



Source: See endnote 5 for this module.

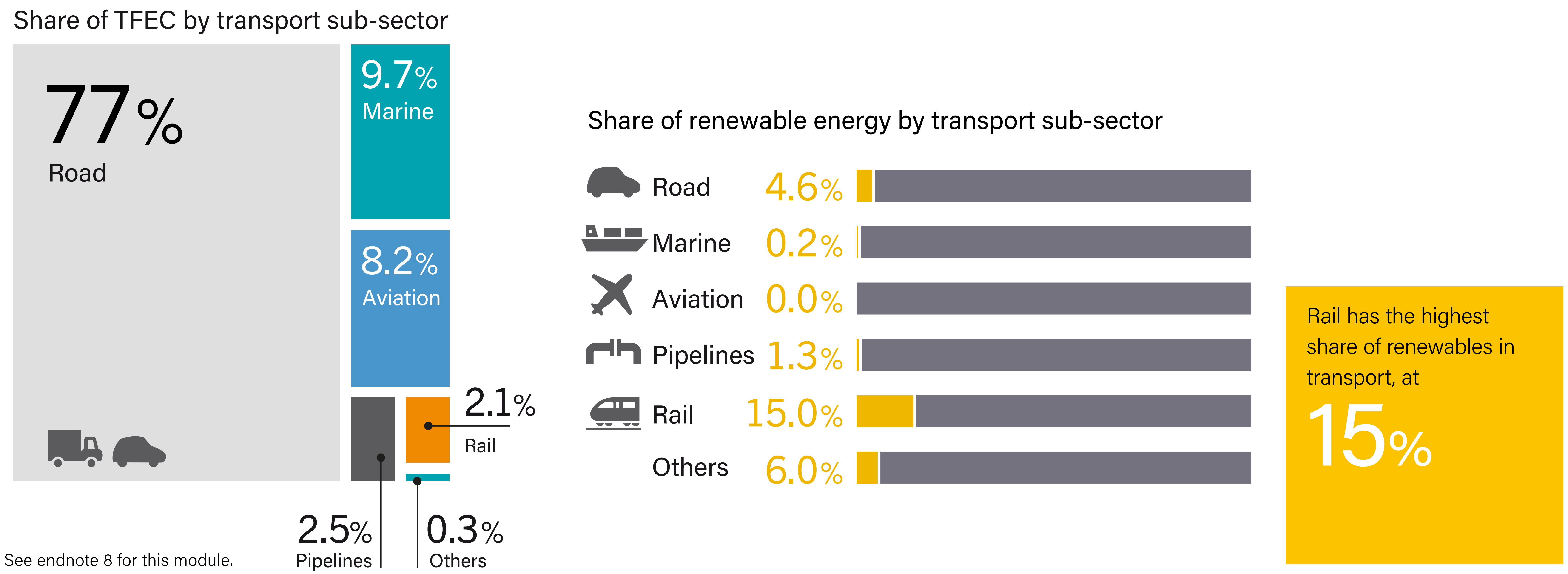
i The renewable electricity share is estimated by applying the global share of renewables in electricity generation to the amount of electricity consumed in the transport sector.

ii Here, the focus is on energy use per sub-sector rather than greenhouse gas emissions per sub-sector because the emission data on energy use do not include emissions from electricity use in the sector, thus under-representing rail and increasingly road transport.

After the severe drop in greenhouse gas emissions from transport during the pandemic, the sector's emissions continued to increase in 2022.[13] Driven mostly by growth in aviation, transport emissions grew another 3% to reach nearly 8 gigatonnes of carbon dioxide (CO_2)[i], still 4% below pre-pandemic levels.[14] The movement of freight contributed just over half of transport emissions in 2022, a share that is projected to reach 60% by 2050 under current policies, driven mainly by rising demand for freight transport due to economic growth, and to limited policies for decarbonising freight.[15]

Measures to address greenhouse gas emissions and to reduce oil dependence in the transport sector are generally described within the "avoid-shift-improve" framework.[16] This multi-dimensional approach aims to 1) avoid unnecessary motorised trips, for example through improved spatial planning; 2) shift to less carbon-intensive modes, for example through promoting walking, cycling, public transport and freight transport by rail or ship; and 3) improve vehicle design, energy efficiency and fuel sources. Renewable fuels are key in this framework, but achieving high levels of renewables will be easier if total energy demand is reduced through the other elements described. Such measures provide multiple co-benefits including reducing congestion and improving air quality and health.[17]

FIGURE 16.
Shares of Total Final Energy Consumption (TFEC) and Renewable Energy in Transport, by Sub-Sector, 2021



Source: See endnote 8 for this module.

Rising demand for transport is a key driver of energy use in the sector (→ *see Market Developments section*). Avoiding unnecessary motorised trips and shifting to less carbon-intensive modes (including zero-carbon options such as walking and cycling) can help slow this growth. Yet not all transport modes are equally efficient. Freight trains use one-tenth the energy per tonne-kilometre as trucks, whereas passenger trains use around 18% and buses 41% of the energy per passenger-kilometre compared to cars.[18] Shifting to more efficient transport modes can enable drastic reductions in energy demand. Improvements in vehicle efficiency can similarly reduce energy demand. Between 2000 and 2021, the average energy intensity of trucks improved 14.3% and the average energy intensity of cars improved 11.1%.[19]

A range of renewable fuels are available for use in the transport sector, including electricity and hydrogen produced from renewable sources, as well as biofuels, biogas and various synthetic fuels based on biomass or hydrogen. Some renewable fuels – such as liquid biofuels, synthetic fuels and upgraded biomethane – can be used in conventional internal combustion engines, either directly or with small adjustments to the motor. Other fuels, such as renewable electricity and hydrogen, require changes in vehicle technology.[20] Ammonia, currently used mainly in fertiliser production, is a potential fuel for marine applications. It can be produced from green hydrogen, making production renewable, although emissions of nitrogen oxides and nitrogen dioxide may occur during combustion.[21] Some of the technologies for renewable transport fuels are commercially available, while others are under development.[22]

i In this report, greenhouse gas emissions for transport refer to tank-to-wheel emissions only and do not include upstream emissions associated with the production of energy or fuel sources, including electricity generation.

POLICIES AND TARGETS

Governments worldwide are implementing diverse policies to bolster the integration of renewables across the transport sector, aiming to reduce carbon emissions and dependency on fossil fuels. Initiatives include the promotion of electric vehicles (EVs) powered by renewable sources, and the encouragement of biofuel use, including ethanol and biodiesel, in conventional internal combustion engines. Standards and certifications for the environmental sustainability of biofuels also are getting policy attention.

Governments have employed a variety of policy instruments – including targets, fiscal incentives such as tax rebates and grants, financial support mechanisms and blending mandates – to encourage the use of renewables in transport. However, rail, aviation and shipping have seen less policy-driven support.

As of 2023, 49 countries had enacted **renewable energy targets** specifically for the transport sector.[23] The European Union's (EU) New Renewable Energy Directive, adopted in October 2023, includes the choice for Member States between a binding target of a 14.5% reduction in greenhouse gas intensity in transport from the use of renewables by 2030, or a binding share of at least 29% renewables in the sector's final energy consumption by 2030.[24]

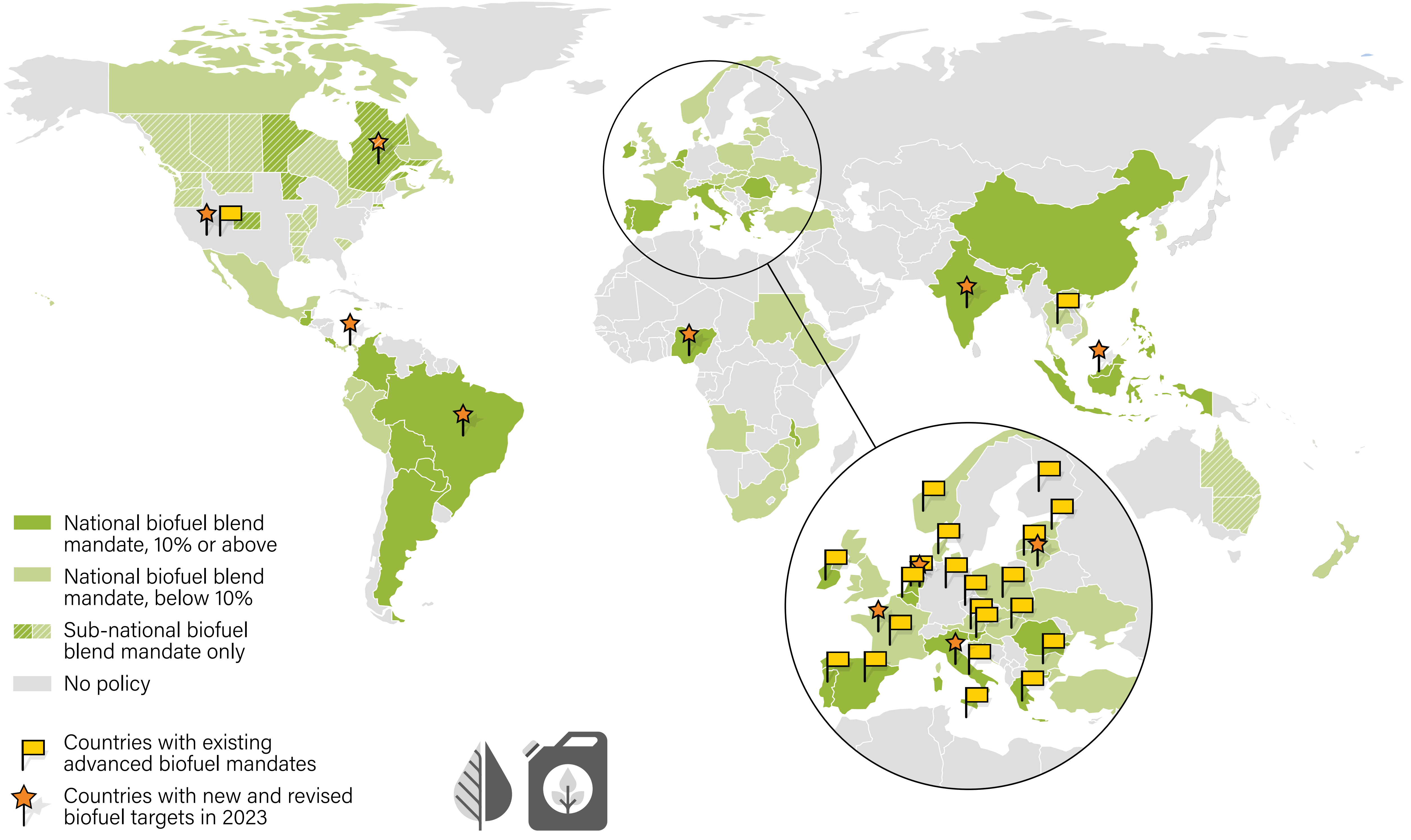
As EU Member States updated their National Energy and Climate Plans, they also revised their targets for the renewable share in transport for 2030. The highest targeted shares are in Spain (78%), Denmark (41%), and Finland (51%), followed by Italy (30.7%), Germany (30%), Hungary (30%), Romania (29.8%), Greece (29%), the Netherlands (28%), Slovenia (26%), Portugal (23%), Croatia (21.6%), the Czech Republic (19%), Luxembourg (18%), Lithuania (15%), Ireland (14.9%), the Slovak Republic (14.7%), Cyprus (14.6%) and Estonia (14%).[25]

ROAD TRANSPORT

Governments around the world are actively shaping the renewable energy policy landscape for road transport. This includes a substantial focus on biofuel blending mandates, which have experienced varying levels of adjustment across countries. Concurrently, electric vehicles benefit from increasingly robust policies that encourage their uptake. These efforts are complemented by various strategies such as vehicle-to-grid projects and financial incentives aimed at boosting EV infrastructure and adoption. Other policies, such as bans on fossil fuel cars, indirectly support the uptake of renewables.

In 2023, 10 countries introduced new or revised **biofuel blending mandates**, bringing the total to 60, with trends moving in different directions depending on the country (→ *See Figure 17*).[26] The United States slightly raised its biofuel mandates for a three-year period.[27] South Africa increased its requirement to 5% biodiesel blended with low-sulphur diesel.[28] In Asia, Indonesia upped its biofuel blending mandate for 2030 from 30% to 35%, Malaysia increased its 2030 blending mandate from 20% to 30%, and India announced a phased mandatory blending of biogas with compressed natural gas for transport.[29] Brazil increased its mandatory biodiesel blend from 13% to 14% as of March 2024.[30]

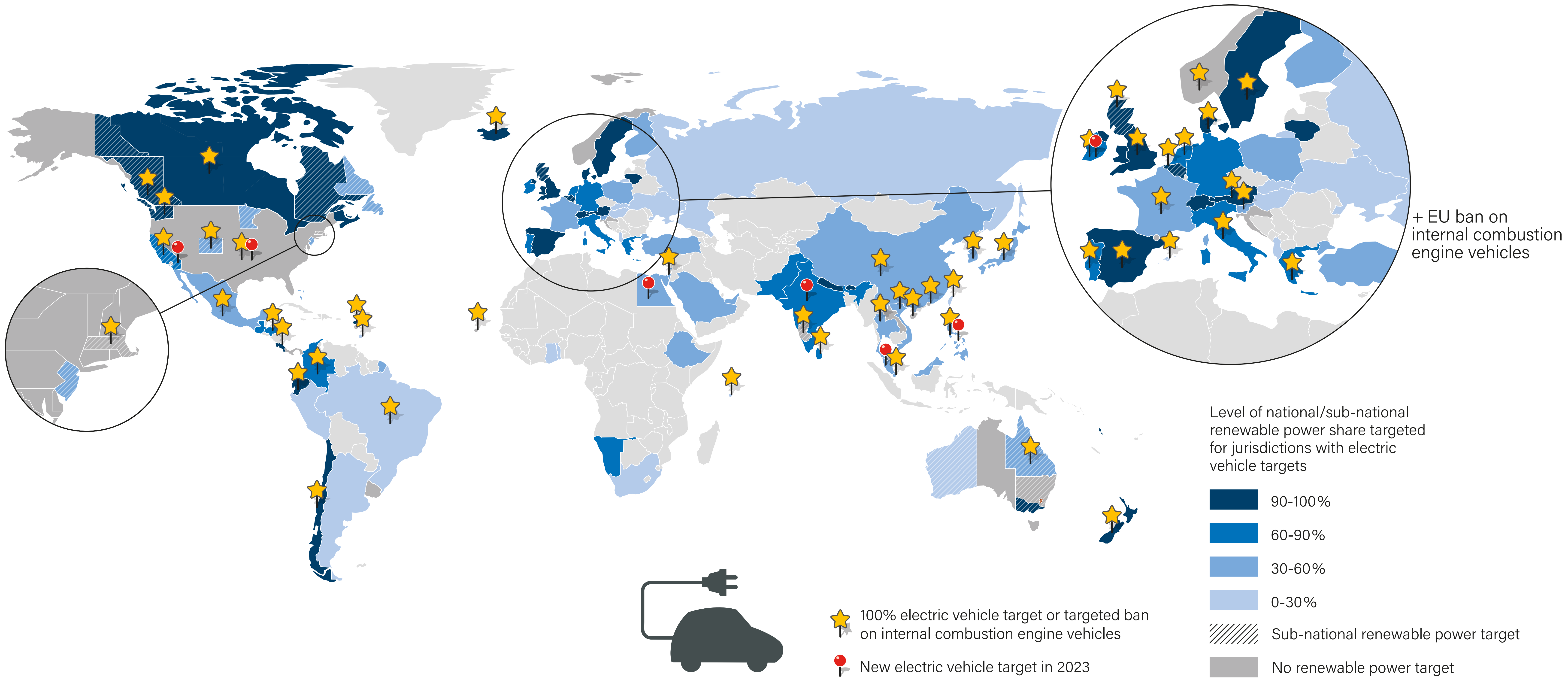
FIGURE 17.
National and Sub-National Renewable Biofuel Mandates and Targets, end-2023



Notes: Advanced biofules or second-generation biofuels are fuels that can be manufactured from various types of non-food biomass. Shading shows countries, and states/provinces with mandates for either bodiesel, ethanol or both. Some countries have temporarily reduced or removed their biofuel mandates in 2022. Countries with temporarily suspended mandates are excluded from this figure. Number of countries with targets is not comparable to previous years because of improved methodology. Countries with target years prior to 2023 are excliuded from this figure as they are considered expired.

Source: REN21 Policy Database. See endnote 26 for this module.

FIGURE 18.
Targets for Renewable Power and Electric Vehicles, end-2023



Notes: Renewable power targets include only targets for a specific share of electricity generation by a future year. Where a jurisdiction has multiple targets, the highest target is shown. Nepal and Quebec show actual renewable power shares; both jurisdictions along with Iceland and Norway have already achieved nearly 100% renewable power. Clean power and non official EV and power targets are not included in this figure. For example, Costa Rica has an aspirational power target of 100% renewbale power by 2030, Canada an unofficial target of 90% by 2030 and Brazil an intended renewable power target of 23% by 2030 excluding hydropower. The United States does not have a national renewable electricity target. De facto state-level targets have been set through RPS policies. Some countries have targeted ICE bans for public transportation or a target of 100% EV buses in their fleet, these are cosidered full bans in the scope of this figure and are marked to differenciate from other full bans. Hungary have a target for 90% carbon-neutral power generation by 2030. Nepal and Quebec do not have renewable power targets; the values in the table are actual renewable power shares (close to 100%). Iceland and Norway have already achieved 100% renewable power. Russian Federation power target includes large hydropower. The target excluding large hydro is 4.5% by 2024. The EU has a regional ban on new sales of fossil fuel cars from 2035. For countries with targets or policies in multiple unspecified sub-national jurisdictions, the whole country is shaded in stripes, this is based on IEA EV data.

Source: REN21 Policy Databse. See endnote 33.

Sweden, in contrast, continued a countertrend from 2022, reducing its blending mandate in response to the ongoing cost-of-living crisis.[31] During the G20 meeting in India in 2023, Argentina, Brazil, Canada, India, Italy, South Africa and the United States became the first members of the newly created Global Biofuel Alliance, whose objective is to promote the use and development of biofuels globally.[32]

Targets promoting **electric vehicles** continued to lead in road transport, with a total of 74 countries with such targets by the end of 2023 (→ *See Figure 18*). Additionally, at least 18 countries announced new policies supporting EV uptake in 2023.[33] The global surge in EV adoption marked a pivotal shift in the sector, driven by comprehensive policies implemented in recent years. This upward trend is assisted by the recognition that electrifying transport is a key strategy for integrating more renewables into the economy. Although most policies focus on passenger cars, many national, state and local governments also support the adoption of electric buses, bikes and commercial vehicles.

To effectively expand the penetration of renewables in transport, EV policies need to be analysed conjointly with nationwide renewable energy targets and policies. For example, many countries are experimenting with vehicle-to-grid projects, which are especially relevant to renewable energy uptake when the national grid includes high shares of renewables. China announced new rules to integrate EVs with the grid, including incentives to charge the vehicles during off-peak hours and then sell the stored power back to the grid during times of higher demand.[34] South Australia is trialling a similar vehicle-to-grid effort with EV owners.[35] However, policies in this area remain scarce globally, and governments face the challenge of having to lobby EV manufacturers to remove the stipulation that use of the EV battery for vehicle-to-home or vehicle-to-grid automatically voids the car warranty.[36]

During 2023, 6 countries announced new **national targets** to promote EVs and to support related private sector initiatives. Ireland set a target for 100% of new vehicles sold to be zero-emission by 2030, and for 35% of registrations of heavy-duty vehicles to be zero-emission.[37] Australia released a National Electric Vehicle Strategy and a National Battery Strategy.[38] Morocco announced a budget of USD 2.24 billion (MAD 22.5 billion) for electric mobility, including support for local manufacturing capacity, charging stations and e-mobility for public transport.[39] Brazil released a new National Green Mobility and Innovation Program (Mover) aimed at decarbonising the country's vehicle fleet by providing tax incentives and putting in place new standards.[40] Some countries also have focused on two- and three-wheelers, with India and Pakistan both having set a target specifically for these vehicles as of 2023.[41] Although electric two- and three-wheelers are increasingly being used across Africa and South East Asia, few specific policy frameworks have been put in place.[42]

Fiscal and financial incentives – including grants, rebates, and tax reductions or exemptions – have been popular measures to support EV uptake. In 2023, France renewed its consumer subsidy scheme for EV purchases.[43] Poland is providing subsidies for up to 90% of the cost of 79 different EV models as well as for charge points in national parks.[44] Estonia is distributing grants to individuals and companies for the purchase of electric and hydrogen fuel cell vehicles and electric cargo bikes.[45] Meanwhile, rebates for electric bikes are available in nearly all US states, with most of the rebates established in 2023.[46]

The Republic of Korea provides grants for purchases of electric buses and commercial EVs, and Cyprus offers grants for the purchase of electric cars, two- and three-wheelers, and buses.[47] Austria provides several financial incentives, including grants and tax reductions, for electric cars and two- and three-wheelers.[48] Indonesia enabled a reduction in value-added tax (VAT) on EV batteries for 2023, and Malaysia included in its 2023 budget tax incentives for companies renting EVs.[49] Denmark introduced a tax reimbursement for EV purchases and removed the tax on charging stations at workplaces.[50] The United States implemented tax credits for commercial EVs as well as heavy-duty vehicles.[51] Some countries have issued road tax exemptions for EVs.[52]

At the **sub-national level**, the US state of California adopted new zero-emission vehicle mandates, targeting a 100% sales share for cars and trucks by 2035 and for heavy-duty vehicles by 2042.[53] The Indian state of Tamil Nadu set a target for 30% of all operating buses to be electric by 2030.[54] In China, the provinces of Guangxi, Guangdong, Shanghai and Shanxi set targets for 40% EV shares among all vehicle fleets.[55] At the city level, New York in the United States received USD 77 million in grants for electric school buses and trucks.[56] India introduced a new electric bus grant programme in 2023 targeting 10,000 buses in 169 cities as well as the charging technology.[57]

Some countries scaled back support for EVs in 2023. Iceland reduced its annual VAT incentive for EV purchases, citing the measure's success and the reduced need for policy intervention in the EV market.[58] Germany ended subsidies for new purchases of electric passenger cars.[59]

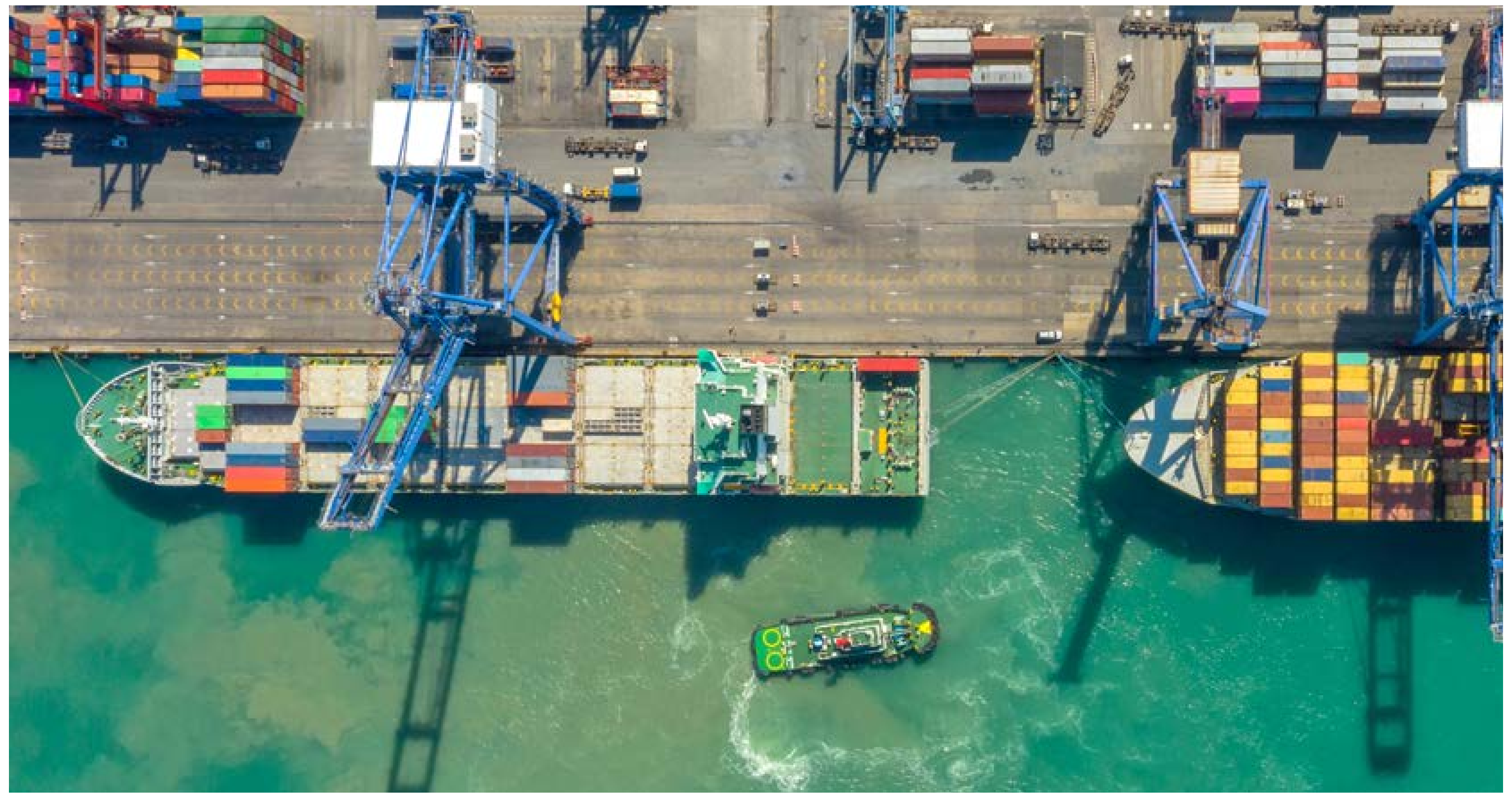
Bans on internal combustion vehicles provide indirect policy support for renewable energy, although they can be challenging to implement. In 2022, the EU approved a ban on internal combustion engine vehicles by 2035 but had to lower its ambition by allowing a loophole permitting the vehicles to be sold provided they are able to use exclusively e-fuels.[60] The United Kingdom pushed back a similar ban from 2030 to 2035.[61] In contrast, Norway is on track to reach its goal of having 100% of new cars sold by 2025 be electric or hydrogen; it is now moving to ban the sale of trucks with internal combustion engines.[62] Ethiopia announced a ban on imports of non-electric vehicles as of 2024.[63]

Similar policy successes occurred at the state and municipal levels in 2023. Amsterdam (Netherlands) will ban most internal combustion engine vehicles (taxis, vans, trucks, scooters and mopeds) by 2025, with the exception of passenger cars, which will be banned by 2030.[64] Stockholm (Sweden) introduced a ban on petrol and diesel cars in the city centre that will enter into force at the end of 2024.[65] The US state of New Jersey is banning the sale of new petrol-powered vehicles by 2035.[66]

Policies promoting the use of renewable hydrogen for road transport are usually embedded in national hydrogen policies. Estonia allocated close to USD 54 million (EUR 50 million) in subsidies for the creation of a renewable energy hydrogen value chain for the transport sector, among others.[67] France is providing an ecological bonus for the purchase of hydrogen-based vehicles.[68]

34 countries
had enacted renewable energy targets specifically for the transport sector as of 2023.

7 countries introduced targets for sustainable aviation fuel in 2023.



AVIATION, RAIL AND SHIPPING

Efforts to integrate renewables into **aviation, rail and shipping** have increased. However, policies remain in the early stages and still face obstacles towards being politically acceptable. As of 2023, 10 countries had announced renewable energy policies in these sub-sectors (7 for aviation, 2 for rail and 2 for shipping).[69]

For **rail transport**[i], electricity is the energy source of choice, although hydrogen also has received some policy attention. In 2023, Italy allocated USD 326 million (EUR 300 million) for the development of a railway system powered by renewable hydrogen, including to support hydrogen production plants and the purchase of hydrogen-powered trains.[70] To compensate for high electricity prices, Germany announced a USD 1.2 billion (EUR 1.1 billion) support scheme subsidising the electricity bills of freight and passenger rail operators that use electric traction[ii].[71]

In the area of **sustainable aviation fuel (SAF)**, the EU's ReFuelEU legislation established a mandate to use 2% SAF in all planes at EU airports by 2025 and 5% by 2030, increasing to 70% by 2070.[72] The United Arab Emirates announced a 1% SAF blending target by 2031 and aims to be a major SAF exporter by 2050.[73] The United Kingdom allocated USD 208 million (GBP 165 million) for SAF production, and in the United States SAF gained substantial support through the Inflation Reduction Act of 2022 and related rules published in 2023.[74] Sweden provided USD 1.4 million (SEK 15 million) for research and development of electric aircraft.[75] Brazil's new Fuel of the Future Program mandates airlines to progressively blend a minimum of 1% SAF in 2027, rising to a minimum of 10% by 2037.[76]

For **marine shipping**, Singapore is tightening its regulation for suppliers of bunker fuel to issue a proof of sustainability for all biofuel sourced.[77] The EU adopted the FuelEU maritime initiative to decarbonise the maritime sector through fuel provision, including biofuels.[78] The EU's 2023 Renewable Energy Directive places a focus on Renewable Fuels of Non-Biological Origin (RFNBOs)[iii], setting a binding target of 1.2% RFNBOs for shipping by 2030.[79] Meanwhile, the number of green shipping corridor[iv] initiatives more than doubled from 21 in 2022 to 44 in 2023.[80] Several new corridors were announced at the 2023 United Nations Climate Conference in Dubai, United Arab Emirates – including corridors between Canada, the Republic of Korea and Japan; between the United States and Belgium; and in the Caribbean.[81]

i These policies include diverse types of incentives such as taxes, subsidies, grants and plans/strategies; they also include incentives for "production" of fuels.

ii Electric traction is the use of electric motors to power the wheels of vehicles, commonly found in rail transport systems, allowing for efficient and often cleaner propulsion compared to conventional internal combustion engines.

iii RFNBOs is a broad term for all renewable gaseous and liquid fuels not derived from biomass. The primary method for creating these fuels involves using electrolysis, powered by renewable electricity, to generate hydrogen. This hydrogen can then be mixed with substances like nitrogen to create ammonia or with carbon to produce different synthetic hydrocarbons, such as e-methanol, e-kerosene, e-diesel, and e-petrol, also known as power-to-liquids (PtL).

iv Green shipping corridors are specific maritime routes for the use of low-emission or zero-emission vessels, aimed at reducing the environmental impact of the shipping industry and fostering the transition to cleaner energy sources.

