RENEWABLES IN AGRICULTURE

KEY FACTS FOR 2024

- Agrivoltaics, or the combination of solar PV power plants with agricultural activities, is shifting from the stage of pilot projects to a productive economic activity.
- Electrification of agricultural activities, including through solar irrigation systems, is increasingly the focus of policymakers.
- Most new policies supporting renewables in the agriculture sector in recent years focused on incentivising the adoption of on-farm solar PV.

The agriculture sector represented **2.5 %** of total final energy consumption (TFEC) in 2022.

17.8 % is the share of renewables in agricultural energy use as of 2022.

23 countries had policies targeting renewables in agriculture as of 2024.

SECTOR OVERVIEW

The agriculture sector, including crop and livestock farming, hunting, fisheries, aquaculture and forestry, represented 2.5% of global total final energy consumption (TFEC) in 2022, up from 2.2% in 2021.[i] China alone accounted for one-fifth (20.1%) of this consumption, and Brazil, the European Union, India and the United States together made up 41%.[1] About 70% of the energy consumed in the agriculture sector is in the form of heat, of which about 11% is renewable; almost all renewable heat in the sector is produced using modern bioenergy, with geothermal making up 1.1%, while the use of solar thermal heating remains negligible.[2] The share of renewable energy in the agriculture sector's TFEC was 17.8% in 2022, up from 11.4% in 2012.[3] (→ *See figure A-1.*).

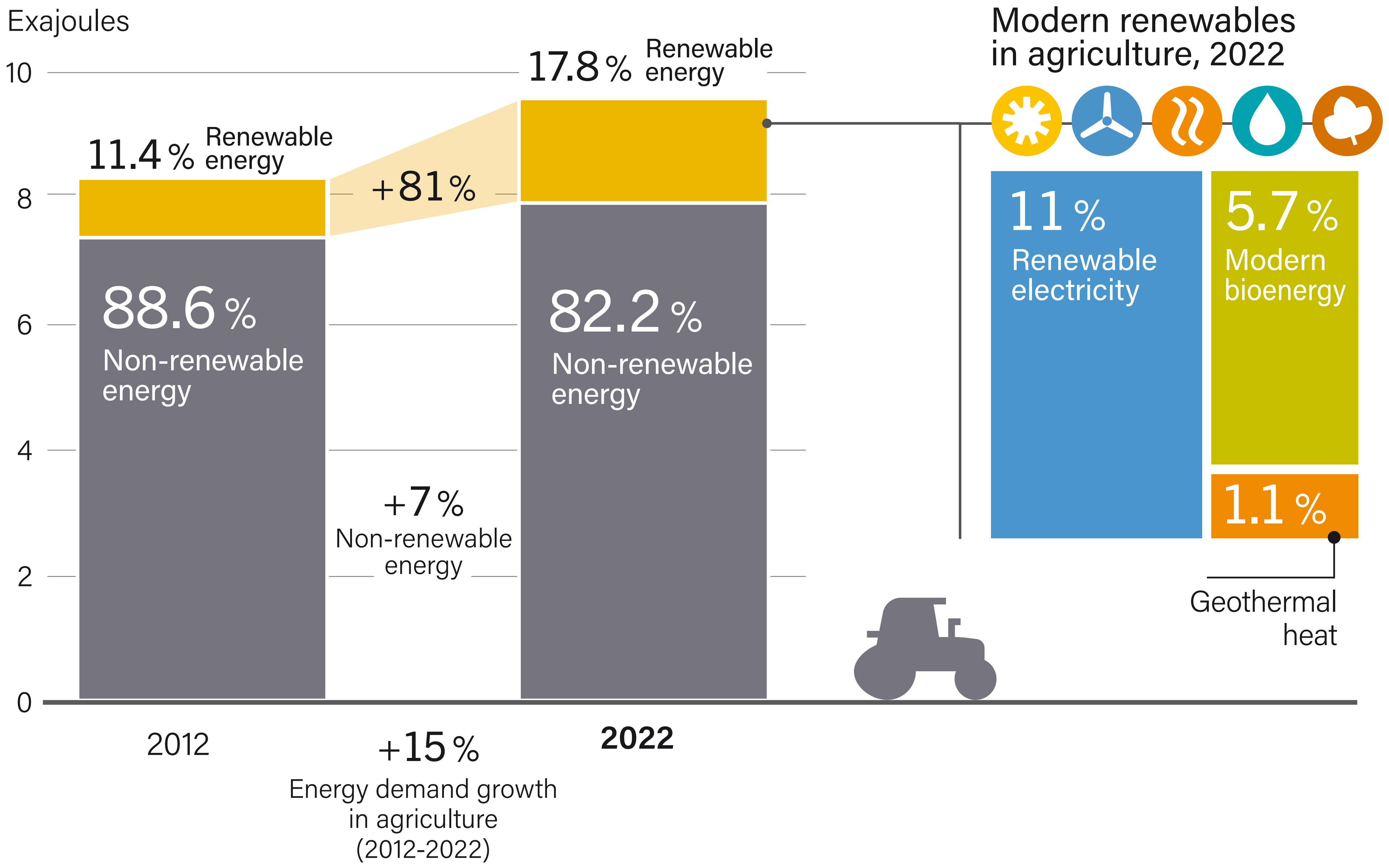
The global agrifood sector is responsible for 30% of global anthropogenic greenhouse gas (GHG) emissions, at 16.2 billion tonnes of CO_2 equivalent (Gt CO_2eq) in 2022, of which on-farm crop and livestock activities represented 48% (7.8 Gt CO_2eq).[4] Emissions from energy use on farms were 0.9 Gt CO_2eq, representing 12% of total on-farm emissions. This share has remained steady for the past decade.[5]

