Last update: 7 February 2020  
  
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all   
  
Target 7.3: By 2030, double the global rate of improvement in energy efficiency   
  
Indicator 7.3.1: Energy intensity measured in terms of primary energy and GDP   
  
  
  
Institutional information   
  
  
  
Organization(s):   
  
  
  
International Energy Agency (IEA)   
  
United Nations Statistics Division (UNSD)   
  
  
  
Concepts and definitions   
  
  
  
Definition:   
  
  
  
Energy intensity is defined as the energy supplied to the economy per unit value of economic output.   
  
  
  
Rationale:   
  
  
  
Energy intensity is an indication of how much energy is used to produce one unit of economic output. It is a proxy of the efficiency with which an economy is able to use energy to produce economic output. A lower ratio indicates that less energy is used to produce one unit of output.   
  
  
  
Concepts:   
  
  
  
Total energy supply, as defined by the International Recommendations for Energy Statistics (IRES), is made up of production plus net imports minus international marine and aviation bunkers plus-stock changes. Gross Domestic Product (GDP) is the measure of economic output. For international comparison purposes, GDP is measured in constant terms at purchasing power parity   
  
  
  
Comments and limitations:   
  
  
  
Energy intensity is only an imperfect proxy for energy efficiency. It can be affected by a number of factors, such as climate, structure of the economy, nature of economic activities etc. that are not necessarily linked to pure efficiency.   
  
  
  
Methodology   
  
  
  
Computation Method:   
  
  
  
This indicator is based on the development of comprehensive energy statistics across supply and demand for all energy sources – statistics used to produce a national energy balance. Internationally agreed methodologies for energy statistics are described in the “International Recommendations for Energy Statistics” (IRES), adopted by the UN Statistical Commission, available at: unstats.un.org/unsd/energystats/methodology/ires/.  
  
  
  
Once a national energy balance is developed, the indicator can be obtained by dividing total energy supply over GDP.   
  
  
  
Disaggregation:   
  
  
  
Disaggregation of energy intensity, e.g. by final consumption sectors or end-uses, could provide further insights into progress towards energy efficiency. At present it is only feasible to calculate such sector disaggregations for the following sectors – industry, residential, transport, agriculture, households – as reported in the Tracking SDG7: The Energy Progress Report (formerly Sustainable Energy for All Global Tracking Framework). It would be desirable, over time, to develop more refined sectoral level energy intensity indicators that make it possible to look at energy intensity by industry (e.g. cement, steel) or by type of vehicle (e.g. cars, trucks), for example. Doing so will not be possible without statistical collaboration with the relevant energy consuming sectors.   
  
Decomposition analysis of energy intensity trends seeks to filter out factors that affect energy demand, such as economy wide scale and structure shifts, from more narrowly defined energy intensity shifts. The methodology applies decomposition analysis to isolate a more refined measure of energy intensity, one that sifts out the temporal shift of relative sector weights. This analysis is also reported in the Tracking SDG7: The Energy Progress Report.   
  
  
  
Regional aggregates:   
  
  
  
Aggregates are calculated, whether by region or globally, by summing both total energy supply and gross domestic products over relevant countries.   
  
  
  
Data Sources   
  
  
  
Total energy supply is typically calculated in the making of national energy balances. Energy balances are compiled based on data collected for around 150 economies from the International Energy Agency (IEA) and for all countries in the world from the United Nations Statistics Division (UNSD).   
  
  
  
GDP data are taken mainly from the World Bank – World Development Indicator database.  
  
  
  
Data Availability   
  
  
  
Description:   
  
  
  
IEA and UN Energy Balances combined provide total energy supply data for all countries on an annual basis. GDP data are available for most countries on an annual basis.   
  
  
  
Time series:   
  
  
  
2000 – present   
  
  
  
Calendar   
  
  
  
Data collection:   
  
  
  
Data are collected on an annual basis.   
  
  
  
Data release:   
  
  
  
The IEA Energy Balances are published in summer (publishing information for two calendar years prior). The UN Energy Balances are made available towards the end of the calendar year (publishing information for two calendar years prior).  
  
  
  
Data providers   
  
  
  
National administrations, as described in documentation on sources for IEA and UNSD:  
  
http://wds.iea.org/wds/pdf/WORLDBAL\_Documentation.pdf  
  
 unstats.un.org/unsd/energystats/data/  
  
  
  
Data compilers   
  
  
  
Name:  
  
  
  
The International Energy Agency (IEA) and the United Nations Statistics Division (UNSD)   
  
  
  
  
  
Description:   
  
  
  
The IEA and UNSD are the primary compilers of national energy statistics and develop internationally comparable energy balances based on internationally agreed methodologies. Aggregates are based on a merging between IEA and UNSD data.   
  
  
  
References   
  
  
  
URL:   
  
  
  
iea.org; unstats.un.org/unsd/energystats  
  
  
  
References:   
  
  
  
IEA Energy Balances and Statistics   
  
http://www.iea.org/statistics/  
  
  
  
UN Energy Statistics Database   
  
 unstats.un.org/unsd/energystats/data (description) and data.un.org/Explorer.aspx?d=EDATA (data)  
  
  
  
IEA SDG 7 webpage: http://www.iea.org/sdg   
  
  
  
International Recommendations for Energy Statistics (IRES) unstats.un.org/unsd/energystats/methodology/ires  
  
  
  
International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), the World Bank, World Health Organization (WHO). 2019. “Tracking SDG7: The Energy Progress Report 2019”.   
  
International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), the World Bank, World Health Organization (WHO). 2018. “Tracking SDG7: The Energy Progress Report 2018”. trackingsdg7.esmap.org/   
  
  
  
International Energy Agency (IEA) and the World Bank. 2017. “Global Tracking Framework 2017—Progress toward Sustainable Energy”. World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO  
  
  
  
International Energy Agency (IEA) and the World Bank. 2015. “Global Tracking Framework 2015—Progress Toward Sustainable Energy”, World Bank, Washington, DC. Doi: 10.1596/978-1-4648 -0690-2 License: Creative Commons Attribution CC BY 3.0 IGO  
  
  
  
International Energy Agency (IEA) and the World Bank. 2013. “Global Tracking Framework 2013”

Last updated: 28 March 2020  
  
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all  
  
Target 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services  
  
Indicator 7.1.1: Proportion of population with access to electricity  
  
  
  
Institutional information  
  
  
  
Organization(s):  
  
World Bank Group  
  
  
  
Concepts and definitions  
  
  
  
Definition:  
  
  
  
Proportion of population with access to electricity is the percentage of population with access to electricity.  
  
  
  
SDG7 ensures access to affordable, reliable, sustainable and modern energy for all. Specifically, Indicator 7.1.1 refers to the proportion of population with access to electricity. This is expressed in percentage figures and is disaggregated by total, urban and rural access rates per country, as well as by UN regional and global classifications.   
  
  
  
Rationale:  
  
  
  
Access to electricity addresses major critical issues in all the dimensions of sustainable development. The target has a wide range of social and economic impacts, including facilitating development of income generating activities and lightening the burden of household tasks.  
  
  
  
Under the global target of equal access to energy, SDG7.1.1 focuses specifically on electricity access available to the global population. In order to gain a clear picture, access rates are only considered if the primary source of lighting is the local electricity provider, solar systems, mini-grids and stand-alone systems. Sources such as generators, candles, batteries, etc., are not considered due to their limited working capacities and since they are usually kept as backup sources for lighting.  
  
  
  
  
  
Concepts:  
  
  
  
Electricity access in this scenario refers to the proportion of population in the considered area (country, region or global context) that has access to consistent sources of electricity.  
  
The World Bank’s Global Electrification Database compiles nationally representative household survey data as well as census data from 1990 to 2018. It also incorporates data from the Socio-Economic Database for Latin America and the Caribbean, the Middle East and North Africa Poverty Database, and the Europe and Central Asia Poverty Database, all of which are based on similar surveys. At the time of this analysis, the Global Electrification Database contained 1,215 surveys from 140 countries, excluding surveys from high-income countries as classified by the United Nations.  
  
  
  
Comments and limitations:  
  
  
  
The World Bank aims to estimate demand side access rates in order to better understand the access levels experienced by the population. This is different from the supply side access rates usually provided by governments, ministries, etc. The data collected is compiled from national household surveys and censuses. But since these are carried out infrequently, it is difficult to understand the ground level trends for short term periods. Collecting data for rural areas as well as last-mile connectivity problems also cause errors in data collection that could skew results.   
  
  
  
While the existing global household survey evidence base provides a good starting point for tracking household energy access, it also presents several limitations that will need to be addressed over time. In many parts of the world, the presence of an electricity connection in the household does not necessarily guarantee that the energy supplied is adequate in quality and reliability or affordable in cost and it would be desirable to have fuller information about these critical attributes of the service, which have been highlighted in SDG7.  
  