INVESTMENT AND FINANCE

Spending on **electric vehicles and charging infrastructure**[i] dominated investment in the transport sector in 2023 and increased 36% during the year to reach USD 634 billion.[82] This growth reflected a combination of policy support for electrification in core auto markets, improvements in battery technologies, additional charging infrastructure and new models from automakers.[83]

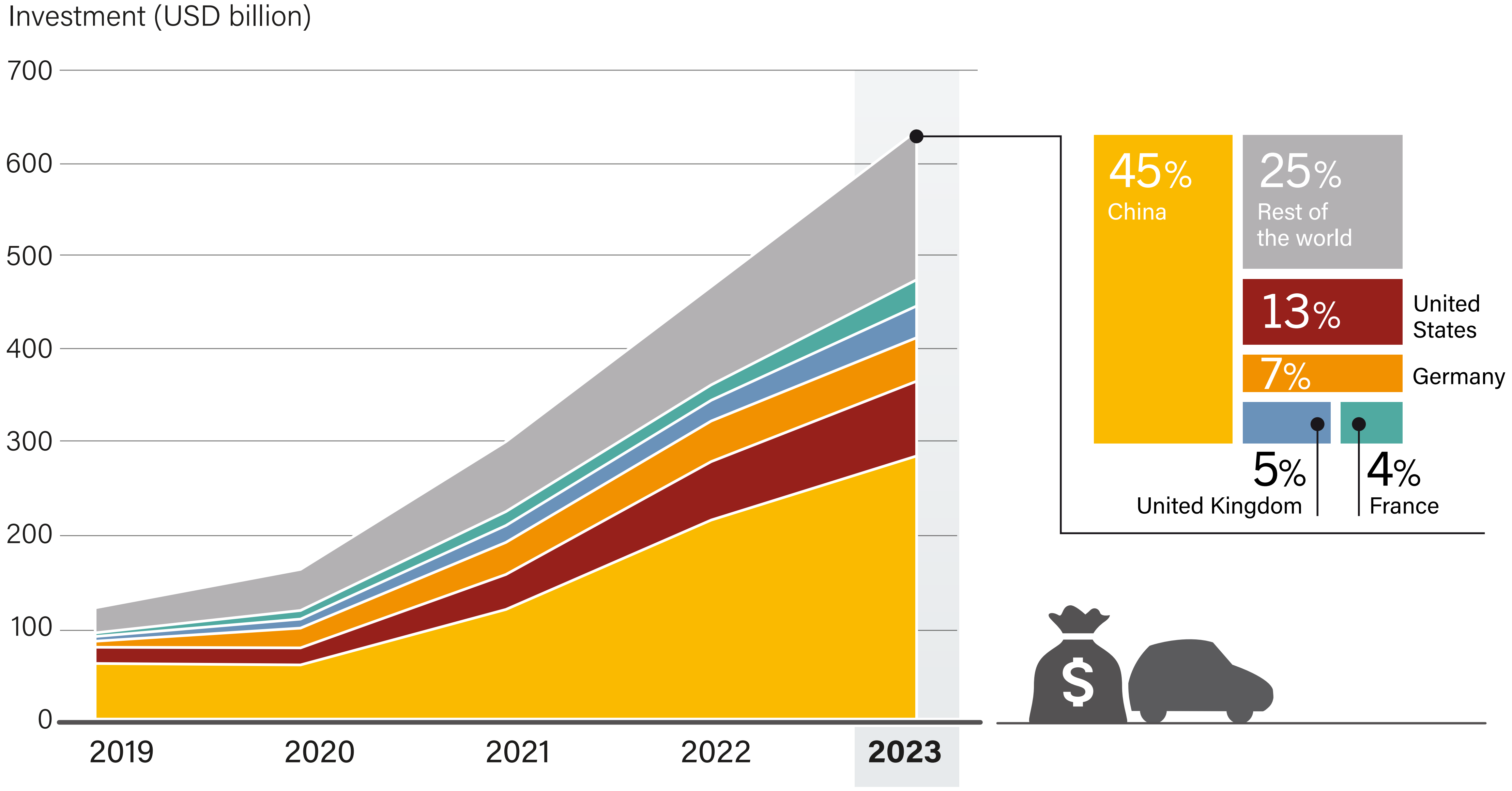
The bulk of EV investment in 2023 was in three markets: China, Europe and the United States.[84] (→ *See Figure 19.*) Despite China's dominance in this area, intense competition and continuing price wars in the country's EV market began to shake investor confidence by year's end.[85] In Europe, Germany abruptly halted its EV subsidy programme in December, which could affect future domestic EV sales and spending.[86] The United States saw a flurry of investment in EVs and vehicle battery manufacturing, as domestic manufacturers looked to ramp up production and to take advantage of new incentives offered under the Infrastructure Investment and Jobs Act and the Inflation Reduction Act.[87] However, US EV sales slowed in late 2023 due in part to consumer concerns about prices, battery range and a lack of charging stations, prompting companies to trim production plans and pause some investments.[88] Spending on EVs grew in emerging markets such as India, Indonesia and Thailand.[89]

Several notable announcements in 2023 pertained to investments in new EV **battery manufacturing**. In Europe, Automotive Cells Company (ACC) – with its shareholders Stellantis, Mercedes-Benz and Saft (a subsidiary of TotalEnergies) – raised USD 4.7 billion (EUR 4.4 billion) in debt funding to build two new gigafactories in Italy and one in Germany, and to expand its first gigafactory in Billy-Berclau, France (which opened in June 2023).[90]

Volkswagen began converting one of its motor plants in Salzgitter, Germany to an EV battery factory with an investment of USD 2.2 billion (EUR 2 billion).[91] Volkswagen also started work on two additional battery factories, in Valencia (Spain) and St. Thomas (Canada).[92] The Valencia plant is part of a USD 10.9 billion (EUR 10 billion) investment by Volkswagen and other partners in Spain accompanied by a large government subsidy.[93] The St. Thomas plant is supported by USD 9.6 billion (CAD 13 billion) in subsidised loans and a USD 515 million (CAD 700 million) grant.[94]

Elsewhere in Canada, in 2022 Stellantis N.V. and LG Energy Solution announced a USD 4.1 billion (CAD 5 billion) investment to establish an EV battery manufacturing plant in Ontario.[95] Construction was halted in 2023 amid disputes over federal funding but was later resumed once federal and provincial support was solidified.[96] In India, a USD 3.2 billion government incentive programme helped attract USD 8.3 billion in investments for EV and component manufacturing.[97] Suzuki (Japan) announced that it would invest USD 1.37 billion (INR 104.4 billion) in its India factory to produce EV batteries.[98]

FIGURE 19.
Global Investment in Electric Vehicles by Major Country, 2019-2023



Source: Bloomberg. See endnote 84 for this module.

The share of government spending in EVs fell from 20% in 2017 to **10%** in 2022.

i Data are from BloombergNEF and include commercial EV and fuel cell vehicle sales, electric two- and three-wheeler and bus sales, fuel cell bus sales, home charging, hydrogen refuelling stations, passenger EV and fuel cell vehicle sales, and public charging.

Global investment in **biofuels**[i] fell sharply in 2023, down 82.7% to USD 1.02 billion, the lowest level since 2016.[99] In wealthier countries, biofuel investment has been constrained by rising EV adoption, vehicle efficiency improvements, high biofuel costs and technical limitations.[100] In Latin America (outside of Brazil), uncertainty about regulatory changes and a lack of supporting policies has hampered biofuel investment.[101]

Despite the drop in biofuel investment, a growing number of refineries that produce renewable diesel, also known as hydrotreated vegetable oil (HVO), have received financing in recent years.[102] ExxonMobil announced a USD 560 million investment in 2023 to build what would be Canada's largest renewable diesel facility.[103] In Brazil, investments in HVO and SAF have expanded slowly but steadily, based on a broad range of feedstocks.[104] In Portugal, a new HVO and SAF production business is to be operated by the country's biggest energy company, Galp, with investment from Japan's Mitsui & Co. Ltd.[105]

In the **aviation** industry, investment in SAF, although in its early stages, has attracted growing attention, driven by commitments to net zero emissions and by supportive policy initiatives. In 2023, the EU set provisional targets specific to SAF, the United Kingdom advanced its discussions of national SAF mandates, and the United States continued to develop federal tax credits for SAF, all of which are expected to drive investment.[106] European airlines already have ramped up investments and signed agreements to secure sufficient SAF to meet EU targets.[107] In 2023, Air France announced a USD 4.7 million investment in a SAF plant in the US state of Louisiana, and Finnair signed a five-year, USD 192 million deal with renewable fuel producer Gevo for SAF supplies starting in 2027.[108] Wizz Air announced a USD 6.1 million investment in the biofuel company Firefly to supply SAF for its operations, beginning in 2028.[109]

Although comparatively nascent, financing for **electric aircraft** has increased, spurred in part by the drive to shift the aviation industry away from fossil fuels.[110] In 2022, the market totalled an estimated USD 8.8 billion, and investments globally came from major manufacturers such as Airbus SE (France) and Eve Air Mobility (Brazil) as well as smaller start-ups such as Heart Aerospace (Sweden), XPeng Motors (China) and Regent Craft (United States).[111]

Global investment in biofuels dropped to its **lowest level** since 2016.

In the **rail** sector, solar-powered trains[ii] continued to gain interest, reaching an estimated global market value of USD 1.9 billion in 2022.[112] In 2023, the California High Speed Rail Authority was in talks with energy suppliers to develop a USD 200 million utility-scale solar power system, which it would own and operate to power an ongoing rail project to connect cities across the US west coast.[113]

Although efforts are under way to advance renewable energy use in the shipping sector (such as wind-powered vessels), investment has been hampered mainly by the lock-in of investment into existing fossil fuel-based fleets.[114] Among notable investments during 2023, Port Augusta (Australia) secured USD 26 million (AUD 40 million) in public funds to develop a solar thermal-powered methanol production facility that will provide fuel for shipping and aviation.[115]

Eve Air Mobility (Brazil)

i Data are from BloombergNEF and include all biofuel production facilities (ethanol, biodiesel, renewable diesel and SAF) with an annual production capacity of 1 million litres or more.

ii Solar-powered trains have solar PV panels installed on or near rail lines that provide the electricity to power trains.

MARKET DEVELOPMENT

TRANSPORT ACTIVITY

In 2021, global **passenger transport** activity totalled nearly 54 trillion passenger-kilometres, up 8.5% from 2020 but still below pre-pandemic levels.[116] Passenger activity was expected to return to 2019 levels in 2023.[117] Half of all passenger-kilometres (50.2%) in 2021 were travelled in Asia, followed by the "UCAN" countries (United States, Canada, Australia and New Zealand) (19%) and Europe (13%).[118]

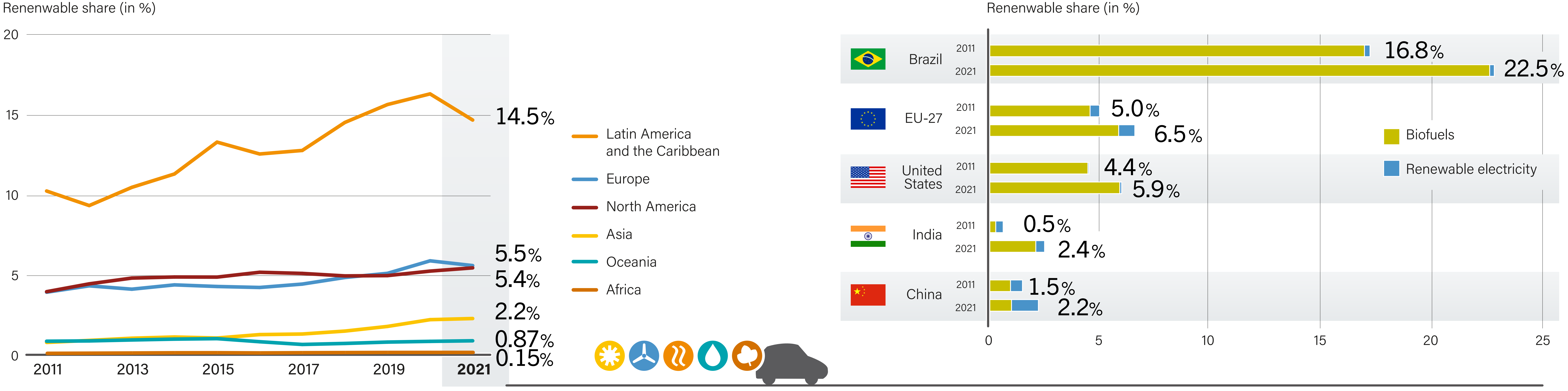
The pandemic's impact was less pronounced for freight transport, where activity dropped only 3% in 2020 and surpassed 2019 levels by 2021, reaching 170 trillion tonne-kilometres.[119] The bulk of the freight activity (around 70%) in 2021 was from maritime transport in international waters and inland waterways.[120] The remaining 30% was on land and by air, with half of this occurring in East and Northeast Asia and in the UCAN countries.[121]

TOP MARKETS

Energy use in transport is closely linked to population and economic development, and it is distributed unequally across regions. In 2021, North America and Asia together accounted for nearly 61% of the world's transport energy use.[122] The share of renewables used in transport also varies by region, reaching 14.5% in Latin America in 2021 (driven mostly by dedicated biofuel policies in Brazil), 5.5% in Europe (driven by the EU Renewable Energy Directive) and 5.4% in North America (driven by the US Renewable Fuel Standard).[123]

Asia experienced the largest growth in transport's renewable energy share over the last decade, nearly tripling from 0.7% in 2010 to 2.2% in 2021, driven by growing renewable electricity use in China.[124] (→ *See Figure 20.*) However, the share of renewables in transport decreased in all major transport energy consuming countries between 2020 and 2021, except India, where the share increased from 1.5% to 2%, caused by a doubling of biofuel use and an increasing share of renewables in the electricity mix.[125]

FIGURE 20.
Renewable Share of Total Final Energy Consumption in Transport, by Region and in the Top Five Energy-Consuming Economies, 2011-2021



Source: See endnote 124 for this module.

BIOFUELS

Biofuels[i] remain the dominant renewable fuel in transport, supplying 90% of the sector's renewable energy use.[126] Biofuel consumption increased 3% in 2021, remaining slightly below pre-pandemic levels.[127] Road transport accounted for nearly all liquid biofuel use.[128]

Global biofuel production totalled 4.3 exajoules (EJ) in 2022, with around 90% of it from sugar cane, maize, soybean oil, rapeseed oil and palm oil.[129] Only 10% was produced using waste and residue feedstocks, such as used cooking oil and animal fats.[130] The use of energy crops as feedstock is limited by regulation in some markets, such as the EU, and the supply of used waste streams and residues is low.[131] To further expand biofuels, new feedstock sources are required, including ones that are compatible with existing technologies and can be grown on marginal lands or as cover crops. Other potential feedstocks include agricultural and forestry residues and organic components of municipal solid waste, although in many cases the relevant processing technologies are still under development, such as for aviation and shipping.[132]

In addition to government incentives for biofuels through blending mandates and other instruments, other stakeholders are investing in promoting the fuels. In Spain, the global energy company Repsol was supplying 100% renewable diesel to 60 service stations by the end of 2023, and it launched a pilot to supply 100% renewable petrol at three of the stations.[133] The new bio-petrol is based on waste from biomass, the agri-food industry and used cooking oils.[134] New York City announced that it would transition the city's entire heavy-duty fleet to 100% renewable diesel by the end of fiscal year 2024.[135]

In the Netherlands, a demonstration plant aims to produce drop-in bio-based liquefied natural gas (LNG) derived from household waste starting in 2024, for use as marine fuel.[136] The production of biomethanol based on landfill gas is even further along, having fuelled the maiden voyage of the first green methanol-powered container ship from the Republic of Korea to Denmark in late 2023.[137] If announced projects are realised, the existing production capacity could nearly double by 2028.[138]

Although advanced biofuels from waste and residues are quickly approaching commercial operations, renewable fuels based on algae are still largely under development. Efforts continued in 2023, with California-based algae biofuel company Viridos securing new funding after ExxonMobil pulled out as an investor in February.[139] Commercial production at scale is estimated to be at least a decade away.[140]

RENEWABLE ELECTRICITY

Electric vehicles, especially fully battery-operated vehicles, were still a novelty a decade ago. However, advances in technology, reductions in cost, and policy support have led to exponential growth, which continued in 2022. The global stock of **electric cars** quadrupled between 2018 and 2023, reaching an overall share of 2%, up from 0.45% in 2018.[141] Electric car sales grew from 2.3% of total car sales in 2018 to 18% in 2023.[142] The development of electric buses and trucks continued at a slower pace.[143] By the end of 2022, 3% of **buses** globally were electric, but only 0.4% of **trucks** were.[144]

The number of electric **two- and three-wheelers** exceeded some 250 million worldwide by the end of 2022, dominated by the Asian market.[145] Electrification of these vehicles also has gained attention in Africa, where tailored solutions can address multiple energy, mobility and development challenges.

Since 2023, the Mobility for Africa Fund has provided electric tricycles to rural communities in Zimbabwe, with business models ranging from upfront purchasing to lease-to-purchase and rental. The service comes with battery swapping based on off-grid renewable electricity as well as training for drivers and technicians.[146] In November 2023, the South African company Zero Carbon Charge began rolling out a network of 120 off-grid, fully renewable vehicle charging stations across the country. The goal is to install solar-powered ultra-fast 720 direct current (DC) as well as 240 alternating current (AC) charging facilities at least every 150 kilometres.[147] (→ *See Snapshot: South Africa.*)

Increasing the use of renewable energy through electric vehicles is only possible if countries expand their renewable electricity generation. As of 2022, just six countries were home to 86% of the global electric car stock: Norway, China, Germany, the United Kingdom, France and the United States.[148] (→ *See Figure 22.*) These countries have increased not only the number of EVs on the road since 2018, but also their shares of renewable electricity generation (although at varying paces and from very different starting points).[149] The two countries with the largest electric car fleets, China and the United States, have made greater progress in electrifying transport than in decarbonising the electricity supply.[150]

i For a discussion of the environmental and social implications of biofuels and other renewable energy technologies, see REN21's *Renewable Energy and Sustainability Report*, https://www.ren21.net/wp-content/uploads/2019/05/REN21-RESR-2023_LowRes.pdf.

SNAPSHOT SOUTH AFRICA

SOUTH AFRICA ADOPTING RENEWABLE CHARGING SOLUTIONS TO SUPPORT ELECTRIC VEHICLE REVOLUTION

In 2022, South Africa's automobile manufacturing sector was valued at USD 35.2 billion (ZAR 656 billion), contributing nearly 5% of the country's gross domestic product and accounting for 16.5% of its total trade. In 2023, the industry generated 0.8% of all jobs and paid around USD 1.55 billion (ZAR 30 billion) in wages. However, the sector's heavy reliance on auto exports – with two-thirds of all vehicles manufactured in South Africa leaving the country – presents challenges amid the global shift to electric vehicles. To ensure continued global competitiveness and export prominence, the domestic auto industry will need to pivot towards EV production.

Nearly half of South Africa's automobile exports go to the EU and the United Kingdom. With the EU aiming to ban sales of internal combustion engine vehicles starting in 2035, there is urgency for South African manufacturers to transition to EV production. The country has an opportunity to bolster the large-scale production of EVs and related components by leveraging existing infrastructure and resources, as well as local supply chains.

Globally, EV sales reached 14% of total vehicles sold in 2022, yet in South Africa EV adoption remained minimal at only 0.17%. Domestic EV sales increased from 218 units in 2021 to 506 units in 2022. Sales are projected to accelerate in the coming years, and the Ministry of Trade, Industry and Competition anticipates domestic EV production by 2026.

The country's energy supply crisis and resulting constraints in grid capacity have challenged the EV transition. As stipulated in South Africa's 2023 Electric Vehicles White Paper, which provides the long-term strategy for the EV transition, the national grid will be unequipped to accommodate the sharp increase in energy demand that EV growth will require. The draft Integrated Resource Plan, released in late 2023, predicts that EV energy demand will require an additional 5 terawatt-hours of electricity capacity by 2034.

Because the country's grid was not designed for high power loads, charging times for EVs are currently slow at two to three hours. EV adoption also remains low due to the limited number of charging stations. As of mid-2023, South Africa had only 350 public charging stations, leaving much of the country unserved. National "load shedding" events, whereby national energy supply is unable to meet demand, reduce the reliability of the power supply, adding uncertainty and further stagnating the demand for EVs.

The climate benefits of transitioning to EVs in South Africa are much lower than in countries that have high renewable energy capacities, as the power supply currently depends heavily on fossil fuels. South Africa is among the most coal-reliant countries globally, with coal contributing 70% of the energy supply and 85% of electricity generation in 2023. The transport sector is the country's second biggest polluter after the power industry, and road transport accounts for 91.2% of transport emissions.

SNAPSHOT SOUTH AFRICA (continued)

To alleviate this challenge, private companies are planning to install off-grid charging stations. **Zero Carbon Charge aims to establish a national network of 120 off-grid, sustainable charging stations across South Africa.** These stations will generate electricity using on-site solar PV, storing energy in lithium iron phosphate batteries, and will provide back-up power using generators fuelled by hydrotreated vegetable oil. The goal is to install a total of 720 ultra-fast direct current (DC) charge points for EVs and 240 alternating current (AC) charge points for plug-in hybrids at the stations.

The strategically planned network aims to alleviate "range anxiety" among drivers by enabling a swift charging period of 20 minutes, with stations located 150 kilometres apart on all major routes (see Figure 21). The entire network is scheduled for completion by September 2025, with 115 agreements already secured with landowners, and 15 of the 120 sites granted environmental and land use approvals as of early 2023. Over the coming years, the company plans to add charging stations for freight vehicles, such as the coal trucks owned by energy company Eskom, which alone emit 230,000 tonnes of CO_2 annually.

Source: See endnote 147 for this module.

120
solar-powered off-grid charging stations are scheduled for completion by 2025.

FIGURE 21.
Planned Distribution of Electric Vehicle Chargers Across South Africa

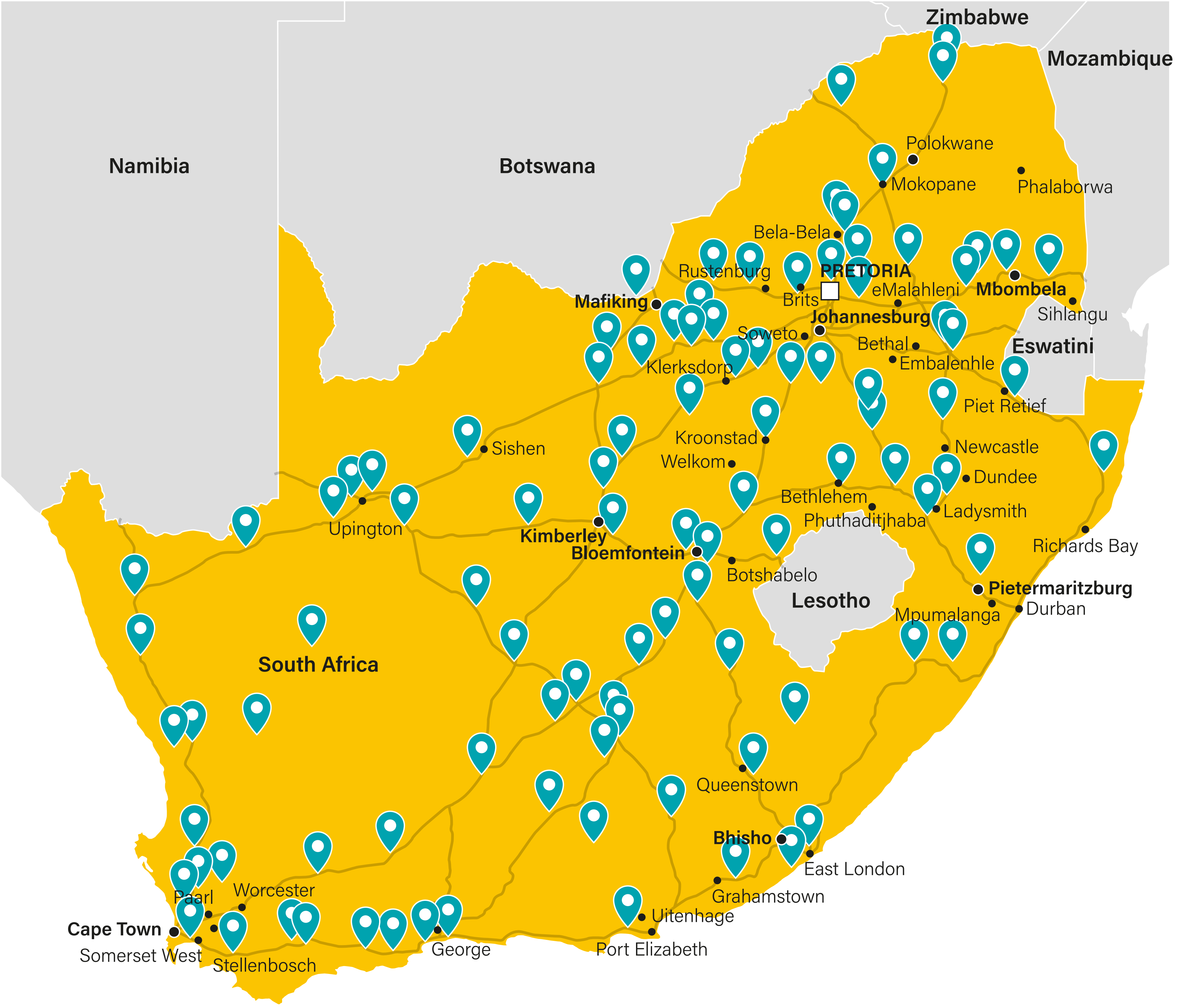
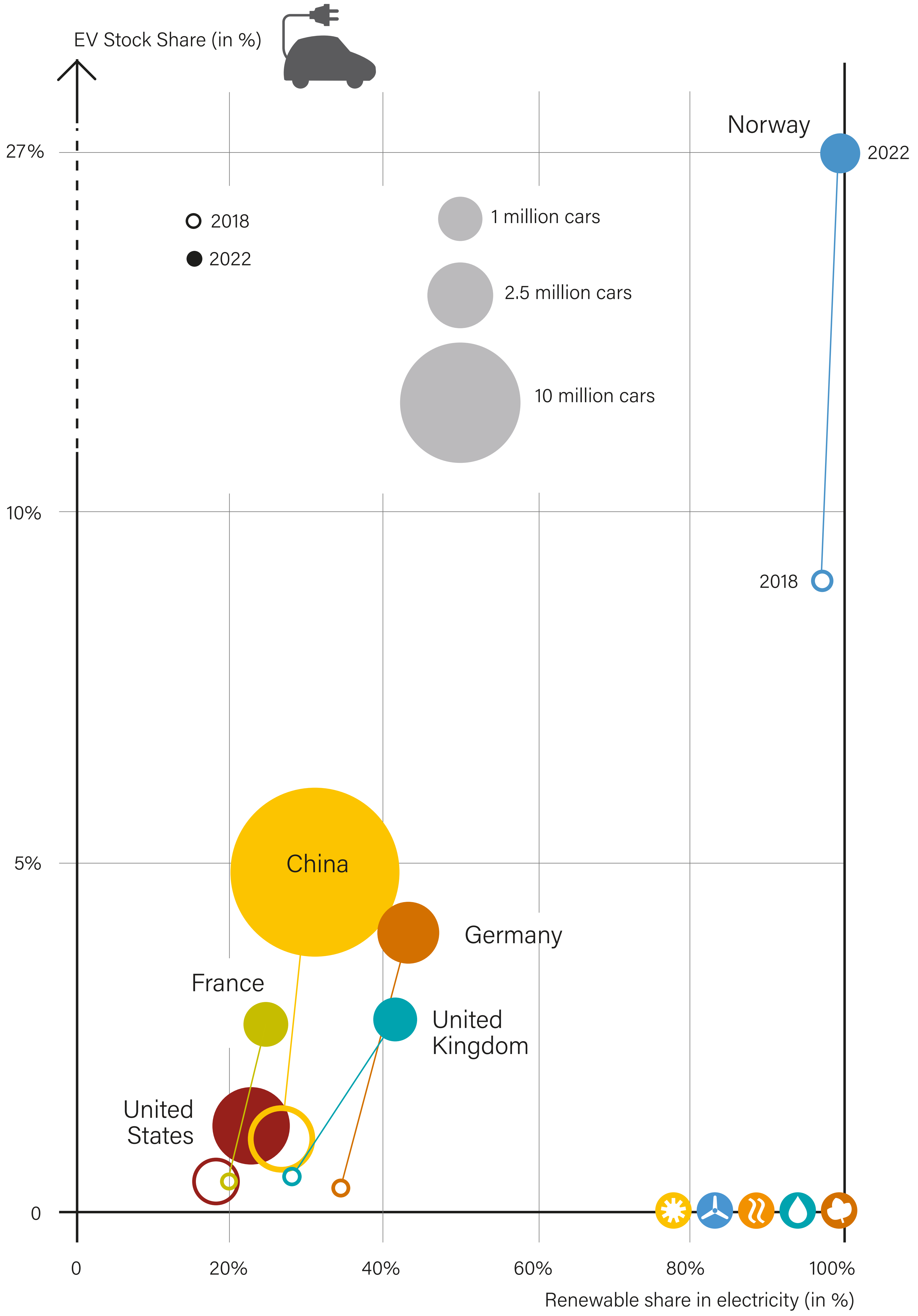


FIGURE 22. Renewable Share in Electricity Production, and Electric Car Stocks and Shares, Selected Countries, 2018 and 2022

Source: See endnote 148 for this module.



In 2022, Norway had the highest share of electric vehicles in its car stock at

27%

Several electric **aircraft** designed to carry small numbers of passengers over relatively short distances are under development.[151] As of May 2023, US-based Eviation, which successfully completed the maiden flight of its "Alice" commuter plane in September 2022, had 253 aircraft orders valued at more than USD 2 billion.[152]

For **maritime transport**, electricity is currently used mainly in pleasure boats and for short-haul shipping such as ferries, using battery or hybrid systems. More than 70 electric ferries are in operation in Norway, with others under construction.[153] Several ferry connections in Asia, Denmark, Sweden and the United States also have been electrified in recent years.[154] For freight, the first electric vessels have started operations but are not yet common.[155] A key challenge in the shift towards alternative drive technologies in shipping is long vessel life spans (30 to 45 years or more), leading to slow turnover.[156]

Another area for electrification is the provision of onshore power during docking. Conventionally, ship motors are kept running to generate the required electricity, burning the heavy fuel oil still used in most vessels and emitting both greenhouse gases and high levels of air pollutants.[157] Many ports, especially in Europe and North America, provide the opportunity for berthed ships to connect to the local power supply (often driven by regulation), and more ports globally are planning or considering this.[158] In the US state of California, most larger vessels are required to reduce emissions during berthing, effectively promoting onshore electricity supply.[159] In the EU, onshore power will become mandatory for container ships and passenger ships at major EU ports by 2030 and the rest by 2035.[160]

Rail is the most electrified transport mode, with electricity accounting for just over 45% of the sector's total energy consumption in 2022, up from 39% in 2010.[161] In 2022, 85% of all rail passengers were transported by electric rail, compared with only 55% for rail freight.[162] In most countries, rail is the transport sector with the highest renewable energy share.[163]

In addition to electrification of rail lines, many rail operators are actively generating or sourcing renewable power. Indian Railways, one of the largest rail operators globally, has a target for net zero emissions by 2030 and has already installed solar PV at many of its rail stations.[164] (→ *See Snapshot: India.*) As of October 2023, Indian Railways had commissioned 211 megawatts (MW) of solar PV and 103 MW of wind power, as well as securing 2,150 MW of further renewable energy capacity.[165] In July 2023, the French railway operator SNCF signed a power purchase agreement to obtain 88 gigawatt-hours annually of renewable electricity.[166]

RENEWABLE HYDROGEN

Most of the direct use of hydrogen in transport today is through fuel cell electric vehicles, and hydrogen use will likely continue mainly in the road sector for the coming years (although at much lower levels than battery electric vehicles).[167] Despite hydrogen's lower efficiency compared to the direct use of electricity, its applicability for long distances and its rapid speed of re-fuelling make it an attractive option for decarbonising transport modes where direct electrification can be a challenge, such as for heavy-duty vehicles, vessels and aircraft.[168]

SNAPSHOT INDIA

ELECTRIFYING THE RAILWAY SECTOR: INDIA'S RENEWABLE ENERGY TRANSITION ON THE RIGHT TRACK

Since 2014, India's national railway system, Indian Railways, has undergone a monumental electrification drive, surging ahead at a rate nine times faster than the preceding decade and becoming India's largest consumer of electricity. As of early 2024, the country had electrified around 40,000 kilometres of railway lines across 14 states and Union Territories, funded largely by the Central Organization for Railway Electrification (CORE).

