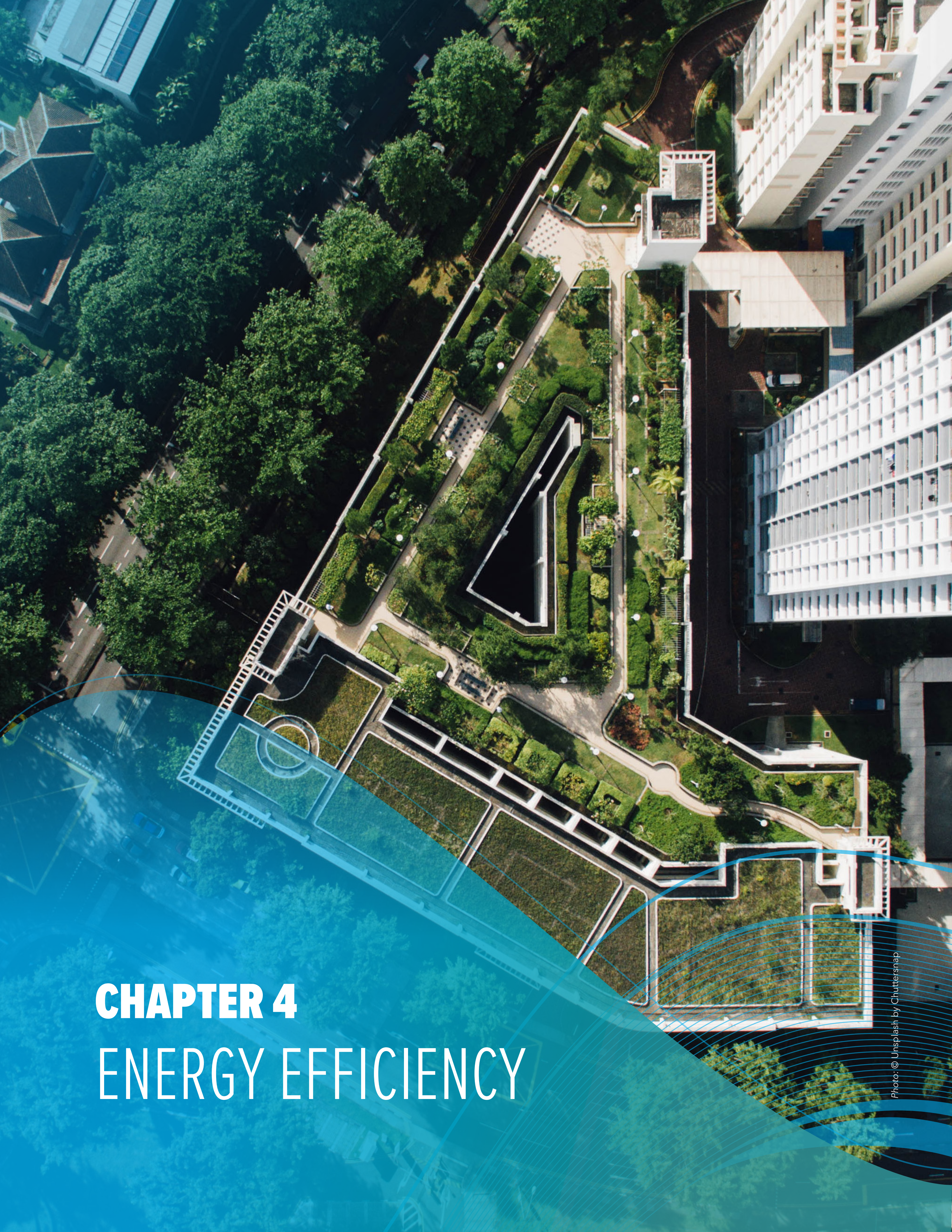


CHAPTER 4
ENERGY EFFICIENCY

Photo: © Unsplash by Chuttersnap

Main Messages

- **Global trend.** Primary energy intensity[54]—defined as the percentage decrease in the ratio of total energy supply per unit of gross domestic product (GDP)—improved at a consistently higher rate over the past decade (2010–20) than it did in the previous two (1990–2010). However, the rate of improvement declined to 0.6 percent in 2020, largely because of Covid-19–induced lockdowns and travel restrictions, and the radical shifts in the global economy that accompanied the initial lockdowns in that year. This makes 2020 the worst year for energy intensity improvement since the global financial crisis, with worldwide energy intensity declining to 4.63 megajoules (MJ) per 2017 US dollar. The pandemic makes it difficult to draw firm conclusions regarding whether the slowdown in 2020 reflects wider changes in the pace of structural energy efficiency improvements. However, the low energy prices seen during the pandemic have quickly faded, replaced by record high energy prices, prompting a renewed focus on improving energy efficiency, shielding consumers and industry, and improving energy security and sustainability.
- **2030 target.** The decade 2010–20 saw stronger energy intensity improvements on average, yet these remained below the target set under the United Nations Sustainable Development Goals (SDGs), of achieving, on average, a doubling of the global energy efficiency improvement rate between 2010 and 2030, compared with the 1990–2010 level. Globally, energy intensity improved at 1.8 percent annually between 2010 and 2020, surpassing the 1.2 percent rate seen between 1990 and 2010, although it remains well below the SDG target 7.3 of 2.6 percent on average required over the entire SDG time horizon (2010–30). Estimates for 2021 point to continued low progress in intensity improvement due to the COVID-19 crisis, although early estimates for 2022 suggest a rebound to higher levels of improvement, aided by renewed policy support and urgency in the wake of the energy crisis. Future annual improvements would need to increase to over 3.4 percent per year to make up for lost ground and meet SDG target 7.3 .
- **Regional highlights.** Eastern and South-eastern Asia came close to the initial target of 2.6 percent improvements annually, reaching 2.3 percent on average between 2010 and 2020. This was driven by robust efforts to phase out older, inefficient industrial capacity, improve the energy efficiency of buildings and industry, and shift increasingly toward industries that are less energy intensive. Average annual improvement rates in Northern America and Europe (2.0 percent), Central Asia and Southern Asia (2.0 percent), and Oceania (1.8 percent) were also above the global average and historical trends. The lowest improvement rates were achieved in Western Asia and Northern Africa (0.7 percent), followed by Latin America and the Caribbean (1.0 percent) and Sub-Saharan Africa (1.0 percent). Data on absolute energy intensity reveal wide regional differences, especially in regions with low access levels, and where households must rely on the traditional use of bioenergy for cooking. For example, energy intensity in Sub-Saharan Africa is close to double that in Latin America and the Caribbean. This highlights the strong interlinkage between universal access to clean cooking and reaching SDG target 7.3. In a similar manner, increasing renewables' shares in electricity generation improves supply efficiency by eliminating losses incurred in the conversion of primary (nonrenewable) fuels into electricity. This relationship highlights the synergies between SDG targets 7.2 and 7.3.

54 Hereafter referred to as "energy intensity." See note to figure 4.8 for the definition of energy intensity by sector.

- **Trends in the top 20 energy-consuming countries.** Comparing the periods 2000–10 and 2010–20, the annual rate of energy intensity improvement increased in 14 of the 20 countries with the largest total energy supply in the world. However, less than half of the top energy-consuming countries had improvement rates higher than the global average. Energy intensity continued to improve the fastest in the United Kingdom and China, at an annual average of 3.5 percent and 3.3 percent, respectively, between 2010 and 2020, followed by Indonesia, at 3.1 percent. Energy intensity also continued to improve at rates beyond SDG target 7.3 in Japan and Germany (at 2.9 and 2.7 percent, respectively). In 2020, the COVID-19 pandemic slowed energy intensity improvements across 12 of the top 20 energy-consuming countries, including routine leaders in efficiency, such as China and Indonesia.
- **End-use trends.** Energy intensity improved faster across all sectors, except the residential buildings sector, in 2010–20 compared with the previous decade. Intensity improvement was the fastest in the freight transport sector, at 2.2 percent a year, followed by passenger transport, at 1.9 percent. Notable progress can also be seen in industry (1.6 percent), which spans a range of energy-intensive economic activities. This is a major enhancement since sectoral energy intensity had deteriorated in the preceding period. Sectoral improvement rates were the lowest in the residential sector, where energy intensity improvement slowed from 1.9 percent in the previous period to 1.2 percent annually between 2011 and 2020.
- **Policies and investment in efficiency.** The year 2020 saw only a slight decline in overall energy efficiency investments (at nearly USD 380 billion) despite the COVID-19 crisis, even though trends differed widely across sectors and regions. Europe, China, and Northern America accounted for nearly 80 percent of the spending. Moreover, in recent years, energy efficiency incentives, regulations, and information campaigns have received major support from clean energy recovery spending and energy crisis packages. Over USD 250 billion of government spending has been allocated to efficiency in buildings and industry, and an additional USD 180 billion has been allocated to low-carbon vehicles between 2020 and December 2022. It is important to continually update energy efficiency standards and labels, building codes, and energy efficiency obligation (EEO) schemes to reflect the latest technology and market trends.

Are We on Track?

SDG 7 commits the world to ensure universal access to affordable, reliable, sustainable, and modern energy. Under this goal, target 7.3 calls for global advances in energy efficiency by doubling the global rate of energy intensity improvement relative to the average rate over the period 1990–2010—which meant improving energy intensity by 2.6 percent per year in 2010–30.[55] Energy efficiency improvement and energy wastage reduction also play a part in the pace and cost of progress on universal access to energy and renewable energy. Energy intensity is the ratio of the total energy supply to the annual GDP created—in essence, the energy used per unit of wealth created. We can use this measure of energy intensity to observe how energy use rises or falls, while also looking for the (social and economic) development factors that may affect the corresponding rates, along with other factors, such as weather and behavior change. In general, energy intensity declines as energy efficiency improves.

Progress toward SDG target 7.3 is measured by tracking the year-on-year percentage change in energy intensity. Initially, the United Nations recommended an annual improvement rate of 2.6 percent between 2010 and 2030 to achieve the target, although global progress has been slower than that in all years except 2015. This means that energy intensity now needs to improve at no less than 3.4 percent globally from 2020 to 2030. In other words, energy intensity needs to improve at almost twice the rate in the past decade (which was itself almost 50 percent faster than between 1990 and 2010). An even greater improvement, at 4.2 percent, is needed to reach the International Energy Agency's (IEA's) Net Zero Emissions by 2050 Scenario (NZE)[56] (figure 4.1).

Globally, energy intensity has improved gradually since 1990[57] (figure 4.2). Recent numbers show that global energy intensity improved only 0.6 percent in 2020, to 4.63 MJ/USD (2017 PPP [purchasing power parity]), in the context of the COVID-19 crisis. This was the lowest rate of improvement since the global financial crisis. Moreover, historical GDP and energy intensity data suggest that large declines in GDP, such as those occurring in 2020, tend to be followed by declines in future energy intensity improvement rates (IEA 2020). For example, GDP was increasing at over 5 percent per year globally in 2006 and 2007; it fell to 3 percent in 2008 and then to zero in 2009. Energy intensity data show corresponding declines in energy intensity improvement rates not only in 2008 and 2009 but also 2010, when global GDP growth returned to precrisis levels of about 5 percent. This is consistent with the low expected energy efficiency improvement for 2021.

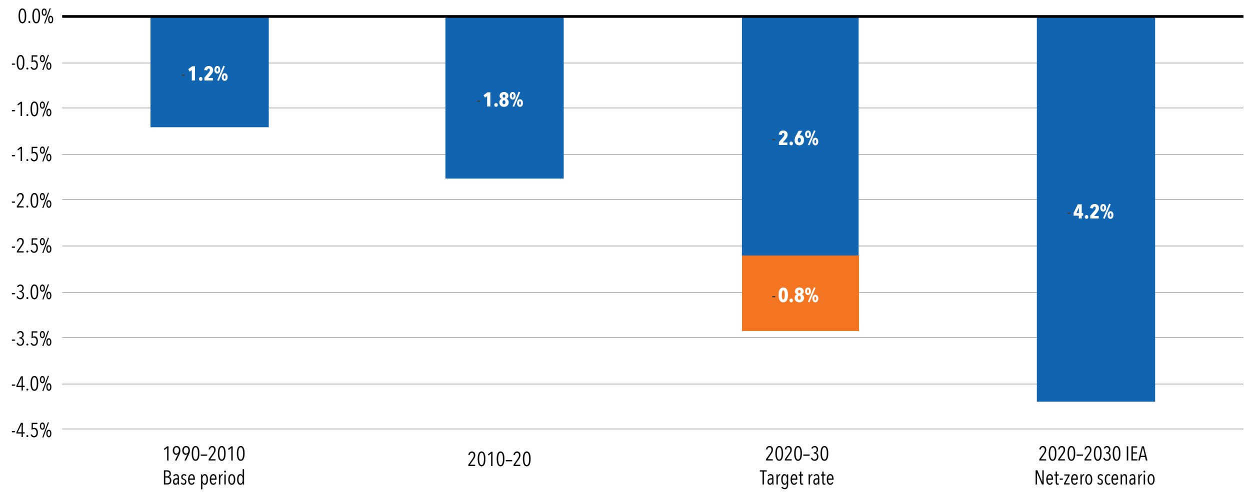
---

55 Revisions of underlying statistical data and methodological improvements explain the slight changes in growth rates in the base period (1990–2010) from previous editions. SDG target 7.3 of improving energy intensity by 2.6 percent per year in 2010–30 remains the same, however.