  
  
Substantial progress has already been made toward developing and piloting a new methodology known as the Multi-Tier Framework for Measuring Energy Access (World Bank) which is able to capture these broader dimensions of service quality and would make it possible to go beyond a simple yes/no measure of energy access to a more refined approach that recognizes different levels of energy access, and also takes into account the affordability and reliability of energy access explicitly referenced in the language of SDG7. The methodology for the Multi-Tier Framework for Measuring Energy Access has already been published based on a broad consultative exercise and represents a consensus view across numerous international agencies working in the field. Discussions are also progressing with the World Bank’s Household Survey Technical Working Group regarding the mainstreaming of this methodology into the standardized household questionnaire design that will be applied every three years in all low-income countries between 2015 and 2030 as part of the broader SDG monitoring exercise.  
  
  
  
The adoption of this methodology will allow – over time – the more refined measurement of energy access, making it possible to report more disaggregated information regarding the type of electricity supply (grid or off-grid), the capacity of electricity supply provided (in Watts), the duration of service (daily hours and evening hours), the reliability of service (in terms of number and length of unplanned service interruptions), the quality of service (in terms of voltage fluctuations), as well as affordability and legality of service.  
  
  
  
Another advantage of this approach is that they can be applied not only to measuring energy access at the household level, but also its availability to support enterprises and deliver critical community services, such as health and education.  
  
  
  
Methodological challenges associated with the measurement of energy access are more fully described the Global Tracking Framework (2013) (Chapter 2, Section 1, page 75-82), and in the ESMAP (2015) Report “Beyond Connections: Energy Access Redefined” both of which are referenced below.  
  
  
  
  
  
Methodology  
  
  
  
Computation Method:  
  
  
  
The World Bank’s Global Electrification Database compiles nationally representative household survey data as well as census data from 1990 to 2018. It also incorporates data from the Socio-Economic Database for Latin America and the Caribbean, the Middle East and North Africa Poverty Database, and the Europe and Central Asia Poverty Database, all of which are based on similar surveys. At the time of this analysis, the Global Electrification Database contained 1,215 surveys from 140 countries, excluding surveys from high-income countries as classified by the United Nations.  
  
  
  
To estimate values, a multilevel nonparametric modelling approach—developed by the World Health Organization to estimate clean fuel usage—was adapted to predict electricity access and used to fill in the missing data points for the time period between 1990 and 2018. Where data is available, access estimates are weighted by population. Multilevel nonparametric modelling considers the hierarchical structure of data (country and regional levels), using the regional classification of the United Nations.   
  
The model is applied for all countries with at least one data point. In order to use as much real data as possible, results based on real survey data are reported in their original form for all years available. The statistical model is used to fill in data only for years where they are missing and to conduct global and regional analyses. In the absence of survey data for a given year, information from regional trends was borrowed. The difference between real data points and estimated values is clearly identified in the database.    
  
Countries considered “Developed” by the United Nations and classified as “High Income” are assumed to have electrification rates of 100 percent from the first year the country joined the category.   
  
In the present report, to avoid having electrification trends from 1990 to 2010 overshadow electrification efforts since 2010, the model was run twice:   
  
With survey data + assumptions from 1990–2018 for model estimates from 1990–2018   
  
With survey data + assumptions from 2010–2018 for model estimates from 2010–2018   
  
  
  
Given the low frequency and the regional distribution of some surveys, several countries have gaps in available data. To develop the historical evolution and starting point of electrification rates, a simple modelling approach was adopted to fill in the missing data points. This modelling approach allowed the estimation of electrification rates for 212 countries over these time periods. The SE4ALL Global Tracking Framework Report (2013) referenced below provides more details on the suggested methodology for tracking access to energy (Chapter 2, Section 1, page 82-87).  
  
  
  
Disaggregation:  
  
  
  
Electricity access rates are disaggregated by geographic location into total, urban and rural rates. Countries that are classified as “Developed” or “High Income” are assumed to have 100 percent from the first year it was added to the category. Disaggregation of access to electricity by rural or urban place of residence is possible for all countries.  
  
  
  
Treatment of missing values:  
  
  
  
At country level  
  
  
  
Given the low frequency and regional distribution of some surveys, many countries have gaps in data availability. A simple modelling approach was adopted to fill in the missing data points, in order to develop the historical evolution and starting point of the electrification rates. The estimation is conducted using a model with region, country and time variables. The model keeps the original observation if data is available. The statistical model is used to fill in data only for years where they are missing and to help conduct global and regional analyses. In the absence of survey data for a given year, information from regional trends was borrowed. The estimated values are clearly identified (“Estimate”) in the database.    
  
  
  
At regional and global levels  
  
  
  
Values for regional and global levels are calculated by incorporating all survey data along with model-estimated values substituting missing values. Regional and global classifications are based on the UN M49 series for statistical use.  
  
  
  
Regional aggregates:  
  
  
  
Global coverage is available through the World Bank Global Electrification Database 2019.  
  
  
  
Sources of discrepancies:  
  
  
  
The World Bank database compiles electricity usage data, while many international agencies and national ministries report electricity production data. This is the main cause for data discrepancies.  
  
The quality and accuracy of population data can also lead to differences in assessing electrification.   
  
  
  
Methods and guidance available to countries for the compilation of the data at the national level:  
  
  
  
Countries generally use internationally accepted methods of conducting censuses and national surveys. There is some level of disparity between countries and regional methodologies, but the efforts to harmonize data is improving.   
  
  
  
  
  
  
  
(same answer from previous question?)  
  
  
  
  
  
Quality assurance  
  
  
  
A multi-level review process in collaboration with industry experts, national statistical offices, country and regional experts as well as partnering international agencies and UN bodies is conducted before finalizing the data.  
  
  
  
Before finalizing electricity access data, the World Bank team contacts the relevant national statistical offices as well as the UN regional commissions asking for reviews and suggestions for the prepared figures. The data also goes through multiple rounds of vetting process internally through departments. The relevant links are provided below under References.  
  
  
  
Data Sources  
  
  
  
Description:  
  
  
  
Data for access to electricity is collected from household surveys and censuses, tapping into a wide number of different household survey types including: Multi-tier Framework (MTF), Demographic and Health Surveys (DHS) and Living Standards Measurement Surveys (LSMS), Multi-Indicator Cluster Surveys (MICS), the World Health Survey (WHS), other nationally developed and implemented surveys, including those by various government agencies (for example, ministries of energy and utilities).  
  
  
  
The World Bank is the agency that has taken responsibility for compiling a meta-database of statistics on electricity access harvested from the full global body of household surveys. The World Bank Electrification Database covers more than 220 countries for the period 1990-2018 and is updated regularly.  
  
  
  
For more information on compiling access to energy data see Global Tracking Framework report (2013) (Chapter 2, Annex 2, page 127-129).  
  
  
  
Reports produced by international agencies such as the UN, World Bank, USAID, National Statistics Offices, as well as country censuses are used to collect data. Though some of the reports might not directly focus on energy access, they tend to include questions regarding access to electricity.   
  
  
  
Collection process:  
  
  
  
If data sources have any information on electricity access, it is collected and analysed in line with the previous trends and future projections of each country. Data validation is conducted by checking that the figures are reflective of the ground level scenario as well as are in line with country populations, income levels and electrification programs.   
  
  
  
Data Availability  
  
  
  
Description:  
  
  
  
Data is currently collected for 140 countries from 1990 to 2018, excluding “High Income” or “Developed” countries as classified by the United Nations.   
  
  
  
Time series:  
  
  
  
Data for countries have been compiled for the 1990-2018 period, though there are gaps in accurate data availability.  
  
Calendar  
  
  
  
Data collection:  
  
   
  
 The next round of data collection is planned for the second half of 2020.  
  
   
  
Data release:  
  
  
  
The annual release of new data for SDG7.1.1 is usually in the month of May.  
  
  
  
Data providers  
  
  
  
It varies according to the country and its context. Data is collected from national statistics agencies as well as international agencies such as the UN and World Bank.  
  
  
  
Data compilers  
  
  
  
World Bank Group  
  
  
  
References  
  
  
  
URL:  
  
  
  
https://databank.worldbank.org/source/world-development-indicators  
  
https://trackingsdg7.esmap.org/  
  
  
  
References:   
  
  
  
Multi-Tier Framework for Measuring Energy Access https://www.esmap.org/node/55526  
  
Global Tracking Framework Report (2013) http://trackingenergy4all.worldbank.org  
  
Global Tracking Framework Report (2015) http://trackingenergy4all.worldbank.org/  
  
  
  
  
  
  
  
Related indicators as of February 2020  
  
  
  
SDG7

Last updated: 7 February 2020  
  
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all  
  
Target 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix  
  
Indicator 7.2.1: Renewable energy share in the total final energy consumption  
  
  
  
Institutional information  
  
  
  
Organization(s):  
  
  
  
International Energy Agency (IEA)   
  
United Nations Statistics Division (UNSD)   
  
International Renewable Energy Agency (IRENA)  
  
  
  
Concepts and definitions  
  
  
  
Definition:  
  
  
  
The renewable energy share in total final consumption is the percentage of final consumption of energy that is derived from renewable resources.  
  