Indian Railways has pledged to achieve 100% electrification by mid-2024, and in 2021 the Ministry of Railways released a policy document outlining the system's objectives for achieving this goal. As of January 2024, 94% of Indian Railways' lines had been electrified, and the company was determined to electrify the remaining 6,000 kilometres of railway by mid-year. The rapid electrification of rail in India has far outpaced other regions, with the share of electrified rail reaching 56% in the EU, 38% in the United Kingdom and only 1% in the United States as of the end of 2023.

The success of India's electrification surge is attributed to a convergence of factors including expedited permitting processes; streamlined engineering, procurement and construction efforts; decentralised decision making; and assured funding. Since 2014, the country has spent more than USD 5.5 billion (464.25 billion INR) on railway electrification. This substantial investment aims to support greater energy independence for India and to alleviate the burden of substantial crude oil imports. As of 2023, the country's import dependency on oil and oil-equivalent gas was 78.6%, and total spending on these fuels was USD 100 billion between April and December 2023 alone.

So far, India's rapid electrification of rail has not resulted in significant decarbonisation, as around 70% of the country's electricity continues to come from coal rather than from renewable energy sources. However, **Indian Railways aims to reach net zero carbon emissions by 2030 and to supply all its energy requirements (projected at more than 33 billion units) mainly through the use of solar power and other renewable technologies.** With government support, the company has already commissioned around 211 MW of solar plants and 103 MW of wind power plants, with an overall target of reaching 20 GW generated by solar plants on vacant railway land by 2030.

In tandem with its commitment to renewables, Indian Railways is prioritising energy-efficient technologies such as three-phase electric locomotives, head on generation (HOG) technology, and LED lights in coaches and railway buildings.

Source: See endnote 164 for this module.

By the end of 2022, an estimated 58,000 hydrogen fuel cell **cars and vans** were on the world's roads, compared to more than 25 million battery electric cars.[169] Around 15,000 fuel cell cars were sold during the year, increasing the total stock by 40%.[170] Two-thirds of this growth was in the Republic of Korea, followed by the United States and Japan.[171] Although Korean manufacturers continue to dominate the market, other automakers are introducing fuel cell vehicle offerings: for example, BMW launched its iX5 pilot fleet in 2022, and the Moroccan start-up NamX presented a fuel cell sport utility vehicle (SUV) that can be fuelled in part by replaceable hydrogen capsules.[172]

The market for fuel cell buses also continued to grow, reaching 6,200 vehicles by the end of 2022, 87% of which were in China.[173] The number of fuel cell **trucks** surged more than 60% during the year, to total 7,100 vehicles, with 95% of these in China.[174] The market for fuel cell trucks and buses is more diverse than for cars, with multiple companies offering truck models and around 20 companies producing fuel cell buses.[175] There are also efforts to retrofit diesel combustion engines to use hydrogen, and to develop pure hydrogen or dual-fuel combustion models, mostly for cars and trucks.[176]

No commercial models for hydrogen **aircraft** were available in 2023, although several companies were developing prototypes. Airbus aims to bring a hydrogen-powered commercial aircraft to the market by 2035, with a range of up to 2,000 kilometres and a capacity of up to 200 passengers.[177] A Dutch consortium plans to launch the first hydrogen-fuelled flight of 40-80 passengers as early as 2028.[178]

For **maritime transport**, the development of hydrogen combustion engines is ongoing, including dual-fuel engines (diesel and hydrogen) and full hydrogen vessels.[179] In 2022, the Norwegian Maritime Authority approved the development by HAV Hydrogen of a containerised, deck-based fuel cell system to support propulsion and to provide on-board electricity while under way and at port; the system can be retrofitted to existing vessels and was in its final development phase as of late 2023.[180] Shipbuilders also are working on fuel cell container ships, mostly for shorter distances.[181] For passenger transport, the world's first liquid hydrogen fuel cell ferry started operating in Norway in March 2023, followed by others during the year.[182]

Overall, the transport sector consumed around 32 kilotonnes of hydrogen in 2022, representing 0.003% of global hydrogen use.[183] However, only 0.1% of transport hydrogen was produced through electrolysis, which can potentially be powered by renewable electricity.[184] Another 0.6% was produced using fossil fuels with carbon capture and storage.[185] Rising interest in hydrogen for aviation fuel alone could increase hydrogen demand by 1 million tonnes by 2030.[186] Demand for hydrogen will likely grow in sectors beyond transport, creating resource competition. The use of hydrogen in transport will only be renewable – delivering emission reduction benefits[i] – if the share of production based on renewable electricity or bioprocesses is greatly increased.[187] (→ *See Renewables in Energy Supply Module.*)

HYDROGEN-BASED FUELS

If renewable hydrogen is used, a variety of fuels based on hydrogen can be considered renewable. These fuels are produced by combining hydrogen with carbon that is captured either from the air or from industrial sites. Some of these fuels, called drop-in e-fuels, have the same properties as their fossil fuel counterparts and can be used in existing motors and with current fuelling infrastructure, with limited constraints. Others, such as methanol, offer alternatives to fossil fuels but require investment in new infrastructure and vehicle technologies. Combining hydrogen with nitrogen produces ammonia, which can be used as a fuel. Methanol and ammonia are discussed mainly as alternatives to fossil fuels in shipping.[188] Further processing of these fuels typically requires additional energy and cost.[189]

To achieve a 10% share of hydrogen-based fuels in aviation and shipping by 2030, an estimated 2,100 terawatt-hours of renewable electricity would be required, or more than India's total electricity generation in 2022.[190] Production capacity and supply chains would need to expand rapidly. As of 2023, however, most of the 70-plus production plants in operation globally to produce hydrogen from electrolysis (which is then used to obtain hydrogen-based fuels) were still at a demonstration scale, producing less than 20 kilotonnes of hydrogen[ii,191] Announced projects for renewable hydrogen could increase production to nearly 14 million tonnes by 2030, with 90% of the projects aiming to produce ammonia and the majority (nearly 8 million tonnes) still in the early stages of development.[192]

0.1%
of the hydrogen consumed in transport in 2022 was produced through electrolysis.

i If hydrogen from non-abated fossil hydrogen is used, the greenhouse gas emissions from fuel cell vehicles could be higher than from internal combustion engines using diesel or petrol. See endnote 187 for this module.

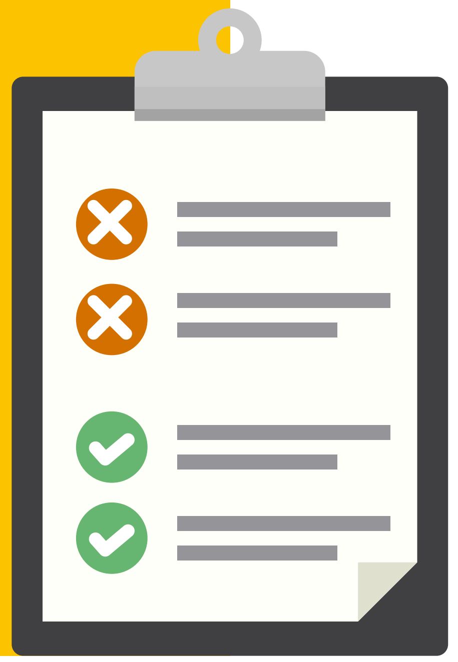
ii Quantities of e-fuels in this section are given in hydrogen-equivalent terms, i.e., the "stoichiometric" hydrogen requirement to produce the e-fuel.

CHALLENGES

- **Transport energy use and emissions** keep increasing owing to rising demand for transportation, mainly due to increasing freight transport demand driven by economic growth.
- **Sufficient renewable electricity supply** is key to decarbonise the sector through electric mobility and green hydrogen-based fuels.
- **Investment in renewable fuels production capacity** requires clear and stable policy support through government incentives for biofuels such as blending mandates.

OPPORTUNITIES

- **Decarbonisation of transport modes** along with a reduction of total energy demand in the sector can create multiple benefits for energy security, air quality, health, safety and access to mobility.
- **Electrification offers economic opportunities** for local manufacturing and supply chains.
  - An increasing range of heavy-duty and long-distance electric vehicles open up new opportunities for freight and buses.



RENEWABLES IN AGRICULTURE

Renewable energy solutions are gaining momentum in the agriculture sector but progress is constrained by affordability concerns and a lack of integrated regulatory frameworks.

4 countries had renewable energy targets in the agriculture sector as of 2023

32 national and sub-national jurisdictions had renewable energy policies for agriculture as of 2023

About 2.2% of total final energy consumption in 2021 is from the agriculture sector

KEY FACTS

- **15.4% renewable energy use in the agriculture, forestry, and fisheries sectors** in 2021, up from 10.8% in 2011
- Of the **renewable energy used in agriculture** in 2021, 55% was from electricity.
- 1,165 MW of **off-grid solar water pumps installed globally** as of 2022, led by India with 1,083 MW
- Up to 40% increase in income for **farmers adopting renewable cooling technologies**

MODULE OVERVIEW

The agriculture, forestry, fisheries and aquaculture sectors[i] together contributed around 4.3% of the world's gross domestic product in 2022.[1] These sectors grew 2.6% in value during the year, similar to the growth observed annually since 2018.[2] They employed just over one-quarter (26.2%) of the global working population in 2022.[3] In developing countries, most of the workers in these sectors are small-scale farmers and fishers.[4]

Agriculture and forestry accounted for around 2.1% of the world's total final energy consumption in 2021, and fisheries and aquaculture represented around 0.07%.[5] These four sectors accounted for around 15% of the energy use across the food value chain[ii] in 2021.[6]

Of the total energy use in these sectors in 2021, around 73% was in the form of heat and 26.9% was in the form of electricity (up from 19.7% in 2010).[7] Drivers behind this rising electrification include environmental concerns, government subsidies and other incentives, cost-saving potential, technological advancements and improved performance of electric machinery.[8]

In total, energy use in the agriculture, fisheries and aquaculture sectors contributed around 0.93 gigatonnes of carbon dioxide (CO_2) equivalent emissions in 2021, similar to the level in 2020.[9] Most of these emissions (95%) were CO_2, followed by nitrogen dioxide (4%) and methane (1%).[10] The CO_2 emissions come from the use of electricity (45.8%), petroleum products (38.4%), coal (11.6%) and fossil gas (3.3%).[11] Nearly all of the nitrogen dioxide emissions in these sectors are from the use of petroleum products, and around 80% of the methane emissions are from coal use.[12]

The share of renewable energy used in the agriculture, forestry and fisheries sectors increased from 10.8% in 2011 to 15.4% in 2021.[13] (→ *See Figure 23.*) Of the 2021 share, 55% was renewable electricity, 6.5% was solar thermal and geothermal heat, and 32% was modern bioenergy.[14] Renewable energy sources supplied only 10% of the heat used in agriculture in 2021, although this share has increased gradually over the years.[15] Of this 10% share, 72% was derived from modern bioenergy, 15% from direct geothermal and 13% from renewable electricity.[16]

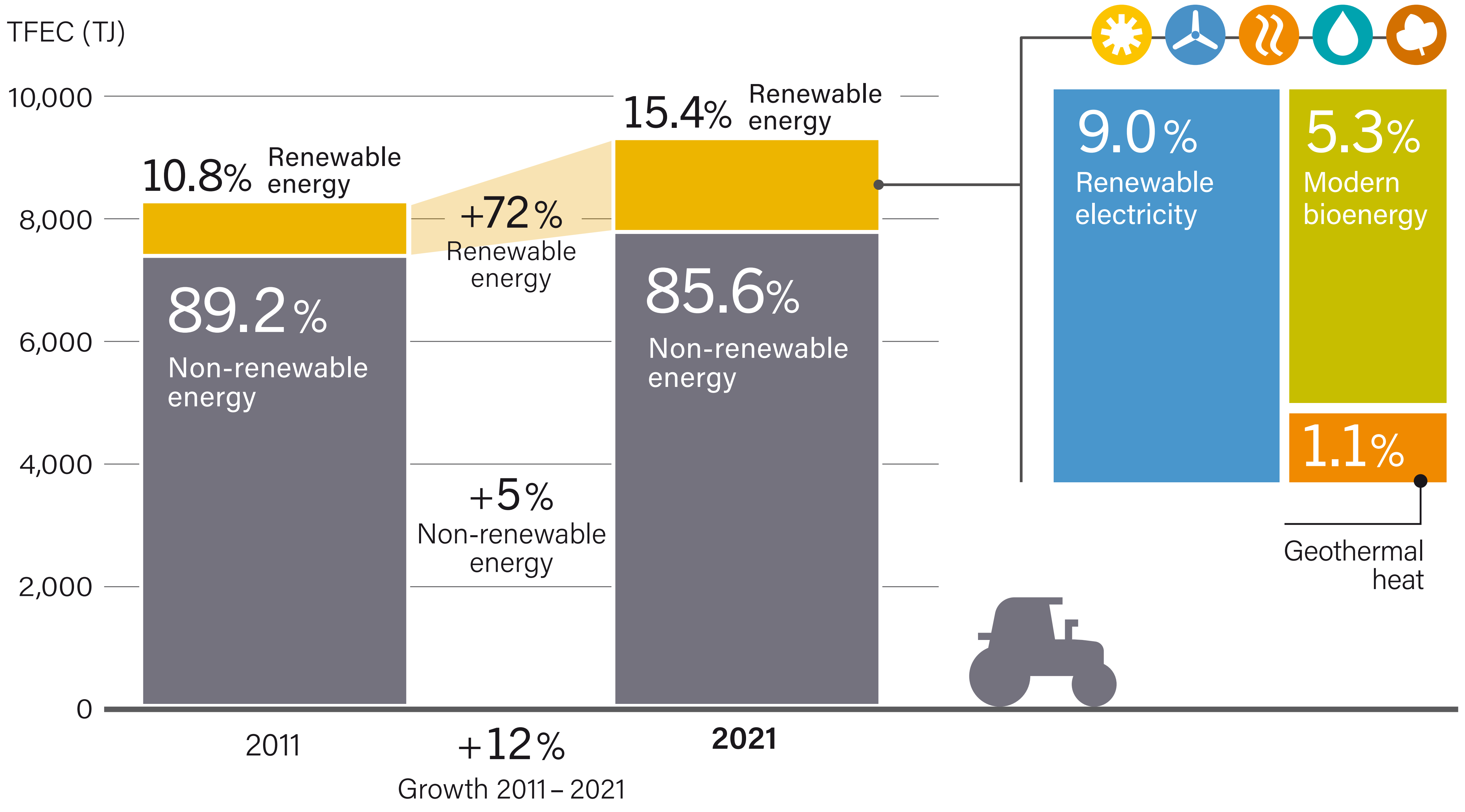
Despite growing recognition of the importance of energy efficiency in the agriculture sector, it has been largely overlooked in political and research agendas, and no major policy developments occurred in 2023.[17] Among the key benefits to farmers and fishers of adopting renewables and energy efficiency are improved energy access and energy reliability, fuel cost savings, reduced food losses, increased levels of mechanisation, improved duration of productive seasons, expanded market reach, and environmental and health benefits.[18]

The agriculture, forestry, fisheries and aquaculture sectors employed

26.2%

of the global working population in 2022.

FIGURE 23.
Renewable Energy Share of Total Final Energy Consumption (TFEC) in Agriculture, 2011-2021



Source: See endnote 16 for this module.

i This module covers agriculture (including livestock farming and hunting), forestry, fisheries and aquaculture. When the module presents combined figures for more than one of these sectors, this was either the only or the most accurate information available. Energy use in agriculture includes fuels to operate machinery and tractors but does not include energy used for manufacturing of machinery, pesticides, or fertilisers, or for food packaging, processing, or transport, which are included with industry or transport. Forestry does not include the manufacture of wood and wood products and the pulp and paper industry, which are included with 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 covered in the GSR 2024 Transport module.

ii Food value chains refers to the whole value chain involved in producing food: planting and harvesting but also fertiliser production, transport, storage, processing and packaging and retail businesses.

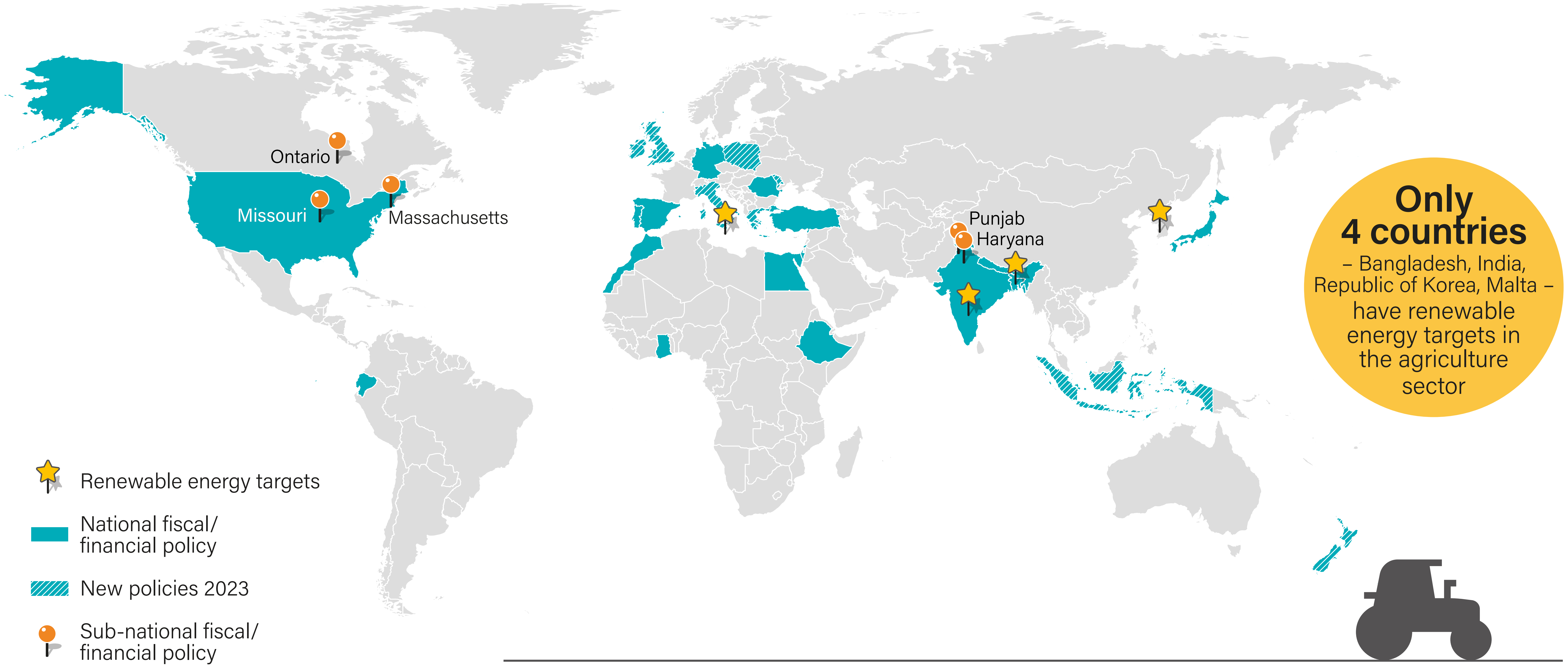
POLICY AND TARGETS

In 2023, the policy landscape for renewables in the agriculture sector remained constrained by fragmented policies and a siloed approach, with national agricultural policy documents seldom mentioning renewable energy.[19] The focus was mainly on biogas and solar water pumps, sidelining the vast potential of other renewable technologies, while agrivoltaics was still considered to be at the frontier of innovation.[20] Rising consumer demand for sustainably produced goods has helped push the sector to adopt cleaner energy options to meet market expectations.[21]

By the end of 2023, 4 countries had **renewable energy targets** in the agriculture sector. For example, in 2022, India announced its aim to replace diesel use in agriculture with renewable energy by 2024, while the Republic of Korea added a target to reach 10 GW of agrivoltaics capacity by 2030 under its Renewable Energy 2030 plan.[22] A total of 32 national and sub-national jurisdictions had **renewable energy policies** for agriculture as of 2023.[23] (→ *See Figure 24.*)

The European Union (EU) adopted the 2023-2027 Common Agricultural Policy (CAP), which supports biogas production and renewable energy investments on farms, with the aim of installing 1,556 MW of renewable capacity.[24] The CAP provides support for nearly 180,000 farms to engage in renewables and promotes energy efficiency and precision farming to enhance resource management.[25] The European Commission also issued a strategy on energy transitions for the EU fisheries and aquaculture sector.[26]

FIGURE 24.
National and Sub-National Renewable Energy Policies for Agriculture, 2023



Note: The number includes countries and subnational jurisdiction with financial and regulatory incentives. Italy and Romania have both type of policies and are counted only once.

Source: See endnote 23 for this module.

In 2023, Indonesia increased its support to fishers and farmers through the distribution of converter kits.[27] The Philippines' National Irrigation Administration funded solar irrigation systems on plantations and offered up sites for floating solar PV projects after the successful completion of a floating solar demonstration project.[28] Egypt established a Centre for Renewable Energy in Aquaculture, financed by Norway, to test innovative renewable energy solutions among 5,000 fish producers throughout the country.[29]

Fiscal and financial policies continued to be widely used for renewables in the agriculture sector in 2023. Greece offered grants to farmers covering up to 60% of the cost of PV systems, and the EU allocated USD 1.8 billion (EUR 1.7 billion) to Italy to support agrivoltaics.[30] The United States allocated USD 300 million in loans and grants to support rural electricity providers through the Rural Clean Energy Initiative.[31] Poland launched a USD 244,790 (EUR 230,000) subsidy programme to help farmers and energy co-operatives in rural communes finance renewable energy and energy storage systems, and also put in place a subsidy scheme to develop co-generation from biogas produced using municipal organic waste.[32] Brazil extended grants to a local company to develop a biogas production line.[33] In India, the state of Haryana announced new subsidies to cover 75% of the cost of solar pumps, encompassing the difference between the PM KUSUM Scheme subsidies and the actual cost of the system for the years 2023-2024.[34]

In a counter trend, Sweden reduced its tax on agricultural diesel to provide farmers with relief from inflation and to match levels required by the EU.[35] Spain put in place transport fuel subsidies for farmers in a similar policy response to the price crisis.[36]

INVESTMENT AND FINANCE

Data on renewable energy investment in the agriculture sector remain limited. For most regions, information is lacking on energy flows across local agri-food value chains and on spending for farm and non-farm enterprises.[37]

Investment in renewables in agriculture often has been motivated by the wish to shield activities in the sector from volatile fossil fuel prices and supply shocks.[38] However, the seasonal nature of farm incomes, along with the capital-intensive structure of most renewable energy investments, makes the affordability of renewables a challenge for participants in small and medium-sized agri-food chains.[39] A variety of programmes are aimed at providing finance for renewable energy installations in agriculture, with the goals of boosting farmer incomes and reducing fossil fuel reliance.[40] (→ *See Policy section.*)

Investment in **agrivoltaics**[i] continued to increase globally, building on demonstration projects that began in the early 2000s.[41] Agrivoltaics that supports livestock grazing or pollinator habitat has been more financially competitive than agrivoltaics linked to crop production, which is impeded by the cost required to elevate the PV panels.[42] Drivers for investment in crop agrivoltaics vary by region. In Europe and some Asian countries (such as Japan), aggressive goals for solar energy development – supported by public funds and coupled with strict rules on the use of agricultural land – have led to a flux in private finance.[43]

In Europe, the Danish renewable energy company Eurowind Energy invested USD 54.7 million (EUR 50 million) in a 70 MW agrivoltaic park in Romania, which began construction in late 2023.[44] An initiative in France launched by Sun'Agri and RGreen Invest continued efforts to mobilise USD 1.1 billion (EUR 1 billion) in public and private funds for 300 agrivoltaic projects nationwide by 2025.[45] The French energy giant TotalEnergies acquired Ombrea, a company with dedicated expertise in agrivoltaics, to help expand its agrivoltaic portfolio and meet criteria set out under France's Renewable Energy Acceleration Law.[46]

In the United States, public support for agrivoltaics has been mixed, with financing for crop-based projects driven mainly by community solar initiatives or small on-farm investors.[47] Farmers are attracted by the possibility of steady income from electricity production to offset the potentially risky returns from crops.[48] In Massachusetts, state-level incentives have supported the development of several local agrivoltaic projects.[49] BlueWave, a solar developer, owner and operator in the US Northeast, announced a USD 91 million financing package (USD 64 million in debt and USD 27 million in tax equity) to begin construction of five agrivoltaic projects in the area.[50] In Africa, agrivoltaic projects in Kenya and Tanzania have been supported mainly by international development funds.[51]

i Agrivoltaics describes the dual use of agricultural land whereby solar PV systems are elevated to enable plants to be grown or animals to be raised underneath and/or alongside.

The agriculture sector plays an important role in the **biogas** market, given the high availability of feedstocks such as animal manure and crop residues. Supportive policy targets for biogas and biomethane have helped boost investment. In Europe, around USD 4.5 billion (EUR 4.1 billion) was allocated for biomethane projects between 2023 and 2025, mostly in France (USD 1.5 billion or EUR 1.4 billion) and Italy (USD 1.2 billion or EUR 1.1 billion).[52] In Pune, India, the company Sistema.bio inaugurated the world's largest manufacturing facility for biodigesters; the USD 1.8 million facility has a production capacity of 100,000 biodigesters annually, aimed at supplying small farms in Asia and the Pacific, Sub-Saharan Africa and Latin America.[53] In Brazil, RDP Energia announced a USD 10 million (BRL 50 million) investment in a biomethane refinery in Paraná that will operate on pig farming waste.[54]

Investments in biogas projects in the agriculture sector are complicated by the logistics of raising capital. The loan requirements are often too small to attract financing from local banks and too large for individual investors (farmers) to raise the required equity.[55] Risk perceptions, such as the ability to secure reliable feedstocks, can raise the cost of capital or reduce the loan tenure available to potential investors.[56]

The agriculture sector plays an important role in the **biogas market**

MARKET DEVELOPMENTS

The agriculture sector has integrated various renewable energy and energy efficiency technologies, depending on the application and context. Successful initiatives have occurred in all regions, with the greatest uptake being in solar PV applications, especially as the cost of PV panels falls and their efficiency in high temperatures improves.[57] In addition to using renewables for self-consumption, farmers produce energy to sell to the grid in the form of bioenergy (biofuels, biogas and solid bioenergy) and renewable electricity (agrivoltaics, small-scale hydropower and wind power), making the sector an energy supplier.[58]

Hundreds of thousands of **solar water pumps and irrigation systems** have been installed worldwide, including an estimated 500,000 pumps in South Asia alone.[59] The global capacity of off-grid solar pumps for agriculture increased from 804 MW in 2021 to around 1,165 MW in 2022, with the largest total capacities for 2022 to be found in India (1,083 MW), Bangladesh (49 MW) and Ethiopia (17 MW).[60] Despite this growth and the more than 80% decline in the price of solar water pumps in the past two decades, they account for only 1% of installed irrigation systems.[61] Yet momentum is growing, especially in Sub-Saharan Africa.[62] (→ *See Snapshot: Rwanda.*)

Renewable cooling technologies used for cold storage have helped communities reduce food losses, increase incomes and reach additional markets.[63] In Kenya's agriculture sector, several energy-efficient and solar-powered cooling solutions – such as the off-grid evaporative charcoal cooler, the zero energy brick cooler and solar-powered cold storage – have been affordable and reliable options for small-scale farmers.[64] (→ *See Snapshot: Kenya.*) Walk-in cold rooms have helped increase farmer incomes in the country an estimated 40% by reducing food loss.[65] In Nigeria, solar-powered cooling has enabled farmers and market agents to generate more income and avoid food loss at a lower cost than grid access.[66]

Solar thermal energy, used for both cooling and heating, has diverse applications in the agriculture sector, including for drying and dehydration, cooking, and heating and cooling of greenhouses and other spaces.[67] The ICaRE4Farms project, completed in north-west Europe in December 2023, promotes the use of solar thermal energy on farms in sectors that have high hot water demand, and will reduce a projected 1 million tonnes of CO_2 over the project's 10-year lifespan.[68]

Photovoltaic thermal (PVT) systems, which combine solar PV and solar thermal technologies to produce electricity and heat, offer a potentially more efficient option for livestock and dairy farming than either technology separately.[69] An experimental project on a swine farm in Italy found that PVT technology – combined with a solar central unit, thermal energy storage and a heat pump – is fully capable of replacing the use of fossil fuels.[70] A project in Germany showed that the technology was efficient and had a payback period of six years.[71]

SNAPSHOT RWANDA

TRANSFORMING AGRICULTURE AND MITIGATING CLIMATE CHANGE: THE NASHO SOLAR-POWERED IRRIGATION PROJECT

In Rwanda, as in many Sub-Saharan African countries, the expansion of irrigation is essential for agricultural development, food security and climate resilience. The agriculture sector contributes 90% of the country's food production and 35% of GDP. It is integral to Rwanda's socio-economic development, with around 70% of the population depending on the sector for their livelihoods. However, a large share of the population remains food insecure, particularly in rural areas.

Consistent access to water is essential for maintaining and improving agricultural yields, as Rwanda supports diverse crop production throughout the year. However, fluctuating rainfall patterns, water management challenges and competing demands limit farmers' access to reliable water sources. Irrigation plays an important role in securing water for agriculture, yet only around 9.5% of the country's potential irrigable land has formal infrastructure. Inadequate energy access and reliance on costly fuel-based irrigation systems have slowed uptake.

Off-grid solar-powered irrigation pumps offer a solution to these challenges, yet their adoption remains low in Rwanda and across Sub-Saharan Africa due to systemic barriers such as high costs, lack of regulation and limited market development. In 2020, a promising initiative was launched to help surmount these obstacles and enhance agricultural productivity in the Nasho region in the southern expanse of the Eastern Province. The Nasho Solar-powered Irrigation Project, covering around 1,100 hectares, was a collaborative effort between the Rwandan government and the Howard G. Buffett Foundation, which channelled USD 54 million in funding to the project.

The project deployed 63 pivot irrigation systems – powered by a 3.3 MW solar plant with 2.4 MW of battery storage – and benefited 2,099 small-scale farmers. Farmers, organised under the Nasho Irrigation Cooperative (NAICO), managed the infrastructure with technical assistance from Rwanda Agriculture and Animal Resources Development, ensuring the sustainability of the project. This enabled year-round cultivation, more efficient use of resources (including water and fertiliser), and improved crop yields.

According to some estimations, the system could empower small-scale producers to elevate their annual production from 3-5 tonnes per hectare to nearly 10 tonnes per hectare. Alongside these anticipated crop yield gains, the project aimed to ensure access to and adoption of technologies that enhance agricultural value chains and promote soil conservation. The project also enhanced transport infrastructure, with 24 kilometres of existing roads resurfaced and 10 kilometres of new roads introduced.

The Nasho Solar-powered Irrigation Project is set to expand by an additional 1,050 hectares in 2024. This expansion aims to cut emissions 10% by 2030, enhance food security, and reduce dependency on imported fossil fuels, while increasing the land surface under irrigation. The investment needed to realise this vision is projected to be around USD 280 million, requiring participation from the government, the private sector and international partnerships.

Source: See endnote 62 for this module.

SNAPSHOT KENYA

SOLAR-POWERED COLD STORAGE SOLUTIONS SUPPORT SUSTAINABLE AGRICULTURE AND FOOD SECURITY

Globally, food waste and agricultural losses total more than 931 million tonnes annually. The challenge is particularly acute in rural areas that have limited access to power and inadequate storage facilities, leading to significant spoilage of produce. Cold storage infrastructure has immense potential to reduce these losses in Sub-Saharan Africa, where 30-40% of post-harvest food is lost. The technology will only become more crucial in the context of climate change, with the demand for cooling devices globally expected to quadruple by 2050.