56 The Net Zero Emissions by 2050 Scenario maps out a path to stabilize the global average temperature rise to 1.5°C, alongside universal access to modern energy by 2030.

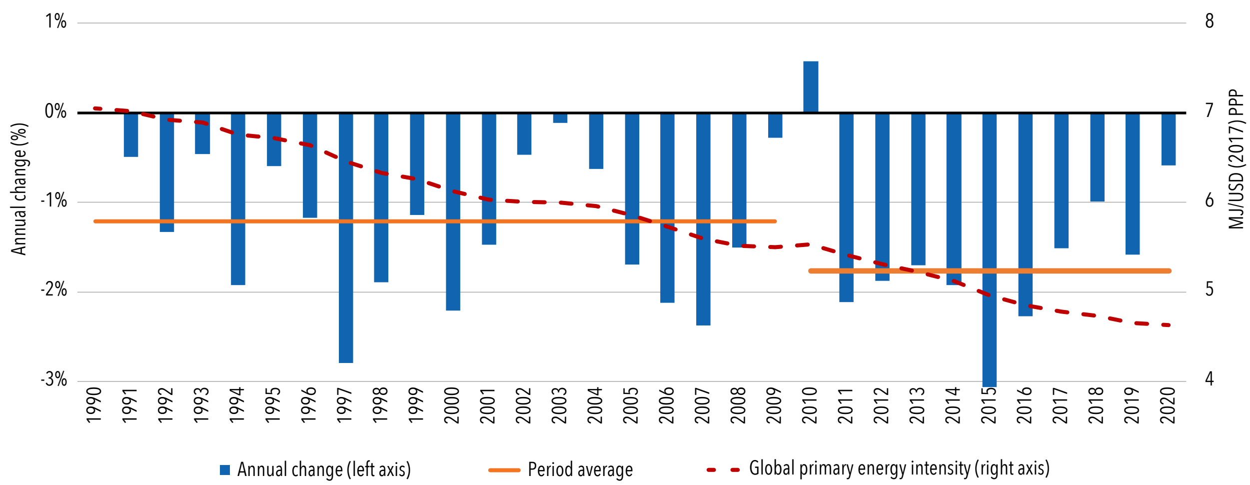
57 The majority of the energy data in this chapter comes from a joint data set built by the International Energy Agency (https://www.iea.org/data-and-statistics/) and the United Nations Statistics Division (https://unstats.un.org/unsd/energystats/). GDP data are sourced from the World Bank's World Development Indicators database (http://datatopics.worldbank.org/world-development-indicators/).

Figure 4.1 • Growth of primary energy intensity by period and target rate, 1990–2030



Sources: IEA, UN, and World Bank (see footnote 4).

Figure 4.2 • Global primary energy intensity and its annual change, 1990–2020



Sources: IEA, UN, and World Bank (see footnote 4).
MJ = megajoule; PPP = purchasing power parity.

Looking Beyond the Main Indicators

COMPONENT TRENDS

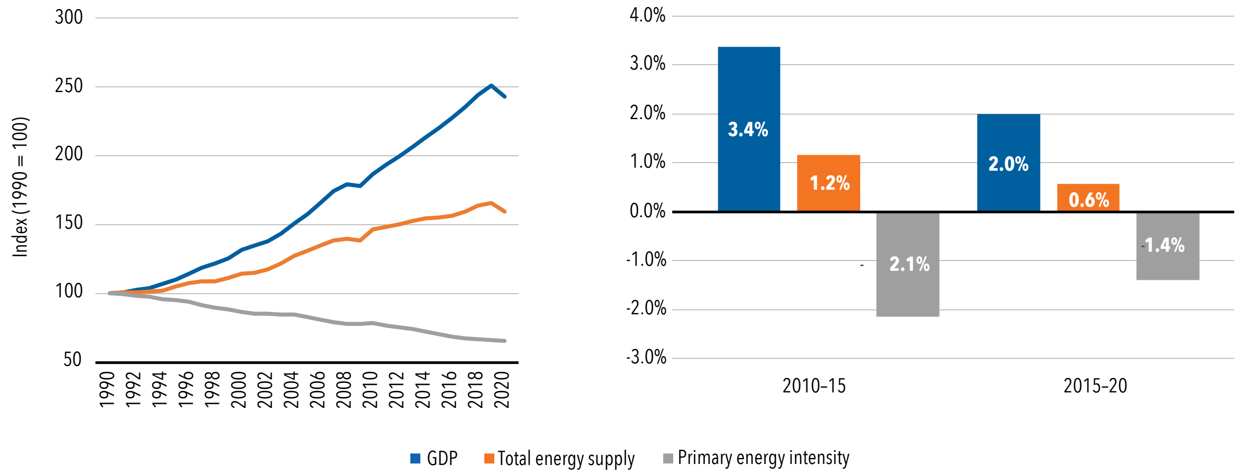
Between 2019 and 2020, for the first time since the global financial crisis in 2009, both GDP and total energy supply decreased, by 3.2 and 3.8 percent, respectively. Meanwhile, GDP declining slightly less than energy supply, resulting in a small improvement in energy intensity. However, this improvement was the smallest since 2010, and in the aftermath of the global financial crisis. This trend is due to energy-intensive industry's larger share of energy demand and slower efficiency progress, especially in the buildings and industrial sectors (IEA 2021d).

Over the longer term, the impact of energy intensity improvement is revealed by trends in its underlying components (figure 4.3, left). Between 1990 and 2020, global GDP increased by a factor of 2.4, whereas global total energy supply[58] grew 60 percent, signaling trends in the decoupling of energy use from economic growth. This resulted in a consistent improvement in global energy intensity, which fell by more than a third between 1990 and 2020.

However, there has been a decline in energy intensity improvements more recently. Between 2010 and 2015, energy intensity improved by 10.2 percent, but it grew much slower, at 6.8 percent, between 2015 and 2020 (figure 4.3, right).

Recent trends in energy efficiency are discussed in box 4.1.

Figure 4.3 • Trends in the underlying components of global primary energy intensity, 1990–2020; and growth rates of GDP, total energy supply, and primary energy intensity, 2010–20



Sources: IEA, UN, and World Bank (see footnote 6).
GDP = gross domestic product.

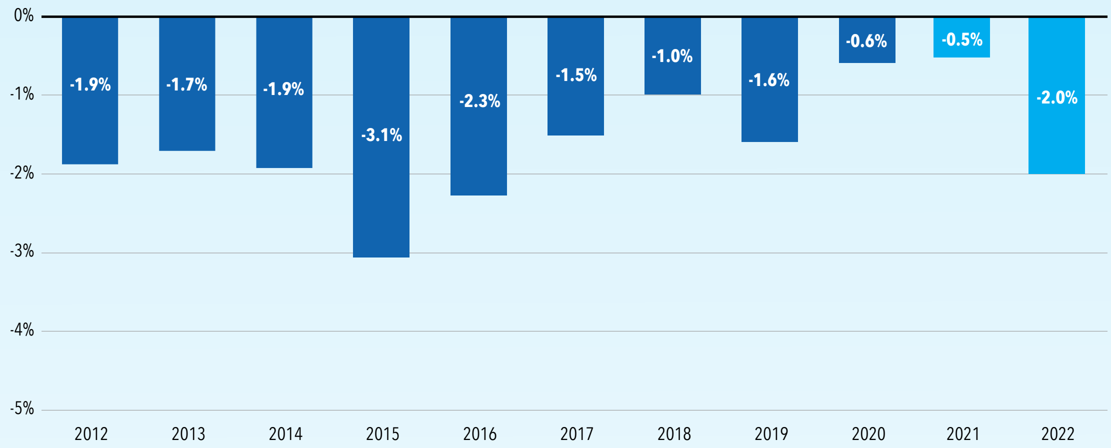
58 "Total primary energy supply" has been renamed "Total energy supply" in accordance with the International Recommendations for Energy Statistics (UN 2018).

Box 4.1 • Recent energy efficiency trends

The COVID-19 pandemic and then the energy crisis following Russia's invasion of Ukraine have disrupted energy and economic trends in recent years.

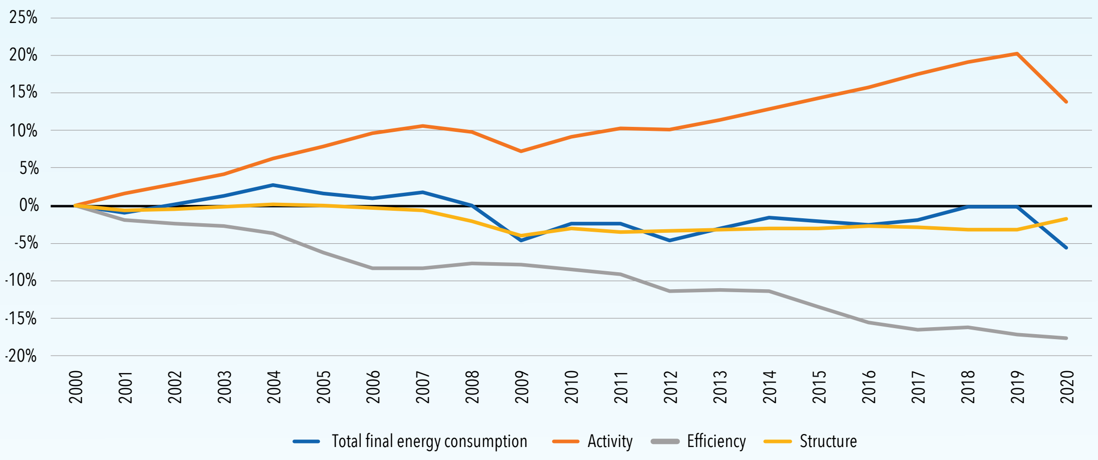
The year 2020 was one of the worst in terms of advancement in energy efficiency. Energy intensity improved by a mere 0.6 percent owing to low energy demand and prices, technical efficiency sluggish improvements in technical efficiency, and a shift in economic activity away from less energy-intensive services, such as hospitality and tourism. Initial estimates for 2021 suggest even less improvement of energy efficiency, at 0.5 percent, although there may have been a turning point in 2022, with initial estimates suggesting progress at about 2 percent.

Figure B4.1.1 • Growth rate of global primary energy intensity, 2012–22



Sources: IEA, UN, and World Bank (see footnote 4); IEA 2022c.

Figure B4.1.2 • Change in energy demand and demand drivers in IEA countries, 2000–20



Sources: IEA, UN, and World Bank (see footnote 4); IEA 2022c.
Note: Change in total final energy consumption is the net effect of changes in activity, efficiency, and structure across buildings, transport, and industry. For example, in residential buildings, activity refers to population, structure refers to per capita floor area, and efficiency refers to energy use per floor area.

However, early estimates suggest that 2022 could be a turning point for energy efficiency. The energy crisis proved a strong reminder of the importance of energy efficiency for energy security as well as energy and carbon dioxide emissions savings. Price increases also increased the value of energy efficiency, and diminished payback times. This led to accelerated energy efficiency investments, a rising wave of energy awareness campaigns, strengthening of building codes, and increased electrification of transport and heating (IEA 2022b). Improvement in energy efficiency is therefore expected to rebound, at 2 percent. However, this is still slower than what is needed to reach SDG 7 targets. Sustained effort is needed to accelerate that trend.