  
  
Rationale:  
  
  
  
The target “By 2030, increase substantially the share of renewable energy in the global energy mix” impacts all three dimensions of sustainable development. Renewable energy technologies represent a major element in strategies for greening economies everywhere in the world and for tackling the critical global problem of climate change. A number of definitions of renewable energy exist; what they have in common is highlighting as renewable all forms of energy that their consumption does not deplete their availability in the future. These include solar, wind, ocean, hydropower, geothermal resources, and bioenergy (in the case of bioenergy, which can be depleted, sources of bioenergy can be replaced within a short to medium-term frame). Importantly, this indicator focuses on the amount of renewable energy actually consumed rather than the capacity for renewable energy production, which cannot always be fully utilized. By focusing on consumption by the end user, it avoids the distortions caused by the fact that conventional energy sources are subject to significant energy losses along the production chain.  
  
  
  
Concepts:  
  
  
  
Renewable energy consumption includes consumption of energy derived from: hydro, solid biofuels, wind, solar, liquid biofuels, biogas, geothermal, marine and waste. Total final energy consumption is calculated from national balances and statistics as total final consumption minus non-energy use.   
  
  
  
Comments with regard to specific renewable energy resources:   
  
Solar energy consumption includes solar PV and solar thermal.   
  
Liquid biofuel energy consumption includes biogasoline, biodiesels and other liquid biofuels.   
  
Solid biofuel consumption includes fuelwood, animal waste, vegetable waste, black liquor, bagasse and charcoal.   
  
Waste energy covers energy from renewable municipal waste.   
  
  
  
Comments and limitations:  
  
  
  
A limitation with existing renewable energy statistics is that they are not able to distinguish whether renewable energy is being sustainably produced. For example, a substantial share of today’s renewable energy consumption comes from the use of wood and charcoal by households in the developing world, which sometimes may be associated with unsustainable forestry practices. There are efforts underway to improve the ability to measure the sustainability of bio-energy, although this remains a significant challenge.   
  
Off-grid renewables data are limited and not sufficiently captured in the energy statistics   
  
The method of allocation of renewable energy consumption from electricity and heat output assumes that the share of transmission and distribution losses are the same between all technologies. However, this is not always true because renewables are usually located in more remote areas from consumption centers and may incur larger losses.   
  
Likewise, imports and exports of electricity and heat are assumed to follow the share of renewability of electricity and heat generation, respectively. This is a simplification that in many cases will not affect the indicator too much, but that might do so in some cases, for example, when a country only generates electricity from fossil fuels but imports a great share of the electricity it uses from a neighboring country’s hydroelectric power plant.   
  
Methodological challenges associated with defining and measuring renewable energy are more fully described in the Global Tracking Framework (IEA and World Bank, 2013) Chapter 4, Section 1, pages 194-200. Data for traditional use of solid biofuels are generally scarce globally, and developing capacity in tracking such energy use, including developing national level surveys, is essential for sound global energy tracking.  
  
  
  
Methodology  
  
  
  
Computation Method:  
  
  
  
This indicator is based on the development of comprehensive energy statistics across supply and demand for all energy sources – statistics used to produce a national energy balance. Internationally agreed methodologies for energy statistics are described in the “International Recommendations for Energy Statistics” (IRES), adopted by the UN Statistical Commission, available at: unstats.un.org/unsd/energystats/methodology/ires .  
  
  
  
Once a national energy balance is developed, the indicator can be calculated by dividing final energy consumption from all renewable sources by total final energy consumption. Renewable energy consumption is derived from three tables of the IEA world energy statistics and balances: total final consumption, electricity output and heat output. All volumes reported in the total final consumption table are taken as reported. Since volumes for electricity and heat in the final consumption table are not broken down by technology, electricity and heat output tables are used instead to break down final consumption of electricity and heat by technology. The allocation by technology is done by deriving the share of technology in electricity and heat output tables and multiplying that share by final energy consumption of electricity and heat, respectively. For instance, if total final consumption table reports 150 TJ for biogas energy, while total final consumption of electricity is 400 TJ and heat 100 TJ, and the share of biogas in total electricity output is 10 percent and 5 percent in heat, the total reported number for biogas consumption will be 195 TJ (150 TJ+400TJ\*10%+100TJ\*5%). The Global Tracking Framework Report (IEA and World Bank, 2013) provides more details on the suggested methodology for defining and measuring renewable energy (Chapter 4, Section 1, page 201-202). UNSD follows the same methodology to compute the indicators, though information may come from different tables.  
  
  
  
Disaggregation:  
  
  
  
Disaggregation of the data on consumption of renewable energy, e.g. by resource and end-use sector, could provide insights into other dimensions of the goal, such as affordability and reliability. For solar energy, it may also be of interest to disaggregate between on grid and off-grid capacity.   
  
  
  
Regional aggregates:  
  
  
  
Aggregates are calculated, whether by region or global, using final energy consumption as weights.   
  
  
  
Data Sources  
  
  
  
Data on renewable energy consumption are available through national energy balances compiled based on data collected by the International Energy Agency (for around 150 countries) and the United Nations Statistics Division (UNSD) for all countries. The energy balances make it possible to trace all the different sources and uses of energy at the national level.   
  
  
  
Some technical assistance may be needed to improve these statistics, particularly in the case of renewable energy sources. Specialized industry surveys (e.g. on bioenergy use) or household surveys (in combination with the measurement of other indicators) would be feasible approaches to filling in data gaps (e.g. for use of firewood, off-grid solar energy).   
  
  
  
Data Availability  
  
  
  
Description:  
  
  
  
Between the various existing data sources, primarily the IEA Energy Balances and the UN Energy Statistics Database, annual total and renewable energy consumption for every country and area can be collected. The Tracking SDG7: The Energy Progress Report (formerly Sustainable Energy for All Global Tracking Framework) is reporting this indicator at a global level between 2010 and 2030.   
  
  
  
Time series:  
  
  
  
2000 – present   
  
  
  
Calendar  
  
  
  
Data collection:  
  
  
  
Data are collected on an annual basis.  
  
  
  
Data release:  
  
  
  
The IEA Energy Balances are published in summer (publishing information for two calendar years prior). The UN Energy Statistics Database is made available towards the end of the calendar year (publishing information for two calendar years prior).  
  
  
  
Data providers  
  
  
  
National administrations, as described in documentation on sources for IEA and UNSD:  
  
http://wds.iea.org/wds/pdf/WORLDBAL\_Documentation.pdf  
  
unstats.un.org/unsd/energystats/data  
  
  
  
Data compilers  
  
  
  
Name:  
  
  
  
The International Energy Agency (IEA) and the United Nations Statistics Division (UNSD)   
  
  
  
  
  
Description:  
  
  
  
The IEA and UNSD are the primary compilers of national energy statistics and develop internationally comparable energy balances based on internationally agreed methodologies. Aggregates are based on analysis merging of IEA and UNSD data.   
  
  
  
References  
  
  
  
URL:   
  
  
  
iea.org; unstats.un.org/unsd/energystats  
  
  
  
References:   
  
  
  
IEA Energy Balances and Statistics   
  
http://www.iea.org/statistics/   
  
UN Energy Statistics Database   
  
 unstats.un.org/unsd/energystats/data (description) and data.un.org/Explorer.aspx?d=EDATA (data)  
  
  
  
IEA SDG 7 webpage: http://www.iea.org/sdg  
  
International Recommendations for Energy Statistics (IRES) unstats.un.org/unsd/energystats/methodology/ires  
  
International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), the World Bank, World Health Organization (WHO). 2019. “Tracking SDG7: The Energy Progress Report 2019”. trackingsdg7.esmap.org/   
  
International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), the World Bank, World Health Organization (WHO). 2018. “Tracking SDG7: The Energy Progress Report 2018”. trackingsdg7.esmap.org/   
  
International Energy Agency (IEA) and the World Bank. 2017. “Global Tracking Framework 2017—Progress toward Sustainable Energy”. World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO  
  
International Energy Agency (IEA) and the World Bank. 2015. “Global Tracking Framework 2015—Progress Toward Sustainable Energy”, World Bank, Washington, DC. Doi: 10.1596/978-1-4648 -0690-2 License: Creative Commons Attribution CC BY 3.0 IGO  
  
International Energy Agency (IEA) and the World Bank. 2013. “Global Tracking Framework 2013”  
  
IRENA Renewable Energy Database   
  
http://resourceirena.irena.org/gateway/dashboard.

Last updated: April 2019  
  
  
  
Goal: 7. Ensure access to affordable, reliable, sustainable and modern energy for all.  
  
Target: 7.a. By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.  
  
Indicator: 7.a.1: International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems.  
  
  
  
Institutional information  
  
  
  
Organization(s):  
  
Organisation for Economic Co-operation and Development (OECD) and International Renewable Energy Agency (IRENA)  
  
  
  
Concepts and definitions  
  
  
  
Definition:  
  
The flows are covered through two complementary sources.  
  