In Kenya, where a large rural population relies on small-scale farming, the lack of cold storage facilities exacerbates the effects of significant post-harvest losses. An estimated 65% of Kenya's rural population lacks access to the national grid, leading to reliance on kerosene and firewood for energy needs, and presenting challenges to obtaining cold storage infrastructure. In March 2019, the Rural Electrification and Renewable Energy Corporation (REREC) was established to execute rural electrification projects and lead renewable energy efforts. The initiative has supported the uptake of off-grid solar solutions, including solar-powered cooling.

Off-grid cooling services have been piloted in several areas of Kenya. In 2024, a first-of-its-kind solar-powered cold storage facility for sweet potatoes was inaugurated in Mwea County, by Baridi, a company that provides solar-powered refrigeration across East Africa, and FarmWorks, a Kenyan agricultural company, in partnership with the International Potato Centre (CIP) and the US Department of Agriculture. The project aims to provide affordable solar-powered cooling solutions and received USD 40,000 from the Gender4Climate Africa Challenge, a competition in East Africa that awards funding to organisations that prioritise climate change and gender-inclusive solutions. The project is working to link markets, agribusiness processors and cold chain stakeholders, helping to unify the sector and to reduce risks for small-scale farmers that are more vulnerable to the impacts of food losses and unreliable brokers.

The Indian-based company Inficold developed the solar-powered cooling facility, which can preserve or store up to 5 metric tonnes of agricultural produce, and Baridi was responsible for overseeing the installation. There are plans to expand this project, and CIP and FarmWorks received a grant from the Kenya Catalytic Job Fund to finance the launch of more such containers.

Source: See endnote 64 for this module.

Agrivoltaics offers an opportunity to reconcile competing land uses for energy and agriculture.

In the fisheries sector, communities in East Africa and India have successfully adopted **solar PV and battery**-powered lamps and lighting for night fishing, allowing fishers to save on kerosene costs.[72] In Chile, a 1 MW **floating solar PV** project was implemented on a water storage reservoir to power nearby agricultural activities, covering part of the electricity needs and slowing water evaporation.[73]

Agrivoltaics offers an opportunity to reconcile competing land uses for energy and agriculture. Germany, France and Japan were early adopters of agrivoltaics, and other countries have since followed with pilot projects.[74] In India, notable projects include the 7 MW peak Grosolar Agrivoltaic in Maharashtra and the 3 MW peak Solar-Agri electric model in Gujarat.[75] Case studies in Portugal found that the use of agrivoltaics is more efficient than the single use of land for either agriculture or solar PV, with the generated electricity being used for both self-consumption and as a source of income through sales to the grid.[76] As of 2024, the United States had installed a reported 73 MW of agrivoltaics on crop production land and more than 5 GW on grazing land.[77] Türkiye launched its first agrivoltaics project in 2023 with a capacity of 122 kilowatts peak.[78]

Solar mini-grid projects improve energy access for agricultural activities such as irrigation water pumping, food drying, agricultural grinding and milling, and cold storage.[79] Sites near agricultural fields are good targets for mini-grid development, as agricultural loads compensate for the small sizes of rural communities, and most agricultural demand occurs during daylight.[80] In Nigeria, projects have enabled rural communities to electrify productive uses in agriculture and fisheries, such as using electric motorbikes for logistics and providing power to rice and grain mills and to cold rooms for fish storage.[81] In Uganda, a hybrid 600 kilowatt peak solar mini-grid with battery storage on the Lolwe Islands replaced some fossil fuel uses for ice making and fish drying.[82]

Geothermal energy has many uses in the sector, including greenhouse heating, soil warming, aquaculture, and the drying of fish, grains, fruits and vegetables.[83] The energy is used to heat aquaculture ponds and to dry fish, either directly in drying tunnels (as in Iceland) or indirectly by powering the drying systems.[84] For greenhouse heating, geothermal maintains a steady temperature and reduces condensation, mitigating the impacts of pests and fungal growth and improving crop yield.[85] Geothermal heating and cooling in fish farming and crop drying has grown in the last decade, although enormous potential remains.[86] In 2021, the United States used 122 megawatts-thermal (MW_{th}) of geothermal for fish farming and 80 MW_{th} for greenhouse heating.[87] More than 28,000 heating or cooling geothermal systems were operating in the country as of 2022 to meet agricultural, livestock farming and aquaculture needs.[88]

In aquaculture, micro-**hydropower** systems are used to heat fishponds and to provide the electricity that powers the aquaculture system.[89] In the United States, the number of small hydropower systems in agriculture increased around 50% between 2017 and 2022, to more than 2,500 installations.[90]

The EU and the United Kingdom are the only regions where **biogas** has been used significantly in agriculture and forestry (compared to the other sectors).[91] On the supply side, energy crops (such as maize and cereal grains), agricultural residues and manure are feedstocks for biogas and biomethane production.[92] Almost all off-grid biogas production for agriculture occurs in South America, with Brazil dominating the world's supply (96.5%).[93]

Globally, fish farmers use **solid bioenergy** – in the form of briquettes, pellets or charcoal produced from woody or crop residues – instead of traditional firewood to dry or smoke fish, with resulting health, environmental and combustion efficiency benefits.[94] In the United States, the number of farms that harvest **biomass** for use in renewable energy has grown from around 9,500 in 2017 to more than 16,000 in 2022.[95]

Wind energy is used to power productive activities in both agriculture and aquaculture. An aquaculture site in Chile is sourcing all its energy from a nearby wind and solar PV site through a 1.2-kilometre underwater electricity cable.[96] On the supply side, wind turbines installed on agricultural lands in Australia and the United States provide valuable income for farmers.[97]As of 2022, more than 20,000 US farms had contracts for wind rights leasing, roughly the same number as in 2017.[98]

Most of the renewable energy technologies used in agriculture and fisheries – from solar lighting to renewable cooling, bioenergy and PV thermal – are **energy efficient**.[99] Modern energy-efficient kilns used for drying fish, such as the FAO-Thiaroye fish processing technique and the Chokor kiln, have been successfully used in sub-Saharan Africa to help reduce fuel consumption and emissions.[100]

CHALLENGES

- **Fragmented policy landscape:**
  - The lack of comprehensive support for renewable energy in agriculture impedes widespread adoption.
- **Affordability:**
  - The cost of renewable technologies is a significant challenge, especially for small and medium-sized agri-food enterprises.
  - The seasonal nature of farm incomes complicates securing financing.
  - The capital-intensive nature of renewable energy projects impedes uptake.
- **Investment barriers in biogas projects:**
  - Barriers include logistical and capital constraints, mismatched loan requirements, difficulty raising equity, and risk perceptions related to feedstock availability.

OPPORTUNITIES

- **Rising market demand, technological advancements and diverse applications:**
  - Advancements in renewable energy technologies are improving their affordability and accessibility for farmers.
  - A wide range of renewable energy technologies can be used in diverse agricultural activities.
  - The agriculture sector is also an energy producer.
  - The demand for sustainably produced goods is increasing.
- **Diverse financing mechanisms:**
  - The growing availability of grants, subsidies and public-private partnerships can help to overcome affordability barriers and stimulate investment in renewable energy projects.

ENDNOTES | GLOBAL TRENDS

1 International Energy Agency, "World Energy Outlook 2023", 2023, https://iea.blob.core.windows.net/assets/42b23c45-78bc4482-b0f9-eb826ae2da3d/WorldEnergyOutlook2023.pdf.

2 International Monetary Fund, "World Economic Outlook (October 2023) – Inflation Rate, Average Consumer Prices", accessed 21 December 2023, https://www.imf.org/external/datamapper/PCPIPCH@WEO; International Energy Agency, "World Energy Outlook 2023", 2023, https://iea.blob.core.windows.net/assets/42b23c45-78bc4482-b0f9-eb826ae2da3d/WorldEnergyOutlook2023.pdf.

3 BloombergNEF, "G-20 Member States More Than Doubled Fossil-Fuel Support in 2022 to $1.3 Trillion", 21 November 2023, https://about.bnef.com/blog/g-20-member-states-more-than-doubled-fossil-fuel-support-in-2022-to-1-3-trillion; International Monetary Fund, "Fossil Fuel Subsidies Surged to Record $7 Trillion", 24 August 2023, https://www.imf.org/en/Blogs/Articles/2023/08/24/fossil-fuel-subsidies-surged-to-record-7-trillion; Subel Rai Bhandari, "IMF: China Leads as Global Fossil Fuel Subsidies Hit Record $7 Trillion", Radio Free Asia, 25 August 2023, https://www.rfa.org/english/news/environment/global-fuel-subsidies-08252023061051.html.

4 BloombergNEF, "Energy Transition Investment Trends 2024", 2024, https://about.bnef.com/energy-transition-investment. **Sidebar 1** from the following sources: Patrick Jowett, "AirTrunk, ib vogt Sign Virtual PPA for 29.9 MW of Solar in Malaysia", pv magazine Australia, 12 February 2024, https://www.pv-magazine.com/2024/02/12/airtrunk-ib-vogt-sign-virtual-ppa-for-29-9-mw-of-pv-in-malaysia; Nick Ferris, "Nine Sectors Beyond IT and Heavy Industry Reach Corporate Renewable PPA Landmark", Energy Monitor, 27 October 2023, https://www.energymonitor.ai/sectors/power/data-insight-nine-sectors-beyond-it-and-heavy-industry-reach-corporate-renewable-ppa-landmark; Pilar Sánchez Molina, "Record Number of European PPAs in 2023, Says Pexapark", pv magazine, 29 January 2024, https://www.pv-magazine.com/2023/11/27/pexapark-says-european-developers-secured-1-6-gw-solar-ppas-in-october; J.P. Casey, "Europe Renews Appetite for PPAs, Signs 16.2GW of Renewable Deals in 2023, Including 10.5GW of Solar", PV-Tech, 18 January 2024, https://www.pv-tech.org/europe-renews-appetite-for-ppas-signs-16-2gw-of-renewable-deals-in-2023-including-10-5gw-of-solar; M. Stafford, "Solar Power Purchase Agreement Prices Rise 15% Year-Over-Year in U.S.", pv magazine, 31 January 2024, https://pv-magazine-usa.com/2024/01/30/solar-power-purchase-agreement-prices-rise-15-year-over-year; Colton Poore, "Most Clean Power Purchasing Strategies Do Little to Cut Emissions, Study Finds", TechXplore, 23 January 2024, https://techxplore.com/news/2024-01-power-strategies-emissions.html; BloombergNEF, "Corporate Clean Power Buying Grew 12% to New Record in 2023, According to BloombergNEF", 13 February 2024, https://about.bnef.com/blog/corporate-clean-power-buying-grew-12-to-new-record-in-2023-according-to-bloombergnef; Stuart Stone, "Corporates Contract Record 46GW of Wind and Solar PPAs in 2023", BusinessGreen, 19 December 2023, https://www.businessgreen.com/news/4173725/corporates-contract-record-46gw-wind-solar-ppas-2023. **Figure 1** from BloombergNEF, op. cit. this note.

5 Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2023 Global Status Report: Global Overview Module", 2023, https://www.ren21.net/wp-content/uploads/2019/05/GSR2023_GlobalOverview_Full_Report_with_endnotes_web.pdf; REN21, "Renewables 2024 Global Status Report: Global Overview", 2024, https://www.ren21.net/wp-content/uploads/2019/05/GSR2024_GlobalOverview_Full_Report_with_endnotes_web.pdf.

6 See, for example: Henry Zeffman, Chris Mason and Brian Wheeler, "Rishi Sunak Considers Weakening Key Green Policies", BBC News, 19 September 2023, https://www.bbc.com/news/uk-politics-66857551; Derek Harrison, "Climate Rules Reach Finish Line, in Weakened Form, as Biden Races Clock", Inside Climate News, 6 March 2024, https://insideclimatenews.org/news/06032024/biden-climate-rules-reach-finish-line-in-weakened-form; Julian Wettengel, "German Government MPs Agree Climate Law Reform That Weakens Sector Targets", Clean Energy Wire, 16 April 2024, https://www.cleanenergywire.org/news/german-government-mps-agree-climate-law-reform-weakens-sector-targets; Erwida Maulia, Norman Goh and Lien Hoang, "Greenflation Causes Indonesia and Vietnam to Backtrack on Renewables", Nikkei Asia, 25 March 2024, https://asia.nikkei.com/Business/Energy/Greenflation-causes-Indonesia-and-Vietnam-to-backtrack-on-renewables.

7 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21). **Figure 2** from ibid.

8 Global Sustainable Electricity Partnership, "2023 Global Electrification Monitor: Trends in End-Use Sectors", 2023, https://www.globalelectricity.org/publication/global-electrification-monitor-2023. **Sidebar 2, Figure 3** and **Figure 4** from International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

9 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

10 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand. **Figure 5** from idem.

11 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

12 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

13 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand. **Figure 6** from idem.

14 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

15 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

16 Global Alliance for Buildings and Construction, "2023 Global Status Report for Buildings and Construction", United Nations Environment Programme, 2023, https://wedocs.unep.org/bitstream/handle/20.500.11822/45095/global_status_report_buildings_construction_2023.pdf.

17 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

18 GOV.UK, "Powering Up Britain", 4 April 2023, https://www.gov.uk/government/publications/powering-up-britain; European Commission, "Carbon Border Adjustment Mechanism", accessed April 2024, https://taxationcustoms.ec.europa.eu/carbon-border-adjustment-mechanism_en

19 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

20 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

21 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

22 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

23 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

24 International Energy Agency (IEA), "SEK 380 Million: Temporary Tax Reduction on Agricultural Diesel – Policies", 20 April 2023, https://www.iea.org/policies/17497-sek-380-milliontemporary-tax-reduction-on-agricultural-diesel; IEA, "2023 Price Crisis Response Policies – Policies", 11 May 2023, https://www.iea.org/policies/17484-2023-price-crisis-response-policies.

25 European Commission – Agriculture and Rural Development, "Common Agricultural Policy for 2023-2027 – 28 CAO Strategic Plans at a Glance", 2022, https://agriculture.ec.europa.eu/system/files/2022-12/csp-at-a-glance-eu-countries_en.pdf.

26 BloombergNEF, "Energy Transition Investment Trends 2024", 2024, https://about.bnef.com/energy-transition-investment.

27 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

28 International Energy Agency (IEA), "Photovoltaics on the Roof Programme – Policies", 11 May 2023, https://www.iea.org/policies/17357-photovoltaics-on-the-roof-programme; IEA, "The Future of Heat Pumps", 2022, https://doi.org/10.1787/2bd71107-en.

29 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

30 Owais Ali, "Green Hydrogen for Steel Production", AZoCleantech, 27 July 2022, https://www.azocleantech.com/article.aspx?ArticleID=1606; Loz Blain, "World's Largest Hydrogen 'Green Steel' Plant to Open in Sweden by 2024", New Atlas, 26 February 2021, https://newatlas.com/energy/h2gs-green-hydrogen-steel; International Energy Agency (IEA), "Biomass for Industrial Heat", Energy Post, 10 March 2022, https://energypost.eu/biomass-for-industrial-heat; Jaap Koppejan, "Bioenergy for High Temperature Heat in Industry", IEA Bioenergy, 2020, https://www.ieabioenergy.com/blog/task/bioenergy-for-high-temperature-heat-in-industry; Caitlin Swalec and Astrid Grigsby-Schulte, "Pedal to the Metal", Global Energy Monitor, 2023, https://globalenergymonitor.org/report/pedal-to-themetal-2023-time-to-shift-steel-decarbonization-into-high-gear.

31 Solar Payback, "Turnkey SHIP Supplier World Map", cited in Bärbel Epp, "The Netherlands and Spain Drive SHIP Market 2023", Solar Thermal World, 28 March 2024, https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023; Spectra, "The Large Heat Pumps Transforming Gas-Intensive Industries Like Pulp and Paper", 3 August 2023, https://spectra.mhi.com/the-large-heat-pumps-transforminggas-intensive-industries-like-pulp-and-paper; Sarah Azau, "Saving 50% Energy in Paper Industry Through Heat Pumps", European Heat Pump Association, 6 February 2023, https://www.ehpa.org/news-and-resources/news/saving-50-energy-in-paper-industry-through-heat-pumps.

32 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

33 BloombergNEF, "Energy Transition Investment Trends 2024", 2024, https://about.bnef.com/energy-transition-investment.

34 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

35 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

36 Stephan Schindele et al., "Implementation of Agrophotovoltaics: Techno-Economic Analysis of the Price-Performance Ratio and Its Policy Implications", *Applied Energy* 265 (1 May 2020): 114737, https://doi.org/10.1016/j.apenergy.2020.114737; Anas Rahman et al., "Agrivoltaics in India: Challenges and Opportunities for Scale-Up", International Institute for Sustainable Development, 2023, https://www.jstor.org/stable/resrep49783.

37 Energy Sector Management Assistance Program (ESMAP), "Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers", 2022, https://www.esmap.org/mini_grids_for_half_a_billion_people_the_report; ESMAP, "Energy Storage for Mini Grids: Status and Projections of Battery Deployment", 2023, https://www.esmap.org/Energy_Storage_for_Mini_Grids; Energizing Agriculture Programme, "Results", accessed 1 February 2024, https://energizingagricultureprogramme.org/results; Andrew Allee, "Electrifying Nigerian Agriculture with Clean Minigrids to Improve Livelihoods", Energizing Agriculture Programme, 11 February 2023, https://energizingagricultureprogramme.org/2023/02/11/electrifying-nigerian-agriculture-with-clean-minigrids-toimprove-livelihoods; Ayodeji Ojo, "As Petrol Prices Climb, Nigerian Agriculture Extension Officers Cut Fuel Costs with Electric Motorbikes", Energizing Agriculture Programme, 21 December 2023, https://energizingagricultureprogramme.org/2023/12/21/ev-pilot; Habiba Daggash, "Electric Rice Mills Reduce Reliance on Soaring Diesel Prices in Niger State, Nigeria", Energizing Agriculture Programme, 8 November 2023, https://energizingagricultureprogramme.org/2023/11/08/ricemill-launch; Folawiyo Aminu, "Pilot Updates: Minigrid-Powered Cold Room", Energizing Agriculture Programme, 26 June 2023, https://energizingagricultureprogramme.org/2023/06/26/kiguna-fish-cold-storage.

38 International Renewable Energy Agency, "Global Geothermal Market and Technology Assessment", 2023, https://www.irena.org/Publications/2023/Feb/Global-geothermal-market-and-technology-assessment; US Department of Agriculture, National Agricultural Statistics Service, "2022 Census of Agriculture", February 2024, https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report.

ENDNOTES | INDUSTRY

1 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

2 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

3 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

4 World Bank, "Industry (Including Construction), Value Added (% of GDP)", accessed 27 March 2024, https://data.worldbank.org/indicator/NV.IND.TOTL.ZS; World Bank, "Employment in Industry (% of Total Employment) (Modeled ILO Estimate)", accessed 27 March 2024, https://data.worldbank.org/indicator/SL.IND.EMPL.ZS.

5 International Energy Agency, "World Energy Outlook 2023", 2023, https://www.iea.org/reports/world-energy-outlook-2023.

6 International Energy Agency, "CO2 Emissions in 2023", 2024, https://www.iea.org/reports/co2-emissions-in-2023.

7 International Energy Agency, "CO2 Emissions in 2023", 2024, https://www.iea.org/reports/co2-emissions-in-2023.

8 International Energy Agency, "CO2 Emissions in 2023", 2024, https://www.iea.org/reports/co2-emissions-in-2023.

9 International Energy Agency, "CO2 Emissions in 2023", 2024, https://www.iea.org/reports/co2-emissions-in-2023.

10 International Energy Agency, "CO2 Emissions in 2023", 2024, https://www.iea.org/reports/co2-emissions-in-2023.

11 International Energy Agency, "CO2 Emissions in 2023", 2024, https://www.iea.org/reports/co2-emissions-in-2023.

12 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21). **Figure 7** from idem.

13 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

14 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net.gsr2024-data-pack/demand.

15 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net.gsr2024-data-pack/demand.

16 S. Madeddu et al., "The CO2 Reduction Potential for the European Industry via Direct Electrification of Heat Supply (Power-to-Heat)", *Environmental Research Letters* 15, no. 12 (November 2020): 124004, https://doi.org/10.1088/1748-9326/abbd02.

17 P. Fornari and C. Abbruzzese, "Copper and Nickel Selective Recovery by Electrowinning from Electronic and Galvanic Industrial Solutions", *Hydrometallurgy* 52, no. 3 (1 June 1999): 209-222, https://doi.org/10.1016/S0304-386X(99)00019-5; Arne Petter Ratvik, Roozbeh Mollaabbasi and Houshang Alamdari, "Aluminium Production Process: From Hall–Héroult to Modern Smelters", *ChemTexts* 8, no. 2 (25 February 2022): 10, https://doi.org/10.1007/s40828-022-00162-5.

18 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net.gsr2024-data-pack/demand.

19 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

20 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

21 International Energy Agency, "Paper", 2023, https://www.iea.org/energy-system/industry/paper.

22 Ilaria Mazzocco, "Green Industrial Policy: A Holistic Approach", Center for Strategic and International Studies, 27 February 2024, https://www.csis.org/analysis/green-industrial-policy-holistic-approach.

23 Nurzat Myrsalieva and Tareq Emtairah, United Nations Development Organisation (UNIDO), personal communication with REN21, 28 November 2023.

24 International Energy Agency, "Electricity, Gas and Heating Price Brakes – Policies", 24 May 2023, https://www.iea.org/policies/17535-electricity-gas-and-heating-price-brakes; International Energy Agency, "State Aid for Energy Costs of Energy Intensive Sectors – Policies", 12 May 2023, https://www.iea.org/policies/17228-state-aid-for-energy-costs-of-energy-intensive-sectors.

25 European Council, "Renewable Energy: Council Adopts New Rules", 9 October 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules.

26 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net.gsr2024-data-pack/demand.

27 European Commission, "Spain – Draft Updated NECP 2021-2030", 2023, https://www.miteco.gob.es/content/dam/miteco/es/energia/files-1/_layouts/15/Borrador%20para%20la%20actualizaci%C3%B3n%20del%20PNIEC%202023-2030-64347.pdf.

28 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

29 International Energy Agency, "Carbon Contracts for Difference (CCfD) Program for Energy-Intensive Industries – Policies", 11 May 2023, https://www.iea.org/policies/17538-carbon-contracts-for-difference-ccfd-program-for-energy-intensive-industries.

30 International Energy Agency, "Support for the Security of Supply of Industrial Companies – Policies", 15 May 2023, https://www.iea.org/policies/17147-support-for-the-security-of-supply-of-industrial-companies.

31 GOV.UK, "Powering Up Britain", 4 April 2023, https://www.gov.uk/government/publications/powering-up-britain.

32 European Parliament, "EU Carbon Border Adjustment Mechanism: Implications for climate and competitiveness", 13 June 2023, https://www.europarl.europa.eu/thinktank/fr/document/EPRS_BRI(2022)698889; Ian Bott et al., "How Global Trade Could Fragment After the EU's Tax on 'Dirty' Imports", *Financial Times*, 9 January 2024, https://www.ft.com/content/ca51ebf5-fbb8-4c88-a93d-ded3d6d3bcdd. **Sidebar 3** from European Commission, "Carbon Border Adjustment Mechanism", accessed March 2024, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en, and from World Bank, "Relative CBAM Exposure Index", 15 June 2023, https://www.worldbank.org/en/data/interactive/2023/06/15/relative-cbam-exposure-index#1.

33 International Energy Agency, "Amendment to the Energy Conservation Act – Policies", 8 May 2023, https://www.iea.org/policies/17441-amendment-to-the-energy-conservation-act.

34 Planalto, "Brazil Launches New Industrial Policy with Development Goals and Measures up to 2033", 26 January 2024, https://www.gov.br/planalto/en/latest-news/2024/01/brazil-launches-new-industrial-policy-with-development-goals-and-measures-up-to-2033.

35 European Council, "Renewable Energy: Council Adopts New Rules", 9 October 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules.

36 European Commission, "Call for Proposals 2023 – Closed", 31 January 2023, https://www.clean-hydrogen.europa.eu/call-proposals-2023-closed_en.

37 International Energy Agency, "Support for Green Hydrogen in Transport and Chemical Industry – Policies", 20 April 2023, https://www.iea.org/policies/17156-support-for-green-hydrogen-in-transport-and-chemical-industry.

38 The White House., "Treasury Sets Out Proposed Rules for Transformative Clean Hydrogen Incentives", 22 December 2023, https://www.whitehouse.gov/cleanenergy/clean-energy-updates/2023/12/22/treasury-sets-out-proposed-rules-for-transformative-clean-hydrogen-incentives.

39 US Department of Energy, "Regional Clean Hydrogen Hubs", July 2023, https://www.energy.gov/oced/regional-clean-hydrogen-hubs-0.

40 International Energy Agency, "Support for Energy Intensive SMEs Extended to 2023 – Policies", 9 May 2023, https://www.iea.org/policies/17164-support-for-energy-intensive-smes-extended-to-2023.

41 International Energy Agency, "Support for Decarbonising the Economy – Policies", 11 May 2023, https://www.iea.org/policies/17552-support-for-decarbonising-the-economy.

42 European Commission, "European Green Deal: EU Agrees Stronger Rules to Boost Energy Efficiency", 10 March 2023, https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1581.

43 Bärbel Epp, "Technical Tour to Europe's Largest Solar Industrial Heat Plant at Heineken Spain", Solar Thermal World, 30 October 2023, https://solarthermalworld.org/news/technical-tour-to-europes-largest-solar-industrial-heat-plant-at-heineken-spain.

44 Bärbel Epp, "Technical Tour to Europe's Largest Solar Industrial Heat Plant at Heineken Spain", Solar Thermal World, 30 October 2023, https://solarthermalworld.org/news/technical-tour-to-europes-largest-solar-industrial-heat-plant-at-heineken-spain.

45 NewHeat, "Newheat, en partenariat avec Lactalis, inaugure la plus grande centrale solaire thermique de France, qui alimentera en chaleur le site laitier de Verdun (55) pour les 25 prochaines années", 11 December 2023, https://newheat.com/wp-content/uploads/231208-CP-Newheat_Lactalis_Inauguration.pdf.