REGIONAL TRENDS

The COVID-19 crisis significantly affected both energy consumption and GDP in all regions. As a general trend, GDP declined in all regions in 2020. This was followed by a rebound in 2021, with regional variations depending on the timing and length of pandemic-related restrictions. In 2020, these shifts brought about significant swings in energy intensity, as energy consumption in Eastern Asia, South-eastern Asia, Sub-Saharan Africa, and Oceania continued to rise, putting upward pressure on energy intensity. And while energy consumption declined in Latin America, the decline in GDP was greater, also leading to a slowdown in energy intensity improvements. In Northern America and Northern Africa, energy intensity improved generally (that is, it decreased), although at lower rates than in the previous years. In Europe, energy intensity worsened slightly (that is, increased), while remaining stable in Western Asia and Northern Africa, and in Central Asia and Southern Asia.

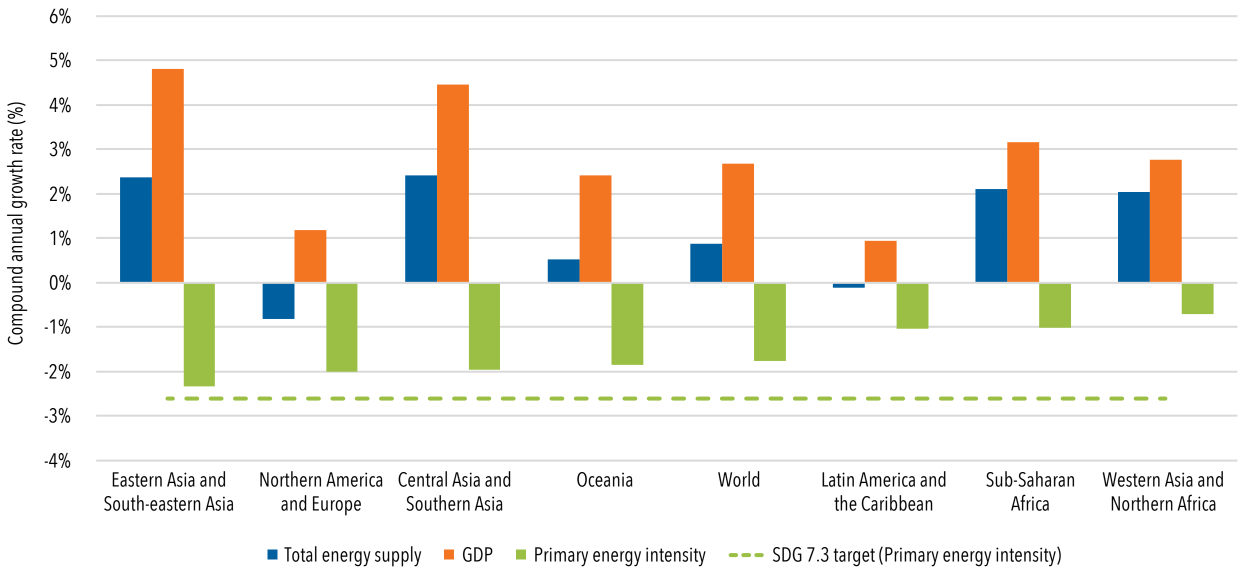
Energy intensity has improved across the world since 2010, but significant differences in trends are observed across regions (figure 4.4). Economies in Central, Southern, Eastern, and South-eastern Asia have seen a rapid increase in economic activity, and the associated increase in total energy supply has been mitigated in part by significant improvements in energy efficiency, which have put downward pressure on the global average.

Over the same period, economies in Northern America and Europe experienced a slight decrease in their total energy consumption, which reflects slower economic growth and a decoupling of the economy from energy usage. This last trend was enabled by a continued shift toward industrial activities consuming less energy and the greater energy efficiency that is typically observed when mature policies are in place, especially in buildings (Northern America) and industry (Europe). In these economies, energy intensity improved at rates slightly above global trends, leading to absolute energy intensity levels slightly below the global average (figure 4.5). Similar trends and absolute energy intensity levels have been observed for Oceania, where total energy supply increased modestly, whereas GDP grew faster than in Northern America and Europe.

Latin America and the Caribbean, Western Asia and Northern Africa, and Sub-Saharan Africa recorded the smallest average gains in energy intensity improvement over the period 2010–20 (1 percent per year or less). However, trends differed across these regions. In Latin America and the Caribbean, total energy supply decreased slightly, and GDP growth was among the lowest worldwide. The region is also the less energy-intensive in the world, at 3.3 MJ/USD (2017 PPP) (figure 4.5). On the other hand, in Western Asia and Northern Africa, and Sub-Saharan Africa, total energy supply and GDP grew at rates higher than the global average. In absolute terms, economic output in Sub-Saharan Africa is highly energy intensive, at 6.3 MJ/USD (2017 PPP). The figure for Western Asia and Northern Africa was 4.3 MJ/USD (2017 PPP) (figure 4.5).

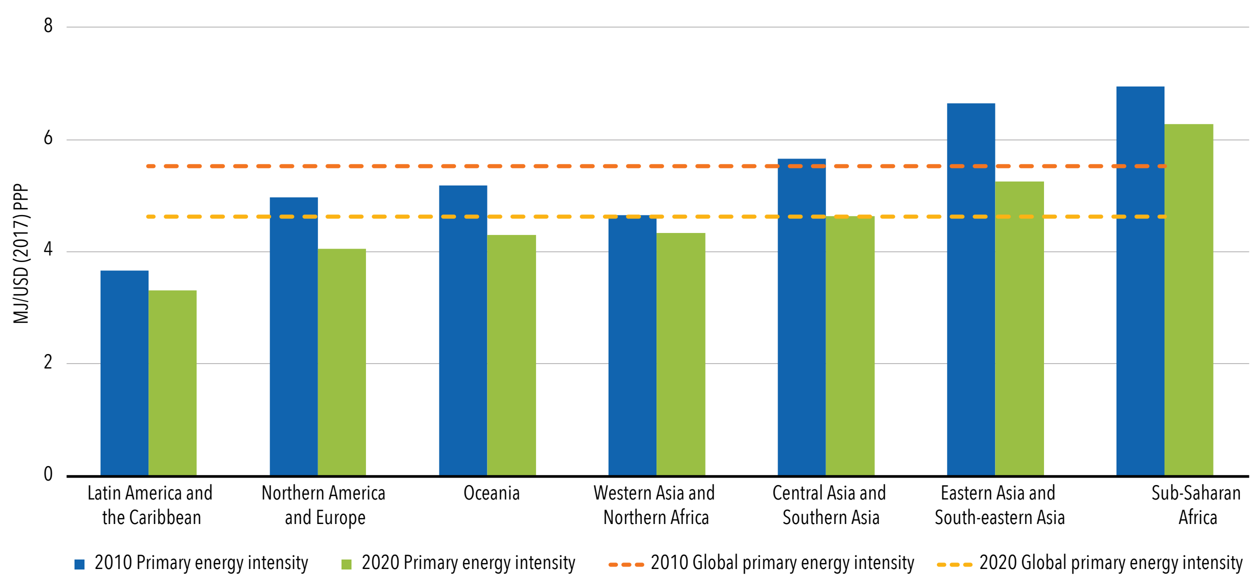
Three regions (Eastern Asia and South-eastern Asia, Latin America and the Caribbean, Western Asia and Northern Africa) saw energy efficiency improvements double in 2010–20 compared with those in 1990-2010. However, the absolute level remained relatively low, at 0.7 and 1 percent, respectively, for the last two regions.

Figure 4.4 • Growth rate of total energy supply, GDP, and primary energy intensity at a regional level, 2010–20



Sources: IEA, UN, and World Bank (see footnote 4).
GDP = gross domestic product; SDG = Sustainable Development Goal.

Figure 4.5 • Primary energy intensity at a regional level, 2010 and 2020



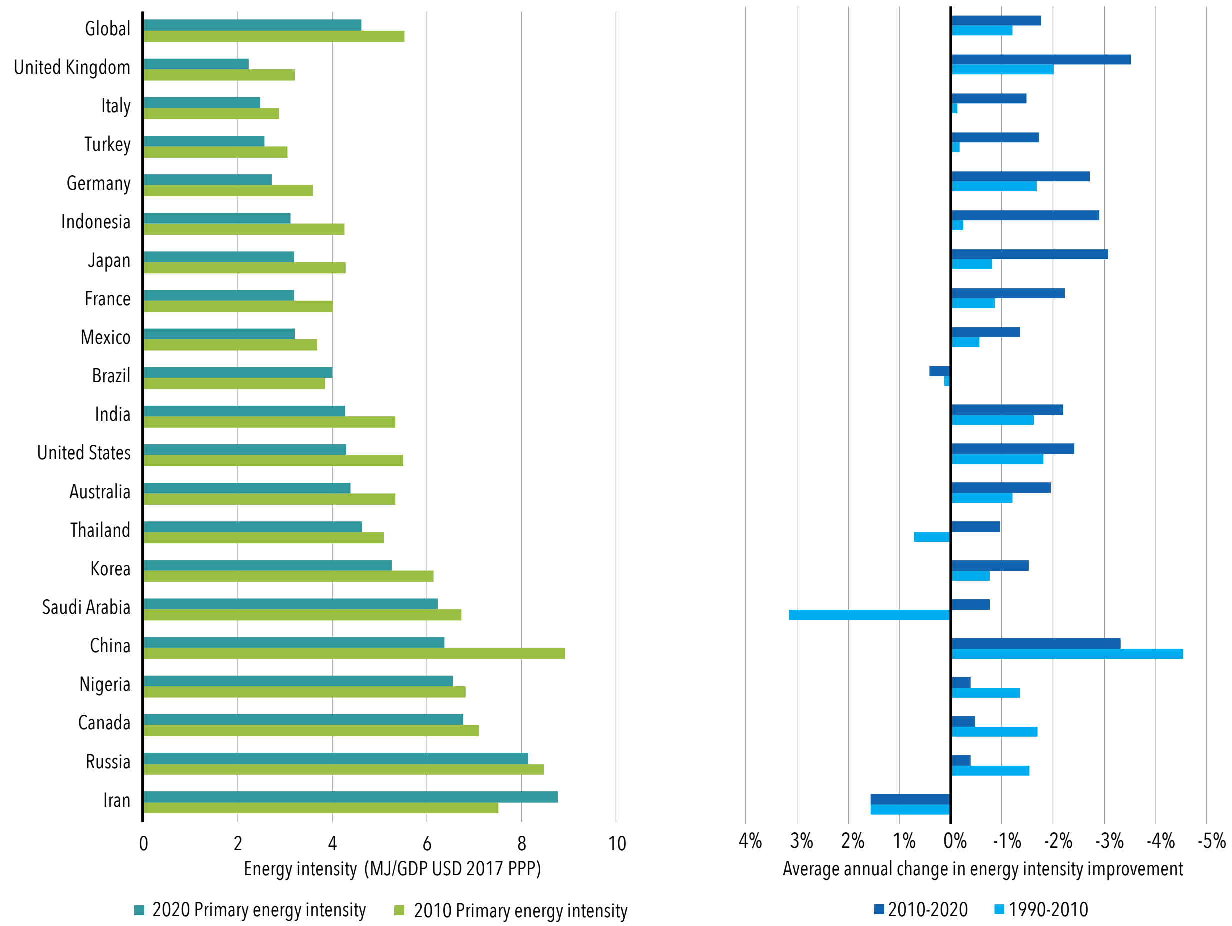
Sources: IEA, UN, and World Bank (see footnote 4).
MJ = megajoule; PPP = purchasing power parity.

MAJOR COUNTRY TRENDS

Improving energy intensity in the top 20 energy-consuming countries is central to realizing SDG target 7.3, considering these countries account for approximately three-quarters of the global GDP and energy consumption. Over the period 2010–20, 14 of these 20 countries achieved faster energy intensity improvements than the previous decade, although only five (China, the United Kingdom, Indonesia, Japan, and Germany) exceeded the level of 2.6 percent required by SDG 7.3 (figure 4.6). In addition, intensity improvement doubled in six countries in 2010–20 compared with 1990–2010. These are Mexico, France, Indonesia, Japan, Turkey, and Italy. This list includes both developed economies and major emerging economies, showing that all countries can double their energy efficiency improvement rates, despite differences in their starting improvement levels.