OECD: The flows covered by the OECD are defined as all official loans, grants and equity investments received by countries on the DAC List of ODA Recipients from foreign governments and multilateral agencies, for the purpose of clean energy research and development and renewable energy production, including in hybrid systems extracted from the OECD/DAC Creditor Reporting System (CRS) with the following sector codes:  
  
23210 Energy generation, renewable sources – multiple technologies - Renewable energy generation programmes that cannot be attributed to one single technology (codes 23220 through 23280 below). Fuelwood/charcoal production should be included under forestry 31261.   
  
23220 Hydro-electric power plants - Including energy generating river barges.   
  
23230 Solar energy - Including photo-voltaic cells, solar thermal applications and solar heating.   
  
23240 Wind energy - Wind energy for water lifting and electric power generation.   
  
23250 Marine energy - Including ocean thermal energy conversion, tidal and wave power.   
  
23260 Geothermal energy - Use of geothermal energy for generating electric power or directly as heat for agriculture, etc.   
  
23270- Biofuel-fired power plants Use of solids and liquids produced from biomass for direct power generation. Also includes biogases from anaerobic fermentation (e.g. landfill gas, sewage sludge gas, fermentation of energy crops and manure) and thermal processes (also known as syngas); waste fired power plants making use of biodegradable municipal waste (household waste and waste from companies and public services that resembles household waste, collected at installations specifically designed for their disposal with recovery of combustible liquids, gases or heat). See code 23360 for non-renewable waste-fired power plants.  
  
Research and development of energy efficiency technologies and measures is captured under CRS sector code 23182 on Energy research. The above flows also include technical assistance provided to support production, research and development as defined above.  
  
IRENA: The flows covered by IRENA are defined as all additional loans, grants and equity investments received by developing countries (defined as countries in developing regions, as listed in the UN M49 composition of regions) from all foreign governments, multilateral agencies and additional development finance institutions (including export credits, where available) for the purpose of clean energy research and development and renewable energy production, including in hybrid systems. These additional flows cover the same technologies and other activities (research and development, technical assistance, etc.) as listed above and exclude all flows extracted from the OECD/DAC CRS.  
  
  
  
Rationale:  
  
Total ODA and OOF flows to developing countries quantify the public financial effort (excluding export credits) that donors provide to developing countries for renewable energies. The additional flows (from the IRENA database) capture the flows to non-ODA Recipients in developing regions, flows from countries and institutions not currently reporting to the DAC and certain other types of flows, such as export credits.   
  
Energy access is a major development constraint in many developing countries and, while starting from a relatively low base, energy demand is expected to grow very rapidly in many of these countries in the future. This presents an opportunity for developing countries to utilize clean and renewable technologies to meet their future energy needs if they can gain access to the appropriate technologies and expertise. This indicator provides a suitable measure of the international support given to developing countries to access these technologies.  
  
  
  
Concepts:  
  
The definition and classification of renewable technologies complies with the UN Standard International Energy Product Classification (SIEC). Definitions of other concepts are given above.  
  
  
  
Comments and limitations:  
  
Data in the Creditor Reporting System are available from 1973. However, the data coverage is considered complete since 1995 for commitments at an activity level and 2002 for disbursements. At present, flows to clean energy research and development are only partially covered by the database and a few other areas (e.g. off-grid electricity supply, investments in improved cookstove projects) may be covered only partially.   
  
The IRENA database currently only covers financial institutions that have invested a total of USD 400 million or more in renewable energy. The process of continuous improvement of the database includes verifying the data against data produced by the multilateral development banks for climate finance reporting and by comparing the data with other independent reporting by international development finance agencies.  
  
  
  
Methodology  
  
  
  
Computation Method:  
  
The OECD flows are calculated by taking the total official flows (ODA and OOF) from DAC member countries, multilateral organisations and other providers of development assistance to the sectors listed above. The IRENA (additional) flows are calculated by taking the total public investment flows from IRENA’s Public Renewable Energy Investment Database and excluding: domestic financial flows; international flows to countries outside developing regions; and flows reported by OECD (as described above). The flows are commitments measured in current United States Dollars (USD).  
  
  
  
Disaggregation:  
  
Data in the CRS contain markers which reflect whether a policy objective is attained through the activity. Measuring gender equality is included in the CRS. Data from the CRS are reported at the project level and can be disaggregated by type of flow (ODA or OOF), by donor, recipient country, type of finance, type of aid (project, agriculture sub-sector, etc.).  
  
Data in IRENA are stored by country (source and recipient) at the project-level, allowing disaggregation of the data in several dimensions. For example, financial flows can be divided by technologies (i.e. bioenergy, geothermal energy, hydropower, ocean energy, solar energy, and wind energy) and sub-technologies (e.g. onshore and offshore wind), by geography (both at the country and regional level), by financial instrument and by type of recipient.  
  
  
  
Treatment of missing values:  
  
  
  
At country level  
  
Not applicable - there is no imputation of missing values.  
  
  
  
At regional and global levels  
  
Not applicable - there is no imputation of missing values to obtain regional or global totals.   
  
  
  
Regional aggregates:  
  
Regional and global totals are calculated by summing all available data from countries.  
  
  
  
Sources of discrepancies:  
  
Neither OECD nor IRENA make estimates of these figures. The data all come from national sources reported to OECD or, in the case of IRENA, from officially published statistics.  
  
  
  
Methods and guidance available to countries for the compilation of the data at the national level:  
  
Not applicable.  
  
  
  
Quality assurance:  
  
OECD/DAC data are reported by donors according to the same standards and methodologies (see here: http://www.oecd.org/dac/stats/methodology.htm). IRENA data are compiled from national sources following the United Nations Fundamental Principles of Official Statistics: https://unstats.un.org/unsd/dnss/gp/fundprinciples.aspx.   
  
  
  
Consultation/validation process with countries for adjustments and estimates  
  
For OECD, see: http://www.oecd.org/dac/stats/methodology.htm  
  
  
  
Data Sources  
  
  
  
Description:  
  
The OECD/DAC has been collecting data on official and private resource flows from 1960 at an aggregate level and 1973 at an activity level through the Creditor Reporting System (CRS data are considered complete from 1995 for commitments at an activity level and 2002 for disbursements). Data are reported on an annual calendar year basis by statistical reporters in national administrations (aid agencies, Ministries of Foreign Affairs or Finance, etc.  
  
IRENA’s data on financial flows from public sources in support of renewable energy are available in IRENA’s Public Renewable Energy Investment Database. IRENA collects this data from a wide range of publicly available sources, including the databases and annual reports of all of the main development finance institutions and 20 other bilateral and multilateral agencies investing in renewable energy. The database is updated annually and (at end-2016) covers public renewable energy investment flowing to 29 developed countries and 104 developing countries, for the period 2000-2015. As new publicly-funded financial institutions start investing in renewable energy, the IRENA database will expand to include these new investors over time.  
  
  
  
Collection process:  
  
See above.  
  
  
  
Data Availability  
  
  
  
Description:  
  
The CRS contains flows to all DAC recipient countries. Global and regional figures are based on the sum of ODA and OOF flows to the renewable energy projects.  
  
IRENA currently includes data about renewable energy projects in 29 developed countries and 104 developing countries (133 countries overall).  
  
  
  
Time series:  
  
OECD: annual data from 1960 onwards (see above). IRENA: annual data from 2000 onwards.  
  
  
  
Calendar  
  
  
  
Data collection:  
  
 Data for a year is collected during the following year.  
  
   
  
Data release:  
  
OECD DAC data is updated four time a year, with complete and detailed data published at year-end (covering the previous year). IRENA investment data is available at year-end (covering the previous year).  
  
  
  
Data providers  
  
  
  
See above.  
  
  
  
Data compilers  
  
  
  
Organisation for Economic Co-operation and Development (OECD) and International Renewable Energy Agency (IRENA).  
  
  
  
References  
  
  
  
CRS: See all links here: http://www.oecd.org/dac/stats/methodology.htm   
  
IRENA Renewable Energy Finance Flows: http://resourceirena.irena.org/gateway/dashboard/?topic=6&subTopic=8   
  
  
  
Related indicators as of February 2020  
  
  
  
Not applicable.

Last updated: May 2020  
  
  
  
Goal: 7. Ensure access to affordable, reliable, sustainable and modern energy for all.  
  
Target: 7.b. By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing states and landlocked developing countries, in accordance with their respective programmes of support.  
  
Indicator: 7.b.1: Installed renewable energy-generating capacity in developing countries (in watts per capita)  
  
  
  
Institutional information  
  
  
  
Organization(s):  
  
International Renewable Energy Agency (IRENA)  
  
  
  
Concepts and definitions  
  
  
  
Definition:  
  
The indicator is defined as the installed capacity of power plants that generate electricity from renewable energy sources divided by the total population of a country. Capacity is defined as the net maximum electrical capacity installed at the year-end and renewable energy sources are as defined in the IRENA Statute (see concepts below).   
  