46 NewHeat, "Newheat, en partenariat avec Lactalis, inaugure la plus grande centrale solaire thermique de France, qui alimentera en chaleur le site laitier de Verdun (55) pour les 25 prochaines années", 11 December 2023, https://newheat.com/wp-content/uploads/231208-CP-Newheat_Lactalis_Inauguration.pdf.
47 Nayara Figueiredo, "São Martinho invests R$250m in biomethane plant", Valor International, 1 November 2023, https://valorinternational.globo.com/agribusiness/news/2023/11/01/sao-martinho-invests-r250m-in-biomethane-plant.ghtml.
48 Florence Jones, "Europe's Largest Concentrated Solar Unit Commissioned in Belgium", Power Technology, 7 September 2023, https://www.power-technology.com/news/europe-largest-concentrated-solar-belgium; Avery Dennison, "Avery Dennison Commissions Europe's Largest Concentrated Solar Thermal Platform and Thermal Storage Unit in Turnhout, Belgium", 6 September 2023, https://www.averydennison.com/en/home/news/press-releases/avery-dennison-commissions-europes-largest-concentrated-solar-thermal-platform-and-thermal-storage-unit-in-turnhout-belgium.html.
49 Papnews, "Essity Invests in World's First Tissue Machine Running on Geothermal Steam", 6 October 2021, https://www.papnews.com/essity-invests-in-worlds-first-tissue-machine-running-on-geothermal-steam; Sorbent, "About", accessed 7 February 2024, https://sorbent.co.nz/pages/about.
50 Carlo Cariaga, "KenGen Offers Land Leases in Geothermal-Powered Green Energy Park in Olkaria", ThinkGeoEnergy, 26 April 2023, https://www.thinkgeoenergy.com/kengen-offers-land-leases-in-geothermal-powered-green-energy-park-in-olkaria.
51 International Energy Agency Solar Heating and Cooling Programme, "Mixed Solar Thermal Market Development in 2022", 14 June 2023, https://www.iea-shc.org/Data/Sites/1/media/documents/press/2023-06-14--solar-heat-worldwide-press-release.pdf; GlassPoint, "Ma'aden Solar I", accessed 29 February 2024, https://www.glasspoint.com/projects/maaden-solar.
52 Neste, "Neste Supports Rio Tinto U.S. Borax Mining Site to Transition to Renewable Diesel", 2 June 2023, https://www.neste.us/releases-and-news/renewable-solutions/neste-supports-rio-tinto-us-borax-mining-site-transition-renewable-diesel.
53 "Rio Tinto to Fully Move towards Renewable Diesel at Kennecott", *Reuters*, 5 December 2023, https://www.reuters.com/sustainability/rio-tinto-fully-move-towards-renewable-diesel-kennecott-2023-12-05.
54 Bärbel Epp, "Big Solar Heat Deal in the Chilean Copper Sector Made Possible by Two People", Solar Thermal World, 23 February 2024, https://solarthermalworld.org/news/big-solar-heat-deal-in-the-chilean-copper-sector-made-possible-by-two-people.
55 Neil Beaumont, "Risks and Rewards: Energy and Power in Sub-Saharan African Mining", Marsh, 24 January 2024, https://www.marsh.com/content/marsh2/mea/za/en_za/industries/mining/insights/risks-and-opportunities-sub-saharan-africa-for-mining-companies.html. **Snapshot: Sub-Saharan Africa** from the following sources: sectoral value from ABiQ, "New Mining and Industrial Growth in Sub-Saharan Africa", 3 February 2023, https://www.abiq.io/new-mining-and-industrial-growth-in-sub-saharan-africa; investment from Giorgia Albertin, Dan Devlin and Boriana Yontcheva, "Countering Tax Avoidance in Sub-Saharan Africa's Mining Sector", International Monetary Fund, 5 November 2021, https://www.imf.org/en/Blogs/Articles/2021/11/05/blog-countering-tax-avoidance-sub-saharan-africa-mining-sector; energy sector demand, challenges and costs from Boqiang Lin and Rockson Sai, "Has Mining Agglomeration Affected Energy Productivity in Africa?" Energy 244 (2022): 122652, https://doi.org/10.1016/j.energy.2021.122652; African countries experiencing power shortages from B. Moyo, "Electricity Disruptions and the Efficiency of Manufacturing Firms in Africa: A Stochastic Frontier Analysis," *Studies in Economics and Econometrics* 42, no. 3 (December 1, 2018): 115–35, https://doi.org/10.1080/10800379.2018.12097340; effects on mining from Cane O'Neill, "How Hybrid Microgrids Are Transforming Africa's Mining Industry and Economic Outlook", Piller Power Systems, 22 December 2023, https://www.piller.com/article/how-hybrid-renewable-microgrids-are-revolutionising-africas-mining-industry-and-with-it-the-continents-economic-prospects; mining sector impacts from O'Neill, op. cit. this note; reliance on diesel from Mining.com, "Mining Companies Operating in Sub-Saharan Africa Should Invest in Renewable Energy – Report", 20 February 2019, https://www.mining.com/mining-companies-operating-sub-saharan-africa-invest-renewable-energy-report; hybrid mini-grids from Simon Cudennec and Laura Kiwelu, "Powering Mining in Africa – The Rise of the Mini-Grid and Captive Model", Norton Rose Fulbright, 26 April 2021, https://www.nortonrosefulbright.com/en/inside-africa/blog/2021/04/powering-mining-in-africa-the-rise-of-the-mini-grid-and-captive-model, and from Mining.com, op. cit. this note; larger trend from Neil Beaumont, "Risks and Rewards: Energy and Power in Sub-Saharan African Mining", Marsh, 24 January 2024, https://www.marsh.com/content/marsh2/mea/za/en_za/industries/mining/insights/risks-and-opportunities-sub-saharan-africa-for-mining-companies.html, from Cudennec and Kiwelu, op. cit. this note, and from Mining.com, op. cit. this note; Mauritania from Theodore Reed-Martin, "ABB and Voltalia Power Up Mine with Solar in Mauritania", Energy Global, 14 November 2023, https://www.energyglobal.com/solar/14112023/abb-and-voltalia-power-up-mine-with-solar-in-mauritania, and from Anne Laure Klein, "Mauritania: ABB Electrification, Voltalia Partner on Tasiast 24k Mining Project", Energy Capital & Power, 23 November 2023, https://energycapitalpower.com/mauritania-abb-electrification-voltalia-partner-on-tasiast-24k-mining-project; Burkina Faso from Wärtsilä, "Essakane & Wärtsilä: Africa's Largest Engine-Solar PV Hybrid Power Plant", 2024, https://www.wartsila.com/energy/learn-more/references/mining-cement/essakane-solar-sas-burkina-faso; Jean Marie Takouleu, "Madagascar: A 2.6 MW Hybrid Solar Power Plant Comes on Stream at the Molo Mine", Afrik 21, 26 October 2023, https://www.afrik21.africa/en/madagascar-a-2-6-mw-hybrid-solar-power-plant-comes-on-stream-at-the-molo-mine; South Africa from the following sources: Energy Capital & Power, "Five Mining Companies Adopting Solar Energy in South Africa", 14 June 2022, https://energycapitalpower.com/mining-firms-solar-energy-in-south-africa; "South Africa's Gold Fields Bets on Solar to Cut Costs and Carbon", *Reuters*, 13 October 2022, https://www.reuters.com/business/sustainable-business/south-africas-gold-fields-bets-solar-cut-costs-carbon-2022-10-13; Martin Creamer, "Green 175 MW Power for Sibanye-Stillwater Platinum Group Metal Mines", Mining Weekly, 27 September 2021, https://www.miningweekly.com/article/green-175-mw-power-for-sibanye-stillwater-platinum-group-metals-mines-2021-09-27; Gold Fields, "The South Deep Khanyisa Solar Plant", 2022, https://www.goldfields-southdeep.co.za/resources/the-south-deep-solar-plant; Mining.com, "Harmony Gold Starts Construction of Three 10 MW Solar Photovoltaic Plants", 2 June 2022, https://www.mining.com/web/harmony-gold-starts-construction-of-three-10-mw-solar-photovoltaic-plants; Megan J. Cole, "ESG Risks to Global Platinum Supply: A Case Study of Mogalakwena Mine, South Africa", *Resources Policy* 85 (2023): 104054, https://doi.org/10.1016/j.resourpol.2023.104054.
56 Lukas Hermwille et al., "A Climate Club to Decarbonize the Global Steel Industry", *Nature Climate Change* 12, no. 6 (June 2022): 494-96, https://doi.org/10.1038/s41558-022-01383-9.
57 Owais Ali, "Green Hydrogen for Steel Production", AZoCleantech, 27 July 2022, https://www.azocleantech.com/article.aspx?ArticleID=1606; Loz Blain, "World's Largest Hydrogen 'Green Steel' Plant to Open in Sweden by 2024", New Atlas, 26 February 2021, https://newatlas.com/energy/h2gs-green-hydrogen-steel.
58 Rod Nickel, "Canadian wind-hydrogen project delayed one year in race to first European exports", Reuters, 4 December 2023, https://www.reuters.com/sustainability/climate-energy/canadian-wind-hydrogen-project-delayed-one-year-race-first-european-exports-2023-12-04; Polly Martin, "H2 Green Steel's World-Leading Hydrogen-Based Steel Project at Risk After Grid Connection "illegally" Denied", Hydrogen Insights, 19 March 2024. https://www.hydrogeninsight.com/production/h2-green-steels-world-leading-hydrogen-based-steel-project-at-risk-after-grid-connection-illegally-denied/2-1-1614385; Polly Martin, "Uniper Delays Major Offshore-Wind Green Hydrogen Project to End of Decade, Hands Back EU Subsidies", Hydrogen Insight, 3 April 2024, https://www.hydrogeninsight.com/production/exclusive-uniper-delays-major-offshore-wind-green-hydrogen-project-to-end-of-decade-hands-back-eu-subsidies/2-1-1620287.
59 Yash Kashyap and Vivek Sen, "Financing Steel Decarbonization", CPI, 29 September 2022, https://www.climatepolicyinitiative.org/publication/financing-steel-decarbonization.
60 Lukas Hermwille et al., "A Climate Club to Decarbonize the Global Steel Industry", *Nature Climate Change* 12, no. 6 (June 2022): 494-96, https://doi.org/10.1038/s41558-022-01383-9.
61 Clean Industry Solutions, "Industrial Solar Signs Contract to Build Fresnel Collector for Unilever", 6 July 2023, https://news.cision.com/clean-industry-solutions-holding-europe/r/industrial-solar-signs-contract-to-build-fresnel-collector-for-unilever,c3766652.
62 Stefano De Marzo, "British Cleantech Sonichem Secures €1.4 Million to Convert Sawdust into High-Value Bio-Based Chemicals", EU-Startups, 29 February 2024, https://www.eu-startups.com/2024/02/british-cleantech-sonichem-secures-e1-4-million-to-convert-sawdust-into-high-value-bio-based-chemicals/.
63 Alex Pacanowsky, "Types of Industrial Process Heating and Applications", Powerblanket, 22 February 2022, https://www.powerblanket.com/blog/types-of-industrial-process-heating-and-applications; World Economic Forum, "Heat Is the Greatest Challenge in Tackling Climate Change", 16 March 2023, https://www.weforum.org/agenda/2023/03/heat-heres-why-its-the-elephant-in-the-room-for-decarbonization.

64 TrustEE, "Process Heating", 2020, https://www.trust-ee.eu/discovery/process-heating. **Figure 8** from International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

65 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

66 S. Madeddu et al., "The CO2 Reduction Potential for the European Industry via Direct Electrification of Heat Supply (Power-to-Heat)", *Environmental Research Letters* 15, no. 12 (November 2020): 124004, https://doi.org/10.1088/1748-9326/abbd02; International Renewable Energy Agency, "Green Hydrogen for Industry: A Guide to Policy Making", 2022, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Mar/IRENA_Green_Hydrogen_Industry_2022_.pdf; International Energy Agency, "Biomass for Industrial Heat", Energy Post, 10 March 2022, https://energypost.eu/biomass-for-industrial-heat; Jaap Koppejan, "Bioenergy for High Temperature Heat in Industry", IEA Bioenergy, 2020, https://www.ieabioenergy.com/blog/task/bioenergy-for-high-temperature-heat-in-industry.

67 Systemiq, "Catalysing the Global Opportunity for Electrothermal Energy Storage", 2024, https://www.systemiq.earth/wp-content/uploads/2024/03/Global-ETES-Opportunity-Report-240227.pdf.

68 Jordan Cox et al., "High-Temperature Heat Pump Model Documentation and Case Studies", National Renewable Energy Laboratory, 1 August 2023, https://doi.org/10.2172/1995807.

69 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

70 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

71 International Renewable Energy Agency, 'Solar Heat for Industrial Processes', *International Renewable Energy Agency*, January 2015, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_ETSAP_Tech_Brief_E21_Solar_Heat_Industrial_2015.pdf.

72 Bärbel Epp, "Structural Changes in Solar Industrial Heat Supply Industry", Solar Thermal World, 6 July 2022, https://solarthermalworld.org/news/structural-changes-in-solar-industrial-heat-supply-industry.

73 Siôn Geschwind, "Europe's Largest Solar Thermal Energy Plant Opens in Belgium", The Next Web, 19 September 2023, https://thenextweb.com/news/europes-largest-solar-thermal-energy-plant; Avery Dennison, "Avery Dennison Commissions Europe's Largest Concentrated Solar Thermal Platform and Thermal Storage Unit in Turnhout, Belgium", 6 September 2023, https://www.averydennison.com/en/home/news/press-releases/avery-dennison-commissions-europes-largest-concentrated-solar-thermal-platform-and-thermal-storage-unit-in-turnhout-belgium.html.

74 Solar Payback, "Turnkey SHIP Supplier World Map", cited in Bärbel Epp, "The Netherlands and Spain Drive SHIP Market 2023", Solar Thermal World, 28 March, 2024, https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023.

75 Solar Payback, "Turnkey SHIP Supplier World Map", cited in Bärbel Epp, "The Netherlands and Spain Drive SHIP Market 2023", Solar Thermal World, 28 March, 2024, https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023.

76 Bärbel Epp, "Promising Solar Industrial Heat Outlook 2023-2026", Solar Thermal World, 27 September 2023, https://solarthermalworld.org/news/promising-solar-industrial-heat-outlook-2023-2026.

77 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

78 BloombergNEF and World Business Council on Sustainable Development, "Hot Spots for Renewable Heat. Decarbonizing Low- to Medium-Temperature Industrial Heat Across the G-20", 13 September 2021, https://www.wbcsd.org/contentwbc/download/12957/190622/1.

79 International Energy Agency, "Electricity 2024", 2024, https://www.iea.org/reports/electricity-2024.

80 World Business Council for Sustainable Development, 'Industrial Heat Pumps: It's Time to Go Electric', 21 September 2022, https://www.wbcsd.org/wgthg; European Commission, 'Heat Pumps', accessed 16 May 2024, https://energy.ec.europa.eu/topics/energy-efficiency/heat-pumps_en.

81 MAN Energy Solutions, "Industrial Heat Pumps and EMS", accessed March 2024, https://www.man-es.com/process-industry/campaigns/industrial-heat-pumps-and-ems.

82 Jörg Freckmann, "Heat Pumps: Decarbonizing the Process Industries", Chemical Engineering, 1 February 2024, https://www.chemengonline.com/heat-pumps-decarbonizing-the-process-industries.

83 Moutaz Altaghlibi et al., 'Financing Green Hydrogen', ABN AMRO Bank, 18 September 2023, https://www.abnamro.com/research/en/our-research/sustainaweekly-financing-green-hydrogen; Deloitte, 'Actualizing the Green Hydrogen Economy', 2023, https://www2.deloitte.com/content/dam/Deloitte/de/Documents/sustainability/Deloitte_Actualizing-green-hydrogen-economy.pdf; International Renewable Energy Agency, 'Carbon Contracts for Difference', accessed 16 May 2024, https://www.irena.org/Innovation-landscape-for-smart-electrification/Power-to-hydrogen/16-Carbon-contracts-for-difference.

84 Léonor Tissot-Pontabry, "'DKarbonation': Dunkerque lance un projet pour une industrie bas carbone", Initiatives, 9 February 2024, https://initiatives.media/dkarbonation-dunkerque-lance-un-projet-pour-une-industrie-bas-carbone.

85 World Economic Forum, "How Are Tech and Other Innovations Driving a Net-Zero China?" 17 June 2023. https://www.weforum.org/agenda/2023/06/carbon-neutral-technological-and-management-innovations-chinese-industry.

86 World Economic Forum, "How Are Tech and Other Innovations Driving a Net-Zero China?" 17 June 2023. https://www.weforum.org/agenda/2023/06/carbon-neutral-technological-and-management-innovations-chinese-industry.

87 Vienna Energy Forum, "Summary of the Vienna Energy Forum 2021: 5-7 July," 2021, https://www.viennaenergyforum.org/wp-content/uploads/2021/08/Report.pdf.

88 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

89 **Figure 9** from International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

90 Zhiyuan Fan and S. Julio Friedmann, 'Low-Carbon Production of Iron and Steel: Technology Options, Economic Assessment, and Policy', *Joule* 5, no. 4 (21 April 2021): 829–62, https://doi.org/10.1016/j.joule.2021.02.018; Andrew J. Pimm, Tim T. Cockerill, and William F. Gale, 'Energy System Requirements of Fossil-Free Steelmaking Using Hydrogen Direct Reduction', *Journal of Cleaner Production* 312 (20 August 2021): 127665, https://doi.org/10.1016/j.jclepro.2021.127665.

91 Kathiann Kowalski, "How an Ohio-Based Steel Company Cut Greenhouse Gas Emissions by Nearly a Third", Energy News Network, 10 November 2023, http://energynews.us/2023/11/10/how-an-ohio-based-steel-company-cut-greenhouse-gas-emissions-by-nearly-a-third.

92 International Iron Metallics Association, "DRI Production", 3 November 2021, https://www.metallics.org/dri-production.html.

93 Caitlin Swalec and Astrid Grigsby-Schulte, "Pedal to the Metal", 2023, https://globalenergymonitor.org/report/pedal-to-the-metal-2023-time-to-shift-steel-decarbonization-into-high-gear/.

94 "Europe Can Still Avoid the Coming 'Green Steel' Crunch", *Financial Times*, 29 January 2024, https://www.ft.com/content/ffaae533-b555-4a40-8b77-d0dda278b874.

95 Robin Whitlock, "Vestas Introduces Low-Emission Steel for Wind Turbines", Renewable Energy Magazine, 16 January 2024, https://www.renewableenergymagazine.com/wind/vestas-introduces-lowemission-steel-for-wind-turbines-20240116.

96 Kathiann Kowalski, "How an Ohio-Based Steel Company Cut Greenhouse Gas Emissions by Nearly a Third", Energy News Network, 10 November 2023, http://energynews.us/2023/11/10/how-an-ohio-based-steel-company-cut-greenhouse-gas-emissions-by-nearly-a-third.

97 Kathiann Kowalski, "How an Ohio-Based Steel Company Cut Greenhouse Gas Emissions by Nearly a Third", Energy News Network, 10 November 2023, http://energynews.us/2023/11/10/how-an-ohio-based-steel-company-cut-greenhouse-gas-emissions-by-nearly-a-third.

98 Alex Donaldson, "Tata Steel Announces Blast Furnace Hydrogen Injection Trial", Power Technology, 24 April 2023, https://www.power-technology.com/?p=234804.

99 Leadership Group for Industry Transition, "Green Steel Tracker", https://www.industrytransition.org/green-steel-tracker.

100 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

101 Gabriel Lopez et al., "From Fossil to Green Chemicals: Sustainable Pathways and New Carbon Feedstocks for the Global Chemical Industry", *Energy & Environmental Science* 7 (2023), https://doi.org/10.1039/D3EE00478C.

102 En:former, "Why the Chemical Sector Needs So Much Hydrogen", 15 August 2023, https://www.en-former.com/en/why-the-chemical-sector-needs-so-much-hydrogen.

103 Sustainable Plastics, "Ineos Goes Solar to Reduce Carbon Footprint of PVC Production", 20 February 2024, https://www.sustainableplastics.com/news/ineos-goes-solar-reduce-carbon-footprint-pvc-production; EnergyTech, "INEOS Inovyn and Partners Installing 90,000 PV Panels for Belgium Solar Farm", 21 February 2024, https://www.energytech.com/renewables/article/21283158/ineos-inovyn-and-partners-installing-90000-pv-panels-for-belgium-solar-farm.

104 CBN, "BASF and MAN Energy Solutions Plan Industrial-Scale Heat Pump", Cape Business News, 24 October 2023, https://www.cbn.co.za/industry-news/boilers-burners/basf-and-man-energy-solutions-plan-industrial-scale-heat-pump.

105 Kelly Travers, "To Decarbonize the Chemical Industry, Electrify It", MIT Energy Initiative, 25 January 2023, https://energy.mit.edu/news/to-decarbonize-the-chemical-industry-electrify-it; Methanol Institute, "Renewable Methanol", accessed February 2024, https://www.methanol.org/renewable.

106 LEGO, "European Energy Partners with Novo Nordisk & the LEGO Group", 20 April 2023, https://www.lego.com/en-us/aboutus/news/2023/april/european-energy-partners-with-novo-nordisk-and-the-lego-group.

107 Agora Industry, "Green Chemicals", accessed 27 March 2024, https://www.agora-industry.org/topics/green-chemistry.

108 Braskem, "Braskem and SCG Chemicals Join Forces to Advance in the Bio-based Ethylene Project in Thailand", 17 August 2023, https://www.braskem.com.br/imgreen/details-news/braskem-and-scg-chemicals-join-forces-to-advance-in-the-bio-based-ethylene-project-in-thailand.

109 Dow, "Dow and New Energy Blue Announce Collaboration to Develop Renewable Plastic Materials from Corn Residue", 25 May 2023, https://corporate.dow.com/en-us/news/press-releases/dow-and-new-energy-blue-announce-collaboration-to-develop-renewa.html.

110 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

111 International Energy Agency, "Industry", 2023, https://www.iea.org/energy-system/industry.

112 International Energy Agency, "Cement", accessed 27 March 2024, https://www.iea.org/energy-system/industry/cement.

113 Rosamund Pearce, "Q&A: Why Cement Emissions Matter for Climate Change", Carbon Brief, 13 September 2018, https://www.carbonbrief.org/qa-why-cement-emissions-matter-for-climate-change.

114 International Energy Agency, "Cement", accessed 27 March 2024, https://www.iea.org/energy-system/industry/cement; Statista, "Production Volume of Cement Worldwide from 1995 to 2023", 9 February 2024, https://www.statista.com/statistics/1087115/global-cement-production-volume.

115 Grupo Argos, 'Grupo Empresarial Argos Inaugurated the Second Largest Solar Farm in the Cement Industry in Honduras, Further Solidifying Its Leadership in Central America in the Implementation of Sustainable Projects.', 20 September 2023, https://www.grupoargos.com/en/news/grupo-empresarial-argos-inaugurated-the-second-largest-solar-farm-in-the-cement-industry-in-honduras-further-solidifying-its-leadership-in-central-america-in-the-implementation-of-sustainable-project/.

116 Capital Business, "Bamburi Cement Commences Construction of Two Solar PV Plants", 30 November 2023. https://www.capitalfm.co.ke/business/2023/11/bamburi-cement-commences-construction-of-two-solar-pv-plants; Michael Schoeck, "Cement Manufacturer to Generate 75% of Onsite Power with 25 MW Solar Array", pv magazine USA, 15 June 2023, https://pv-magazine-usa.com/2023/06/15/cement-manufacturer-to-generate-75-of-onsite-power-with-25-mw-solar-array.

117 Susan Kraemer, "Synhelion and CEMEX Make Further Progress Toward the World's First Fully Solar-Powered Cement Plant", SolarPACES, 4 August 2023, https://www.solarpaces.org/synhelion-and-cemex-make-further-progress-toward-the-worlds-first-fully-solar-powered-cement-plant.

118 D. Cheng et al., "Projecting Future Carbon Emissions from Cement Production in Developing Countries", *Nature Communications* 14, 8213 (2023), https://doi.org/10.1038/s41467-023-43660-x.

119 Engie, "Filinvest and Engie Secure Over 13 MW of Solar and 11.4k RT of Sustainable Cooling Projects in the Philippines", 14 December 2023, https://www.engie-sea.com/news-inner/Filinvest%20and%20ENGIE%202023%20Wins.

120 Specify Concrete, "Kiln Electrification Takes a Step Forward", 23 February 2023, https://www.specifyconcrete.org/blog/kiln-electrification-takes-a-step-forward.

121 Julian Spector, "Industrial Heat Startup Rondo to Open World's Largest Battery Factory", Canary Media, 27 June 2023, https://www.canarymedia.com/articles/energy-storage/industrial-heat-startup-rondo-to-open-worlds-largest-battery-factory.

122 Bärbel Epp, "Worldwide Overview of High-Temperature Energy Storage System Providers", Solar Thermal World, 5 March 2024, https://solarthermalworld.org/news/worldwide-overview-of-high-temperature-energy-storage-system-providers. The United States leads with 10 high-temperature storage providers, thanks to US Department of Energy funding and success at raising venture capital; Germany has 5 firms and leads in Europe, which has a total of at least 17) firms, from idem.

123 Dylan D. Del Rio et al., "Decarbonizing the Glass Industry: A Critical and Systematic Review of Developments, Sociotechnical Systems and Policy Options", *Renewable and Sustainable Energy Reviews* 155 (2022): 111885, https://doi.org/10.1016/j.rser.2021.111885.

124 Glass for Europe, "Continuous Energy Supply Is Essential for the Flat Glass Industry", March 2022, https://glassforeurope.com/continuous-energy-supply-is-essential-for-the-flat-glass-industry.

125 Leigh Collins, "Blow for Green Glass: Hydrogen Reduces Product Quality When Replacing Natural Gas, Pilot Finds", Recharge, 10 May 2022, https://www.rechargenews.com/energy-transition/blow-for-green-glass-hydrogen-reduces-product-quality-when-replacing-natural-gas-pilot-finds/2-1-1216468.

126 "Saint-Gobain First to Produce Flat Glass Using Hydrogen", GW News, 30 March 2023, https://www.gw-news.eu/manufacturing/sustainable-production-saint-gobain-first-produce-flat-glass-using-hydrogen.

127 Packaging Europe, "Plug's 5MW Electrolysers to Facilitate 'First Ever' Use of Green Hydrogen in Aluminium Recycling and Manufacture of Glass and Steel", 24 May 2023, https://packagingeurope.com/news/plugs-5mw-electrolysers-to-facilitate-first-ever-use-of-green-hydrogen-in-aluminium-recycling-and-manufacture-of-glass-and-steel/9846.article.

128 Leigh Collins, "Blow for Green Glass: Hydrogen Reduces Product Quality When Replacing Natural Gas, Pilot Finds", Recharge, 10 May 2022, https://www.rechargenews.com/energy-transition/blow-for-green-glass-hydrogen-reduces-product-quality-when-replacing-natural-gas-pilot-finds/2-1-1216468.

129 International Energy Agency, "Light Industry", 2023, https://www.iea.org/energy-system/industry/light-industry.

130 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

131 **Figure 10** from International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

132 International Energy Agency, "Industry", 2023, https://www.iea.org/energy-system/industry.

133 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

134 Spectra, "The Large Heat Pumps Transforming Gas-Intensive Industries Like Pulp and Paper", 3 August 2023, https://spectra.mhi.com/the-large-heat-pumps-transforming-gas-intensive-industries-like-pulp-and-paper; Sarah Azau, "Saving 50% Energy in Paper Industry Through Heat Pumps", European Heat Pump Association, 6 February 2023, https://www.ehpa.org/news-and-resources/news/saving-50-energy-in-paper-industry-through-heat-pumps.

135 Spectra, "The Large Heat Pumps Transforming Gas-Intensive Industries Like Pulp and Paper", 3 August 2023, https://spectra.mhi.com/the-large-heat-pumps-transforming-gas-intensive-industries-like-pulp-and-paper.

136 ACCIONA Energía, "ACCIONA Energía Signs PPA with Sofidel for the Supply of 100% Renewable Energy to Its Plant in Buñuel", 20 February 2023. https://www.acciona.com/updates/news/acciona-energia-signs-ppa-sofidel-supply-100-renewable-energy-plant-bunuel.

137 Pamela Largue, "Doosan Škoda Power Commissions Steam Turbine at Paper Mill", Power Engineering International, 12 February 2024. https://www.powerengineeringint.com/renewables/finnish-paper-mill-commissions-steam-turbine-to-reduce-footprint.

138 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

139 Italian Food Tech, "Heat Generation, a Key Factor for the Food Industry", 15 October 2020, https://www.italianfoodtech.

com/heat-generation-a-key-factor-for-the-food-industry; Robert Walton, "Heat Pumps Can Decarbonize Food and Beverage Processing, But Report Warns of Bottlenecks", Utility Dive, 16 August 2023, https://www.utilitydive.com/news/heat-pumps-decarbonize-food-beverage-processing-requires-wwf-report/690995.

140 Bioenergy Insight, "German Sugar Manufacturer Pfeifer & Langen Converts to Biomass Boilers", 26 September 2023, https://www.bioenergy-news.com/news/german-sugar-manufacturer-pfeifer-langen-converts-to-biomass-boilers.

141 Robert Walton, "Heat Pumps Can Decarbonize Food and Beverage Processing, But Report Warns of Bottlenecks", Utility Dive, 16 August 2023, https://www.utilitydive.com/news/heat-pumps-decarbonize-food-beverage-processing-requires-wwf-report/690995.

142 Emiliano Bellini, "Industrial Renewable Heating System Based on 780 kW Heat Pump", pv magazine International, 27 July 2023, https://www.pv-magazine.com/2023/07/27/industrial-renewable-heating-system-based-on-780-kw-heat-pump.

143 Dino Grandoni, "The World's Biggest Chocolate Bar Factory Has a Sweet Secret: Heat Pumps", *Washington Post*, 12 June 2023, https://www.washingtonpost.com/climate-solutions/2023/06/12/heat-pumps-industrial-factory.

144 "Company in BiH Installs the Biggest Solar Power Plant with the Help of EU", *Sarajevo Times*, 7 May 2022, https://sarajevotimes.com/company-in-bih-installs-the-biggest-solar-power-plant-with-the-help-of-eu.

ENDNOTES | BUILDINGS

1 United Nations Environment Programme, "2023 Global Status Report for Buildings and Construction: Beyond Foundations – Mainstreaming Sustainable Solutions to Cut Emissions from the Buildings Sector", March 2024, https://doi.org/10.59117/20.500.11822/45095.
2 **Figure 11** from International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
3 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
4 **Figure 12** from International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
5 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
6 International Energy Agency, "Renewables 2023: Analysis and Forecast to 2028", 2023, https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.
7 International Energy Agency, "Space Cooling", accessed 6 May 2024, https://www.iea.org/energy-system/buildings/space-cooling.
8 **Box 1** from the following sources: three to five times from International Energy Agency (IEA), "The Future of Heat Pumps", 2022, https://doi.org/10.1787/2bd71107-en; new policies from Renewable Energy Policy Network for the 21st Century (REN21), "REN 21 Database", 2023; Estonia from IEA, "EUR 80 Million for Apartment Buildings Retrofits – Policies", 9 May 2023, https://www.iea.org/policies/17146-eur-80-million-for-apartment-buildings-retrofits; Ireland from IEA, "Support Scheme for Renewable Heat – Expanded Grants – Policies", 11 May 2023, https://www.iea.org/policies/17361-support-scheme-for-renewable-heat-expanded-grants; Poland from IEA, "2023 Clean Air Programme Extension – Policies", 20 April 2024, https://www.iea.org/policies/17230-2023-clean-air-programme-extension; Emiliano Bellini, "Slovakia Offers $156.1 Million for 2023 Residential PV, Heat Pump Rebates", pv magazine International, 13 July 2023, https://www.pv-magazine.com/2023/07/13/slovakia-offers-156-1-million-for-2023-residential-pv-heat-pump-rebates. **Figure 13** from IEA, "Heating – Analysis," 2022, https://www.iea.org/reports/heating.
9 International Energy Agency, "Space Cooling", accessed 6 May 2024, https://www.iea.org/energy-system/buildings/space-cooling.
10 International Energy Agency, "Space Cooling", accessed 6 May 2024, https://www.iea.org/energy-system/buildings/space-cooling.
11 International Energy Agency, "Space Cooling", accessed 6 May 2024, https://www.iea.org/energy-system/buildings/space-cooling.
12 International Energy Agency, "The Energy Efficiency Policy Package: Key Catalyst for Building Decarbonisation and Climate Action – Analysis", 6 September 2023, https://www.iea.org/commentaries/the-energy-efficiency-policy-package-key-catalyst-for-building-decarbonisation-and-climate-action.
13 **Box 2** from UN Environment "The Buildings Breakthrough: Global Push for near-Zero Emission and Resilient Buildings by 2030 Unveiled at COP28", 12 June 2023. http://www.unep.org/news-and-stories/press-release/buildings-breakthrough-global-push-near-zero-emission-and-resilient.
14 Renewable Energy Policy Network for the 21st Century (REN21), "REN 21 Database", 2023.
15 European Council, "Renewable Energy: Council Adopts New Rules", 9 October 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules.
16 Government of Portugal, "Updated National Energy and Climate Plan – Portugal", 2023, https://commission.europa.eu/system/files/2023-07/EN_PORTUGAL%20DRAFT%20UPDATED%20NECP.pdf.
17 European Commission, "Slovenia – Draft Updated NECP 2021-2030", 13 July 2023, https://commission.europa.eu/publications/slovenia-draft-updated-necp-2021-2030_en; European Commission, "Latvia – Draft Updated NECP 2021-2030", 15 December 2023, https://commission.europa.eu/publications/latvia-draft-updated-necp-2021-2030_en.
18 Energy Foundation China, "China's 14th Five-Year Plans on Renewable Energy Development and Modern Energy System", 5 September 2022, https://www.efchina.org/Blog-en/blog-20220905-en.
19 Heinrich Böll Stiftung, "China's Climate Transition: Outlook 2023", 2023, https://www.boell.de/de/2023/11/27/chinas-climate-transition-outlook-2023.
20 European Council, "Renewable Energy: Council Adopts New Rules", 9 October 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules.
21 Renewable Energy Policy Network for the 21st Century (REN21), "REN 21 Database", 2023.
22 Government of Denmark, "National Energy and Climate Plan – Denmark", 2023, https://commission.europa.eu/system/files/2023-07/EN_DENMARK%20DRAFT%20UPDATED%20NECP.pdf; Government of Croatia, "Updated Energy and Climate Plan – Croatia", 2023, https://commission.europa.eu/system/files/2023-07/CROATIA_%20DRAFT%20UPDATED%20NECP%202021%202030%20%282%29_0.pdf.
23 Susana Paardekooper et al., "Heat Roadmap Europe Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps", 2018, https://vbn.aau.dk/ws/portalfiles/portal/288075507/Heat_Roadmap_Europe_4_Quantifying_the_Impact_of_Low_Carbon_Heating_and_Cooling_Roadmaps..pdf.
24 Susana Paardekooper et al., "Heat Roadmap Europe Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps", 2018, https://vbn.aau.dk/ws/portalfiles/portal/288075507/Heat_Roadmap_Europe_4_Quantifying_the_Impact_of_Low_Carbon_Heating_and_Cooling_Roadmaps..pdf.
25 Heat Roadmap Europe, "Heat Roadmaps", accessed 30 April 2024, https://heatroadmap.eu/roadmaps.
26 **Figure 14** from Renewable Energy Policy Network for the 21st Century (REN21), "REN 21 Database", 2023.
27 Renewable Energy Policy Network for the 21st Century (REN21), "REN 21 Database", 2023.
28 Japanese Housing Finance Agency, "JHF Activities – Flat 35 Home Loan", 2023, https://www.jhf.go.jp/files/400348582.pdf.
29 International Renewable Energy Agency, "Renewable Energy in District Heating and Cooling, A Sector Roadmap for REmap", 2017, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_DHC_Report_2017.pdf?rev=4a5c685d39ee42fc905257adeed461d5.
30 GOV.UK, "Energy Security Bill Factsheet: Heat Networks Regulation and Zoning (Updated 20 March 2023)", 2023, https://www.gov.uk/government/publications/energy-security-bill-factsheets/energy-security-bill-factsheet-heat-networks-regulation-and-zoning.
31 Neil Merrett, "First Funding Awarded via the Green Heat Network Fund", Heating and Ventilation News, 11 January 2023, https://www.hvnplus.co.uk/news/first-funding-awarded-via-the-green-heat-network-fund-11-01-2023.
32 Energistyrelsen, "Tilskudsordningen til etablering af eldrevne varmepumper og solvarmeanlæg til produktion af fjernvarme åbner for ansøgninger den 1. juni 2023", 17 May 2023, https://ens.dk/presse/tilskudsordningen-til-etablering-af-eldrevne-varmepumper-og-solvarmeanlaeg-til-produktion-af; Government of Denmark, "National Energy and Climate Plan – Denmark", 2023, https://commission.europa.eu/system/files/2023-07/EN_DENMARK%20DRAFT%20UPDATED%20NECP.pdf.
33 European Commission, "State Aid: Commission Approves €1.2 Billion Czech Scheme", 16 December 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7680.
34 International Energy Agency, "The Future of Cooling in Southeast Asia", 2019, https://iea.blob.core.windows.net/assets/dcadf8ee-c43d-400e-9112-533516662e3e/The_Future_of_Cooling_in_Southeast_Asia.pdf.
35 Arjun Flora and Gerard Wynn, "New Incentives Brighten Turkey's Rooftop Solar Sector", Institute for Energy Economics & Financial Analysis, 1 December 2019, https://ieefa.org/resources/new-incentives-brighten-turkeys-rooftop-solar-sector.
36 International Energy Agency, "Photovoltaics on the Roof Programme – Policies", 11 May 2023, https://www.iea.org/policies/17357-photovoltaics-on-the-roof-programme.
37 Tom inverter, "Bulgaria Launches Household Solar Rebate Scheme", PV magazine International, 11 May 2023, https://www.pv-magazine.com/2023/05/11/bulgaria-launches-household-solar-rebate-scheme.
38 "PM Modi Launches New Rooftop Solar Power Scheme: What It Is, Why It Is Needed", The Indian Express, 22 January 2024, https://indianexpress.com/article/explained/modi-launches-new-rooftop-solar-scheme-pradhan-mantri-suryodaya-yojana-9122514.
39 Elizabeth Mbithe, "Kenya Gazettes Regulations for Solar Water Heating Industry", Pumps Africa, 16 January 2023, https://pumps-africa.com/solar-water-heating-industry.
40 Global Alliance for Buildings and Construction, "2023 Global Status Report for Buildings and Construction", United Nations Environment Programme, Nairobi, https://wedocs.unep.org/bitstream/handle/20.500.11822/45095/global_status_report_buildings_construction_2023.pdf.