However, in more than half of these 20 countries, the COVID-19 crisis reversed the trend, with energy intensity worsening. For a quarter of them, including countries like China and the United Kingdom, which had significantly decreased their energy intensity over the decade, 2020 turned out to be the worst year for energy efficiency.

Figure 4.6 • Primary energy intensity, 2010 and 2020; and average improvement in annual energy intensity, 1990–2010 and 2010–20, in the top 20 energy-consuming countries with the largest total energy supply



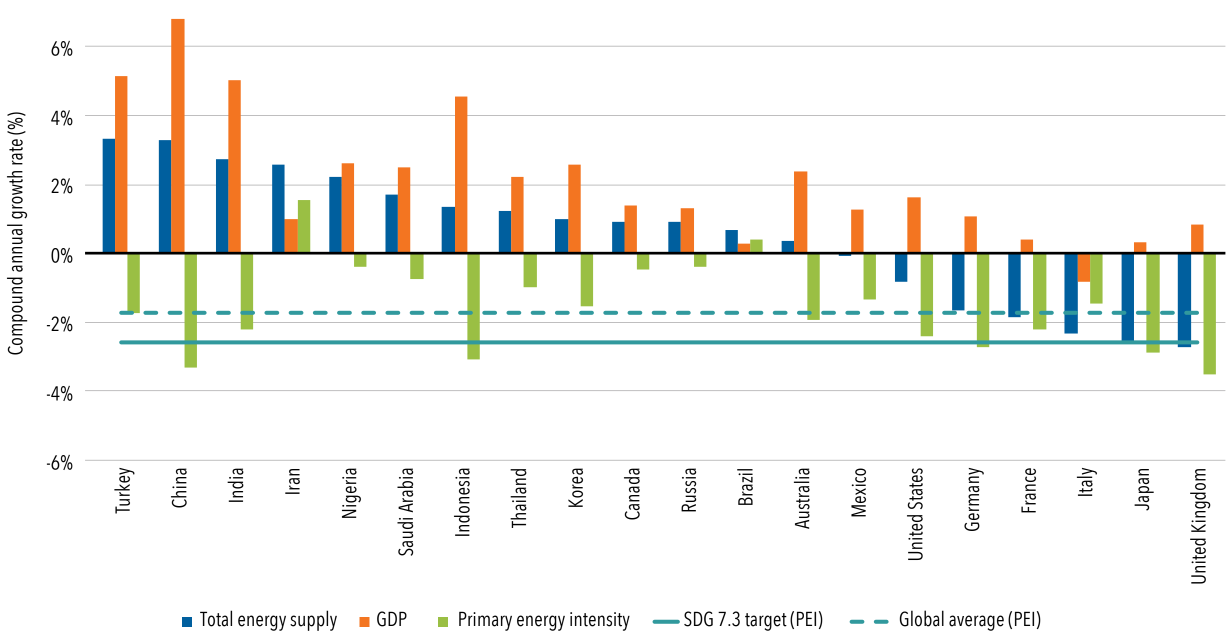
Sources: IEA, UN, and World Bank (see footnote 4).
Note: Countries along the y-axis are ordered by total energy supply. The average annual change in energy intensity improvement is based on a compound annual growth rate.
GDP = gross domestic product; MJ = megajoule; PPP = purchasing power parity.

In absolute terms, the energy intensity of 8 of the top 20 energy-consuming countries has remained above the global average over the past decade (figure 4.6). Two of these, the Islamic Republic of Iran and Russia, are also among the 25 countries with the highest energy intensities worldwide.

Countries where progress has been the slowest include those where energy-intensive fossil fuel extraction represents a major share of GDP. These include the Islamic Republic of Iran, Brazil, Nigeria, Saudi Arabia, the Russian Federation, and Canada. In this respect, a relatively high level of energy intensity reflects a challenge as well as an opportunity for strategies to diversify to more knowledge-based or service-oriented economies. The annual rate of change in energy intensity therefore represents an important indicator and a potential policy target to track both diversification and energy efficiency goals.

On the other hand, certain countries have made progress by diminishing energy intensity further below the global average, including Australia, India, Indonesia, Japan, and the United Kingdom. While China still remains above the global average in energy intensity, it has diminished significantly over the past decade.

Figure 4.7 • Growth rate of total energy supply, GDP, and primary energy intensity in the 20 countries with the largest total energy supply, 2010–20



Sources: IEA, UN, and World Bank (see footnote 4).
Note: Countries along the x-axis are ordered by total energy supply.
GDP = gross domestic product; PEI = primary energy intensity; SDG = Sustainable Development Goal.

Between 2010 and 2020, the economies of the United States, the United Kingdom, Japan, Germany, and France expanded as their energy use declined (figure 4.7). These trends suggest that economic growth is being decoupled from energy use. The economies of these countries have strong, decade-long records of policy action on energy efficiency and have economic structures characterized by high-value, service-related activities that consume less energy. Meanwhile, in countries to the left in the above chart, such as China, India, the Islamic Republic of Iran, Nigeria, Saudi Arabia, and Indonesia, higher growth rates of energy demand are generally expected as new infrastructure requiring energy-intensive industrial products, such as steel and cement, is being built. Many people may also be gaining access to modern energy services for the first time, which also results in higher energy demand in the buildings and transport sectors.

In 2020, GDP fell by approximately 3 percent globally and energy consumption declined by 4 percent due to the temporary effects of COVID-19. This was followed by 6 percent global GDP growth and 5 percent growth in energy demand in 2021. This means particular care must be taken while interpreting results that use 2020 as the latest year of comparison for energy consumption, considering it was an exceptional year.

END-USE TRENDS

A variety of metrics (as discussed in the note to figure 4.8) can be used to examine energy intensity across key sectors, such as industry, transport, buildings, and agriculture. Over the period 2010–20, energy intensity improved at an accelerated rate across all sectors, except the residential buildings sector (figure 4.8).

In the industry sector, which comprises highly energy-intensive economic activities, for example, cement, iron, and steel manufacture, energy intensity improved by 1.6 percent per year, on average, during the 2010s. Energy intensity improved at an annual average rate of 1–2 percent over 2010–20 for chemicals, nonmetallic minerals, and metals. In manufacturing consuming less energy, annual efficiency improvements averaged at 2–4 percent per year over the same period (IEA 2022b). This was a major improvement since sectoral energy intensity had deteriorated in the preceding period. The progress was largely driven by emerging Asian economies, such as China and India, through, for example, more efficient manufacturing processes (IEA 2017). Furthermore, the framework for mandatory energy efficiency policies tends to be more developed in the industry sector than any other sector around the world (IEA 2018). Industrial energy consumption declined 3 percent in 2020 due to the COVID-19 crisis. This decline was however cushioned by the rising share of energy-intensive activities in China, which navigated the year with fewer restrictions. This increase in energy-intensive activities also accounts for energy intensity deteriorating in the industry for the first time since the global financial crisis.

Between 2010 and 2020, energy intensity declined the fastest in the freight transport sector, at 2.2 percent annually. This decline is steeper than the 0.4 percent annual decrease observed in 2000–10. Energy intensity for passenger transport also improved slightly faster (at 1.9 percent a year) in the past decade than in the earlier one (1.8 percent). In 2020, the largest decline in energy consumption was in the transport sector (falling 14%). Lower occupancy rates in planes, trains, and public transport resulted in less efficient use of energy in the sector. Sales of new cars also fell, resulting in an overall vehicle stock that was older and less efficient. However, electric car sales performed well in 2020, with 3 million cars sold. This accounted for 5 percent of global car sales. To put this in context, however, sales of sport utility vehicles (SUVs) constituted about 40 percent of all passenger car sales in 2019, up from just 20 percent 10 years earlier. Such vehicles are typically heavier and less efficient, consuming approximately 20 percent more energy than medium-sized vehicles (IEA 2021b).

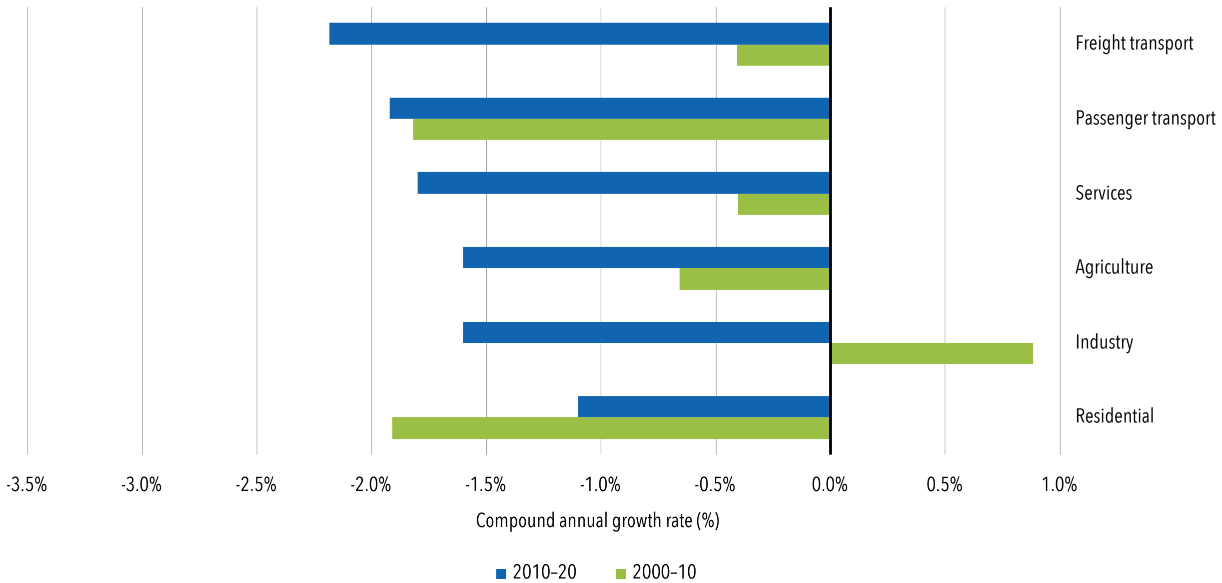
More broadly, electric vehicles saw a decade of rapid growth, which is expected to continue in the 2020s, thanks to supportive policy frameworks, financial incentives, reducing cost, and expanding charging infrastructure. Based on current trends and policies, the number of electric cars, vans, heavy trucks, and buses on the road is set to reach 145 million worldwide by 2030 (IEA 2021h).

The residential sector, which accounts for nearly a third of the global energy consumption, saw a slowdown in energy intensity improvements, from 1.9 percent in the first decade of the new century to 1.1 percent annually between 2010 and 2020. The sectoral final energy demand was the least affected by the COVID-19 restrictions in 2020. It decreased by just 0.3 percent, with a slight increase in floor area, 1.3 percent, and energy intensity improving at a pace comparable to that in previous years.

In the services sector, energy intensity improved by 1.8 percent annually between 2010 and 2020, a significant improvement from the 0.4 percent rate in the previous decade. The sector was deeply affected by the COVID-19 crisis, with energy consumption down 6 percent and energy intensity down 3.1 percent.

Energy intensity also improved significantly for agriculture—from 0.7 percent a year in 2000–10 to 1.6 percent between 2010 and 2020. This resulted from the sector's economic output outpacing the growth in energy demand.

Figure 4.8 • Compound annual growth rate of energy intensity by sector, 2000–10 and 2010–20



Sources: IEA, UN, and World Bank (see footnote 4).
Note: The measures for energy intensity used here differ from those applied to global primary energy intensity. Here, energy intensity for freight transport is defined as the final energy use per tonne-kilometer. For passenger transport, it is defined as the final energy use per passenger-kilometer. For residential use, it is defined as the final energy use per square meter of floor area. In the service, industry, and agriculture sectors, energy intensity is defined as the final energy use per unit of gross value-added (USD 2017 PPP). In the longer term, it would be desirable to develop more refined sectoral and end-use-level indicators that make it possible to examine energy intensity by industry (e.g., cement, steel) or end use (e.g., heating, cooling). Doing so will not be possible without more disaggregated data and statistical collaboration with relevant energy-consuming sectors.

Box 4.2 • Expanding the scope and scale of efficiency

The scope and scale of energy efficiency are being driven by a more systemic thinking, use of digitalization, and more integrated policy making.