  
  
Rationale:  
  
The infrastructure and technologies required to supply modern and sustainable energy services cover a wide range of equipment and devices that are used across numerous economic sectors. There is no readily available mechanism to collect, aggregate and measure the contribution of this disparate group of products to the delivery of modern and sustainable energy services. However, one major part of the energy supply chain that can be readily measured is the infrastructure used to produce electricity.   
  
   
  
Renewables are considered a sustainable form of energy supply, as their current use does not usually deplete their availability to be used in the future. The focus of this indicator on electricity reflects the emphasis in the target on modern sources of energy and is particularly relevant for developing countries where the demand for electricity is often high and its availability is constrained. Furthermore, the focus on renewables reflects the fact that the technologies used to produce renewable electricity are generally modern and more sustainable than non-renewables, particularly in the fastest growing sub-sectors of electricity generation from wind and solar energy.  
  
  
  
The division of renewable electricity capacity by population (to produce a measure of Watts per capita) is proposed to scale the capacity data to account for the large variation in needs between countries. It uses population rather than GDP to scale the data, because this is the most basic indicator of the demand for modern and sustainable energy services in a country.  
  
  
  
This indicator should also complement indicators 7.1.1 and 7.2. With respect to electricity access, it will provide additional information to the proportion of people with electricity access by showing how much infrastructure is available to deliver that access (in terms of the amount of capacity per person). The focus on renewable capacity will also add-value to the existing renewables indicator (7.2) by showing how much renewable energy is contributing to the need for improved electricity access.   
  
  
  
Concepts:  
  
Electricity capacity is defined in the International Recommendations for Energy Statistics or IRES (UN, 2018) as the maximum active power that can be supplied continuously (i.e., throughout a prolonged period in a day with the whole plant running) at the point of outlet (i.e., after taking the power supplies for the station auxiliaries and allowing for the losses in those transformers considered integral to the station). This assumes no restriction of interconnection to the network. It does not include overload capacity that can only be sustained for a short period of time (e.g., internal combustion engines momentarily running above their rated capacity).  
  
  
  
The IRENA Statute defines renewable energy to include energy from the following sources: hydropower; marine energy (ocean, tidal and wave energy); wind energy; solar energy (photovoltaic and thermal energy); bioenergy; and geothermal energy.  
  
  
  
Comments and limitations:  
  
At present, electricity only accounts for about one-quarter of total energy use in the World and an even lower share of energy use in most developing countries. The focus of this indicator on electricity capacity does not capture any trends in the modernisation of technologies used to produce heat or provide energy for transport.  
  
  
  
However, with the growing trend towards electrification of energy end-uses, the focus here on electricity may become less of a weakness in the future and may also serve as a general indicator of the progress towards greater electrification in developing counties. That, in itself, should be seen as a shift towards the use of more modern technology to deliver sustainable energy services.  
  
  
  
Furthermore, as reflected in many national policies, plans and targets, increasing the production of electricity and, in particular, renewable electricity, is seen by many countries as a first priority in their transition to the delivery of more modern and sustainable energy services. Thus, this indicator is a useful first-step towards measuring overall progress on this target that reflects country priorities and can be used until other additional or better indicators can be developed.  
  
  
  
Methodology  
  
  
  
Computation Method:  
  
For each country and year, the renewable electricity generating capacity at the end of the year is divided by the total population of the country in that year.  
  
  
  
Disaggregation:  
  
IRENA’s renewable capacity data is available for every country and area in the world from the year 2000 onwards. These figures can also be disaggregated by technology (solar, hydro, wind, etc.) and by on-grid and off-grid capacity.  
  
  
  
Treatment of missing values:  
  
  
  
At country level  
  
At the country level, electricity capacity data is sometimes missing for two reasons:  
  
  
  
Delays in responding to IRENA questionnaires or publication of official data. In such cases, estimates are made so that global and regional totals can be calculated. The most basic treatment is to repeat the value of capacity from the previous year. However, IRENA also checks unofficial data sources and collects data about investment projects (see Indicator 7.a.1). These other sources can be used to identify if any new power plants have been commissioned in a year and are used where available to update the capacity value at the end of a year. Any such estimates are eventually replaced by official or questionnaire data when that becomes available.  
  
Off-grid capacity data is frequently missing from national energy statistics, or is presented in non-standard units (e.g. numbers of mini-hydro plants in a country rather than their capacity in MW). Where official data is not available, off-grid capacity figures are collected by IRENA from a wide variety of other official and unofficial sources in countries (e.g. development agencies, government departments, NGOs, project developers and industry associations) and this information is added to the capacity database to give a more complete picture of developments in the renewable energy sector in a country. This data is peer reviewed each year through an extensive network of national correspondents (the REN21 Network) and is checked with IRENA country focal points when they attend IRENA meetings and training workshops.  
  
  
  
At regional and global levels  
  
See above. Regional and global totals are only estimated to the extent that figures for some countries may be estimated in each year. (See also data availability below).   
  
  
  
Regional aggregates:  
  
Regional and global totals are calculated by summing the renewable generating capacity for a region or the World and dividing that by the corresponding figure for total population.  
  
  
  
Sources of discrepancies:  
  
The main source of discrepancies between different sources of electricity capacity data are likely to be due to the under-reporting or non-reporting of off-grid capacity data (see above) or slight variations in the definition of installed capacity. IRENA uses the IRES definition of capacity agreed by the Oslo Group on Energy Statistics, while some countries and institutions may use slightly different definitions of capacity to reflect local circumstances (e.g. the reporting of derated rather than maximum net installed capacity or the reporting of built rather than commissioned capacity at year-end).  
  
  
  
Methods and guidance available to countries for the compilation of the data at the national level:  
  
Guidance for the collection of electricity capacity data is provided by the International Recommendations for Energy Statistics. IRENA also produces methodological guidance for countries, specifically about how to measure renewable energy and collect renewable energy data. This is supported by a comprehensive programme of regional renewable energy statistics training workshops and ongoing communications with countries as part of the annual questionnaire cycle.   
  
  
  
Quality assurance:  
  
IRENA data are compiled from national sources following the United Nations Fundamental Principles of Official Statistics: https://unstats.un.org/unsd/dnss/gp/fundprinciples.aspx.   
  
  
  
Consultation/validation process with countries for adjustments and estimates  
  
All countries are invited to provide their capacity data or at least review the data that IRENA has compiled (from other official and unofficial sources) through an annual process of data collection using the IRENA Renewable Energy Questionnaire. This process is reinforced through IRENA’s renewable energy statistics training workshops, which are held twice a year in different (rotating) regions. To date, over 200 energy statisticians have participated in these workshops, many of whom provide renewable energy data to IRENA. In addition, IRENA’s statistics are presented each year to member countries at one of IRENA’s three governing body meetings, where discrepancies or other data issues can be discussed with country representatives.  
  
  
  
Data Sources  
  
  
  
Description:  
  
IRENA’s electricity capacity database contains information about the electricity generating capacity installed at the year-end, measured in MW. The dataset covers all countries and areas from the year 2000 onwards. The dataset also records whether the capacity is on-grid or off-grid and is split into 36 different renewable energy types that can be aggregated into the six main sources of renewable energy.   
  
  
  
Collection process:  
  
The capacity data is collected as part of IRENA’s annual questionnaire cycle. Questionnaires are sent to countries at the start of a year asking for renewable energy data for two years previously (i.e. at the start of 2019, questionnaires ask for data for the year 2017). The data is then validated and checked with countries and published in the IRENA Renewable Energy Statistics Yearbook at the end of June. To minimise reporting burden, the questionnaires for some countries are pre-filled with data collected by other agencies (e.g. Eurostat) and are sent to countries for them to complete any additional details requested by IRENA.  
  
  
  
At the same time as this, preliminary estimates of capacity for the previous year are also collected from official sources where available (e.g. national statistics, data from electricity grid operators) and from other unofficial sources (mostly industry associations for the different renewable energy sectors). These are published at the end of March.   
  
  
  
Population data:  
  
For the population part of this indicator, IRENA uses a 6-source consolidation by the World Bank, which is available through the World Bank’s World Development Indicators database. The indicator reflects the residents in a country or area regardless of legal status or citizenship. The values are midyear estimates.  
  
  
  
The World Bank publishes more information about this indicator in their metadata:  
  
https://databank.worldbank.org/reports.aspx?source=2&type=metadata&series=SP.POP.TOTL  
  
Data Availability  
  
  
  
Description:  
  
The total number of capacity records in the database (all developing countries/areas, all years since 2000, all technologies) is 11,000. In terms of numbers of records, 3,120 (28%) are estimates and 740 (7%) are from unofficial sources. The remaining records (65%) are all from returned questionnaires or official data sources.   
  
  
  
However, in terms of the amount of capacity covered in the database, the shares of data from estimated and unofficial sources is only 5% and 1% respectively. The large difference between these measures is due to the inclusion of off-grid capacity figures in the database. The amount of off-grid generating capacity in a country is quite frequently estimated by IRENA, but the amounts of off-grid capacity recorded in each case is often relatively small.  
  