On farms, energy is mainly used for mechanised field operations (such as ploughing, planting and harvesting), irrigation and the operation of agricultural machinery. Additional demands arise from lighting, heating and cooling in controlled-environment agriculture, such as greenhouses and livestock

About **70 %** of energy consumed in the sector is used for heating.

i This section covers agriculture (including livestock farming and hunting), forestry, fisheries and aquaculture. When the section presents combined figures for more than one of these sub-sectors, these are either the only or the most accurate data 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 manufacturing of wood and wood products or 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.

FIGURE A-1
Renewable share in Total Final Energy Consumption in Agriculture, 2012 and 2022



Source: See endnote 3 for this section.

housing, and in on-farm (cold) storage facilities.[6] Approximately 70% of energy used within agrifood systems is consumed beyond the farm gate, primarily in activities such as transportation, processing, packaging, storage, distribution and marketing of agricultural inputs and outputs.[7]

In the fisheries and aquaculture sector, energy is used along the entire value chain, including for harvesting, processing, transportation and distribution, and in 2022 only 1% of the energy consumed in the sector was renewable.[8] Fishing vessels consume the largest amount of energy, both for propulsion (primarily oil and diesel fuel) and for onboard operations. Post-harvest stages, such as freezing, refrigeration and processing of fish, also require significant energy inputs. Additionally, energy is used in aquaculture systems for water pumping, aeration and temperature control.[9]

Globally, 30.7% of the agriculture sector's TFEC in 2022 was in the form of electricity.[10] The rate of electrification and the shares of other energy sources used in the sector vary widely across countries and regions. In the European Union, 58.4% of energy consumed in the agriculture and forestry sectors in 2022 was derived from oil and petroleum products[i]. This share is higher than the whole-economy average of 36.8%. However, in Greece, 69.5% of energy used in agriculture and forestry is electricity, and in Sweden, renewables and biofuels accounted for 39.1% of energy use in the sector.[11]

UPTAKE OF RENEWABLES IN THE AGRICULTURE SECTOR

Though energy use accounts for just 12% of on-farm emissions, the benefits of deploying renewable energy in the agriculture sector are increasingly recognised around the world. Integrating renewables into agroecological systems not only supports climate change mitigation targets but can also enhance climate resilience and strengthen rural livelihoods.[12]

Agrivoltaics, or the combination of solar PV facilities with agricultural activities, can mitigate the potential competition for land between energy and food production, while providing other benefits such as the reduction of irrigation demand and wind erosion, as well as the protection of crops and livestock against adverse weather events.[13]