There is a growing necessity for energy efficiency given the mounting pressures to decarbonize and electrify in conjunction with emerging disruptions in clean technology supply chains and critical mineral supply risks (IEA 2023). System efficiency, encompassing circularity and efficient use of resources, can unlock energy efficiency potential across the entire energy value chain and can reduce energy consumption in all sectors. Systematic reviews of greenhouse gas emissions and resource flows indicate that material handling and use account for 70 percent of greenhouse gases emitted (CGRi 2021). Driving down emissions requires expanding the boundaries of energy efficiency beyond reducing the energy requirements of end uses such as buildings, appliances, industrial plants, and vehicles. Circularity can dramatically improve the efficiency of systems through closing resource loops, slowing resource loops or flows, and narrowing resource flows to reduce environmental and climate pressures, as well as risks of raw material shocks to economies (OECD 2022). Systemwide efficiency is therefore crucial to enable cost-effective decarbonization pathways.

Taking a more systemic approach—enabled by digitalization—is already showing significant improvements and potential across a range of end uses and sectors. In this context, extending product policies to cover relevant energy-consuming systems has the potential to reduce annual global consumption by 9 percent (17 exajoules) (4E IEA 2022b). In Europe alone, sensors and data analytics for optimizing motor-driven systems could bring additional electricity savings of 50–100 terawatt-hours per year by 2030 (4E IEA 2022a). Further, the adoption of energy management systems has been shown to cut energy usage in industries and businesses by up to 30 percent (UNIDO n.d.). Buildings analytics and automation can cut energy use by one-quarter (ACEEE 2017), and smart streetlighting can reduce energy demand by up to 80 percent (IEA 2021g).

Behavioral interventions to support energy efficiency can also be boosted by a digital inclusive systemic approach. Behavioral interventions aim to trigger socially desirable behaviors—by removing barriers to such behaviors or creating disincentives to socially damaging behaviors. Digital devices can simplify energy saving actions and remove unnecessary barriers through automation and clear prompts (IEA 2021i). Successful behavioral interventions to bolster energy efficiency have facilitated conservation by using techniques such as feedback mechanisms, which track households' energy consumption patterns, or targeted prompts, which alert consumers to pay particular attention to their energy usage at peak times. Feedback mechanisms show consumers how their energy consumption patterns evolve throughout the day and across seasons. Consumers can be given real-time feedback via in-home displays, mobile applications, or web portals receiving data from smart metering systems. A 2015 impact assessment by the Smart Metering Early Learning Project observed that consumers with smart meters and in-home displays used 1.5 percent less natural gas and 2.2 percent less electricity in 2011 compared with those equipped with conventional meters (UK Department of Energy and Climate Change 2015).

However, this is only scratching the surface of what digitally powered efficiency can do. Smarter electricity systems can improve the productivity of renewable energy generation, reduce transmission and distribution losses, and extend asset lifetime, and they can increase systems' efficiency, through making electricity demand more flexible. Smarter cities can plan and orchestrate systems to reduce energy demand across buildings, transport, and services. Moreover, digital technologies that allow for greater visibility of energy and resource usage and better management can help deliver efficiency across resource extraction, material production, and component and technology manufacturing so as to enable use at different stages, including end-of-life. Digital technologies can be used to make data-driven decisions and optimize the performance of systems and processes, aside from creating and capturing value throughout the life cycle of assets (OECD 2022). They help reduce the need for materials and critical minerals through resource-efficient manufacturing and product design, improve the productivity of assets, extend products' and assets' life, and enhance resource recovery and material reuse. For example, the recovery of waste heat generated by data centers, wastewater treatment, industries, and commercial sector can in some cases be connected to district heating systems through a circular economy approach. Recent research indicates that circular economy approaches could reduce global greenhouse gas emissions by 39 percent and cut virgin resource use by 28 percent (CGRi 2021).

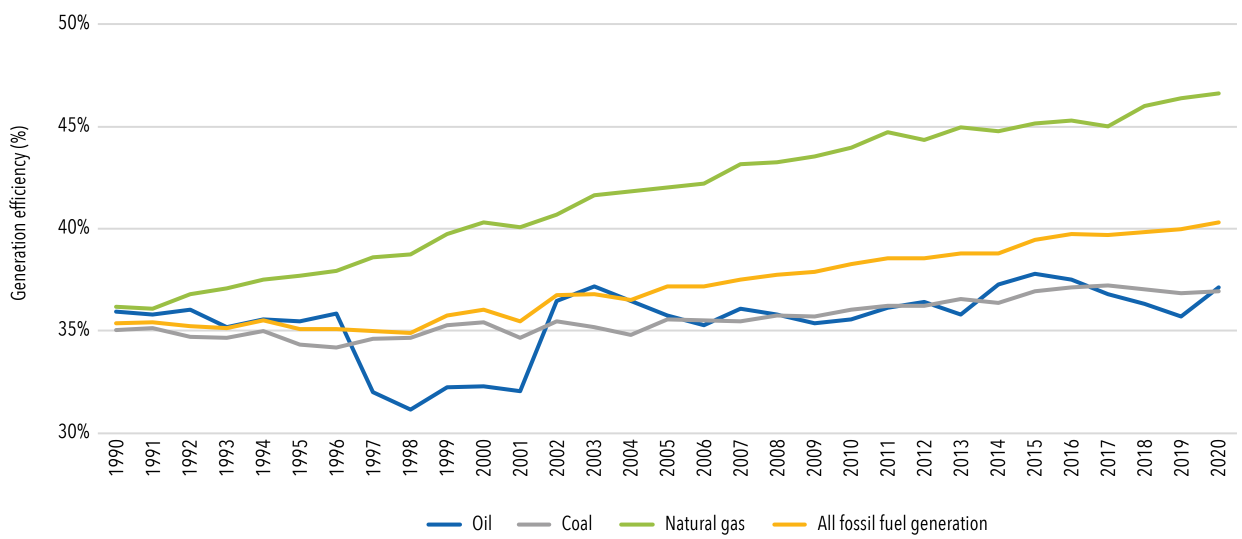
Leveraging these energy efficiency opportunities requires new approaches to more integrated policies. However, here again, digitalization can provide part of the solution. Access to unprecedented volumes of data, which were previously unobservable or were only observable and collected at prohibitive costs, enables policy makers to better understand and manage resources and waste, and this can be combined with advanced analytics to help rethink the design and operation of production and consumption systems, and energy and transportation systems.

TRENDS IN EFFICIENCY OF ELECTRICITY SUPPLY

The rate of improvement in global energy intensity is influenced not only by improvements in end-use efficiency but also by changes in the efficiency of electricity supply. These changes include reductions in transmission and distribution losses due to a modernized supply infrastructure and improvements in the efficiency of fossil fuel generation. After showing flat rates of improvement during the 1990s, the efficiency of fossil fuel–based electricity generation improved steadily between 2000 and 2020 (figure 4.9). Efficiency improvements in natural gas–based electricity generation balanced out slower improvements in the efficiency of coal- and oil-based electricity generation.

Another factor affecting the efficiency of global electricity supply is the share of renewable energy sources in the mix. Statistically, most renewable energy technologies are treated as being 100 percent efficient, even though minor losses do occur in the conversion of resources such as sunlight and wind into electricity. Thus, more renewable energy in the electricity mix generally boosts the efficiency of electricity supply.

Figure 4.9 • Trends in the efficiency of global fossil fuel–based electricity generation, 1990–2020



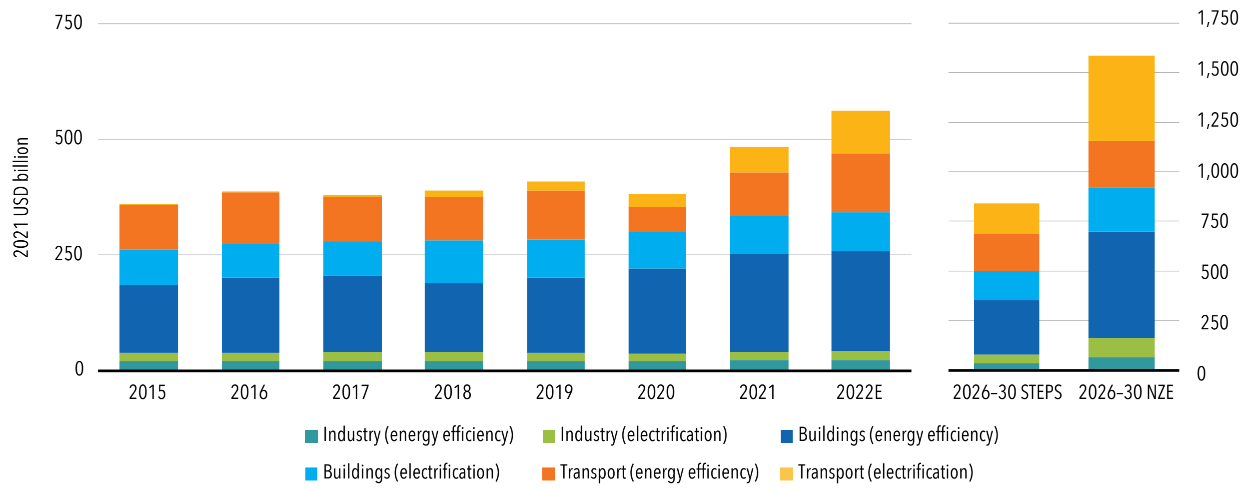
Sources: International Energy Agency; and United Nations Statistics Division.

ENERGY EFFICIENCY INVESTMENTS

In 2020, overall energy efficiency investments declined only slightly (at nearly USD 380 billion) despite the COVID-19 crisis (figure 4.10). However, trends differed widely across sectors and regions, with Europe, China, and Northern America accounting for nearly 80 percent of the spending. Unprecedented growth in the buildings sector, concentrated in Europe, outweighed a substantial decrease in transport efficiency investments, whereas spending in the industry sector remained largely unchanged. Investment in energy efficiency measures in buildings accounted for two-thirds of the total efficiency spending in 2020. This was possible due to the scale-up of the efficiency policies implemented before the COVID-19 crisis and the early effects of economic recovery measures (IEA 2021c).

The current energy crisis then led to accelerated energy efficiency investments, with governments, industry, and households investing USD 560 billion in 2022. This is a new record, yet it is little more than one-third of the more than USD 1.5 trillion in yearly average investments required between 2026 and 2030 to achieve the IEA Net Zero Emissions by 2050 Scenario. Energy efficiency–related spending constitutes two-thirds of all clean energy and energy recovery spending, with USD 1.0 trillion mobilized between 2020 and 2022. However, there exists a regional imbalance in government-approved energy efficiency spending, with the majority coming from developed economies. Governments elsewhere have considerable potential to use recovery packages to boost spending, which would create jobs and promote economic growth (IEA 2022b).

Figure 4.10 • Energy efficiency investment by sector, 2015–22; and by scenario, 2026–30



Source: IEA 2022c.
NZE = Net Zero Emissions by 2050 Scenario; STEPS = Stated Policies Scenario.