  
  
Time series:  
  
Renewable generating capacity data is available from 2000 onwards.   
  
  
  
Calendar  
  
  
  
Data collection:  
  
 Capacity data is recorded as a year-end figure. The data is collected in the first six months of every year  
  
   
  
Data release:  
  
Estimates of generating capacity for a year are published at the end of March in the following year. Final figures for the year before that are published at the end of June.  
  
  
  
Data providers  
  
  
  
Renewable energy generating capacity:  
  
National Statistical Offices and National Energy Agencies of Ministries (the authority to collect this data varies between countries). Data for preliminary estimates may also be collected from industry associations, national utility companies or grid operators.  
  
  
  
Population:  
  
The World Bank consolidates and publishes population data coming from the following data providers:  
  
United Nations Population Division. World Population Prospects.   
  
Census reports and other statistical publications from national statistical offices  
  
Eurostat: Demographic Statistics  
  
United Nations Statistical Division. Population and Vital Statistics Report  
  
U.S. Census Bureau: International Database  
  
Secretariat of the Pacific Community: Statistics and Demography Programme.  
  
Data compilers  
  
  
  
International Renewable Energy Agency (IRENA).  
  
  
  
References  
  
  
  
IRENA Statistical Yearbooks: https://www.irena.org/Statistics.   
  
  
  
Related indicators  
  
  
  
Not applicable.

Last updated: 23 April 2020  
  
  
  
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all  
  
Target 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services  
  
Indicator 7.1.2: Proportion of population with primary reliance on clean fuels and technology  
  
  
  
Institutional information  
  
  
  
Organization(s):  
  
  
  
World Health Organization (WHO)  
  
  
  
Concepts and definitions  
  
  
  
Definition:  
  
  
  
Proportion of population with primary reliance on clean fuels and technology is calculated as the number of people using clean fuels and technologies for cooking, heating and lighting divided by total population reporting that any cooking, heating or lighting, expressed as percentage. “Clean” is defined by the emission rate targets and specific fuel recommendations (i.e. against unprocessed coal and kerosene) included in the normative guidance WHO guidelines for indoor air quality: household fuel combustion.  
  
  
  
Rationale:  
  
  
  
Cooking, lighting and heating represent a large share of household energy use across the low- and middle-income countries. For cooking and heating, households typically rely on solid fuels (such as wood, charcoal, biomass) or kerosene paired with inefficient technologies (e.g. open fires, stoves, space heaters or lamps). It is well known that reliance on such inefficient energy for cooking, heating and lighting is associated with high levels of household (indoor) air pollution. The use of inefficient fuels for cooking alone is estimated to cause over 4 million deaths annually, mainly among women and children. This is more than TB, HIV and malaria combined. These adverse health impacts can be avoided by adopting clean fuels and technologies for all main household energy end-or in some circumstances by adopting advanced combustion cook stoves (i.e. those which achieve the emission rates targets provided by the WHO guidelines) and adopting strict protocols for their safe use. Given the importance of clean and safe household energy use as a human development issue, universal access to energy among the technical practitioner community is currently taken to mean access to both electricity and clean fuels and technologies for cooking, heating and lighting. For this reason, clean cooking forms part of the universal access objective under the UN Secretary General’s Sustainable Energy for All initiative.  
  
  
  
Concepts:  
  
  
  
Current global data collection focuses on the primary fuel used for cooking, categorized as solid or non-solid fuels, where solid fuels are considered polluting and non-modern, while non-solid fuels are considered clean. This single measure captures a good part of the lack of access to clean cooking fuels, but fails to collect data on type of device or technology is used for cooking, and also fails to capture other polluting forms of energy use in the home such as those used for lighting and heating.  
  
  
  
New evidence-based normative guidance from the WHO (i.e. WHO Guidelines for indoor air quality guidelines: household fuel combustion), highlights the importance of addressing both fuel and the technology for adequately protecting public health. These guidelines provide technical recommendations in the form of emissions targets for as to what fuels and technology (stove, lamp, and so on) combinations in the home are clean. These guidelines also recommend against the use of unprocessed coal and discourage the use kerosene (a non-solid but highly polluting fuel) in the home. They also recommend that all major household energy end uses (e.g. cooking, space heating, lighting) use efficient fuels and technology combinations to ensure health benefits.  
  
  
  
For this reason, the technical recommendations in the WHO guidelines, access to modern cooking solution in the home will be defined as “access to clean fuels and technologies” rather than “access to non-solid fuels.” This shift will help ensure that health and other “nexus” benefits are better counted, and thus realized.  
  
  
  
Comments and limitations:  
  
  
  
The indicator uses the type of primary fuels and technologies used for cooking, heating, and lighting as a practical surrogate for estimating human exposure to household (indoor) air pollution and its related disease burden, as it is not currently possible to obtain nationally representative samples of indoor concentrations of criteria pollutants, such as fine particulate matter and carbon monoxide. However epidemiological studies provide a science-based evidence for establishing those estimates using these surrogates.  
  
The indicator is based on the main type of fuel and technology used for cooking as cooking occupies the largest share of overall household energy needs. However, many households use more than one type of fuel and stove for cooking and, depending on climatic and geographical conditions, heating with polluting fuels can also be a contributor to household (indoor) air pollution levels. In addition, lighting with kerosene, a very polluting and hazardous fuel is also often used, and in some countries is the main fuel used for cooking.  
  
  
  
While the existing global household survey evidence base provides a good starting point for tracking household energy access for cooking fuel, it also presents a number of limitations that will need to be addressed over time. Currently there is a limited amount of available data capturing the type of fuel and devices used in the home for heating and lighting. Accordingly WHO in cooperation with World Bank, and the Global Alliance for Clean Cook stoves, is leading a survey enhancement process with representatives from country statistical offices and national household surveying agencies (e.g. Demographic and Health Survey, Multiple Indicator Cluster Survey, Living Standards Measurement Survey) to better gather efficiently and harmoniously information on the fuels and technologies for cooking, heating and lighting. This process is currently in the piloting phase with expected rollout of the final household surveys questions (~6 questions in total) expected in the coming year. These few questions will replace and slightly expand the current set of questions commonly used on national multipurpose surveys to assess household energy.  
  
  
  
Substantial progress has already been made toward developing and piloting a new methodology known as the Multi-Tier Framework for Measuring Energy Access (World Bank) which is able to capture the affordability and reliability of energy access explicitly referenced in the language of SDG7 and harnesses the normative guidance in the WHO guidelines to benchmark tiers of energy access. The methodology for the Multi-Tier Framework for Measuring Energy Access has already been published based on a broad consultative exercise and represents a consensus view across numerous international agencies working in the field. A first Global Energy Access Survey using this methodology has already been launched and is underway expecting to yield results by early 2017.  
  
  
  
Methodology  
  
  
  
Computation Method:  
  
  
  
The indicator is modelled with household survey data compiled by WHO. The information on cooking fuel use and cooking practices comes from about 1300 nationally representative survey and censuses. Survey sources include Demographic and Health Surveys (DHS) and Living Standards Measurement Surveys (LSMS), Multi-Indicator Cluster Surveys (MICS), the World Health Survey (WHS), and other nationally developed and implemented surveys.  
  
  
  
Estimates of primary cooking energy for the total, urban and rural population for a given country and year are obtained together using a single multivariate hierarchical model. Using household survey data as inputs, the model jointly estimates primary reliance on 6 specific fuel types: 1. unprocessed biomass (e.g. wood), 2. charcoal, 3. coal, 4. kerosene, 5. gaseous fuels (e.g. LPG), and 6. electricity; and a final category including other clean fuels (e.g. alcohol). Estimates of the proportion of the population with primary reliance on clean fuels and technology (SDG indicator 7.1.2) are then derived by aggregating the estimates for primary reliance on clean fuel types from the model. Details on the model are published in Stoner et al. (2019).  
  
  
  
Only survey data providing individual fuel breakdowns and with less than 15% of the population reporting “missing” and “no cooking” and “other fuels” were included in the analysis.   
  
  
  
Countries with no household fuel data but classified as high-income according to the World Bank country classification (37 countries) were assumed to have fully transitioned to clean household energy and therefore are reported as >95% access to clean technologies.  
  
  
  
No estimates were reported for low- and middle-income countries without data (Bulgaria, Cuba, Lebanon, Libya). Modelled specific fuel estimates were derived for 135 low- and middle-income countries and estimates of overall clean fuel use were reported for 190 countries.  
  
  
  
Disaggregation:  
  
  
  
Disaggregated estimates for different end-uses (i.e. cooking, heating and lighting; with expected improvements in household surveys, this will be possible for heating and lighting for all countries.  
  
  
  
Disaggregation of access to clean fuel and technologies for cooking by rural or urban place of residence is possible for all countries with survey data.  
  
  
  
Gender disaggregation by main user (i.e. cook) of cooking energy will be available with expected improvements in household surveys.  
  