Agrivoltaics is shifting from the stage of pilot projects to a high-potential economic activity.[14] However, recent global data on installed agrivoltaics capacity remain scarce and scattered. In 2021, global capacity was estimated at approximately 14 GWp, with China accounting for approximately 12 GWp of this,[15] followed by the United States with around 2.8 GW[16] and Japan.[17] More recently, in France, surveys identified around 1,610 agrivoltaics projects in operation or planning, totalling about 17.5 GW across more than 23,000 ha of farmland[ii].[18] In Germany, a 2024 analysis reports 21 agrivoltaics sites (total 81.7 MWp installed) by March 2023, with capacity expected to reach close to 400 MWp by the end of 2024.[19] By November 2024, US agrivoltaics capacity was estimated to have reached 10 GW across 600 sites.[20]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Solar grazing, or the combination of solar PV facilities with grazing pastures, especially for sheep, is expanding rapidly. In the **United States**, by October 2024 approximately 113,000 sheep were grazing under solar panels on about 52,200 ha (129,000 acres) of pastureland, up from 6,000 ha (15,000 acres) in 2021.[21] In **China**, the deployment of solar panels is increasingly combined with grazing and also supports the fight against desertification.[22] The USD 75 million (CNY 540 million) Xiahe Guoneng Complementary Pastoral-Photovoltaic Project, launched in 2023 and 80% completed as of early 2025, combines 100 MW of solar PV with animal husbandry. The land for the project is leased from local herders, whose cattle and sheep graze under the elevated panels, which provide shelter from the sun and wind.[23] The Tara Beach Photovoltaic Power Station in Qinghai began integrating grazing and solar power generation in 2021, with 12 photovoltaic ranches fully operational in Gonghe County as of 2024.[24] The 2 GW Suji Sandland PV project, due for completion by the end of 2025, will operate an innovative PV + ecological restoration model, using the microclimates created by elevated solar PV arrays to allow plant growth in the Inner Mongolian desert.[25] Examples also exist in New Zealand, where the Kohira and Rangitaiki solar farms have elevated solar panels to enable sheep grazing, machinery operations and, in the latter case, strawberry cultivation underneath.[26]

i Petroleum products are products derived from crude oil such as fuel oil, liquefied petroleum gas (LPG), gasoline (motor gasoline), gas/diesel oil (automotive diesel and heating gas/diesel oil), etc. See endnote 11.

ii The survey identifies 16 GW not yet connected to the grid and estimates that one quarter of the projects received authorisation or are already in operation, one quarter have requested a permit, one quarter are in the development stage and one quarter still in a pre-development stage.


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The global agrivoltaics market was valued at around USD **4.59** Bn in 2024.

The global **agrivoltaics market** was valued at approximately USD 4.59 billion in 2024. The value of North America's agrivoltaics market was estimated at USD 1.51 billion in 2024 (33% of the total), making it the largest regional market that year. The majority of installations in North America were found in the United States. Europe was the second-largest regional market (29% of the total), followed by Asia-Pacific (24%). Latin America and the Middle East & Africa represented around 10% and 4% of the 2024 market, respectively.[27]

Greenhouses support the cultivation of vegetables, flowers and seedlings in a controlled environment. They are efficient at trapping heat from the sun, but can also be large energy consumers when heating systems are used for additional warmth, and therefore generate substantial GHG emissions.[28] **Solar PV greenhouses** can significantly reduce emissions by using in-built solar PV systems to power heating, cooling, lighting and irrigation systems. Solar greenhouse systems range from basic rooftop solar panel setups to advanced systems that integrate energy generation with smart climate control, irrigation and monitoring. Uptake is accelerating, particularly in Asia-Pacific, Europe and North America, driven by rising electricity prices, pressure to reduce agricultural emissions and the need to optimise land and water use.[29] In some regions, including the United States and the European Union, the adoption of solar PV by the greenhouse agriculture sub-sector is fostered by policy incentives.[30] While various projections suggest significant growth of the **solar PV greenhouse market** in recent years, the overall valuation remains uncertain due to inconsistent definitions and limited tracking of operational projects.[31] China, the largest greenhouse horticulture market, is seeing increasing adoption of solar PV in greenhouses and research on solar thermal collectors for heating is advancing.[32]