Policy Recommendations and Conclusions

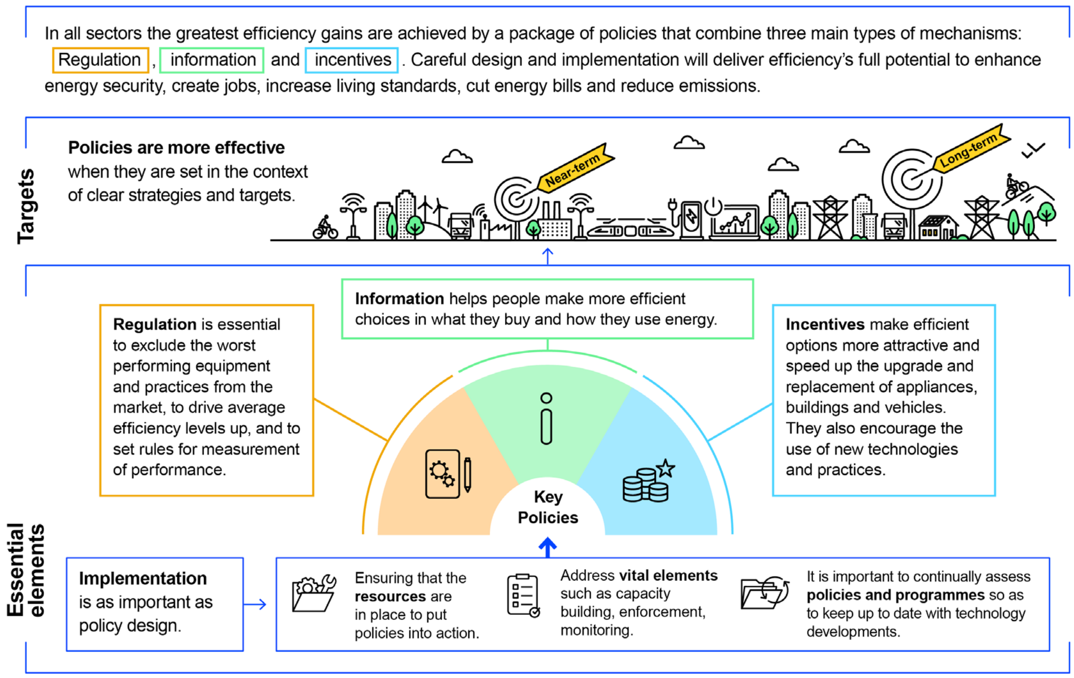
Continued shortfalls in energy intensity improvement, especially in 2020 and 2021, imply that strengthened government policies on energy efficiency are needed to meet SDG target 7.3 by 2030. Energy intensity is expected to improve at a faster pace in 2022, but not on par with the rate now required to reach SDG 7. The current energy crisis was a strong reminder that in addition to helping reach the target, well-designed and well-implemented energy efficiency policies can deliver a range of benefits beyond energy and emissions savings. These include better energy security, reduced exposure to global shifts in energy prices, reduced energy bills for households and businesses, new jobs in energy efficiency retrofits, and improved health owing to better air quality,

Strong policy action is also vital to signal investors that energy efficiency is a long-term priority. This will help to create more certainty for investors and catalyze the transformative investments required to return the world to a path to meet SDG target 7.3.

ENERGY EFFICIENCY POLICY

Governmental policy tools to improve energy efficiency can be grouped in three main categories (figure 4.11): (i) regulatory instruments mandating higher efficiency levels in buildings, appliances, vehicles, and industry; (ii) fiscal or financial incentives to encourage installation of energy-efficient equipment and retrofits; and (iii) information programs to help energy users make informed decisions. The following section describes some options and policies.[59]

Figure 4.11 • Policy package approach to strengthening energy efficiency



Source: IEA 2022e.

59 More information and examples can be found in IEA's Global Policies Database (IEA 2022b), the World Bank's Regulatory Indicators for Sustainable Energy (RISE) (World Bank 2021), and the Global Status Report of Renewable Energy Policy Network for the 21st Century (REN21 2019).

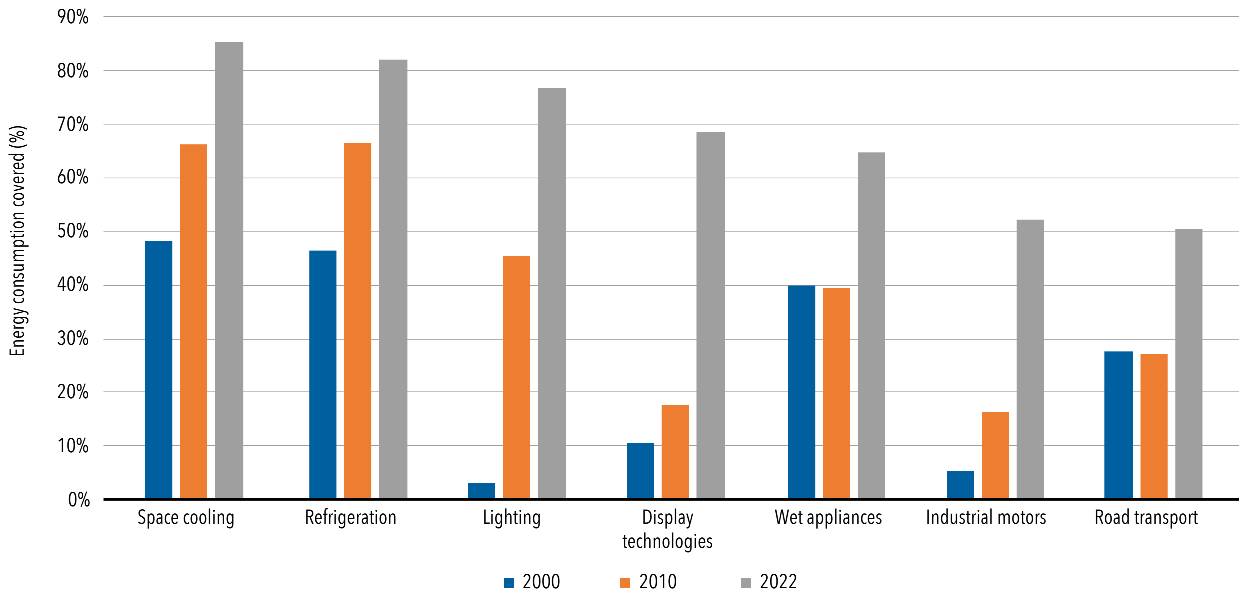
Standards and labels

More than a hundred countries now have mandatory performance standards and/or labels related to the energy efficiency of key end uses such as air conditioners, refrigeration, lighting, industrial motors, and passenger cars (IEA 2021c). Additional or expanded standards and labeling schemes are under development in more than 20 countries, mainly in Asia and East and Southern Africa. Regularly adjusting ambition levels to reflect the latest technological progress, performance standards, and labels can add substantial reductions in energy consumption. This has been demonstrated by well-established programs over recent decades, which delivered annual savings of about 15 percent (IEA 2021a). However, policies are still lacking in many markets seeing rapid growth in the ownership of appliances, industrial equipment, and vehicles.

More broadly, performance standards and labels apply to more than a hundred types of appliances and equipment in the commercial, industrial, and residential sectors. However, policy coverage is often low. For example, only 40–50 countries have implemented minimum performance standards for washing machines, dishwashers, or TVs. As a result, expanding programs in countries where policies presently cover only a limited number of products offers significant scope for further efficiency gains.

Performance standards and labels now cover a high percentage of key energy-consuming end uses in Europe and Northern America, which adopted them early. Globally, such policies are most used for appliances. For example, minimum energy performance standards currently apply to more than 80 percent of the global energy use for air conditioners and refrigerators; this is in comparison with less than half of the energy use for industrial motors and road transport (figure 4.12).

Figure 4.12 • Global energy use coverage of mandatory energy efficiency standards for key end uses, 2000, 2010, and 2022



Source: IEA analysis for IEA (2022b based on CLASP (2021) and other sources.
Note: Coverage for space cooling, refrigeration, and lighting is shown for residential sectors.

There is also significant variation in the strength of programs across countries. Significant scope exists for enhanced international cooperation in this area to help governments introduce new standards, learn from others' experience, and adopt best practices. IEA published several policy toolkits summarizing the main tools policy makers can use to enhance energy efficiency across various sectors (IEA 2022d).

Building codes

Energy codes address a critical part of improving the energy performance of buildings. They set the minimum energy standards for new buildings and can also trigger requirements for major refurbishments or renovations to meet aspects of existing building codes. Building energy codes typically address operational energy use by focusing on envelope performance standards, including for walls, windows, and roofs, as well as major end-use energy services equipment, such as heating, cooling, lighting, and ventilation (IEA 2022b).

Thirty-one emerging and developing countries are actively developing new building codes . This is in addition to the 80 countries that already have fully operational building codes (of which 69 have mandatory requirements, and 11 use performance standards such as voluntary, model codes, or city-based standards). This means the total number of countries with building codes will soon be 111. Approximately 85 countries have no known building codes in place or under development.

Energy efficiency obligation schemes

EEO schemes are commonly used market-based programs that are employed by policy makers to specify an outcome, for example, energy savings or cost-effectiveness to be delivered by a utility or another market participant (e.g., an energy services company). Auction programs, which are related but less commonly used market mechanisms, allow market actors to bid for funds to deliver specific energy savings.

As of 2022, there are 48 EEO programs in 23 jurisdictions. In the European Union, 16 countries are operating EEOs, and in the United States alone, 24 states have EEOs, called Energy Efficiency Resource Standards. A new EEO was launched in Hungary in 2021, whereas no EEOs are being developed in Korea, and Bosnia and Herzegovina. Of the EEOs in force, the vast majority encompasses multiple sectors. Only 4 percent of EEOs target the residential sector and 2 percent are aimed exclusively for the industrial sector.

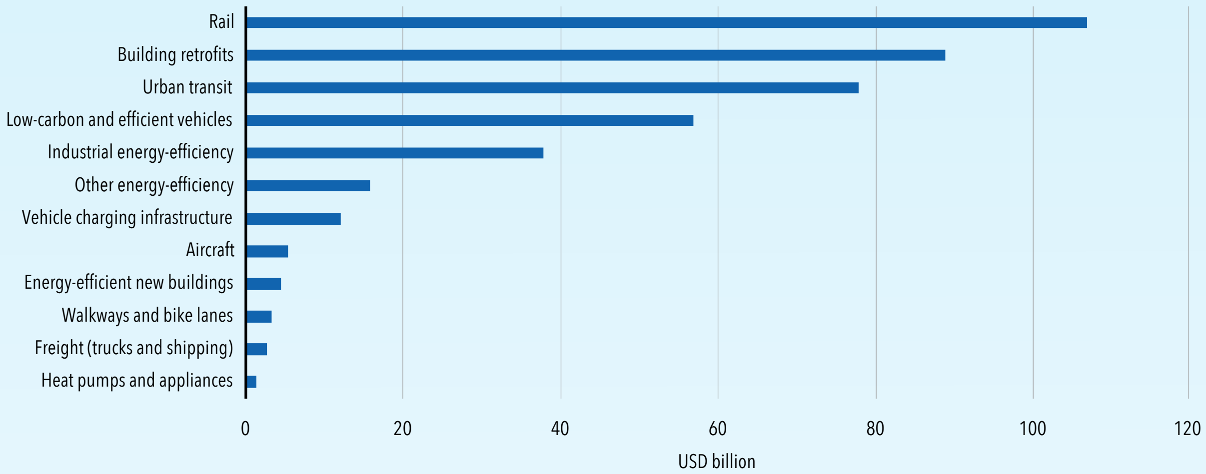
Behavior and awareness campaigns

The 2022 energy crisis also saw a new wave of behavior and awareness campaigns to help consumers reduce energy expenditure and support energy security, especially in Europe. For example, the EU Save Energy Communication outlined the European Commission's two-pronged approach of promoting mid- to long-term efficiency improvements while achieving immediate energy savings through behavioral changes. This is reflected in many national strategies, including Denmark's "Sammen sparer vi på energien" (Together we save energy) campaign and Germany's "80 Millionen gemeinsam für Energiewechsel" (80 million together for energy saving), which also provide citizens with information to carry out home energy retrofits. In Japan, Tokyo Electric Power Company launched Power Saving Challenge 2022, which awarded points for saving power, which could be exchanged for goods using online retailers such as Amazon.

Box 4.3 • Recovery spending and energy efficiency

Between 2020 and April 2022, governments worldwide helped mobilize approximately USD 1 trillion for energy efficiency–related actions. Of this, USD 270 billion was direct public spending by governments, which is projected to mobilize a further USD 740 billion of private and other public spending (IEA 2022c). This amounts to two-thirds of the total clean energy recovery spending. The major share of energy efficiency–related spending targeted transport, especially rail and urban transit, and buildings.

Figure B4.3.1 • Total energy efficiency–related government clean energy recovery spending from 2020, announced as of April 2022



Source: IEA 2022c.

At least 16 high-profile national plans are driving this progress on efficiency.

For instance, the energy efficiency provisions of the US Inflation Reduction Act are estimated at about USD 95 billion. This includes USD 20 billion of clean transportation tax credits for electric vehicles, investment in zero-emissions vehicles for the US Postal Service, public services, and zero-emissions equipment for port infrastructure. About USD 53 billion has been earmarked for energy efficiency in buildings, including tax credits for residential electrification and energy-efficient appliances. Another USD 16 billion is targeted toward the manufacturing sector, including grants and loans for electric vehicle production, and tax credits for other clean manufacturing.

Energy savings is also one of the central pillars of the European REPowerEU plan. The plan foresees an increase in EU-wide energy savings from 9 percent to 13 percent of the target under the Energy Efficiency Directive, with the goal of doubling the deployment rate of heat pumps to about 10 million cumulative units over 2023–27 and accelerating electrification, especially in industry.