  
  
Gender disaggregation of head of household for cooking, lighting and heating is available  
  
Energy is a service provided at the household, rather than individual level.  
  
  
  
Nonetheless, it is used differentially by men and women and has different impacts on their health and well-being. What will be possible, in principle, is to report energy access disaggregated by the main user of cooking energy.  
  
  
  
In addition, WHO's Household energy database includes country data from thirty countries on the time spent by children collecting fuelwood and water disaggregated by sex. With the improvements in data collection via the below mentioned survey harmonization process, data will be available reporting time spent exclusively on fuel collection rather than in combination with water collection.  
  
  
  
Treatment of missing values:  
  
  
  
At country level  
  
  
  
No reporting for low- and middle-income countries with no data.   
  
  
  
High income countries with no data are assumed to have transitioned to clean fuels and technologies, and are therefore reported as >95% of their population using clean fuels and technologies.  
  
  
  
At regional and global levels  
  
  
  
Low- and middle-income countries with no data were excluded from regional and global aggregations.  
  
  
  
High income countries with no data are assumed to have transitioned to clean fuels and technologies, and are therefore assumed to have 100% of their population using clean fuels and technologies for the purpose of calculating regional and global aggregations.  
  
  
  
Regional aggregates:  
  
  
  
Regional and global estimates are population-weighted; i.e. the country estimates (e.g. 56%) is multiplied by its population, this figure is summed (by region or for all countries) and divided by the sum of the population of the countries included.  
  
  
  
Sources of discrepancies:  
  
  
  
There may be discrepancies between internationally reported and nationally reported figures. The reasons are the following:  
  
  
  
- Modelled estimates versus survey data point.  
  
  
  
- Use of different definitions of polluting (or previously solid) fuels (wood only or wood and any other biomass, e.g. dung residues; kerosene included or not as polluting fuels).  
  
  
  
- Use of different total population estimate.  
  
  
  
- Estimates are expressed as percentage of population using polluting (or solid) fuels (as per SDG indicator) as compared to percentage of household using polluting (or solid) fuels (as assessed by surveys such as DHS or MICS).  
  
  
  
- In the estimates presented here, values above 95% polluting fuel use are reported as “>95”, and values below 5% as “<5”.  
  
  
  
Changes in modelling methodology:  
  
  
  
Prior to 2018, estimates of the proportion of the population primarily relying on solid fuels were obtained from a multilevel model with region and nonparametric functions of time as the only covariates (Bonjour et al. 2013). For tracking SDG7 in 2018 and 2019 this model was used to estimate polluting and clean fuel use, though this time it was implemented in the Bayesian framework for increased robustness and more reliable quantification of uncertainty. For 2020, the model has been expanded to allow estimates for individual fuels, and extra flexibility has been added to the functions of time to better capture nonlinear trends in some countries (Stoner et al. 2019). These refinements have been introduced alongside an ever-expanding collection of data, which underwent a major quality-control effort. Due to the increased data availability, borrowing of information across regions is no longer essential, hence time is now the only covariate.   
  
  
  
On both occasions where the model changed, the WHO conducted a thorough sensitivity analysis, including full country-by-country comparisons of estimates between the existing model and the candidate model. In most cases, estimates of the proportion using clean fuels exhibited little change, see annex below. Where larger discrepancies were identified, they were carefully investigated to determine the likely cause. Many of these were in fact the result of the new model better capturing nonlinear trends.  
  
  
  
Data Sources  
  
  
  
Primary household fuels and technologies, particularly for cooking, is routinely collected at the national levels in most countries using censuses and surveys. Household surveys used include: United States Agency for International Development (USAID)-supported Demographic and Health Surveys (DHS); United Nations Children’s Fund (UNICEF)-supported Multiple Indicator Cluster Surveys (MICS); WHO-supported World Health Surveys (WHS); and other reliable and nationally representative country surveys.  
  
  
  
The World Health Organization is the agency that has taken responsibility for compiling a database of statistics on access to clean and polluting fuels and technologies harvested from the full global body of household surveys for cooking, heating and lighting. Currently, the WHO Database covers cooking energy for 170 countries and one territory for the period 1960-2018 and is updated regularly and publicly available. For lighting, the WHO database includes data for 77 countries for the period 1963-2018. For heating, the WHO database includes data for 55 countries for the period 1977 – 2018.  
  
  
  
Presently WHO is working with national surveying agencies, country statistical offices and other stakeholders (e.g. researchers) to enhance multipurpose household survey instruments to gather data on the fuels and technologies used for heating and lighting.  
  
  
  
Data Availability  
  
  
  
Description:  
  
  
  
For cooking fuels, coverage of 170 countries is available through the WHO Global Household Energy Database.  
  
  
  
For lighting fuels, the WHO database includes data for 77 countries.  
  
  
  
For heating fuels, the WHO database includes data for 55 countries.  
  
  
  
Time series:  
  
  
  
From 1960 to 2018  
  
  
  
Calendar  
  
  
  
Data collection:  
  
  
  
Summer/Fall 2019.   
  
  
  
Data release:  
  
  
  
1-May-2020   
  
  
  
Data providers  
  
  
  
Name:  
  
National Statistical Offices  
  
  
  
Description:  
  
  
  
National Statistical Offices or any national providers of household surveys and censuses.  
  
  
  
Data compilers  
  
  
  
WHO, Public health, Social and Environmental Determinants of health Department (PHE).  
  
  
  
References  
  
  
  
URL:  
  
  
  
www.who.int/gho/phe  
  
  
  
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Global Tracking Framework Report (2015)  
  
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Global Tracking Framework database (2015)  
  
http://data.worldbank.org/data-catalog/sustainable-energy-for-all  
  
  
  
Multi-Tier Framework for Measuring Energy Access,  
  
https://www.esmap.org/node/55526  
  
  
  
WHO Guidelines for indoor air quality: Household Fuel Combustion, WHO (2014) http://www.who.int/indoorair/guidelines/hhfc/en/  
  
  
  
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Bonjour S, Adair-Rohani H, Wolf J, Bruce NG, Mehta S, Prüss-Ustün A, Lahiff M, Rehfuess EA, Mishra V, and Smith KR (2013). Solid Fuel Use for Household Cooking: Country and Regional Estimates for 1980–2010. Environmental Health Perspectives 121:7 CID: https://doi.org/10.1289/ehp.1205987  
  
  
  
Population using solid fuels meta-data, WHO  
  
http://apps.who.int/gho/indicatorregistry/App\_Main/view\_indicator.aspx?iid=318  
  
  
  
Related indicators  
  
  
  
3.9.1:  
  
Mortality rate attributed to household and ambient air pollution  
  
  
  
  
  
  
Annex  
  
  
  
A comparison plot is provided to illustrate the differences between existing model and the candidate model. Estimated values for each of the WHO regions are plotted, showing consistency between the existing model and the candidate model.

**Energy**



In [physics,](https://en.wikipedia.org/wiki/Physics) **energy** is the [quantitative](https://en.wikipedia.org/wiki/Physical_quantity) [property](https://en.wikipedia.org/wiki/Physical_property) that must be [transferred](#page8) to an [object](https://en.wikipedia.org/wiki/Physical_body) in order to perform [work](https://en.wikipedia.org/wiki/Work_(thermodynamics)) on,



or to [heat,](https://en.wikipedia.org/wiki/Heat) the object.[note 1] Energy is a [conserved quantity;](https://en.wikipedia.org/wiki/Conservation_law) the law of [conservation of energy](https://en.wikipedia.org/wiki/Conservation_of_energy) states that energy can be [converted](https://en.wikipedia.org/wiki/Energy_transformation) in form, but not created or destroyed. The [SI unit](https://en.wikipedia.org/wiki/International_System_of_Units) of energy is the [joule,](https://en.wikipedia.org/wiki/Joule) which is the energy transferred to an object by the [work](https://en.wikipedia.org/wiki/Work_(physics)) of moving it a distance of 1 [metre](https://en.wikipedia.org/wiki/Metre) against a [force](https://en.wikipedia.org/wiki/Force) of 1 [newton.](https://en.wikipedia.org/wiki/Newton_(unit))



Common forms of energy include the [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) of a moving object, the [potential energy](https://en.wikipedia.org/wiki/Potential_energy) stored by an object's position in a force [field](https://en.wikipedia.org/wiki/Classical_field_theory) [(gravitational,](https://en.wikipedia.org/wiki/Gravitational_field) [electric](https://en.wikipedia.org/wiki/Electric_field) or [magnetic),](https://en.wikipedia.org/wiki/Magnetic_field) the [elastic energy](https://en.wikipedia.org/wiki/Elastic_energy) stored by stretching solid objects, the [chemical energy](https://en.wikipedia.org/wiki/Chemical_energy) released when a fuel [burns,](https://en.wikipedia.org/wiki/Combustion) the [radiant energy](https://en.wikipedia.org/wiki/Radiant_energy) carried by light, and the [thermal energy](https://en.wikipedia.org/wiki/Thermal_energy) due to an object's [temperature.](https://en.wikipedia.org/wiki/Temperature)