Geothermal energy is also used for climate control in greenhouse agriculture, as well as in aquaculture.[33] **Türkiye** is home to one-third of the world's geothermal greenhouses, with more than 500 ha as of 2022, an expansion of 400% since 2002.[34] The country's geothermal greenhouse sector continues to expand rapidly: in early 2024, the Istanbul-based company Yediyol completed the first phase of a 100 ha facility in Konya, aimed at scaling up tomato exports.[35] In the **Netherlands**, the first phase of the Aardwarmte Maasdijk geothermal greenhouse heating project began operations in early 2025.[36] The project will supply 440 ha of greenhouses owned by 80 horticulture companies in the region.[37] In **New Zealand**, the Huka Prawn Park aquaculture facility uses geothermal waste heat from the adjacent Wairakei power station via heat exchangers, and recently upgraded its system to deliver water with temperatures up to 130°C at 5,000 L/min.[38] In **Iceland**, the Friðheimar farm operates six geothermally heated greenhouses (~6,000 m^2 total), producing over 2 t of tomatoes per day, powered by locally sourced 95°C geothermal water.[39] The country's geothermal power stations, such as Hellisheidi and HS Orka, also provide residual steam and hot water for aquaculture activities.[40] In Eastern **China**, growers are increasingly using shallow subsoil geothermal heat for both heating and cooling of greenhouses.[41] However, data specifically on geothermal greenhouse-heating capacity for China in 2024 are unavailable.

Global data on on-farm **biogas** production from manure and other agricultural waste are scarce. Small biodigesters are widespread on farms, with reportedly over 40 million household-scale digesters in operation, mostly in rural China, but also in Brazil, India, Southeast Asia and some parts of Africa.[42]

A 2024 analysis of some of the main biogas producing countries showed that in **Germany**, the largest biogas producer, nearly 8,000 agricultural plants produced about 80% of the country's biogas in 2021.[43] In **China**, the vast majority (>95%) of biodigesters are installed on farms, yet over 60% of biogas was produced in a relatively small number of industrial digesters in 2024.[44] In **Denmark**, however, 52% of biogas facilities were located on farms in 2022 and these produced over 90% of the country's biogas.[45] In **Brazil**, the majority of digesters are found in the agriculture sector, but landfills produce more biogas.[46] In **France**, anaerobic digesters using agricultural feedstocks form the fastest-growing segment of biogas producers, with nearly 1,300 facilities as of 2023, of which almost 1,100 were on farms and 179 centralised. These facilities produced 39% of the country's biogas-generated electricity and 89% of biomethane.[47] Biogas from agricultural waste is mostly used for on-site combined heat and power (CHP) generation on farms, especially in Germany, Brazil and France. In countries including Denmark, France and Germany, a growing share of facilities is able to produce biomethane and feed this into the gas grid, contributing to national renewable gas targets. Biomethane is increasingly used in the transport sector, particularly in France and Germany, where infrastructure for compressed biomethane (bio-CNG) is expanding.[48] In **Japan**, the total number of agriculture-based biogas plants was estimated at 100 in 2021.[49]

In the **United States**, the focus of the biogas sector is shifting from landfill gas to agricultural waste. Policy incentives, including the Inflation Reduction Act (IRA) and state-level schemes, propelled a quadrupling of plant numbers from 2018 to 2023.[50] As of June 2024, there were over 400 manure-based anaerobic digesters operating at livestock farms in the United States and more than 70 additional digesters under construction.[51] Biogas from agricultural waste represented 13% of all biogas production.[52] In the United States, like in Europe, biogas from agricultural waste is mainly used for on-farm CHP, with a growing share used as commercial vehicle fuel (CNG/RNG). Smaller uses include direct boiler fuel, while digestate is used as fertiliser.[53]


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Electrification of agricultural machinery represents a growing opportunity to accelerate the uptake of renewable energy in the agriculture sector. With farm operations historically reliant on diesel-powered equipment, the shift to electric alternatives can contribute to GHG emission reductions while fostering energy autonomy, especially when paired with on-site renewable generation. In 2024, the global market for electric tractors alone was estimated at between USD 640 million and USD 2 billion, depending on the scope of machinery included.[54] The adoption of electric farm machinery is propelled by rising fuel costs, improved battery performance and financial incentives. New electric machinery includes not only tractors, but also battery-powered planters, sprayers, harvesters, tillage equipment and autonomous robotic units, bringing the value of the broader electric agricultural machinery market to an estimated USD 12.5 billion in 2024.[55] North America currently leads in market share, while Europe is seeing rapid growth due to targeted policy support and incentives.