41 Funke Fakunle et al., "Major Barriers to the Enforcement and Violation of Building Codes and Regulations: A Global Perspective", *SPC Journal of Environmental Studies*, 2 (1 March 2020): 12-18, https://www.sciencepubco.com/index.php/JES/article/view/30371/16248.

42 International Energy Agency, "All Countries Targeted for Zero-Carbon-Ready Codes for New Buildings by 2030", 2022, https://www.iea.org/reports/all-countries-targeted-for-zero-carbon-ready-codes-for-new-buildings-by-2030-2.

43 Global Alliance for Buildings and Construction, "2023 Global Status Report for Buildings and Construction", United Nations Environment Programme, Nairobi, https://wedocs.unep.org/bitstream/handle/20.500.11822/45095/global_status_report_buildings_construction_2023.pdf

44 Pooja Chandak, "Turkey Introduces New Energy Efficiency Regulations For Buildings", SolarQuarter, 4 January 2023, https://solarquarter.com/2023/01/04/turkey-introduces-new-energy-efficiency-regulations-for-buildings.

45 US Department of Energy, "Biden-Harris Admin Announces $530 Million for Building Energy Efficiency & Resilience to Cut Consumer Costs", CleanTechnica, 20 December 2023, https://cleantechnica.com/2023/12/19/biden-harris-admin-announces-530-million-for-building-energy-efficiency-resilience-to-cut-consumer-costs.

46 Nordic Sustainable Construction, "Buildings' Life Cycle Assessments Gain Ground in the Nordics", 2 January 2023, https://nordicsustainableconstruction.com/news/2023/january/denmark-introduces-co2-limit-for-new-constructions.

47 European Commission, "Nearly Zero-energy Buildings", accessed April 2024, https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en.

48 European Commission, "Nearly Zero-energy Buildings", accessed April 2024, https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en.

49 Kevin Lockhart, "Making a Net-Zero Emissions Building Code by 2024 a Reality", Efficiency Canada, 31 January 2022, https://www.efficiencycanada.org/net-zero-emissions-building-code-by-2024.

50 Jennifer Henderson, "New Building Codes Coming to Nova Scotia, but Still Concerns about Meeting Energy Efficiency Standard", *Halifax Examiner*, 25 September 2023, http://www.halifaxexaminer.ca/economy/energy/new-building-codes-coming-to-nova-scotia-but-still-concerns-about-meeting-energy-efficiency-standard; City of Victoria, "Low Carbon New Buildings", accessed 6 February 2024, https://www.victoria.ca/community-culture/climate-action/climate-friendly-homes/low-carbon-new-buildings.

51 Canada Green Building Council, accessed April 2024, https://www.cagbc.org.

52 Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2012 Global Status Report", 2012, https://www.ren21.net/Portals/0/documents/activities/gsr/GSR2012.pdf.

53 Government of Ireland, "Major Package of Supports to Protect Families, Households, and Businesses in Budget 2023", 27 September 2022, https://www.gov.ie/en/press-release/19ec4-department-of-the-environment-climate-and-communications-drives-major-package-of-supports-to-protect-families-households-and-businesses-including-600-electricity-credit-to-immediately-help-with-energy-bills-this-winter.

54 International Energy Agency, "Green Fund for the Local Acceleration in Ecological Transitions – Policies", 11 May 2023, https://www.iea.org/policies/16430-green-fund-for-the-local-acceleration-in-ecological-transitions.

55 International Energy Agency, "BAM 12.6 Million for Energy Efficiency – Policies", 11 May 2023, https://www.iea.org/policies/17455-bam-126-million-for-energy-efficiency; International Energy Agency, "EUR 40 Million for Energy Efficiency Renovations of Public Buildings – Policies", 20 April 2023, https://www.iea.org/policies/17392-eur-40-million-for-energy-efficiency-renovations-of-public-buildings.

56 European Commission, "Energy Performance of Buildings Directive", accessed April 2024, https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en.

57 International Energy Agency, "Appliances and Equipment", accessed April 2024, https://www.iea.org/energy-system/buildings/appliances-and-equipment.

58 International Energy Agency, "Energy Efficiency 2023", 2023, https://iea.blob.core.windows.net/assets/dfd9134f-12eb-4045-9789-9d6ab8d9fbf4/EnergyEfficiency2023.pdf.

59 International Energy Agency, "Updated MEPS – Central Air Conditioners and Heat Pumps – Policies", 13 October 2020, https://www.iea.org/policies/11456-updated-meps-central-air-conditioners-and-heat-pumps; US Department of Energy, "DOE Finalizes Efficiency Rules for Room Air Conditioners and Portable Air Cleaners", 23 March 2023, https://www.energy.gov/articles/doe-finalizes-efficiency-rules-room-air-conditioners-and-portable-air-cleaners.

60 Renewable Energy Policy Network for the 21st Century (REN21), "REN 21 Database", 2023.

61 Bundesregierung, "New Heating Systems: Using Renewable Energy Sources as of 2024", 19 April 2023, https://www.bundesregierung.de/breg-en/issues/new-building-energy-act-2185010; Sarah Azau, "German Heating Law: Watered Down but End Goal Unchanged", European Heat Pump Association, 12 September 2023, https://www.ehpa.org/news-and-resources/news/german-heating-law-watered-down-but-end-goal-unchanged.

62 International Energy Agency, "Heat Strategy 2050 – Policies", 16 May 2023, https://www.iea.org/policies/17483-heat-strategy-2050.

63 European Council for an Energy Efficient Economy, "Austria to Ban Gas Boilers in New Buildings as of 2023", 14 June 2022, https://www.eceee.org/all-news/news/austria-to-ban-gas-boilers-in-new-buildings-as-of-2023.

64 Nicolas Rauline, "Interdiction des chaudières à gaz: le gouvernement fait marche arrière", Les Echos, 27 July 2023, https://www.lesechos.fr/industrie-services/energie-environnement/interdiction-des-chaudieres-a-gaz-le-gouvernement-fait-marche-arriere-1966165.

65 Rachel Ramirez Nilsen Ella, "New York Becomes the First State to Ban Natural Gas Stoves and Furnaces in Most New Buildings", CNN, 3 May 2023, https://www.cnn.com/2023/05/03/us/new-york-natural-gas-ban-climate/index.html.

66 Werner Weiss and Monika Spörk-Dür, "Solar Heat Worldwide Edition 2023", International Energy Agency Solar Heating and Cooling Programme, 2023, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2023.pdf.

67 Werner Weiss and Monika Spörk-Dür, "Solar Heat Worldwide Edition 2023", International Energy Agency Solar Heating and Cooling Programme, 2023, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2023.pdf.

68 International Energy Agency, "World Energy Investment 2023", 2023, https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf.

69 International Energy Agency, "Energy Efficiency 2023", 2023, https://iea.blob.core.windows.net/assets/dfd9134f-12eb-4045-9789-9d6ab8d9fbf4/EnergyEfficiency2023.pdf.

70 International Energy Agency, "World Energy Investment 2023", 2023, https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf.

71 International Energy Agency, "World Energy Investment 2023", 2023, https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf.

72 International Energy Agency, "World Energy Investment 2023", 2023, https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf.

73 International Energy Agency, "World Energy Investment 2023", 2023, https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf.

74 Jessica Casey, "The Land of Ice and Fire: Iceland's Renewable Scene", Energy Global, 13 December 2023, https://www.energyglobal.com/special-reports/13122023/the-land-of-ice-and-fire-icelands-renewable-scene; Orkustofnun, "Heat", accessed April 2024, https://orkustofnun.is/en/information/numerical_data/heat; International Energy Agency, "World Energy Balances 2020: Extended Energy Balances", August 2022, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

75 International Energy Agency, "World Energy Balances 2020: Extended Energy Balances", August 2022, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

76 European Commission, "Bioenergy Report Outlines Progress Being Made Across the EU", 27 October 2023, https://energy.ec.europa.eu/news/bioenergy-report-outlines-progress-being-made-across-eu-2023-10-27_en.

77 Umweltbundesamt, "Renewable Energies in Figures", 11 June 2013, https://www.umweltbundesamt.de/en/topics/climate-energy/renewable-energies/renewable-energies-in-figures.

78 Ministry of Energy Transition, "Objectif 2030 et Situation Actuelle de La France | Chiffres Clés Des Énergies Renouvelables 2023", 2023, https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-energies-renouvelables-2023/4-objectif-2030-et-situation-actuelle.

79 International Energy Agency, "The Future of Heat Pumps", 2022, https://doi.org/10.1787/2bd71107-en.

80 International Renewable Energy Agency, "The Renewable Energy Transition in Africa: Country Studies for Côte d'Ivoire, Ghana, South Africa, Morocco and Rwanda", 2021, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/March/Renewable-Energy-Transition-Africa_Country_Studies_2021.pdf; African Development Bank, "$1 Million: Sustainable Energy Fund for Africa Grant to Drive Electric Mobility Shift in Seven African Countries", 31 January 2023, https://www.afdb.org/en/news-and-events/press-releases/1-million-sustainable-energy-fund-africa-grant-drive-electric-mobility-shift-seven-african-countries-58650.

81 Lizzie Stricklin, "New Study Shows Clean Energy Transition Thrives in 2023, Boosted by Federal Policies", The Business of Sustainable Energy, 21 February 2024, https://bcse.org/new-study-shows-clean-energy-transition-thrives-2023-boosted-federal-policies; Solar Energy Industries Association, "Solar Market Insight Report 2023 Year in Review", 2023, https://www.seia.org/research-resources/solar-market-insight-report-2023-year-review; Connor O'Neil, "Renewables Rescue Stability as the Grid Loses Spin", National Renewable Energy Laboratory, 15 September 2020, https://www.nrel.gov/news/features/2020/renewables-rescue-stability-as-the-grid-loses-spin.html.

82 Anh Nguyet Phamneha Mukhi, "The Caribbean's Clean-Energy Potential: From Fuel Trap to Resilient Hub", World Bank, 19 December 2023, https://blogs.worldbank.org/en/latinamerica/caribbean-clean-energy-resilient-hub.

83 Kate Hassen, "Changes to Energy Efficiency Ratings", Construction, Energy Efficiency, Procurement & Project Management Courses Online", 14 February 2023, https://www.transformed.com.au/nathers/changes-to-energy-efficiency-ratings; Master Builders Association, "New National Construction Code Effective 1 May 2023", 2023, https://www.mbansw.asn.au/system/files/2023-04/05%20of%202023%20%20Apr%20New%20National%20Construction%20Code.pdf.

84 International Energy Agency, "Executive Summary – Australia 2023", 2023, https://www.iea.org/reports/australia-2023/executive-summary.

85 International Energy Agency, "Executive Summary – Australia 2023", 2023, https://www.iea.org/reports/australia-2023/executive-summary.

86 International Energy Agency, "Executive Summary – New Zealand 2023", 2023, https://www.iea.org/reports/new-zealand-2023/executive-summary.

87 International Renewable Energy Agency, "MENA's Transforming Role in an Evolving Energy Landscape", 26 October 2023, https://www.irena.org/News/expertinsights/2023/Oct/MENAs-Transforming-Role-in-an-Evolving-Energy-Landscape; Matthieu De Clercq, "Steps Towards a Net Zero GCC: A Dispatch from FII6", OliverWyman, October 2022, https://www.oliverwyman.com/our-expertise/insights/2022/oct/steps-towards-net-zero-gcc-dispatch-from-fii6.html.

88 International Energy Agency, "Renewables 2023", 2023, https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.

89 International Energy Agency, "Approximately 100 Million Households Rely on Rooftop Solar PV by 2030", 2022, https://www.iea.org/reports/approximately-100-million-households-rely-on-rooftop-solar-pv-by-2030.

90 International Energy Agency Photovoltaic Power System Programme, "Snapshot of Global PV Markets – 2023", 2023, https://iea-pvps.org/wp-content/uploads/2023/04/IEA_PVPS_Snapshot_2023.pdf. Note that there is some uncertainty in the data due to a lack of standardised reporting for alternating current and direct current.

91 Beatriz Santos, "Global Rooftop PV Additions Soar by 50% to 118 GW in 2022", pv magazine International, 13 June 2023, https://www.pv-magazine.com/2023/06/13/global-rooftop-pv-additions-soar-by-50-to-118-gw-in-2022.

92 **Snapshot: Hamburg** from the following sources: Erneuerbare Energien Hamburg, "Solarpotenzialstudie Für Hamburg. Nicht Nur Schietwetter in Hamburg!" March 2023, https://www.solarzentrum-hamburg.de/site/wp-content/uploads/2023/04/EEHH-Solarpotenzialstudie.pdf; German Federal Government, "Development of Renewable Energies", 23 December 2022, https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/amendment-of-the-renewables-act-2060448; Hamburg News, "Two-Thirds of Demand for Electricity Could Be Met by Solar Energy", 4 May 2023, https://hamburg-business.com/en/news/two-thirds-demand-electricity-could-be-met-solar-energy; Free and Hanseatic City of Hamburg, "Klimaschutzgesetz", 1 January 2024, https://www.hamburg.de/klimaschutzgesetz; Free and Hanseatic City of Hamburg, "Solar Energy", 2024, https://www.hamburg.com/energy-supply/17042818/solar-energy; Free and Hanseatic City of Hamburg, "Photovoltaik-Pflicht: Hamburg nutzt Solarenergie", 2024, https://www.hamburg.de/klimaschutzgesetz/17318142/photovoltaik-pflicht; German Federal Government, "Mehr Solarstrom, weniger Bürokratie", 26 April 2024, https://www.bundesregierung.de/breg-de/aktuelles/solarpaket-photovoltaik-balkonkraftwerke-2213726; Federal Ministry for Economic Affairs and Climate (BMWK), "Renewable Energy", 2024, https://www.bmwk.de/Redaktion/EN/Dossier/renewable-energy.html; Solarwissen Selfmade Energy, "Solar-Städteranking 2022: (Fast) alle Städte errichten mehr PV-Anlagen", accessed 10 May 2024, https://solarwissen.selfmade-energy.com/deutschland-ranking-solar-2022.

93 International Energy Agency Photovoltaic Power System Programme, "Enabling Framework for the Development of BIPV", accessed 6 May 2024, https://iea-pvps.org/research-tasks/enabling-framework-for-the-development-of-bipv; Becquerel Institute, "BIPV Status Report 2020", 2020, https://solarchitecture.ch/wp-content/uploads/2020/11/201022_BIPV_web_V01.pdf; ICLEI–Local Governments for Sustainability, "Urban Wind Power", 2020, https://renewablesroadmap.iclei.org/wp-content/uploads/2021/11/Urban-Wind-Power_final-1.pdf.

94 International Energy Agency, "Renewables 2023", 2023, https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.

95 International Energy Agency, "Renewables 2023", 2023, https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.

96 International Energy Agency, World Energy Statistics Database, 2023, www.iea.org/statistics, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

97 International Energy Agency, "Solar Thermal Technologies Deployed in Around 400 Million Dwellings by 2030", 2022, https://www.iea.org/reports/solar-thermal-technologies-deployed-in-around-400-million-dwellings-by-2030.

98 International Energy Agency Solar Heating and Cooling Programme, "Solar Heat for Cities, Towns and Energy Communities", accessed 17 November 2023, http://task68.iea-shc.org/Data/Sites/1/publications/Solar-District-Heating-Info-Package-of-IEA-SHC-Task-68.pdf.

99 International Energy Agency, "Renewables 2023", 2023, https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.

100 J.W. Lund and A.N. Toth, "Direct Utilization of Geothermal Energy 2020 Worldwide Review", *Proceedings World Geothermal Congress 2020+1 Reykjavik, Iceland, April – October 2021*, https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01018.pdf.

101 International Energy Agency, "Renewables 2023", 2023, https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.

102 International Energy Agency, "District Heating – Energy System", accessed 6 May 2024, https://www.iea.org/energy-system/buildings/district-heating.

103 International Energy Agency, "District Heating – Energy System", accessed 6 May 2024, https://www.iea.org/energy-system/buildings/district-heating.

104 Euroheat & Power, "DHC Market Outlook Insights & Trends", 2023, https://api.euroheat.org/uploads/DHC_Market_Outlook_Insights_Trends_2023_36d6fe8924.pdf; Sem Oxenaar, Richard Lowes and Jan Rosenow, "Warming Up to It: Principles for Clean, Efficient and Smart District Heating", Regulatory Assistance Project, 2 November 2023, https://www.raponline.org/knowledge-center/warming-up-to-it-principles-clean-efficient-smart-district-heating.

105 Werner Weiss and Monika Spörk-Dür, "Solar Heat Worldwide Edition 2023", International Energy Agency Solar Heating and Cooling Programme, 2023, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2023.pdf.

106 International Energy Agency Solar Heating and Cooling Programme, "Mixed Solar Thermal Market Development in 2022", 14 June 2023, https://www.iea-shc.org/Data/Sites/1/media/documents/press/2023-06-14--solar-heat-worldwide-press-release.pdf; Bärbel Epp, "New Milestones on the German Solar District Heating Market", Solar Thermal World, 19 December 2023, https://solarthermalworld.org/news/new-milestones-on-the-german-solar-district-heating-market.

107 Werner Weiss and Monika Spörk-Dür, "Solar Heat Worldwide Edition 2023", International Energy Agency Solar Heating and Cooling Programme, 2023, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2023.pdf.

108 Bärbel Epp, "37 MW Solar District Heating Plant in the Netherlands with Outstanding Features", Solar Thermal World, 11 November 2022, https://solarthermalworld.org/news/37-mw-solar-district-heating-plant-in-the-netherlands-with-outstanding-features.

109 Werner Weiss and Monika Spörk-Dür, "Solar Heat Worldwide Edition 2023", International Energy Agency Solar Heating and Cooling Programme, 2023, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2023.pdf.

110 ASHRAE, "Solar-Assisted Air Conditioning: What Engineers Need to Know", *ASHRAE Journal Newsletter*, 8 September

2020, https://www.ashrae.org/news/ashraejournal/solar-assisted-air-conditioning-what-engineers-need-to-know .

111 Meticulous Market Research Pvt Ltd, "Southeast Asia Air Conditioners Market to Be Worth $8.66 Billion by 2030", GlobeNewswire News Room, 28 August 2023, https://www.globenewswire.com/en/news-release/2023/08/28/2732630/0/en/Southeast-Asia-Air-Conditioners-Market-to-be-Worth-8-66-Billion-by-2030-Exclusive-Report-by-Meticulous-Research.html.

112 United Nations Environment Programme, "Cambodia Sets Example for Climate Action in the Cooling Sector", 3 September 2023, http://www.unep.org/technical-highlight/cambodia-sets-example-climate-action-cooling-sector; United Nations Economic and Social Commission for Asia and the Pacific, "Cambodia Announces Its National Cooling Action Plan", 17 November 2022, https://www.unescap.org/news/cambodia-announces-its-national-cooling-action-plan.

113 Government of South Africa, "South Africa National Cooling Plan (NCP)", 2023, https://eta-publications.lbl.gov/sites/default/files/sa_ncp_full_report_2023.pdf.

114 Fortune Business Insights, "District Cooling Market Size [2023-2030] Worth $44.46 Billion", GlobeNewswire News Room, 17 October 2023, https://www.globenewswire.com/en/news-release/2023/10/17/2761170/0/en/District-Cooling-Market-Size-2023-2030-worth-44-46-Billion-Growing-Demand-for-Sustainable-and-Energy-Efficient-Cooling-Solutions-and-Rising-Installation-of-DC-Technology-to-Expedit.html.

115 **Snapshot: Africa** from the following sources: Ayat Soliman and Saroj Kumar Jha, "Closing the Access Gap for Water and Sanitation in Eastern and Southern Africa: Raising the Ambition", World Bank, 27 March 2023, https://blogs.worldbank.org/en/water/closing-access-gap-water-and-sanitation-eastern-and-southern-africa-raising-ambition; World Health Organization, "Electricity in Health-Care Facilities", 31 August 2023, https://www.who.int/news-room/fact-sheets/detail/electricity-in-health-care-facilities; Sustainable Energy for All, "1 in 7 People Globally Currently at High Risk Due to Lack of Access to Cooling", 17 May 2022, https://www.seforall.org/press-releases/1-in-7-people-globally-currently-at-high-risk-due-to-lack-of-access-to-cooling; International Energy Agency, "Africa Energy Outlook 2022", 2022, https://www.iea.org/reports/africa-energy-outlook-2022; SophiA, "Sustainable Off-Grid Solutions for Pharmacies and Hospitals in Africa", 21 March 2024, https://sophia4africa.eu; SophiA, "SophiA Solar Cooling Container", accessed May 2024, https://sophia4africa.eu/sophia-solar-cooling; SophiA, "SophiA Solar Water Container", accessed May 2024, https://sophia4africa.eu/sophia-solar-water-container; GEA, "What Are Natural Refrigerants?" accessed May 2024, https://www.gea.com/en/campaigns/natural-refrigerants/natural-refrigerants-climate-neutral; Institute for Energy Research, "Environmental Impacts of Lithium-Ion Batteries", Institute for Energy Research, 11 May 2023, https://www.instituteforenergyresearch.org/renewable/environmental-impacts-of-lithium-ion-batteries; Oliver Schmid, Hochschule Karlsruhe, personal communication with REN21, 16 April 2024; SophiA, "Solar Technologies", accessed April 2024, https://sophia4africa.eu/solar-technologies.

ENDNOTES | TRANSPORT

1 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances.
2 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances.
3 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
4 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
5 **Figure 15** from International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
6 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
7 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
8 **Figure 16** from International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
9 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
10 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
11 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
12 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).
13 International Energy Agency, "Transport", July 2023, https://www.iea.org/reports/transport.
14 International Energy Agency, "Transport", July 2023, https://www.iea.org/reports/transport.
15 International Transport Forum, "ITF Transport Outlook 2023", 24 May 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.
16 SLOCAT Partnership on Sustainable, Low Carbon Transport, "SLOCAT Transport, Climate and Sustainability Global Status Report – 3rd Edition", 2023, https://tcc-gsr.com.
17 SLOCAT Partnership on Sustainable, Low Carbon Transport, "SLOCAT Transport, Climate and Sustainability Global Status Report – 3rd Edition", 2023, https://tcc-gsr.com.
18 International Energy Agency, "Energy Efficiency Indicators Data Explorer", accessed 9 January 2024, https://www.iea.org/data-and-statistics/data-tools/energy-efficiency-indicators-data-explorer.
19 International Energy Agency, "Energy Efficiency Indicators Data Explorer", accessed 9 January 2024, https://www.iea.org/data-and-statistics/data-tools/energy-efficiency-indicators-data-explorer.
20 SLOCAT Partnership on Sustainable, Low Carbon Transport, "SLOCAT Transport, Climate and Sustainability Global Status Report – 3rd Edition", 2023, https://tcc-gsr.com.
21 M. Cames, N. Wissner and J. Sutter, "Ammonia as a Marine Fuel: Risks and Perspectives", Öko-Institut, 2021, https://en.nabu.de/imperia/md/content/nabude/verkehr/210622-nabu-study-ammonia-marine-fuel.pdf.
22 International Energy Agency, "The Role of E-Fuels in Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport; SLOCAT Partnership on Sustainable, Low Carbon Transport, "SLOCAT Transport, Climate and Sustainability Global Status Report – 3rd Edition", 2023, https://tcc-gsr.com.
23 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.
24 European Commission. "Renewable Energy Directive", October 2023. https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en.
25 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.
26 **Figure 17** from REN21 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.
27 Stephanie Kelly and Jarrett Renshaw, "US Boosts Biofuel Mandates over Next 3 Years, but Biofuel Groups Feel Shortchanged", *Reuters*, 21 June 2023, https://www.reuters.com/markets/commodities/us-boosts-biofuel-mandates-over-next-3-years-biofuel-groups-feel-shortchanged-2023-06-21.
28 International Energy Agency, "Regulation Regarding Petroleum Products Specification and Standards for Implementation – Policies", 2 February 2023, https://www.iea.org/policies/16933-regulation-regarding-petroleum-products-specification-and-standards-for-implementation.
29 Eco-Business, "Asia Grapples with the Consequences of Expanding Transport Biofuel Mandates", 2 May 2023, https://www.eco-business.com/news/asia-grapples-with-the-consequences-of-expanding-transport-biofuel-mandates; Biofuels International, "B30 Biodiesel Mandate Pencilled in for 2030 in Malaysia", 1 September 2023, https://biofuels-news.com/news/b30-biodiesel-mandate-pencilled-in-for-2030-in-malaysia; Gautamee Hazarika, "Government Mandates Blending of Compressed Biogas in CNG and PNG", Mercom India, 27 November 2023, https://mercomindia.com/government-mandates-biogas-in-cng-and-png.
30 Lisandra Paraguassu, "Brazil to Raise Mandatory Biodiesel Mix, Halt Imports", *Reuters*, 19 December 2023, https://www.reuters.com/markets/commodities/brazil-policy-council-approves-raising-biodiesel-mix-2023-12-19.
31 Biofuels International, "New Swedish Government to Reduce Biofuel Mandates", 9 May 2023, https://biofuels-news.com/news/new-swedish-government-to-reduce-biofuel-mandates.
32 India Briefing, "What Is the Global Biofuel Alliance and How Is India Contributing to It?" 16 October 2023, https://www.india-briefing.com/news/understanding-the-global-biofuel-alliance-and-indias-role-within-it-29900.html.
33 International Energy Agency, "IEA Policies Database", accessed 2 January 2024, https://www.iea.org/policies; **Figure 18** from REN21 Policy Database. See GSR 2024 Data Pack available at www.ren21.net/gsr2024-data-pack/demand.
34 Joe Lo, "China Announces Plans to Manage Electric Vehicles Power Demand", Climate Home News, 4 January 2024, https://www.climatechangenews.com/2024/01/04/china-announces-plans-to-manage-electric-vehicles-power-demand.
35 Ben Potter, "EV Owners Make Thousands Selling Energy – Back to the Grid", Australian Financial Review, 15 November 2023, https://www.afr.com/policy/energy-and-climate/these-ev-owners-are-making-thousands-selling-energy-back-to-the-grid-20231114-p5ejtw.
36 Fred Lambert, "Tesla Voids Your Warranty If You Try to Power Your Home with Your Electric Car Battery Pack", Electrek, 23 February 2021, https://electrek.co/2021/02/23/tesla-voids-your-warranty-power-your-home-with-electric-car-battery-pack.
37 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.
38 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.
39 A. Diouf, "Mobilité électrique: comment vont être utilisés les 22,5 milliards de DH de l'Etat", Finances News, 11 September 2023, https://fnh.ma/article/actualite-economique/mobilite-electrique-maroc-onee.
40 Agência Brasil, "Brazil Creates Program to Decarbonize National Fleet", 2 January 2024, https://agenciabrasil.ebc.com.br/en/geral/noticia/2024-01/brazil-creates-program-decarbonize-national-fleet.
41 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.
42 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.
43 International Energy Agency, "2023 Efficient and Electric Vehicle Adoption Incentives – Policies", 11 May 2023, https://www.iea.org/policies/17345-2023-efficient-and-electric-vehicle-adoption-incentives.
44 International Energy Agency, "Electro Parks – Electromobility in National Parks – Policies", 12 May 2023, https://www.iea.org/policies/17239-electro-parks-electromobility-in-national-parks.
45 International Energy Agency, "EUR 8.5 Million for Purchase of Zero Emissions Vehicles and e-Bikes – Policies", 9 May 2023, https://www.iea.org/policies/17158-eur-85-million-for-purchase-of-zero-emissions-vehicles-and-e-bikes.
46 Juiced Bikes, "2023 Guide to U.S. E-Bike Rebates & Tax Credits", 2023, https://www.juicedbikes.com/blogs/news/2023-guide-us-ebike-rebates-and-tax-credits.
47 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

48 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

49 International Energy Agency, "Minister of Finance Order No.38 2023 on VAT Reduction for Battery Electric Vehicle – Policies",11 May 2023, https://www.iea.org/policies/17303-minister-of-finance-order-no38-2023-on-vat-reduction-for-battery-electric-vehicle; International Energy Agency, "Tax Incentive for Company Renting Non-Commercial Electric Vehicle – Policies", 17 May 2023, https://www.iea.org/policies/17248-tax-incentive-for-company-renting-non-commercial-electric-vehicle.

50 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

51 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

52 bp pulse, "Road Tax for Electric Vehicles Explained", 27 February 2023, https://www.bppulse.co.uk/going-electric/road-tax-on-electric-and-hybrid-cars-explained.

53 International Energy Agency, "Transport – Energy System", accessed 2 February 2024, https://www.iea.org/energy-system/transport.

54 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

55 International Energy Agency, "Global EV Policy Explorer – Data Tools", accessed 2 February 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

56 City of New York, "Mayor Adams Announces $77 Million in Federal Grants to Electrify School Buses, Build First-in-the-Nation Electric Truck Charging Depot", 18 March 2024, http://www.nyc.gov/office-of-the-mayor/news/206-24/mayor-adams-77-million-federal-grants-electrify-school-buses-build.

57 Chris Randall, "India Introduces New Electric Bus Grant Programme", Electrive, 18 August 2023, https://www.electrive.com/2023/08/18/india-introduces-new-electric-bus-grant-programme.

58 Government of Iceland, "Medium-Term Fiscal Strategy Plan 2024-2028: To Counter Inflation, Safeguard Living Standards and Support Growth", 29 March 2023, https://www.government.is/news/article/2023/03/29/Medium-term-Fiscal-Strategy-Plan-2024-2028-to-counter-inflation-safeguard-living-standards-and-support-growth.

59 "German Car Sales Surge in 2023, Electric Models Decline with Government Ending EV Subsidies", The Economic Times, 5 January 2024, https://economictimes.indiatimes.com/industry/renewables/german-car-sales-surge-in-2023-electric-models-decline-with-government-ending-ev-subsidies/articleshow/106571110.cms.

60 Ivana Kottasová, "EU Was Set to Ban Internal Combustion Engine Cars. Then Germany Suddenly Changed Its Mind", CNN, 24 March 2023, https://www.cnn.com/2023/03/24/cars/eu-combustion-engine-debate-climate-intl/index.html.