In Japan, the Green Transformation Plan strengthened building codes and annual energy reporting systems for large-scale consumers, including for demand response measures. Through a three-year efficiency investment plan, it will also provide subsidies of JPY 500 billion for replacing old facilities in factories and buildings.

The production-linked incentive in India aims at enhancing the competitiveness of the country's manufacturers, helping them attract investments in cutting-edge technology, create efficiencies and economies of scale and enhance exports. Among others, it targets the automobile industry, specifically to encourage the manufacturing of electric and hydrogen-based vehicles.

Campaigns have also been used to great effect outside of Europe to tackle past and current energy crises. In response to a hydroelectricity supply crisis in Brazil during 2021, the government launched an awareness campaign alongside financial incentives to reduce energy use at peak hours. In Korea, following large-scale blackouts in 2011, awareness campaigns used social media and popular culture channels, as well as conventional media and public advertisements.

The energy crisis has also seen a significant increase in support to consumers to switch to public transport. For example, Luxembourg has implemented one of the world's most generous public transport programs, making bus, tram, and funicular second-class tickets free of charge in Luxembourg City and throughout the country.

POLICIES TO DRIVE DIGITALLY ENABLED SYSTEMWIDE EFFICIENCY

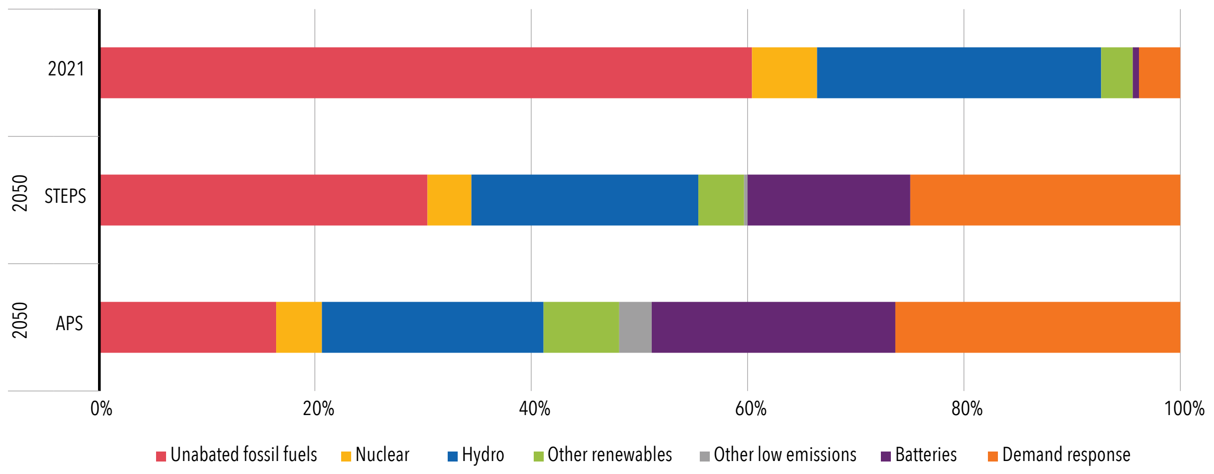
Digitalization is transforming the energy sector and promises to accelerate progress toward SDG target 7.3. With proliferation of digital devices and low-cost sensors, a wealth of granular and continuously updated data is now available to optimize energy supply and use. Over the past five years, there has been a 33 percent increase per year in the deployment of energy-related connected devices with automated controls, the growth being for appliances, devices, and sensors in end-users premises alone. Deployment is expected to reach 13 billion in 2023, up from 11 billion the year before (4E EDNA 2021). Meanwhile, global smart meter deployment reached 1,134 million units, and it could be at 1,598 million units in 2030 (IEA 2022b). Grids, appliances, smart charging, and distributed generation are also being increasingly automated. Approximately 319 million distribution sensors are currently deployed globally, and grid operators are steadily increasing their investments in digital grids.

Digitalization helps direct energy efficiency measures so they have the greatest effect and yield the greatest benefits. For example, energy management systems and related technologies can significantly reduce energy consumption in the buildings sector. In this context, smart energy management by the US General Services Administration, including digitally enhanced energy efficiency and demand response management, could cut the operating costs of buildings by 20 percent (ACEEE 2019). The IEA 4E Technology Collaboration Programme estimates that smart home technologies can help decrease household energy use by 20–30 percent (4E 2018).

Digitalization also offers system-wide benefits, including increased reliability and resilience, improved operational efficiency, cost reductions, and investment optimization. This enables customers to participate more actively, including in voluntary peak reduction schemes. In addition, digitalization can foster economic and social development. For instance, digitally enabled mobile communication technology can play a crucial role in bringing decentralized clean energy solutions to vulnerable urban or marginalized communities via innovative business models. These models, enabled by smart meters and two-way digital communication, have helped customers in urban, peri-urban, and rural areas in developing countries to install efficient technologies in their dwellings by allowing them to pay back the costs in instalments. Across Africa, 5 million people gained access to electricity through pay-as-you-go solar home electricity systems in 2018 alone (IEA 2019). Digitalization can also help monitor and raise awareness on energy use. This can result in actions to increase energy savings and reduce bills, which are of relevance in a number of regions, including Sub-Saharan Africa.

Digitalization is also critical for accommodating growing shares of variable and distributed renewables. According to IEA's Net Zero Emissions by 2050 Scenario, electricity networks will need four times more flexibility by 2050 to accommodate increasing shares of variable renewable resources (wind, solar) (IEA 2022f). A growing share of the flexibility will be added by distributed resources and demand response (figure 4.13) .

Figure 4.13 • Electricity system flexibility by source and scenario, 2021 and 2050



Source: IEA 2022g.
Note: STEPS shows the trajectory implied by today's policy settings. APS assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net-zero and energy-access goals. Unabated fossil fuels include unabated coal and gas, and oil. Other renewables include bioenergy, geothermal, and solar thermal. Other low-emissions sources include hydrogen and ammonia, and fossil fuels with carbon capture, utilization, and storage.
APS = Announced Pledges Scenario; STEPS = Stated Policies Scenario.

To take full advantage of the opportunities offered by digitalization, national and subnational governments should consider developing policies to apply digital technologies comprehensively to improve efficiency and produce positive social and economic outcomes across sectors and systems. They should, for example:

- Leverage digital tools to improve energy efficiency through behavioral change. For instance, providing consumers with real-time energy use–related feedback helps them reduce their consumption. This can often be via connected digital devices, including smart meters, to alert consumers to their consumption patterns or, in cases where they are subject to time-of-use rates, to variations in energy prices. Home energy reports are an example of a feedback mechanism that can help reduce residential electricity consumption by 2.2 percent and natural gas consumption by up to 1.6 percent (IEA 2021i). Japan worked with major utilities to send customized energy use reports to 300,000 households, resulting in a 2 percent sustained decrease in energy consumption. (Users TCP and IEA 2020). Smart technologies such as connected thermostats also add cost-effective energy savings. Case studies show that the installation of a thermostat alone can generate 10 percent savings on heating and space cooling costs (US DoE n.d.).
- Leverage digital tools to increase energy savings at peak times. Several demand response programs were launched or expanded last year (IEA 2022e). For instance, the UK National Grid ESO launched a new program, Demand Flexibility Service, in November to deliver more than 2 gigawatts of demand response when needed.
- Build capacity to use digital tools. A range of actors can provide capacity building to meet differing needs. The World Bank has set up the Utility Knowledge Exchange Platform to provide insights and peer-to-peer learning opportunities for utilities in developing countries. In India, the India Smart Grid Forum published a smart grid handbook for regulators and policy makers with the support of Shakti Sustainable Energy Foundation. This was in response to a need to raise awareness about and build a common understanding of smart grids.
- Chart the steps needed to make progress on standardization and embedded interoperability. They should systematically address barriers to data access, sharing, and use, and ensure robust data protection and cyber resilience mechanisms for the entire energy value chain. In this context, in 2021, the United Kingdom adopted a comprehensive energy system digitalization strategy and action plan (UK BEIS 2021).

- Create innovative approaches to more integrated policies. These would also leverage data and analytics to better design, implement, and monitor energy efficiency policies (IEA 2021f). In 2022, the European Union presented its action plan on digitalization in energy systems to increase the efficient use of energy resources. The plan included measures to increase consumers' control over their energy use and ensure efficiency and circularity of the information and communication technology sector (EC 2022), while strengthening cybersecurity.

Initiatives such as IEA's Digital Demand-Driven Electricity Networks (3DEN) are developing recommendations for how to accelerate the uptake of digital technologies for demand-side flexibility and energy efficiency. 3DEN outputs include two reports:

- A report titled "Smart Grids in Emerging Markets and Developing Economies," which is expected to be published in June 2023 and will focus on the near-term challenges that digitalization can help mitigate and how short- to medium-term investments in physical and digital infrastructure can bring multiple benefits, such as grid resilience and improved financial standing.
- A report titled "Grids of the Future," which is expected to be published in Q4 2023 and focuses on the transformational role that digitalization can play in supporting net-zero transitions and achieving higher power system efficiency.

Outlook

The rate of energy intensity improvement continues to remain below the annual 2.6 percent initially projected as a prerequisite for reaching SDG target 7.3. The COVID-19 crisis only worsened an already concerning trend, with energy intensity improving by only 0.6 percent in 2020, compared with average annual growth of 1.2 percent over 2015–20, and 1.8 percent between 2010 and 2015. To double the global rate of energy intensity improvement by 2030 (i.e., SDG target 7.3), energy intensity must improve at an average of 3.4 percent per year through 2030 to make up for slow progress in the past. This rate would need to be even higher (consistently over 4.2 percent for the rest of this decade) to put the world on track to reach net-zero emissions from the energy sector by 2050, as envisioned in IEA's Net Zero Emissions by 2050 Scenario (IEA 2021d).

Estimates for 2021 point to sustained slow improvement of energy intensity as the effects of the COVID-19 crisis continue. However, early estimates for 2022 suggest that the improvement rate will return to the average of the previous decade, as the energy crisis puts more pressure on energy consumption. The energy crisis led to a swift increase in energy efficiency–related investments, with USD 560 billion invested in energy efficiency by governments, industry, and households in 2022, which is a new record (IEA 2022b).

Nevertheless, energy efficiency policies and investments in cost-effective energy efficiency measures must be scaled up significantly to mitigate the consequences of the energy crisis, as well as bring SDG target 7.3 within reach. Given the multiple benefits of energy efficiency, it is an obvious choice for government support, and this has been reflected in a range of recent stimulus packages throughout the world. Energy efficiency–related spending constitutes approximately two-thirds of the total USD 1 trillion mobilized by governments with their recovery measures between 2020 and 2022 (IEA 2022b).

One of the benefits of energy efficiency is that improved efficiency at scale would be pivotal in achieving affordable and sustainable energy access for all. Continued low levels of intensity improvement, the significant potential opportunities for investment and economic recovery, and the pressing need for expanded access underline the urgency of government actions to foster annual intensity improvement of at least 3.4 percent. As underlined by the recommendations of the United Nations' High-Level Dialogue on Energy, efficiency measures and strategies need to address the main barriers to the adoption of such measures and promote structural and behavioral change to support the achievement of SDG target 7.3 (UN 2021).

Many national and subnational governments already have policies to reach their energy efficiency goals. Successful policies of various types are in force around the world, including energy efficiency standards, financial incentives, market-based mechanisms, capacity-building initiatives, and regulatory measures. All of these encourage investment in energy efficiency and catalyze energy markets in favor of cleaner, more efficient operations. IEA published several policy toolkits summarizing the main tools to use across various sectors (IEA 2022d).

Digitalization has also been an emerging trend reshaping the energy landscape and facilitating progress toward improved energy efficiency. Wide-scale data collection, analysis, and application can help direct energy efficiency measures to where they can be the most impactful. This will in turn offer significant opportunities to improve energy efficiency outcomes. Digitalization can also support deep decarbonization by helping leverage power system flexibility and widen energy access, thanks to innovative business models.

The technology and resources to double energy efficiency improvement by 2030 are all available. Given that, the current low improvement rates and low investments point to a major missed opportunity for the global community. Making energy efficiency a priority in policies and investments over the coming years can help achieve SDG target 7.3, promote economic development, improve health and well-being, and ensure universal access to clean and efficient energy.