Despite this growing momentum, challenges remain. Electric machinery often requires a higher upfront investment, while a lack of charging infrastructure in rural areas may hamper adoption. Battery weight remains an issue, as farm machinery needs to be able to operate for long hours during peak season but cannot get so heavy that its on-field use leads to soil compaction.[56] However, opportunities are seen in specialised farming contexts, where electric equipment is already viable and cost-effective. Innovations from both established manufacturers and startups are expanding the range and functionality of electric options, often integrating autonomy and smart sensors, or even replacing one large unit with a swarm of small autonomous units.[57] Rental, sharing and 'as a service' models for electric agricultural machinery can help overcome the upfront cost barrier and some providers are exploring these solutions.[58]

With diesel fuel accounting for nearly three-quarters (74%) of the energy used for water pumping for irrigation, the deployment of **solar-powered irrigation systems** presents a significant opportunity to increase the uptake of renewables in the sector.[59] In 2023, the global installed solar water pump capacity reached 1.1 GW, up 1.8% from 2022, and India was home to 94% of this capacity.[60] Besides India, only six countries in the world have more than 1 MW of installed capacity: Bangladesh (49.2 MW), Philippines (3.3 MW), Yemen (2.7 MW), Syria (2 MW), Nepal (1.4 MW) and Argentina (1.2 MW).[61] Agriculture represents 63% of the global solar water pump market.[62] The biggest challenge to the widespread adoption of solar irrigation systems is affordability.[63] The off-grid solar industry offers low-cost technologies powered by small solar panels specifically developed for smallholder farmers, with reportedly 291,300 solar water pumps sold in 2024[i],[64]

The uptake of renewables in the **fisheries** sector is at an early stage, as vessels remain largely dependent on fossil fuels for propulsion and on-board activities. Solutions to power fishing boats with alternative fuels (hydrogen, biofuels, including some produced using fish waste, and batteries for smaller vessels) and to power on-board operations using renewables (for instance through on-board solar PV and wind power generation) are being explored by shipping companies and industry associations.[65]


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i Sales reported by GOGLA affiliated companies as of 2024. See endnote 62.

POLICY DEVELOPMENTS

As of 2024, 23 countries had policies in place targeting renewable energy uptake in the agriculture sector; fiscal and financial incentives were the most widely adopted policy instruments.[66] (→ *See figure A-2.*)

Most new policies supporting renewables in the agriculture sector in recent years focused on incentivising the adoption of solar PV technologies for farming activities.[67] Examples include the USD 1.84 billion (EUR 1.7 billion) budget allocated in **Italy** to the deployment of agrivoltaics, subsidies in **Morocco** for the purchase of solar pumps, and the **United Kingdom** Farming Investment Fund supporting the acquisition of new equipment for farmers, which includes solar PV to increase farm productivity.[68] In Türkiye, under certain conditions, renewable energy power plants established for the purpose of agricultural irrigation do not require a license from the Energy Regulatory Authority.[69] **South Korea** set a target of 10 GW of solar PV capacity on agricultural lands by 2030.[70] In **Japan**, a feed-in tariff scheme led to the installation of over 4,000 small overhead solar PV systems on farms, with an average system size of <0.1 hectare.[71]