61 Jonathan Manning, "Fleet Dismay as UK Delays Ban on ICE Vehicles Until 2035", Fleet Europe, 20 September 2023, https://www.fleeteurope.com/en/new-energies/united-kingdom/features/fleet-dismay-uk-delays-ban-ice-vehicles-until-2035.

62 Petro Online, "By 2025, No Norwegian Will Drive a Car with a Combustion Engine", 24 June 2023, https://www.petro-online.com/news/fuel-for-thought/13/international-environmental-technology/by-2025-no-norwegian-will-drive-a-car-with-a-combustion-engine/60647; Chris Randall, "New Trucks in Norway Only Allowed with Electric or Biogas Drives from 2030", 4 December 2023, Electrive, https://www.electrive.com/2023/12/04/new-trucks-in-norway-only-allowed-with-electric-or-biogas-drives-from-2030.

63 Jo Borrás, "It Begins: Ethiopia Set to Become First Country to Ban Internal Combustion Cars", Electrek, 2 February 2024, https://electrek.co/2024/02/02/it-begins-ethiopia-set-to-become-first-country-to-ban-internal-combustion-cars.

64 Nora Manthey, "Amsterdam Brings Forward ICE Ban for Most Vehicles", Electrive, 7 June 2023, https://www.electrive.com/2023/06/07/amsterdam-brings-forward-ice-ban-for-most-vehicles.

65 Angela Symons, "When Will Stockholm's Petrol and Diesel Car Ban Come into Force?" Euronews, 12 October 2023, https://www.euronews.com/green/2023/10/11/plenty-of-space-for-walking-and-cycling-stockholm-hopes-to-transform-its-centre-with-a-car.

66 Wayne Parry, "New Jersey Banning Sale of New Gasoline-Powered Vehicles by 2035", AP News, 21 November 2023, https://apnews.com/article/zero-emission-cars-electric-new-jersey-fba750b735a47bb7fb79087d7ed53e00.

67 International Energy Agency, "Policy Database – Data & Statistics", accessed 9 January 2024, https://www.iea.org/policies.

68 International Energy Agency, "2023 Efficient and Electric Vehicle Adoption Incentives – Policies", 11 May 2023, https://www.iea.org/policies/17345-2023-efficient-and-electric-vehicle-adoption-incentives.

69 REN21 Policy Database. See GSR 2024 Data Pack, available at www.ren21.net/gsr2024-data-pack/demand.

70 International Energy Agency, "Green Hydrogen Production for Rail Transport", 2023, https://www.iea.org/policies/17400-green-hydrogen-production-for-rail-transport.

71 International Energy Agency, "Support Scheme to Rail Transport Operators – Policies", 15 May 2023, https://www.iea.org/policies/17540-support-scheme-to-rail-transport-operators.

72 European Parliament, "70% of Jet Fuels at EU Airports Will Have to Be Green by 2050", 13 September 2023, https://www.europarl.europa.eu/news/en/press-room/20230911IPR04913/70-of-jet-fuels-at-eu-airports-will-have-to-be-green-by-2050.

73 Tony Harrington, "UAE Announces 1% SAF Blending Target by 2031, with Plans to Supply Other Markets", GreenAir News, 20 December 2023, https://www.greenairnews.com/?p=5167.

74 Travel Radar, "UK Government to Encourage Production of Sustainable Aviation Fuel with £165 Million Investment", 10 September 2023, https://travelradar.aero/uk-government-to-encourage-production-of-sustainable-aviation-fuel-with-165-million-investment; International Energy Agency, "Aviation", accessed 2 February 2024, https://www.iea.org/energy-system/transport/aviation; Thomson Reuters, "Notice Provides More Guidance on New Sustainable Aviation Fuel Credit", 18 December 2023, https://tax.thomsonreuters.com/news/notice-provides-more-guidance-on-new-sustainable-aviation-fuel-credit.

75 International Energy Agency, "Aviation", accessed 2 February 2024, https://www.iea.org/energy-system/transport/aviation.

76 Jeff Fick, "Brazil's Lula Launches 'Fuel of the Future' Program to Reduce Emissions", 15 September 2023, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/091523-brazils-lula-launches-fuel-of-the-future-program-to-reduce-emissions.

77 Aparupa Mazumder, "MPA Tightens Biofuel Regulations in Singapore", Engine, 16 October 2023, https://engine.online/news/regulations/mpa-tightens-biofuel-regulations-in-singapore-527e.

78 European Council. "FuelEU Maritime Initiative: Council Adopts New Law to Decarbonise the Maritime Sector", July 2023. https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/fueleu-maritime-initiative-council-adopts-new-law-to-decarbonise-the-maritime-sector/.

79 Transport & Environment, "2023 Renewable Energy Directive Fact Sheet", 27 July 2023, https://www.transportenvironment.org/discover/2023-renewable-energy-directive-fact-sheet.

80 "Green Shipping Corridors Gaining Momentum", BBC News, 18 December 2023, https://www.bbc.com/news/business-67690392.

81 "Green Shipping Corridors Gaining Momentum", BBC News, 18 December 2023, https://www.bbc.com/news/business-67690392.

82 BloombergNEF, "Energy Transition Investment Trends 2024", 2024, https://about.bnef.com/energy-transition-investment.

83 BloombergNEF, "EVO Report 2022", accessed February 7, 2023, https://about.bnef.com/electric-vehicle-outlook.

84 International Energy Agency, "Global EV Outlook 2023", 2023, https://www.iea.org/reports/global-ev-outlook-2023/executive-summary. **Figure 19** from BloombergNEF, "Energy Transition Investment Trends", 2024, https://about.bnef.com/energy-transition-investment/.

85 Sheila Chiang, "China's EV Stocks Start 2024 in Reverse Gear as Price Wars Pressure Profitability", CNBC, 11 January 2024, https://www.cnbc.com/2024/01/11/chinas-ev-stocks-start-2024-in-reverse-gear-as-price-wars-pressure-profitability.html.

86 Soeren Amelang, "Abrupt End to German Electric Car Subsidies Fuels Doubts About Green Mobility Target", Clean Energy Wire, 18 December 2023, https://www.cleanenergywire.org/news/abrupt-end-german-electric-car-subsidies-fuels-doubts-about-green-mobility-target.

87 Nicole Lepre, Spencer Burget and Noah Gabriel, "U.S. Investments in Electric Vehicle Manufacturing (2023)", Atlas Public Policy, 12 January 2023, https://atlaspolicy.com/wp-content/uploads/2023/05/U.S.-Investments-in-Electric-Vehicle-Manufacturing-2023.pdf.

88 Jeanne Whalen, "EV Transition Cools as Demand Slows and Automakers Trim Production", *Washington Post*, 27 December 2023, https://www.washingtonpost.com/business/2023/12/26/ev-demand-slows.

89 International Energy Agency, "Global EV Outlook 2023", 2023, https://www.iea.org/reports/global-ev-outlook-2023/executive-summary.

90 Megan Kelly, "ACC raises €4.4 billion for three gigafactories in Europe", Automotive Logistics, 12 February 2025, https://www.automotivelogistics.media/battery-supply-chain/acc-raises-44-billion-for-three-gigafactories-in-europe/45215.article.

91 Nora Manthey, "First Machines Arrive at German VW Battery Factory", Electrive, 30 June 2023, https://www.electrive.com/2023/06/30/first-machines-arrive-at-vw-battery-factory-in-germany.

92 Nora Manthey, "First Machines Arrive at German VW Battery Factory", Electrive, 30 June 2023, https://www.electrive.com/2023/06/30/first-machines-arrive-at-vw-battery-factory-in-germany.

93 Chris Randall, "VW Starts Battery Plant Construction in Valencia and Plans Third Party Sales", Electrive, 17 March 2023, https://www.electrive.com/2023/03/17/vw-starts-battery-plant-construction-in-valencia-and-plans-third-party-sales.

94 "Stellantis Halts Construction on Windsor, Ont., EV Battery Plant amid Dispute with Ottawa", Financial Post, 16 May 2023, https://financialpost.com/commodities/energy/electric-vehicles/stellantis-halts-construction-ontario-ev-battery-plant.

95 Stellantis, "Stellantis and LG Energy Solution to Invest Over $5 Billion CAD in Joint Venture for First Large Scale Lithium-Ion Battery Production Plant in Canada", 23 March 2022, https://www.stellantis.com/en/news/press-releases/2022/march/stellantis-and-lg-energy-solution-to-invest-over-5-billion-cad-in-joint-venture-for-first-large-scale-lithium-ion-battery-production-plant-in-canada.

96 Steve Scherer and Costas Pitas, "Stellantis Wins Bigger Subsidies for Canada Battery Plant", Reuters, 5 July 2023, https://www.reuters.com/business/autos-transportation/stellantis-says-resume-battery-plant-construction-canada-after-reaching-deal-2023-07-05.

97 International Energy Agency, "Global EV Outlook 2023", 2023, https://www.iea.org/reports/global-ev-outlook-2023/executive-summary.

98 "Japan's Suzuki to Invest $1.4 Billion for EVs at India Factory", Reuters, 21 March 2022, https://www.reuters.com/business/autos-transportation/japans-suzuki-invest-14-bln-evs-india-factory-2022-03-20.

99 BloombergNEF, "Energy Transition Investment Trends 2024", 2024, https://about.bnef.com/energy-transition-investment.

100 International Energy Agency, "Transport Biofuels – Renewables 2023 – Analysis", 2023, https://www.iea.org/reports/renewables-2023/transport-biofuels.

101 Latin American Energy Organization, "Panorama Energetico de America Latina y El Caribe 2023", December 2023, https://www.olade.org/wp-content/uploads/2023/12/PANORAMA-2023.pdf.

102 S&P Global Commodity Insights, "Top Biofuels Market Trends in 2022 and Beyond", 2022, https://commodityinsights.spglobal.com/top-biofuels-market-trends-2022-beyond.html.

103 ExxonMobil, "ExxonMobil Moves Forward with Largest Renewable Diesel Facility in Canada", 26 January 2023, https://corporate.exxonmobil.com/news/news-releases/2023/0126-exxonmobil-moves-forward-with-largest-renewable-diesel-facility-in-canada.

104 Argus Media, "Brazil Biofuels Investments Target Diverse Feedstocks", 26 April 2023, https://www.argusmedia.com/en/news-and-insights/latest-market-news/2443245-brazil-biofuels-investments-target-diverse-feedstocks.

105 Mitsui & Co. LTD., "Mitsui to Invest in Renewable Diesel and SAF Production Business in Portugal", 25 September 2023, https://www.mitsui.com/jp/en/release/2023/1247489_13943.html.

106 SkyNRG, "Sustainable Aviation Fuel Market Outlook 2023", May 2023, https://skynrg.com/thank-you-download-summary-report.

107 Anna Mackenzie et al., "European Airlines Secure Supplies of Low-Carbon Jet Fuel", *Reuters*, 28 November 2023, https://www.reuters.com/business/aerospace-defense/european-airlines-secure-supplies-low-carbon-jet-fuel-2023-11-28.

108 Anna Mackenzie et al., "European Airlines Secure Supplies of Low-Carbon Jet Fuel", *Reuters*, 28 November 2023, https://www.reuters.com/business/aerospace-defense/european-airlines-secure-supplies-low-carbon-jet-fuel-2023-11-28.

109 Anna Mackenzie et al., "European Airlines Secure Supplies of Low-Carbon Jet Fuel", *Reuters*, 28 November 2023, https://www.reuters.com/business/aerospace-defense/european-airlines-secure-supplies-low-carbon-jet-fuel-2023-11-28.

110 John Pullen, "Electric Aviation Continues to Progress in 2023", Avionics International, 12 June 2023, https://www.aviationtoday.com/2023/06/12/electric-aviation-continues-to-progress-in-2023.

111 Coco Liu, "It's Boom Times for Startups Trying to Electrify Aviation", *Bloomberg*, 10 November 2023, https://www.bloomberg.com/news/articles/2023-11-10/when-will-we-get-electric-airplanes.

112 The Brainy Insights, "Solar-Powered Trains Market", 2023, https://www.thebrainyinsights.com/report/solar-powered-trains-market-13473.

113 Ally Wybrew, "The First Solar-Powered Train Is In the Works in California", Euronews, 12 July 2023, https://www.euronews.com/green/2023/07/12/this-high-speed-train-could-be-the-first-to-be-powered-entirely-by-renewable-energy.

114 International Renewable Energy Agency, "Renewable Energy Options for Shipping: Technology Brief", 2015, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_Tech_Brief_RE_for-Shipping_2015.pdf.

115 Susan Kraemer, "Vast Secures $40 Million to Build Its Solar Fuel Plant at Port Augusta to Supply Green Methanol for Shipping", SolarPACES, 16 February 2024, https://www.solarpaces.org/vast-secures-40-million-to-build-its-solar-fuel-plant-at-port-augusta-to-supply-green-methanol-for-shipping.

116 International Transport Forum, "ITF Transport Outlook 2023", 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.

117 International Transport Forum, "ITF Transport Outlook 2023", 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.

118 International Transport Forum, "ITF Transport Outlook 2023", 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.

119 International Transport Forum, "ITF Transport Outlook 2023", 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.

120 International Transport Forum, "ITF Transport Outlook 2023", 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.

121 International Transport Forum, "ITF Transport Outlook 2023", 2023, https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2023_b6cc9ad5-en.

122 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

123 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

124 **Figure 20** from International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

125 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

126 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

127 International Energy Agency, "World Energy Balances", 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

128 International Energy Agency, "The Role of E-fuels in Decarbonising Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.

129 International Energy Agency, "The Role of E-fuels in Decarbonising Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.

130 International Energy Agency, "The Role of E-fuels in Decarbonising Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.

131 European Commission, "Delegated Regulation - 2023/1640 - EN - EUR-Lex", 5 June 2023, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=OJ:JOL_2023_205_R_0001; European Technology and Innovation Platform, 'Sustainable Feedstocks for Advanced Biofuels and Intermediate Bioenergy Carriers Production in Europe', accessed 16 May 2024, https://www.etipbioenergy.eu/value-chains/feedstocks/biofuels-feedstocks-an-overview.

132 International Energy Agency, "The Role of E-fuels in Decarbonising Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.

133 Repsol, "Repsol to Exceed 600 Service Stations with Renewable Fuel in 2024", 16 January 2024, https://www.repsol.com/en/press-room/press-releases/2024/repsol-to-exceed-600-service-stations-with-renewable-fuel/index.cshtml.

134 Repsol, "Repsol to Exceed 600 Service Stations with Renewable Fuel in 2024", 16 January 2024, https://www.repsol.com/en/press-room/press-releases/2024/repsol-to-exceed-600-service-stations-with-renewable-fuel/index.cshtml.

135 City of New York, "Mayor Adams Unveils Plan to Make NYC First East Coast City to Transition City's Heavy-duty Fleet Vehicles to Renewable Fuel", 29 November 2023, https://www.nyc.gov/office-of-the-mayor/news/908-23/mayor-adams-plan-make-nyc-first-east-coast-city-transition-city-s-heavy-duty-fleet.

136 Nordsol, "FirstBio2Shipping", 10 January 2024, https://nordsol.com/cases/wilp.

137 Maersk, "Maersk Secures Green Methanol for Maiden Voyage of the World's First Methanol-enabled Container Vessel", 13 June 2023, https://www.maersk.com/news/articles/2023/06/13/maersk-secures-green-methanol; OCI, "OCI HyFuels Powers the First Green Methanol-powered

Container Ship", 27 September 2023, https://oci-global.com/news-stories/stories/celebrating-the-first-green-methanol-powered-container-ship-fueled-by-oci-hyfuels.

138 International Energy Agency, "Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. 2023 Update", September 2023, https://prod.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach.

139 C. Nairn, "As Exxon Bows Out, Industry Takes Step Toward Sustainable Algae Biofuels", Mongabay, 9 May 2023, https://news.mongabay.com/2023/05/as-exxon-bows-out-industry-takes-step-toward-sustainable-algae-biofuels.

140 A. Westervelt, "Big Oil Firms Touted Algae as Climate Solution. Now All Have Pulled Funding", The Guardian, 17 March 2023, https://www.theguardian.com/environment/2023/mar/17/big-oil-algae-biofuel-funding-cut-exxonmobil.

141 International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.

142 International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.

143 International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.

144 International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.

145 International Energy Agency, "Global EV Outlook 2023", April 2023,https://www.iea.org/reports/global-ev-outlook-2023.

146 Mobility for Africa, accessed 25 March 2024, https://mobilityforafrica.com; I. Kalulu, "Hamba! Solar-powered Tricycles Offer Solution to Transport Problems in Rural Z imbabwe", news24, 6 May 2023, https://www.news24.com/fin24/climate_future/solutions/hamba-solar-powered-tricycles-offer-solution-to-transport-problems-in-rural-zimbabwe-20230506; Xinhua, "(Hello Africa) Rural Women Drive Zimbabwe's Green Transition", 1 June 2023, https://english.news.cn/20230601/7bcd6c162c0c4c6283b04d6059dbe672/c.html.

147 Zero Carbon Charge, "Zero Carbon Charge Starts Construction on First National Network of 100% Renewable Energy Powered EV Charging Stations", 20 November 2023, https://charge.co.za/zero-carbon-charge-starts-construction-on-first-national-network-of-100-renewable-energy-powered-ev-charging-stations. **Snapshot: South Africa** from the following sources: GDP and trade shares from Julia Evans, "Shift to Renewable Energy Vital for Electric Vehicle Transition, Says Minister Patel", Daily Maverick, 4 December 2023, https://www.dailymaverick.co.za/article/2023-12-04-rapid-shiftto-renewable-energy-vital-for-electric-vehicle-transition-says-minister-patel; exports from Julian Turner, "Under the Hood of South Africa's Auto Industry", Investment Monitor, 11 July 2023, https://www.investmentmonitor.ai/sponsored/under-the-hood-of-south-africas-auto-industry, from Virusha Subban, "South Africa: Electric Vehicles White Paper", Baker & McKenzie, accessed 30 January 2024, https://insightplus.bakermckenzie.com/bm/industrials-manufacturingtransportation/south-africa-electric-vehicles-white-paper, and from Department of Trade, Industry and Competition, Republic of South Africa, "Electric Vehicles White Paper", November 2023, https://www.thedtic.gov.za/wp-content/uploads/EV-White-Paper.pdf; EV sales globally and in South Africa from Albertus Scholtz et al., "Insights Into Electric Vehicle Market Growth in South Africa: A System Dynamics Approach", South African Journal of Industrial Engineering 34, no. 3 (2023): 13-27, and from Evans, op. cit. this note; domestic EV production from Adekunle Agbetiloye, "South Africa Plans to Roll Out Its First EVs in 2026", Business Insider Africa, 6 December 2023, https://africa.businessinsider.com/local/markets/south-africa-plans-to-roll-out-its-first-evs-in-2026/g8x8f2r; national EV transition from Department of Trade, Industry and Competition and from Evans, op. cit. this note; Mineral Resources & Energy, Republic of South Africa, "Integrated Resource Plan December 2023", 2023, https://www.energy.gov.za/IRP/2023/IRP-2023-for-Public-Comments-User-friendly.pdf; slow charging times and 350 stations from Evans, op. cit. this note; Sibahle Malinga, "Load-Shedding Could Curb Electric Vehicle Market", ITWeb, 7 October 2022, https://www.itweb.co.za/article/load-shedding-could-curb-electric-vehiclemarket/Pero37Z33BZMQb6m; low climate benefits from Evans, op. cit. this note; coal reliance from Bernard Kengni, "Transition from Coal to Renewables: Is South Africa Ready?" University of Cape Town, 15 February 2023, https://law.uct.ac.za/mineral-law/articles/2023-02-15-transition-coalrenewables-south-africa-ready, and from David Pilling, "The Cost of Getting South Africa to Stop Using Coal", Financial Times, 2 November 2022, https://www.ft.com/content/3c64950c-2154-4757-bf25-d93c7850be8f; transport sector emissions from Andries Malherbe, "Transition to Net Zero Offers Major Opportunities for Green Growth", IOL, 2024, https://www.iol.co.za/businessreport/economy/transition-to-net-zero-offers-major-opportunities-for-green-growth-cc5f5252-f56b-4dc8-bee3-8dcfa5379752; Remeredzai Joseph Kuhudzai, "Zero Carbon Charge Starts Construction on First National Network of 100% Solar-Powered EV Charging Stations in South Africa", CleanTechnica, 20 November 2023, https://cleantechnica.com/2023/11/20/zero-carbon-charge-starts-constructionon-first-national-network-of-100-solar-powered-ev-charging-stations-in-south-africa; network plans from Malherbe, op. cit. this note; **Figure 21** from Myles Illidge, 'Goodbye Eskom — R1 Billion Deal to Bring Fastest off-Grid Car Chargers to South Africa', MYBROADBAND (blog), 2024, https://mybroadband.co.za/news/energy/524140-goodbye-eskom-r1-billion-deal-to-bringfastest-off-grid-car-chargers-to-south-africa.html; Kuhudzai, op. cit. this note; Hanno Labuschagne, "South Africa's First Eskom-Free Electric Car Charging Station Launching Soon", 21 January 2024, https://mybroadband.co.za/news/motoring/522309-south-africas-first-eskom-freeelectric-car-charging-station-launching-soon.html; coal trucks from C.C. De Saxe et al., "High Capacity Coal Trucks to Reduce Costs and Emissions at South Africa's Power Utility", Research in Transportation Business & Management 48 (June 2023): 100898, https://doi.org/10.1016/j.rtbm.2022.100898.

148 **Figure 22** from data generated using International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer; Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2019 Global Status Report", 2019, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf; Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2024 Global Status Report: Global Overview", 2024, https://www.ren21.net/wp-content/uploads/2019/05/GSR2024_GlobalOverview_Full_Report_with_endnotes_web.pdf.

149 Data generated using International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer; Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2019 Global Status Report", 2019, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf; Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2024 Global Status Report: Global Overview", 2024, https://www.ren21.net/wp-content/uploads/2019/05/GSR2024_GlobalOverview_Full_Report_with_endnotes_web.pdf.

150 Data generated using International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer; Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2019 Global Status Report", 2019, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf; REN21, Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2024 Global Status Report: Global Overview", 2024, https://www.ren21.net/wp-content/uploads/2019/05/GSR2024_GlobalOverview_Full_Report_with_endnotes_web.pdf.

151 Casey Crownhart, "The Runway for Futuristic Electric Planes Is Still a Long One", MIT Technology Review, 14 March 2023, https://www.technologyreview.com/2023/03/14/1069724/futuristic-electric-planes-evtols.

152 DHL, "Electricity Is in the Air as E-cargo Planes Take Flight", accessed 30 January 2024, https://www.dhl.com/global-en/delivered/sustainability/electric-aircraft-sustainable-logistics.html; Dayna Fedy-Macdonald, "Orders for Eviation Alice All-electric Aircraft Now Valued at over US$4 Billion", Skies, 11 May 2023, https://skiesmag.com/news/orders-eviation-alice-all-electric-aircraft-valued-over-4-billion.

153 Niels Anner, "The Electrification of Europe's Ferry Fleet", Siemens Energy, 12 August 2022, https://www.siemens-energy.com/global/en/news/magazine/2022/the-electrification-of-europes-ferry-fleet.html.

154 International Transport Forum, "Decarbonisation, Coastal Shipping and Multimodal Transport: Summary and Conclusions", 2023, https://www.itf-oecd.org/sites/default/files/docs/decarbonisation-coastal-shipping-multimodal-transport.pdf.

155 Yara, "Yara to Start Operating the World's First Fully Emission-Free Container Ship", 19 November 2023, https://www.yara.com/corporate-releases/yara-to-start-operating-the-worlds-first-fully-emission-free-container-ship; Sustainable Ships, "COSCO 700 TEU Full Electric Container Ship", 2023, https://www.sustainable-ships.org/stories/2023/cosco-700-teu-full-electric-container-ship; International Transport Forum, "Decarbonisation, Coastal Shipping and Multimodal Transport: Summary and Conclusions", 2023, https://www.itf-oecd.org/sites/default/files/docs/decarbonisation-coastal-shipping-multimodal-transport.pdf.

156 Infineon, "Why Future Will Run on Electricity", 2021, https://www.infineon.com/cms/en/discoveries/electrified-ships.

157 World Ports Sustainability Programme, "Onshore Power Supply", accessed 7 February 2024, https://sustainableworldports.org/ops.

158 Duffy D. and J. Bollermann, "Onshore Power Raises Simple Questions with Complex Answers", LR, 1 June 2023, https://www.lr.org/en/knowledge/horizons/june-2023/onshore-power-raises-simple-questions-with-complex-answers; European Alternative Fuels Observatory, "OPS Infrastructure at Maritime Ports in Europe", 2023, https://alternative-fuels-observatory.ec.europa.eu/transport-mode/maritime-sea/ports-and-infrastructure.
159 California Air Resources Board, "Ocean-Going Vessels At Berth Regulation", accessed 30 January 2024, https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation.
160 European Parliament, "Fit for 55: Deal on New EU Rules for Cleaner Maritime Fuels", 23 March 2023, https://www.europarl.europa.eu/news/en/press-room/20230320IPR77909/fit-for-55-deal-on-new-eu-rules-for-cleaner-maritime-fuels.
161 International Energy Agency, "Rail", July 2023, https://www.iea.org/energy-system/transport/rail.
162 International Energy Agency, "Rail", July 2023, https://www.iea.org/energy-system/transport/rail.
163 Ministry of Railways, "Indian Railways to Become Net Zero Carbon Emitter by 2030", 25 March 2023, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1907230.
164 Ministry of Railways, "Indian Railways to Become Net Zero Carbon Emitter by 2030", 25 March 2023, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1907230.
165 S. Anand, "Indian Railways Commissions 211 MW Solar, 103 MW Wind Power; Electrifies 60,814 km of Tracks", Energyworld, 2 January 2024, https://energy.economictimes.indiatimes.com/news/renewable/indian-railways-commissions-211-mw-solar-103-mw-wind-power-electrifies-60814-km-of-tracks/106463134. **Snapshot: India** based on the following sources: electrification rates from Nick Ferris, "How India Electrified 45% of Its Railway Network in Just Five Years", Energy Monitor, 2 February 2024, https://www.energymonitor.ai/newsleGers/how-india-made-45-of-its-railway-network-electric-in-just-fiveyears; Indian Railways, "Central Organiza(on for Railway Electrifica(on (CORE)", 2016, https://core.indianrailways.gov.in; Indian Railways, "Mission 100% Electrifica(on Moving Towards Net Zero Carbon Emission", 2021, https://indianrailways.gov.in/railwayboard/uploads/directorate/secretary_branches/IR_Reforms/Mission%20100%25%20Railway%20Electrifica(on%20-%20Moving%20towards%20Net%20Zero%20Carbon%20Emission.pdf; 94% from Ferris, op. cit. this note; 6,000 kilometres from Subhash Narayan, "Railways on Track to Meet Target of 100% Electrifica(on by Dec", mint, 28 July 2023, https://www.livemint.com/news/india/railways-on-track-tomeet-target-of-100-electrifica(on-by-dec-11690543908598.html; other regions, expenditure, import dependency and coal reliance from Ferris, op. cit. this note; net zero emissions from PIB Delhi, "Indian Railways Set to Meet All Its Energy Consump(on Needs of More than 33 Billion Units by 2030", Ministry of Railways, 27 August 2020, https://pib.gov.in/PressReleasePage.aspx?PRID=1648937; Anand Saurav, "Indian Railways Commissions 211 MW Solar, 103 MW Wind Power; Electrifies 60,814 Km of Tracks", ETEnergyworld.com, 2 January 2024, https://energy.economic(mes.india(mes.com/news/renewable/indianrailways-commissions-211-mw-solar-103-mw-wind-power-electrifies-60814-km-of-tracks/106463134; solar plants from PIB Delhi, op. cit. this note; energy eYiciency from Saurav, op. cit. this note.
166 E. Dailey, "SNCF and CNR Sign the Largest Wind Energy PPA in France", Railtech, 12 July 2023, https://www.railtech.be/fr/infrastructure/2023/07/12/sncf-et-cnr-signent-le-plus-grand-ppa-eolien-en-france.
167 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
168 SLOCAT Partnership on Sustainable, Low Carbon Transport, "SLOCAT Transport, Climate and Sustainability Global Status Report – 3rd Edition", 2023, https://tcc-gsr.com.
169 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023; International Energy Agency, "Global EV Data Explorer", accessed 10 January 2024, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.
170 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
171 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
172 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023; BMW, "Launch of the BMW iX5 Hydrogen Pilot Fleet", February 2023, https://www.bmwgroup.com/en/news/general/2023/BMWiX5Hydrogen.html.
173 International Energy Agency, "Fuel Cell Electric Vehicle (FCEV) Stock by Region and by Mode, 2022", 2022, https://www.iea.org/data-and-statistics/charts/fuel-cell-electric-vehicle-fcev-stock-by-region-and-by-mode-2022.
174 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
175 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
176 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
177 Airbus, "ZEROe – Low carbon aviation", accessed 7 February 2024, https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe.
178 SLOCAT Partnership on Sustainable, Low Carbon Transport, "SLOCAT Transport, Climate and Sustainability Global Status Report – 3rd Edition", 2023, https://tcc-gsr.com.
179 MAN-ES, "Hydrogen", 11 January 2024, https://www.man-es.com/marine/strategic-expertise/future-fuels/hydrogen; Rachel Parkes, "Ship with Hydrogen-powered Two-stroke Engine Gets Technical Green Light", Hydrogen Insight, 20 October 2023, https://www.hydrogeninsight.com/transport/-world-first-ship-with-hydrogen-powered-two-stroke-engine-gets-technical-green-light/2-1-1538892; Marine Insight, "Yanmar Technology Initiates Hydrogen Fueled 4 Stroke Engine Development", Marine Insight, 10 January 2024, https://www.marineinsight.com/shipping-news/yanmar-technology-initiates-hydrogen-fueled-4-stroke-engine-development; N. Blenkey, "MAN Partners Up to Develop Hydrogen-fueled Medium-speed Engine Concepts", 12 October 2023, https://www.marinelog.com/news/man-partners-up-to-develop-hydrogen-fueled-medium-speed-engine-concepts.
180 HAV Hydrogen, "HAV Group Receives Preliminary Approval for Hydrogen-based Energy System for Ships", 6 May 2022, https://www.havhydrogen.no/news/2022/hav-group-receives-preliminary-approval-for-hydrogen-based-energy-system-for-ships.
181 MAN Energy Solutions, "Hydrogen-Powered Feeder Container Vessels to Be Equipped With MAN 175D GenSets", 21 November 2023, https://www.man-es.com/company/press-releases/press-details/2023/11/21/hydrogen-powered-feeder-container-vessels-to-be-equipped-with-man-175d-gensets.
182 A. Bergenson, "Norled H2 Ferry Sails into Operation, Completing World-first Achievement", 5 April 2023, https://www.hydrogenfuelnews.com/norled-h2-ferry-operation/8558031; International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
183 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
184 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
185 International Energy Agency, "Global Hydrogen Review 2023", September 2023, https://www.iea.org/reports/global-hydrogen-review-2023.
186 International Energy Agency, "Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. 2023 Update", September 2023, https://prod.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach.
187 Kirill Durkin et al., "Hydrogen-Powered Vehicles: Comparing the Powertrain Efficiency and Sustainability of Fuel Cell versus Internal Combustion Engine Cars", Energies 17, no. 5 (2024): 1085, https://doi.org/10.3390/en17051085.
188 International Energy Agency, "The Role of E-Fuels in Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.
189 Elena C. Blanco et al., 'Methanol and Ammonia as Emerging Green Fuels: Evaluation of a New Power Generation Paradigm', Renewable and Sustainable Energy Reviews 175 (1 April 2023): 113195, https://doi.org/10.1016/j.rser.2023.113195.
190 International Energy Agency, "The Role of E-Fuels in Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport; Ember, "Electricity Data Explorer | Open Source Global Electricity Data", accessed 30 January 2024, https://ember-climate.org/data/data-tools/data-explorer.
191 International Energy Agency, "The Role of E-Fuels in Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.
192 International Energy Agency, "The Role of E-Fuels in Transport", December 2023, https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport.