Methodological Notes

Total energy supply (TES) (MJ)	This represents the amount of energy available in the national territory during the reference period. It is calculated as follows: TES = Primary energy production + Import of primary and secondary energy – Export of primary and secondary energy – International (aviation and marine) bunkers – Stock changes (Definition consistent with International Recommendations for Energy Statistics). *Data sources:* Energy balances from the International Energy Agency (IEA), supplemented by United Nations Statistics Division (UNSD) for countries not covered by IEA as of 2017
GDP in USD 2017 PPP	This sum is derived by adding the gross value added by all resident producers in an economy and any product taxes, then subtracting from the result any subsidies not included in products' value. It is calculated without making deductions for the depreciation of fabricated assets or for the depletion and degradation of natural resources. GDP is measured in constant USD 2017 PPP. *Data source:* WDI database: http://datatopics.worldbank.org/world-development-indicators/
Primary energy intensity in MJ/ USD (2017 PPP)	$Primary\ energy\ intensity = \frac{TES\ (MJ)}{GDP\ (USD\ 2017\ PPP)}$ The ratio of TES to GDP is measured in MJ per USD (2017 PPP). Energy intensity indicates how much energy is used to produce one unit of economic output. A lower ratio indicates that less energy is used to produce one unit of economic output. Energy intensity is an imperfect indicator, since changes, especially those in the structure of economic activity, are affected by factors other than energy efficiency.
Average annual rate of improvement in energy intensity (%)	Calculated using compound annual growth rate (CAGR): $CAGR = \left(\frac{EI_{t2}}{EI_{t1}}\right)^{\frac{1}{(t2-t1)}} - 1\ (\%)$ Where: EI_{t2} is energy intensity in year $t1$ and EI_{t1} is energy intensity in year $t2$. Negative values represent decreases (or improvements) in energy intensity (less energy is used to produce one unit of economic output or per unit of activity), whereas positive values indicate increases in energy intensity (more energy is used to produce one unit of economic output or per unit of activity).
Total final energy consumption (TFEC) in MJ	Sum of the energy consumed by different end-use sectors, excluding nonenergy uses of fuels. TFEC is broken down into energy demand in the following sectors: industry, transport, residential, services, agriculture, and others. It excludes international marine and aviation bunkers, except at the world level, where it is included in the transport sector. *Data sources:* Energy balances from IEA, supplemented by UNSD for countries not covered by IEA as of 2017
Value-added in 2017 USD PPP	Value-added is the net output of a sector after adding all outputs and subtracting intermediate inputs. It is calculated without making deductions for the depreciation of fabricated assets or the depletion and degradation of natural resources. The industrial origin of value-added is determined by the International Standard Industrial Classification, revision 3. *Data source:* WDI database

Industrial energy intensity in MJ/USD (2017 PPP)	$Industrial\ energy\ intensity = \frac{Industrial\ TFEC\ (MJ)}{Industrial\ value - added\ (USD\ 2017\ PPP)}$ Ratio of industrial TFEC to industrial value-added. It is measured in MJ per USD (2017 PPP). *Data sources:* Energy balances from IEA and value-added from WDI
Services energy intensity in MJ/USD (2017 PPP)	$Services\ energy\ intensity = \frac{Services\ TFEC\ (MJ)}{Services\ value - added\ (USD\ 2017\ PPP)}$ Ratio of services TFEC and services value-added. It is measured in MJ per USD (2017 PPP). *Data sources:* Energy balances from IEA and value-added from WDI
Agriculture energy intensity in MJ/USD (2017 PPP)	$Agriculture\ energy\ intensity = \frac{Agriculture\ TFEC\ (MJ)}{Agriculture\ value - added\ (USD\ 2017\ PPP)}$ Ratio of agriculture TFEC to agriculture value-added. It is measured in MJ per USD (2017 PPP). *Data sources:* Energy balances from IEA and value-added from WDI
Passenger transport energy intensity in MJ/passenger-kilometer	$Passenger\ transport\ energy\ intensity = \frac{Passenger\ transport\ TFEC\ (MJ)}{Passenger\text{-}kilometers}$ Ratio of passenger transport final energy consumption to passenger transport activity. It is measured in MJ per passenger-kilometer. *Data source:* IEA Mobility Model
Freight transport energy intensity in MJ/tonne-kilometer	$Freight\ transport\ energy\ intensity = \frac{Freight\ transport\ TFEC\ (MJ)}{Tonne\text{-}kilometers}$ Ratio of freight transport final energy consumption to freight transport activity. It is measured in MJ per tonne-kilometer *Data source:* IEA Mobility Model
Residential energy intensity in MJ/unit of floor area	$Residential\ energy\ intensity = \frac{Residential\ TFEC\ (MJ)}{Residential\ floor\ area\ (m^2)}$ Ratio of residential TFEC to square meters of residential building floor area. *Data source:* IEA Mobility Model
Fossil fuel–based electricity generation efficiency (%)	$Generation\ efficiency = \frac{Electricity\ output\ from\ coal, oil, and\ natural\ gas}{Coal, oil, and\ natural\ gas\ input}\ (\%)$ Ratio of fossil fuel–based (coal, oil, and gas) power generation and fossil fuel–based TES input to power generation. *Data source:* IEA Energy Balances
Power transmission and distribution losses (%)	Power transmission and distribution losses (%) $Power\ transmission\ and\ distribution\ losses = \frac{Electricity\ losses}{(Electricity\ output\ main + Electricity\ output\ CHP + Electricity\ imports)}\ (\%)$ Where: Electricity losses are electricity transmission and distribution losses, Electricity output main is electricity output due to the primary activity of producer electricity plants, and Electricity output CHP is electricity output from combined heat and power plants (CHPs). *Data source:* IEA Energy Balances

GDP = gross domestic product; MJ = megajoule; PPP = purchasing power parity; USD = US dollars; WDI = World Development Indicators.

References

4E (Energy Efficient End-Use Equipment Technology Collaboration Programme). 2018. *Intelligent Efficiency: A Case Study of Barriers and Solutions—Smart Homes.* Paris: International Energy Agency. https://www.iea-4e.org/wp-content/uploads/publications/2018/03/Case_Study_HEMS_Final_Report.pdf.

4E EDNA. 2021. "EDNA Total Energy Model 2.0." IEA, Paris. https://www.iea-4e.org/edna/tem/.

4E IEA (International Energy Agency). 2022a. "Digital Technologies for Motor Systems." IEA, Paris. https://www.iea-4e.org/wp-content/uploads/2022/09/EMSA_Policy_Brief_4_20220915.pdf.

4E IEA. 2022b. "Progressing Energy Efficiency Policies for Systems." IEA, Paris. https://www.iea-4e.org/wp-content/uploads/publications/2022/07/4E-Progressing-Energy-Efficiency-Policies-for-Systems-v2.pdf.

ACEEE (American Council for an Energy-Efficient Economy). 2017. *Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings.* Washington, DC: ACEEE.

ACEEE. 2019. "Grid-Interactive Efficient Building Utility Programs: State of the Market." White paper, ACEEE, Washington, DC. https://www.aceee.org/sites/default/files/pdfs/gebs-103019.pdf.

CGRi (Circularity Gap Reporting Initiative). 2021. *The Circularity Gap Report 2021.* https://www.circularity-gap.world/2021.

CLASP. 2021. "CLASP Policy Resource Center." CLASP, Washington, DC. https://cprc-clasp.ngo/.

EC. 2022. "Digitalising the energy system – EU action plan." EC, Brussels, October 10, 2022. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6228.

IEA (International Energy Agency). 2017. *Market Report Series: Energy Efficiency 2017.* Paris: IEA. https://www.iea.org/reports/energy-efficiency-2017.

IEA. 2018. Energy Efficiency 2018: *Analysis and Outlooks to 2040.* Paris: IEA. https://www.iea.org/reports/energy-efficiency-2018.

IEA. 2019 *Africa Energy Outlook 2019: World Energy Outlook Special Report.* Paris: IEA. https://www.iea.org/reports/africa-energy-outlook-2019.

IEA. 2020 *Energy Efficiency 2020.* Paris: IEA. https://www.iea.org/reports/energy-efficiency-2020.

IEA. 2021a. *Achievements of Energy Efficiency Appliance and Equipment Standards and Labelling Programmes: A Global Assessment in 2021.* Paris: IEA. https://www.iea.org/reports/achievements-of-energy-efficiency-appliance-and-equipment-standards-and-labeling-programmes.

IEA. 2021b. "Carbon Emissions Fell across All Sectors in 2020 except for One—SUVs." IEA, Paris. https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs.

IEA. 2021c. *Energy Efficiency Market Report.* Paris: IEA.

IEA. 2021d. Net Zero by 2050: A Roadmap for the Global Energy Sector. Paris: IEA.

IEA. 2021f. *Better Energy Efficiency Policy with Digital Tools.* Paris: IEA. https://www.iea.org/articles/better-energy-efficiency-policy-with-digital-tools.

IEA. 2021g. *Empowering Cities for a Net Zero Future.* Paris: IEA.

IEA. 2021h. *Global EV Outlook 2021*. Paris: IEA. https://www.iea.org/reports/global-ev-outlook-2021.

IEA. 2021i. *The Potential of Behavioural Interventions for Optimising Energy Use at Home.* Paris: IEA. https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home.

IEA. 2022a. "Policies Database." IEA, Paris.

IEA. 2022b. *Energy Efficiency Market Report 2022.* Paris: IEA.

IEA. 2022c. *Government Energy Spending Tracker.* Paris: IEA. https://www.iea.org/reports/sustainable-recovery-tracker.

IEA. 2022d. *The Value of Urgent Action on Energy Efficiency.* Paris: IEA. https://www.iea.org/reports/the-value-of-urgent-action-on-energy-efficiency.

IEA. 2022e. Tracking Clean Energy Progress—*Demand Response.* Paris: IEA.

IEA. 2022f. *World Energy Outlook 2022.* Paris: IEA. https://www.iea.org/reports/world-energy-outlook-2022.

IEA. 2023. *Energy Technology Perspectives 2023.* Paris: IEA. https://www.iea.org/reports/energy-technology-perspectives-2023.

OECD (Organisation for Economic Co-operation and Development). 2022. "Digitalisation for the Transition to a Resource Efficient and Circular Economy." OECD Environment Working Papers 192, OECD, Paris.

REN21 (Renewable Energy Policy Network for the 21st Century). 2019. "Policy Landscape." *In Renewables 2019: Global Status Report.* Paris: REN21. https://www.ren21.net/gsr-2019/chapters/chapter_02/chapter_02/.

SEPSE (Secretaría de Planificación del Subsector Energía). 2021. *Estrategia Nacional de Redes Eléctricas Inteligentes: 2021–2031.* San Jose: SEPSE. https://sepse.go.cr/wp-content/uploads/2021/08/ENREI-FINAL.pdf.

UK BEIS (Department for Business, Energy & Industrial Strategy). 2021. "Digitalising Our Energy System for Net Zero: Strategy and Action Plan 2021." BEIS, London. https://www.gov.uk/government/publications/digitalising-our-energy-system-for-net-zero-strategy-and-action-plan.

UN (United Nations). 2018. *International Recommendations for Energy Statistics (IRES).* New York: UN. https://unstats.un.org/unsd/energystats/methodology/documents/IRES-web.pdf.

UN. 2021. *Theme Report on Energy Transition: Towards the Achievement of SDG 7 and Net-Zero Emissions.* New York: UN. https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf.

UNIDO Industrial Decarbonization Accelerator. N.d. "Energy Management Systems Starter Kit." https://www.industrialenergyaccelerator.org/decarb-solutions/energy-management-systems/.

US DoE (Department of Energy). N.d. "Energy Saver—Porgramable Thermostats." https://www.energy.gov/energysaver/programmable-thermostats.

Users TCP (User-Centred Energy Systems Technology Collaboration Programme) and IEA. 2020. *Behavioural Insights for Demand-Side Energy Policy and Programmes: An Environment Scan.* Users TCP-IEA Technology Collaboration Programme. https://userstcp.org/wp-content/uploads/2020/11/Users-TCP-and-IEA-2020-BI-report.pdf.

World Bank. 2021. *RISE—Regulatory Indicators for Sustainable Energy.* Washington, DC: World Bank. https://www.worldbank.org/en/topic/energy/publication/rise---regulatory-indicators-for-sustainable-energy.