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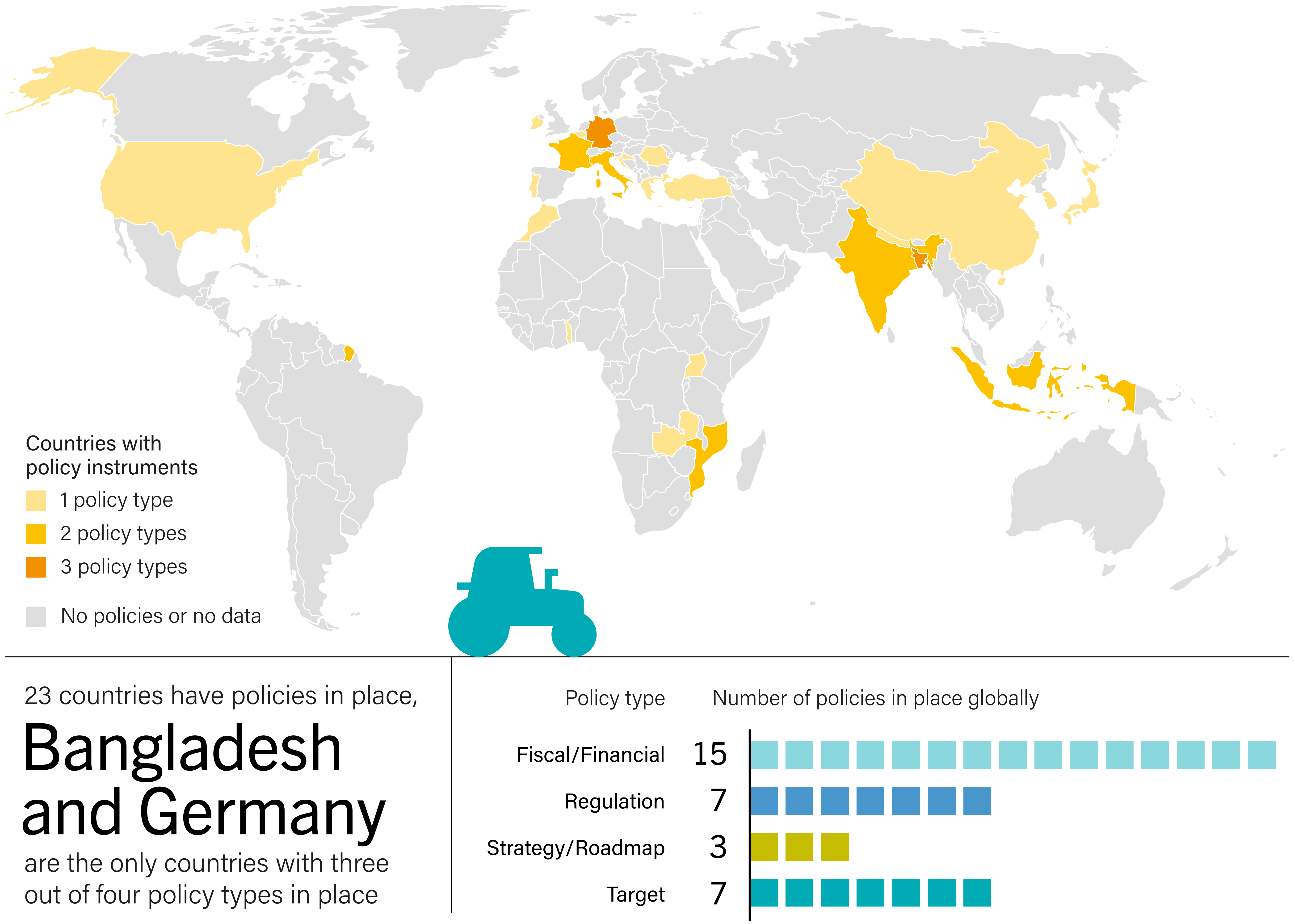
FIGURE A-2
National policies for renewable energy in the agriculture sector, as of 2024



Note: this map does not include subnational policies and NDCs
Source: See endnote 66 for this section.

A growing number of countries, including **Croatia, France, Germany, Italy** and **Japan**, is defining standards and rules for the deployment of solar PV on agricultural land, to prevent land conversion and encourage farmers to continue their farming activities – this is necessary because the revenue generated by the solar PV arrays is often far greater than that derived from the crops grown below them.[72] Standards include criteria for maximum reduction of agricultural yield as a consequence of the solar PV installations (compared to the original situation) to be eligible for support or to obtain permits.[73] EU member states such as **Romania** and **Portugal**, in transposing the EU Common Agricultural Policy (CAP), have proposed subsidies for the installation of on-farm solar and wind generation.[74]