ENDNOTES | AGRICULTURE

1 World Bank, "Agriculture, Forestry, and Fishing, Value Added (% of GDP)", accessed 13 March 2024, https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS.

2 World Bank, "Agriculture, Forestry, and Fishing, Value Added (Annual % Growth)", accessed 22 January 2024, https://data.worldbank.org/indicator/NV.AGR.TOTL.KD.ZG.

3 International Labour Organization, "Employment in Agriculture, World", Data Finder – World Employment and Social Outlook, accessed 13 February 2024, https://www.ilo.org/wesodata/chart/BDdcVrVF4.

4 Sarah K. Lowder, Jakob Skoet and Saumya Singh, "What Do We Really Know About the Number and Distribution of Farms and Family Farms Worldwide?" Food and Agriculture Organization of the United Nations (FAO), 2014, http://www.fao.org/3/a-i3729e.pdf; M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", FAO, 2023, https://doi.org/10.4060/cc4903en.

5 International Energy Agency, "Energy Statistics Data Browser – Data Tools", accessed 26 January 2024, https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser.

6 Global Alliance for the Future of Food, "Power Shift: Why We Need to Wean Industrial Food Systems Off Fossil Fuels", 2023, https://futureoffood.org/insights/power-shift-why-we-need-to-wean-industrial-food-systems-off-fossil-fuels.

7 International Energy Agency, "World Energy Balances 2021: Extended Energy Balances", August 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

8 Elia Scolaro et al., "Electrification of Agricultural Machinery: A Review", *IEEE Access 9* (2021): 164520-41, https://doi.org/10.1109/ACCESS.2021.3135037; Kyle Clark, "Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives", Business & Technology Surveillance, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf; Arash Farokhi Soofi, Saeed D. Manshadi and Araceli Saucedo, "Farm Electrification: A Road-Map to Decarbonize the Agriculture Sector", *The Electricity Journal* 35, no. 2 (2022): 107076, https://doi.org/10.1016/j.tej.2022.107076.

9 Food and Agriculture Organization of the United Nations, "FAOSTAT", accessed 6 February 2024, https://www.fao.org/faostat/en/#data/GN.

10 Food and Agriculture Organization of the United Nations, "FAOSTAT", accessed 6 February 2024, https://www.fao.org/faostat/en/#data/GN.

11 Food and Agriculture Organization of the United Nations, "FAOSTAT", accessed 6 February 2024, https://www.fao.org/faostat/en/#data/GN.

12 Food and Agriculture Organization of the United Nations, "FAOSTAT", accessed 6 February 2024, https://www.fao.org/faostat/en/#data/GN.

13 International Energy Agency, "World Energy Balances 2021: Extended Energy Balances", August 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21). **Figure 23** from Ibid.

14 International Energy Agency, "World Energy Balances 2021: Extended Energy Balances", August 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

15 International Energy Agency, "World Energy Balances 2021: Extended Energy Balances", August 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

16 International Energy Agency, "World Energy Balances 2021: Extended Energy Balances", August 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

17 European Commission, "Final Report Summary – AGREE (Agriculture and Energy Efficiency)", 2013, https://cordis.europa.eu/project/id/289139/reporting/de; Guillaume Martin et al., "Reducing Energy Consumption Without Compromising Food Security: The Imperative That Could Transform Agriculture", *Environmental Research Letters* 18, no. 8 (2023): 081001, https://doi.org/10.1088/1748-9326/ace462.

18 GOGLA, "Powering Adaptation and Climate Justice: The Critical Role of Off-Grid Solar Technologies", 4 September 2023, https://www.gogla.org/reports/powering-adaptation-and-climate-justice; M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en; Jane Ambuko and Willis Owino, "Toward Sustainable Transformation Through Postharvest Management: Lessons from Kenya's Mango Value Chain", in International Food Policy Research Institute, *Food Systems Transformation in Kenya: Lessons from the Past and Policy Options for the Future*, 2023, 433-68, https://doi.org/10.2499/9780896294561_17.

19 Emily Cox, Sarah Royston and Jan Selby, "From Exports to Exercise: How Non-Energy Policies Affect Energy Systems", *Energy Research & Social Science* 55 (1 September 2019): 179-88. https://doi.org/10.1016/j.erss.2019.05.016; Annette Huber-Lee, "Five Key Actions to Plan Effectively for Water, Energy and Food Security", Stockholm Environment Institute, 22 February 2021, https://www.sei.org/featured/five-actions-for-water-energy-food-security; International Renewable Energy Agency, "Renewable Energy for Agri-Food Systems: Towards the Sustainable Development Goals and the Paris Agreement", 2021, https://www.irena.org/publications/2021/Nov/Renewable-Energy-for-Agri-food-Systems; Rima Jreich, "Solar PV Key to Transforming Water, Energy, Food Crises into a Nexus Opportunity", pv magazine International, 21 December 2023, https://www.pv-magazine.com/2023/12/21/solar-pv-key-to-transforming-water-energy-food-crises-into-a-nexus-opportunity.

20 International Renewable Energy Agency, "Renewable Energy for Agri-Food Systems: Towards the Sustainable Development Goals and the Paris Agreement", 2021, https://www.irena.org/publications/2021/Nov/Renewable-Energy-for-Agri-food-Systems; Stephan Schindele et al., "Implementation of Agrophotovoltaics: Techno-Economic Analysis of the Price-Performance Ratio and Its Policy Implications", *Applied Energy* 265 (1 May 2020): 114737, https://doi.org/10.1016/j.apenergy.2020.114737.

21 McKinsey, "Building Food and Agriculture Businesses for a Green Future", accessed 29 January 2024, https://www.mckinsey.com/industries/agriculture/our-insights/building-food-and-agriculture-businesses-for-a-green-future.

22 Press Information Bureau of India, "Power Minister Chairs Virtual Meeting with States & UTs to Discuss Energy Transition Goals of India", accessed 7 May 2024, https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1797488; DAWNBREAKER, "Market Research Study: Agrivoltaics", US Department of Energy, 2022, https://science.osti.gov/-/media/sbir/pdf/Market-Research/SETO---Agrivoltaics-August-2022-Public.pdf.

23 International Energy Agency, "IEA Policies Database", accessed 2 January 2024, https://www.iea.org/policies. **Figure 24** from International Energy Agency, "World Energy Balances 2021: Extended Energy Balances", August 2023, https://www.iea.org/data-and-statistics/data-product/world-energy-balances, all rights reserved, as modified by the Renewable Energy Policy Network for the 21st Century (REN21).

24 European Commission – Agriculture and Rural Development, "Common Agricultural Policy for 2023-2027 – 28 CAO Strategic Plans at a Glance", 2022, https://agriculture.ec.europa.eu/system/files/2022-12/csp-at-a-glance-eu-countries_en.pdf.

25 European Commission – Agriculture and Rural Development, "Common Agricultural Policy for 2023-2027 – 28 CAO Strategic Plans at a Glance", 2022, https://agriculture.ec.europa.eu/system/files/2022-12/csp-at-a-glance-eu-countries_en.pdf.

26 European Economic and Social Committee, "Decarbonisation of the Fishing Fleet", 13 July 2023, https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/decarbonisation-fishing-fleet.

27 International Energy Agency, "Increase in 2023 Electricity Access Enhancement Budget – Policies", accessed 30 January 2024, https://www.iea.org/policies/16830-increase-in-2023-electricity-access-enhancement-budget.

28 Max Hall, "Philippine Irrigation Body Offers Up Sites for Floating Solar", pv magazine International, 2 March 2022, https://www.pv-magazine.com/2022/03/02/philippine-irrigation-body-offers-up-sites-for-floating-solar; National Irrigation Administration, "82 Completed Solar Irrigation Projects in 2023 to Aid in El Nino Mitigation", 15 March 2024, https://www.nia.gov.ph/content/82-completed-solar-irrigation-projects-2023-aid-el-ni%C3%B1o-mitigation.

29 WorldFish, "Centre for Renewable Energy in Aquaculture (CeREA)", 1 June 2023, https://worldfishcenter.org/project/center-renewable-energy-aquaculture-cerea.

30 International Energy Agency, "Photovoltaics on the Roof Programme – Policies", 11 May 2023, https://www.iea.org/policies/17357-photovoltaics-on-the-roof-programme; European Commission, "Commission Approves €1.7 Billion Italian State Aid Scheme", 10 November 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_5451.

31 International Energy Agency, "Rural Clean Energy Initiative & Support to Rural Energy Transition – Policies", 30 November 2022, https://www.iea.org/policies/16609-rural-clean-energy-initiative-support-to-rural-energy-transition.

32 International Energy Agency (IEA), "Energy for the Countryside Programme – Policies", accessed 29 January 2024, https://www.iea.org/policies/17237-energy-for-the-countryside-programme; IEA, "Subsidy Scheme to Develop Cogeneration from Municipal Biogas – Policies", 12 May 2023,, https://www.iea.org/policies/17229-subsidy-scheme-to-develop-cogeneration-from-municipal-biogas.

33 International Energy Agency, "Support for Biogas Production in Goiás – Policies", 25 May 2023, https://www.iea.org/policies/17507-support-for-biogas-production-in-goias.

34 Arjun Joshi, "Haryana to Offer Up to 75% Subsidies on Solar Pumps Installed Under KUSUM", Mercom India, 4 July 2023, https://mercomindia.com/haryana-subsidies-solar-pumps-kusum.

35 International Energy Agency, "SEK 380 Million: Temporary Tax Reduction on Agricultural Diesel – Policies", 20 April 2023, https://www.iea.org/policies/17497-sek-380-million-temporary-tax-reduction-on-agricultural-diesel.

36 International Energy Agency, "2023 Price Crisis Response Policies – Policies", 11 May 2023, https://www.iea.org/policies/17484-2023-price-crisis-response-policies.

37 International Renewable Energy Agency and Food and Agriculture Organization of the United Nations, "Renewable Energy and Agri-Food Systems: Advancing Energy and Food Security Towards Sustainable Development Goals", 2021, https://doi.org/10.4060/cb7433en.

38 International Renewable Energy Agency, "Renewable Energy for Agri-Food Systems", 12 November 2022, https://www.irena.org/News/articles/2022/Nov/Renewable-Energy-for-Agri-food-Systems.

39 International Renewable Energy Agency and Food and Agriculture Organization of the United Nations, "Renewable Energy and Agri-Food Systems: Advancing Energy and Food Security Towards Sustainable Development Goals", 2021, https://doi.org/10.4060/cb7433en.

40 International Renewable Energy Agency and Food and Agriculture Organization of the United Nations, "Renewable Energy and Agri-Food Systems: Advancing Energy and Food Security Towards Sustainable Development Goals", 2021, https://doi.org/10.4060/cb7433en.

41 Stephan Schindele et al., "Implementation of Agrophotovoltaics: Techno-Economic Analysis of the Price-Performance Ratio and Its Policy Implications", *Applied Energy* 265 (1 May 2020): 114737, https://doi.org/10.1016/j.apenergy.2020.114737.

42 Jordan Macknick, National Renewable Energy Laboratory, personal communication with REN21, 8 March 2023.

43 Jordan Macknick, National Renewable Energy Laboratory, personal communication with REN21, 8 March 2023.

44 "Danish Eurowind Energy Developing 70 MW Agrivoltaic Project in Romania", Balkan Green Energy News, 13 June 2023, https://balkangreenenergynews.com/danish-eurowind-energy-developing-70-mw-agrivoltaic-project-in-romania.

45 James Wimberley, "French Consortium Wants to Mobilize €1 Billion for Agrivoltaic Projects", pv magazine International, 6 November 2020, https://www.pv-magazine.com/2020/11/06/french-consortium-wants-to-mobilize-e1-billion-for-agrivoltaic-projects.

46 TotalEnergies, "France: TotalEnergies Acquires Ombrea and Creates a Center of Expertise for Agrivoltaics", 2 February 2024, https://totalenergies.com/media/news/press-releases/france-totalenergies-acquires-ombrea-and-creates-center-expertise.

47 Jordan Macknick, National Renewable Energy Laboratory, personal communication with REN21, 8 March 2023.

48 Katie Brigham, "Why Oil Majors Shell and BP Are Combining Solar Energy and Agricultural Production", CNBC, 14 November 2023, https://www.cnbc.com/2023/11/14/agrvoltaics231106brighamsf.html.

49 M. Taylor et al., "Justice-Driven Agrivoltaics: Facilitating Agrivoltaics Embedded in Energy Justice", *Renewable and Sustainable Energy Reviews* 188 (1 December 2023): 113815, https://doi.org/10.1016/j.rser.2023.113815.

50 BlueWave, "BlueWave Closes First Major Financing Round to Support Agrivoltaic Solar Development and Long-Term Project Ownership", 8 September 2023, https://www.prnewswire.com/news-releases/bluewave-closes-first-major-financing-round-to-support-agrivoltaic-solar-development-and-long-term-project-ownership-301922069.html.

51 Jordan Macknick, National Renewable Energy Laboratory, personal communication with REN21, 8 March 2023.

52 European Biogas Association, "1st EBA Biomethane Investment Outlook", 2023, https://www.europeanbiogas.eu/wp-content/uploads/2023/06/1st-EBA-Biomethane-Investment-Outlook.pdf.

53 Sistema.Bio, "Sistema.Bio Inaugurates 'World's Largest Manufacturing Facility for Biogas Plants' in Pune, Maharashtra and Commits 1% of Global GHG Reduction by 2030", 5 June 2023, https://sistema.bio/blog/sistema-bio-inaugurates-worlds-largest-biogas-plant-manufacturing-facility-in-india-and-commits-1-of-global-ghg-reduction-by-2030.

54 Liege Reis, "Grupo Paranaense Aposta Em Combustível 100% Renovável", *Cibiogas*, 23 November 2023, https://cibiogas.org/noticias/grupo-paranaense-aposta-em-combustivel-100-renovavel-e-investe-r-50-milhoes-na-primeira-refinaria-de-biometano-a-operar-com-residuos-da-suinocultura.

55 International Energy Agency, "Outlook for Biogas and Biomethane", 2020, https://iea.blob.core.windows.net/assets/03aeb10c-c38c-4d10-bcec-de92e9ab815f/Outlook_for_biogas_and_biomethane.pdf.

56 International Energy Agency, "Outlook for Biogas and Biomethane", 2020, https://iea.blob.core.windows.net/assets/03aeb10c-c38c-4d10-bcec-de92e9ab815f/Outlook_for_biogas_and_biomethane.pdf.

57 Hiroyuki Takeshima et al., "Solar-Powered Cold-Storage and Agrifood Market Modernization in Nigeria", *Agricultural Economics* 54, no. 2 (2023): 234-55, https://doi.org/10.1111/agec.12771.

58 Global Alliance for the Future of Food, "Power Shift: Why We Need to Wean Industrial Food Systems Off Fossil Fuels", 2023, https://futureoffood.org/insights/power-shift-why-we-need-to-wean-industrial-food-systems-off-fossil-fuels.

59 GOGLA, "Powering Adaptation and Climate Justice: The Critical Role of Off-Grid Solar Technologies", 4 September 2023, https://www.gogla.org/reports/powering-adaptation-and-climate-justice; Oliver Reynolds and Serra Paixao, "Insights from the January-June 2023 Sales and Impact Data", GOGLA Global Off-Grid Solar Market Data, 4 May 2023, https://www.gogla.org/reports/global-off-grid-solar-market-report; Soumya Balasubramanya et al., "Risks from Solar-Powered Groundwater Irrigation", Science, 19 January 2024, https://doi.org/10.1126/science.adi9497.

60 International Renewable Energy Agency, "Off-Grid Renewable Energy Statistics 2023", December 2023, https://www.irena.org/Publications/2023/Dec/Off-grid-Renewable-Energy-Statistics-2023.

61 Energy Sector Management Assistance Program, "Accelerating the Productive Use of Electricity: Enabling Energy Access to Power Rural Economic Growth", 2023, http://documents.worldbank.org/curated/en/099092023192023389/P1751521d3f58f6f1307c1499619e141b8baef6de8dd.

62 Soumya Balasubramanya et al., "Risks from Solar-Powered Groundwater Irrigation", *Science*, 19 January 2024, https://doi.org/10.1126/science.adi9497; International Renewable Energy Agency, "Off-Grid Renewable Energy Statistics 2023", December 2023, https://www.irena.org/Publications/2023/Dec/Off-grid-Renewable-Energy-Statistics-2023. **Snapshot: Rwanda** from the following sources: irrigation expansion from Brittney C. Sly et al., "Increasing Household Diet Diversity and Food Security in Rural Rwanda Using Small-Scale Nutrition-Sensitive Agriculture: A Community-Engaged Proof-of-Concept Study", *Nutrients* 15, no. 14 (2023): 3137, https://doi.org/10.3390/nu15143137, and from Eliezel Habineza et al., "Profitability Analysis of Small Scale Irrigation Technology Adoption to Farmers in Nasho Sector, Rwanda", *Journal of Agricultural Chemistry and Environment* 09, no. 02 (2020): 73-84, https://doi.org/10.4236/jacen.2020.92007; GDP and livelihoods from Sly et al., op. cit. this note; Water Network Research, "All You Need to Know About Nasho Irrigation Project Inaugurated by President Kagame", The Water Network, 2020, https://thewaternetwork.com/article-FfV/rwanda-nasho-irrigation-project--d1gAAqra8wXqeAx6JUSKA, and from Habineza et al., op. cit. this note; 90% from Habineza et al., idem; food insecurity from Sly et al., op. cit. this note, and from Habineza et al., op. cit. this note; water access from Habineza et al., op. cit. this note; reliable water sources from Ankit Chandra et al., "Water-Energy-Food Linkages in Community Smallholder Irrigation Schemes: Center Pivot Irrigation in Rwanda", *Agricultural Water Management* 289 (2023): 108506, https://doi.org/10.1016/j.agwat.2023.108506; irrigation from Habineza et al., op. cit. this note; Neha Durga et al., "Barriers to the Uptake of Solar-Powered Irrigation by Smallholder Farmers in Sub-Saharan Africa: A Review", *Energy Strategy Reviews* 51 (2024): 101294, https://doi.org/10.1016/j.esr.2024.101294; systemic barriers from Durga et al., idem; Water Network Research, op. cit. this note; Government of Rwanda, "Nasho Solar-Powered Irrigation Project to Boost Productivity and Improve Lives", 2020, https://www.gov.rw/blog-detail/nasho-solar-powered-irrigation-project-to-boost-productivity-and-improve-lives; Government of the Republic of Rwanda, "President Kagame Inaugurates a Solar-Powered Irrigation Scheme in Kirehe District", MINAGRI, 2020, https://www.minagri.gov.rw/updates/news-details/president-kagame-inaugurates-a-solar-powered-irrigation-scheme-in-kirehe-district; Rwanda Agriculture and Animal Resources Development, "The Director General Visits Kirehe Irrigation Infrastructures", 2021, https://www.rab.gov.rw/1-1/news-details/the-director-general-visits-kirehe-irrigation-infrastructures; elevated production from Jean Marie Takouleu, "RWANDA: Howard Buffet Launches Solar-Powered Irrigation System in Nasho", Afrik 21, 2020, https://www.afrik21.africa/en/rwanda-howard-buffet-launches-solar-powered-irrigation-system-in-nasho.

63 Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2023 Global Status Report", 2023, https://www.ren21.net/gsr-2023; M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en.

64 Jane Ambuko and Willis Owino, "Toward Sustainable Transformation Through Postharvest Management: Lessons from Kenya's Mango Value Chain", in International Food Policy Research Institute, *Food Systems Transformation in Kenya: Lessons from the Past and Policy Options for the Future*, 2023, 433-68, https://doi.org/10.2499/9780896294561_17. **Snapshot: Kenya** from the following sources: United Nations Environment Programme (UNEP), "UNEP Food Waste Index Report 2021", 2021, http://www.unep.org/resources/report/unep-food-waste-index-report-2021; US Department of Agriculture (USDA), "Empowering Kenyan Agriculture with Solar-Powered Cold Storage", Climate Hubs, accessed 20 March 2024, https://www.climatehubs.usda.gov/hubs/international/topic/empowering-kenyan-agriculture-solar-powered-cold-storage; food losses in Sub-Saharan Africa from USDA, op. cit. this note, from UNEP, op. cit. this note, and from Food Safety Africa, "Kenyan Innovators Collaborate to Launch First Solar Cold Storage with International Partners", Food Safety Africa Magazine, 2024, https://www.foodsafetyafrica.net/kenyan-innovators-collaborate-to-launch-first-solar-cold-storage-with-international-partners; demand for cooling from Food Safety Africa, op. cit. this note; 65% from United Nations High Commissioner for Refugees, "Access to Clean Energy in Displacement Settings Case Study: Kenya", 2023, https://data.unhcr.org/en/documents/download/104041; REREC from Rural Electrification and Renewable Energy Corporation, "Our Mandate", 2020, https://www.rerec.co.ke/our-work.php, and from Pauline Kimonda Kibet, "Use of Solar Energy to Reduce Food Loss and Waste in Rural Kenya", Norwegian University of Life Sciences Ås, 2023, https://nmbu.brage.unit.no/nmbu-xmlui/bitstream/handle/11250/3121839/Bachelors%20Thesis%202023%20Final%20submission.pdf; off-grid pilots from Harriet Kwamboka, "Kenya: EIB Supports Cutting-Edge Cold Storage Facility", European Investment Bank, 2023, https://www.eib.org/en/press/all/2023-479-eib-supports-africa-s-first-of-a-kind-cold-storage-facility-launch-in-kenya, from Rédaction AfricaNews, "Kenya: Solar Powered Cold Storage Helps Farmers Reduce Costly Waste", 9 November 2023, https://www.africanews.com/2023/09/11/kenya-solar-powered-cold-storage-helps-farmers-reduce-costly-waste, and from Food Safety Africa, op. cit. this note; sweet potato facility from Food Safety Africa, op. cit. this note, and from Baridi, "Solar-Powered Cooling in East Africa's Livestock Value Chain", accessed 20 March 2024, https://baridi.co.ke; FarmWorks, "Feeding Africa, Building Communities", accessed 20 March 2024, https://farmworks.africa; planned expansion from USDA, op. cit. this note.

65 GOGLA, "Adaptation and Resilience in the Face of Climate Disasters in Mozambique: The Role of Off-Grid Solar and Energy Access", December 2023, https://www.gogla.org/reports/adaptation-and-resilience-in-the-face-of-climate-disasters-in-mozambique-the-role-of-off-grid-solar-and-energy-access.

66 Hiroyuki Takeshima et al., "Solar-Powered Cold-Storage and Agrifood Market Modernization in Nigeria", *Agricultural Economics* 54, no. 2 (2023): 234-55, https://doi.org/10.1111/agec.12771.

67 Amir Vadiee, "Solar Heating and Cooling Applications in Agriculture and Food Processing Systems", in *Solar Energy Advancements in Agriculture and Food Production Systems*, 2022, 237-70, https://doi.org/10.1016/B978-0-323-89866-9.00001-8.

68 AC3A, "ICaRE4Farms: Improving Renewable Energy Capacity on Farms in North West Europe Using Solar Thermal Energy", AC3A Association Des Chambres d'Agriculture de l'arc Atlantique, accessed 4 April 2024, https://ac3a.fr/icare4farms.

69 Damu Murali et al., "Experimental Assessment of a Solar Photovoltaic-Thermal System in a Livestock Farm in Italy", *Solar Energy Advances* 4 (1 January 2024): 100051, https://doi.org/10.1016/j.seja.2024.100051.

70 Damu Murali et al., "Experimental Assessment of a Solar Photovoltaic-Thermal System in a Livestock Farm in Italy", *Solar Energy Advances* 4 (1 January 2024): 100051, https://doi.org/10.1016/j.seja.2024.100051.

71 Sahand Hosouli et al., "Evaluation of a Solar Photovoltaic Thermal (PVT) System in a Dairy Farm in Germany", *Solar Energy Advances* 3 (1 January 2023): 100035, https://doi.org/10.1016/j.seja.2023.100035.

72 M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en.

73 Mundoagro, "Inauguración de la planta solar flotante más grande del cono sur: Ministro de Agricultura resalta mejoras en sustentabilidad del sector", 17 November 2023, https://mundoagro.cl/inauguracion-de-la-planta-solar-flotante-mas-grande-del-cono-sur-ministro-de-agricultura-resalta-mejoras-en-sustentabilidad-del-sector; Ministry of Energy of Chile, "Ministros de Energía y Agricultura Inauguran Planta Solar Flotante En Región de O´Higgins", 16 November 2023, https://energia.gob.cl/noticias/nacional/ministros-de-energia-y-agricultura-inauguran-planta-solar-flotante-en-region-de-ohiggins.

74 Stephan Schindele et al., "Implementation of Agrophotovoltaics: Techno-Economic Analysis of the Price-Performance Ratio and Its Policy Implications", *Applied Energy* 265 (1 May 2020): 114737, https://doi.org/10.1016/j.apenergy.2020.114737.

75 Anas Rahman et al., "Agrivoltaics in India: Challenges and Opportunities for Scale-Up", International Institute for Sustainable Development, 2023, https://www.jstor.org/stable/resrep49783.

76 Rafael Faustino Ferreira et al., "Agri-PV in Portugal: How to Combine Agriculture and Photovoltaic Production", *Energy for Sustainable Development* 79 (1 April 2024): 101408, https://doi.org/10.1016/j.esd.2024.101408.

77 National Renewable Energy Laboratory, "Agrivoltaics | Solar Market Research and Analysis", accessed 13 March 2023, https://www.nrel.gov/solar/market-research-analysis/agrivoltaics.html; Open Energy Information, "InSPIRE/Agrivoltaics Map", accessed 13 March 2024, https://openei.org/wiki/InSPIRE/Agrivoltaics_Map.

78 Edgar Meza, "Turkey Launches Agrivoltaics Research Project", pv magazine International, 27 December 2023, https://www.pv-magazine.com/2023/12/27/turkey-launches-agrivoltaics-research-project.

79 Energy Sector Management Assistance Program, "Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers", 2022, https://www.esmap.org/mini_grids_for_half_a_billion_people_the_report; Energy Sector Management Assistance Program, "Energy Storage for Mini Grids: Status and Projections of Battery Deployment", 2023, https://www.esmap.org/Energy_Storage_for_Mini_Grids.

80 Energy Sector Management Assistance Program, "Accelerating the Productive Use of Electricity: Enabling Energy Access to Power Rural Economic Growth", 2023, http://documents.worldbank.org/curated/en/099092023192023389/P1751521d3f58f6f1307c1499619e141b8baef6de8dd.

81 Energizing Agriculture Programme, "Results", accessed 1 February 2024, https://energizingagricultureprogramme.org/results; Andrew Allee, "Electrifying Nigerian Agriculture with Clean Minigrids to Improve Livelihoods", Energizing Agriculture Programme, 11 February 2023, https://energizingagricultureprogramme.org/2023/02/11/electrifying-nigerian-agriculture-with-clean-minigrids-to-improve-livelihoods; Ayodeji Ojo, "As Petrol Prices Climb, Nigerian Agriculture Extension Officers Cut Fuel Costs with Electric Motorbikes", Energizing Agriculture Programme, 21 December 2023, https://energizingagricultureprogramme.org/2023/12/21/ev-pilot; Habiba Daggash, "Electric Rice Mills Reduce Reliance on Soaring Diesel Prices in Niger State, Nigeria", Energizing Agriculture Programme, 8 November 2023, https://energizingagricultureprogramme.org/2023/11/08/rice-mill-launch; Folawiyo Aminu, "Pilot Updates: Minigrid-Powered Cold Room", Energizing Agriculture Programme, 26 June 2023, https://energizingagricultureprogramme.org/2023/06/26/kiguna-fish-cold-storage.

82 Energy Sector Management Assistance Program, "Energy Storage for Mini Grids: Status and Projections of Battery Deployment", 2023, https://www.esmap.org/Energy_Storage_for_Mini_Grids.

83 Energy Sector Management Assistance Program, "Geothermal Energy: Unveiling the Socioeconomic Benefits", 2 January 2024, https://www.esmap.org/Geothermal_Socioeconomic_Benefits; Energy Sector Management Assistance Program, "Direct Utilization of Geothermal Resources. Technical Report 21/22", 2022, http://documents.worldbank.org/curated/en/099041723045541665/P17436403d07210800b1b60ccb0bd9304a9.

84 M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en

85 Energy Sector Management Assistance Program, "Geothermal Energy: Unveiling the Socioeconomic Benefits", 2 January 2024, https://www.esmap.org/Geothermal_Socioeconomic_Benefits.

86 International Renewable Energy Agency, "Global Geothermal Market and Technology Assessment", 2023, https://www.irena.org/Publications/2023/Feb/Global-geothermal-market-and-technology-assessment; Energy Sector Management Assistance Program, "Geothermal Energy: Unveiling the Socioeconomic Benefits", 2 January 2024, https://www.esmap.org/Geothermal_Socioeconomic_Benefits.

87 International Renewable Energy Agency, "Global Geothermal Market and Technology Assessment", 2023, https://www.irena.org/Publications/2023/Feb/Global-geothermal-market-and-technology-assessment

88 US Department of Agriculture, National Agricultural Statistics Service, "2022 Census of Agriculture", February 2024, https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report.

89 M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en
90 US Department of Agriculture, National Agricultural Statistics Service, "2022 Census of Agriculture", February 2024, https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report.
91 International Energy Agency, "Renewables 2023 – Analysis and Forecast to 2028", January 2024, https://www.iea.org/reports/renewables-2023.
92 International Energy Agency, "Renewables 2023 – Analysis and Forecast to 2028", January 2024, https://www.iea.org/reports/renewables-2023.
93 International Renewable Energy Agency, "Off-Grid Renewable Energy Statistics 2023", December 2023, https://www.irena.org/Publications/2023/Dec/Off-grid-Renewable-Energy-Statistics-2023.
94 M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en
95 US Department of Agriculture, National Agricultural Statistics Service, "2022 Census of Agriculture", February 2024, https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report.
96 Salmonexpert Noticias, "Ventisqueros inaugura primer centro que funciona 100% con energía eléctrica renovable", 17 August 2023, https://www.salmonexpert.cl/energias-renovables-ventisqueros/ventisqueros-inaugura-primer-centro-que-funciona-100-con-energia-electrica-renovable/1556880; The Fish Site, "Chile Switches on Its First Fully Renewable-Powered Salmon Farm", 5 September 2023, https://thefishsite.com/articles/chile-switches-on-its-first-fully-renewable-powered-salmon-farm.
97 Liv Casben, "Farmers Cashing in on Renewable Energy Opportunities", Newcastle Herald, 5 February 2024, https://www.newcastleherald.com.au/story/8510546/farmers-cashing-in-on-renewable-energy-opportunities; US Department of Agriculture, National Agricultural Statistics Service, "2022 Census of Agriculture", February 2024, https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report.
98 US Department of Agriculture, National Agricultural Statistics Service, "2022 Census of Agriculture", February 2024, https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report.
99 Gareth Moore and Pål Mugaas Jensen, 'Chile's First 100% Renewably-Powered Salmon Farm Switched On', 17 August 2023, https://www.fishfarmingexpert.com/chile-renewable-power-ventisqueros/chiles-first-100-renewably-powered-salmon-farm-switched-on/1557328.
100 M. Puri et al., "The Small-Scale Fisheries and Energy Nexus: Opportunities for Renewable Energy Interventions", Food and Agriculture Organization of the United Nations, 2023, https://doi.org/10.4060/cc4903en.

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