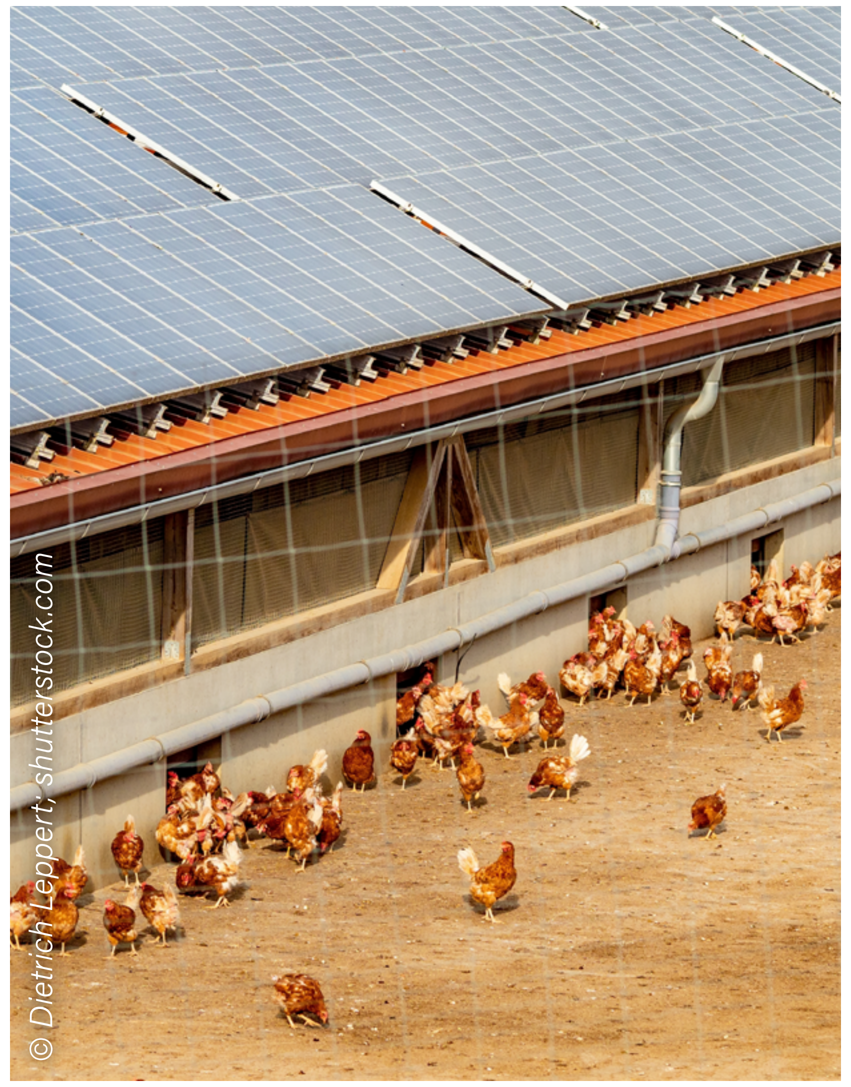
The installation of solar irrigation systems is viewed as an important climate change mitigation measure that also enhances farmer resilience, with more than 20 countries - mostly in Africa and Asia - incorporating deployment targets for such systems in their Nationally Determined Contributions (NDCs) under the Paris Agreement.[75]

Several strategies and roadmaps promote the adoption of renewable energy in the agriculture sector beyond solar PV. **Zambia**'s National Agriculture Mechanisation Strategy 2024-2028 states that the mechanisation of agriculture should be based at least partly on renewable energies.[76] In **Switzerland**, the Climate Strategy for Agriculture and Nutrition 2050 targets the deployment of solar energy in agricultural buildings, as well as the production of energy from biomass following the cascade principle.[i] The strategy states that the agriculture sector shall produce more renewable energy than it consumes.[77] In **Uganda**, the 2023 Energy Policy promotes the deployment of renewable energy in agriculture and includes geothermal energy in addition to solar PV and solar drying systems.[78]

A smaller number of strategies and policies specifically target biogas: the Government of **India** provides incentives for the adoption of on-farm anaerobic digesters, in line with its goal to phase out diesel in farming operations, first announced in 2022.[79] **Kenya**'s Ministry of Energy and Petroleum Strategic Plan 2023-2027 aims to promote clean energy solutions, including by constructing 2,000 biogas demonstration units by 2027.[80] In the **United States**, the IRA supported the construction of anaerobic digesters on farms through grants and loans under the Rural Energy for America Program (REAP).[81]

Policies focusing specifically on promoting geothermal energy, solar thermal heating and wind power in the agriculture sector remain scarce.

i "Cascading refers to consecutive exploitation of resources for multiple ends, typically through various phases of material usage before the final energy production processes"; in this case, the strategy states that biomass should be used and recycled several times before being used to generate energy.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Over
20 countries,
mostly in Africa and Asia, include solar irrigation targets in their NDCs.

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