[Mass](https://en.wikipedia.org/wiki/Mass) and energy are closely related. Due to [mass–energy equivalence,](https://en.wikipedia.org/wiki/Mass–energy_equivalence) any object that has mass when stationary (called [rest mass)](https://en.wikipedia.org/wiki/Rest_mass) also has an equivalent amount of energy whose form is called [rest energy,](https://en.wikipedia.org/wiki/Rest_mass" \l "Rest_energy) and any additional energy (of any form) acquired by the object above that rest energy will increase the object's total mass just as it increases its total energy. For example, after heating an object, its increase in energy could be measured as a small increase in mass, with a sensitive enough [scale.](https://en.wikipedia.org/wiki/Weighing_scale)



Living organisms require energy to stay alive, such as the [energy humans get from food.](https://en.wikipedia.org/wiki/Food_energy) Human civilization [requires energy to function, which it gets from energy resources such as fossil fuels, nuclear fuel, or renewable](https://en.wikipedia.org/wiki/Renewable_energy) [energy. The processes of Earth's](https://en.wikipedia.org/wiki/Renewable_energy) [climate](https://en.wikipedia.org/wiki/Climate) [and](https://en.wikipedia.org/wiki/Renewable_energy) [ecosystem](https://en.wikipedia.org/wiki/Ecosystem) [are driven by the radiant energy Earth receives from the](https://en.wikipedia.org/wiki/Renewable_energy) sun and the [geothermal energy](https://en.wikipedia.org/wiki/Geothermal_energy) contained within the earth.



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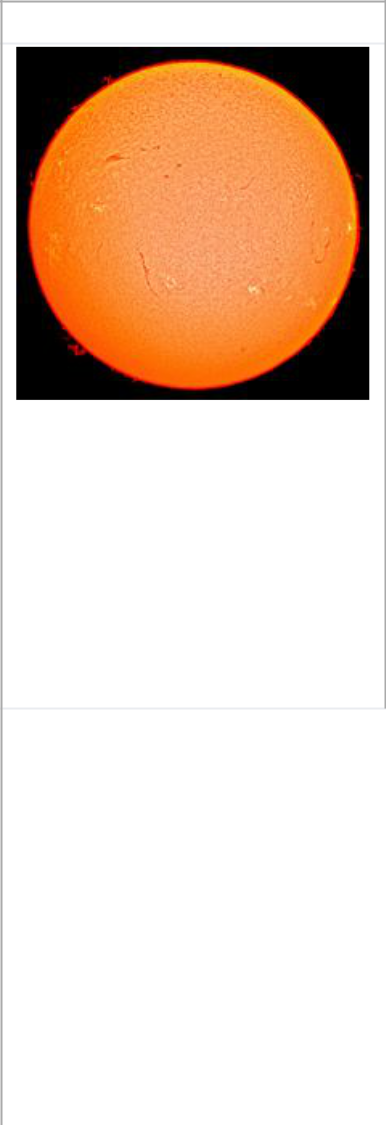
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***Energy***



The [Sun](https://en.wikipedia.org/wiki/Sun) is the source of energy for most of life on Earth. As a star, the Sun is heated to high temperatures by the [conversion of nuclear binding](https://en.wikipedia.org/wiki/Nuclear_binding_energy) [energy due to the fusion of](https://en.wikipedia.org/wiki/Nuclear_binding_energy) hydrogen in its core. This energy is ultimately [transferred](#page8) (released) into space mainly [in the form of radiant](https://en.wikipedia.org/wiki/Radiant_energy) [(light) energy.](https://en.wikipedia.org/wiki/Radiant_energy)

**Forms**



The total energy of a [system](https://en.wikipedia.org/wiki/System) can be subdivided and classified into potential energy, kinetic energy, or combinations of the two in various ways. [Kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) is determined by the [movement](https://en.wikipedia.org/wiki/Motion_(physics)) of an object – or the [composite motion](https://en.wikipedia.org/wiki/Statistical_mechanics) of the components of an object – and [potential energy](https://en.wikipedia.org/wiki/Potential_energy) reflects the potential of an object to have motion, and generally is a function of the position of an object within a [field](https://en.wikipedia.org/wiki/Field_(physics)) or may be stored in the field itself.



While these two categories are sufficient to describe all forms of energy, it is often convenient to refer to [particular combinations of potential and kinetic energy as its own form. For example, macroscopic mechanical](https://en.wikipedia.org/wiki/Mechanical_energy) [energy is the sum of translational and rotational kinetic and potential energy in a system neglects the kinetic](https://en.wikipedia.org/wiki/Mechanical_energy)



energy due to temperature, and nuclear energy which combines utilize potentials from the [nuclear force](https://en.wikipedia.org/wiki/Nuclear_force) and the [weak force),](https://en.wikipedia.org/wiki/Weak_force) among others.



Some forms of energy (that an object or system can have as a measurable property)

In a typical [lightning](https://en.wikipedia.org/wiki/Lightning) strike, 500 [megajoules of electric potential](https://en.wikipedia.org/wiki/Electric_potential_energy) [energy is converted into the](https://en.wikipedia.org/wiki/Electric_potential_energy) same amount of energy in other forms, mostly [light energy,](https://en.wikipedia.org/wiki/Light_energy) [sound energy](https://en.wikipedia.org/wiki/Sound_energy) and [thermal energy.](https://en.wikipedia.org/wiki/Thermal_energy)



[Thermal energy](https://en.wikipedia.org/wiki/Thermal_energy) is energy of microscopic constituents of matter, which may include both [kinetic](https://en.wikipedia.org/wiki/Kinetic_energy) and [potential energy.](https://en.wikipedia.org/wiki/Potential_energy)

**History**



The word *energy* derives from the [Ancient Greek:](https://en.wikipedia.org/wiki/Ancient_Greek_language) ἐνέργεια, [romanized:](https://en.wikipedia.org/wiki/Romanization_of_Ancient_Greek) [*energeia*](https://en.wikipedia.org/wiki/Energeia), [lit.](https://en.wikipedia.org/wiki/Literal_translation) 'activity, operation',[[1]](#page9) which possibly appears for the first time in the work of [Aristotle](https://en.wikipedia.org/wiki/Aristotle) in the 4th century BC. In contrast to the modern definition, energeia was a qualitative philosophical concept, broad enough to include ideas such as happiness and pleasure.



In the late 17th century, [Gottfried Leibniz](https://en.wikipedia.org/wiki/Gottfried_Leibniz) proposed the idea of the [Latin:](https://en.wikipedia.org/wiki/Latin_language) [*vis viva*](https://en.wikipedia.org/wiki/Vis_viva), or living force, which defined as the product of the mass of an object and its velocity squared; he believed that total *vis viva* was conserved. To account for slowing due to friction, Leibniz theorized that thermal energy consisted of the random motion of the constituent parts of matter, although it would be more than a century until this was generally accepted. The modern analog of this property, [kinetic energy,](https://en.wikipedia.org/wiki/Kinetic_energy) differs from *vis viva* only by a factor of two.



[In 1807, Thomas Young was possibly the first to use the term "energy" instead of *vis viva*, in its modern sense.](https://en.wikipedia.org/wiki/Kinetic_energy)[[2]](#page9) [Gustave-Gaspard Coriolis described "kinetic](https://en.wikipedia.org/wiki/Kinetic_energy) [energy" in 1829 in its modern sense, and in 1853,](https://en.wikipedia.org/wiki/Kinetic_energy) [William Rankine](https://en.wikipedia.org/wiki/William_John_Macquorn_Rankine) [coined the term](https://en.wikipedia.org/wiki/Kinetic_energy) ["potential energy".](https://en.wikipedia.org/wiki/Potential_energy) [The law of](https://en.wikipedia.org/wiki/Kinetic_energy) [conservation of energy](https://en.wikipedia.org/wiki/Conservation_of_energy) [was also first postulated](https://en.wikipedia.org/wiki/Kinetic_energy) in the early 19th century, and applies to any [isolated system.](https://en.wikipedia.org/wiki/Isolated_system) It was argued for some years whether heat was a physical substance, dubbed the [caloric,](https://en.wikipedia.org/wiki/Caloric_theory) or merely a physical quantity, such as [momentum.](https://en.wikipedia.org/wiki/Momentum) In 1845 [James Prescott Joule](https://en.wikipedia.org/wiki/James_Prescott_Joule) discovered the link between mechanical work and the generation of heat.



These developments led to the theory of conservation of energy, formalized largely by William Thomson [(Lord Kelvin)](https://en.wikipedia.org/wiki/Lord_Kelvin) as the field of [thermodynamics.](https://en.wikipedia.org/wiki/Thermodynamics) Thermodynamics aided the rapid development of explanations of chemical processes by [Rudolf Clausius,](https://en.wikipedia.org/wiki/Rudolf_Clausius) [Josiah Willard Gibbs,](https://en.wikipedia.org/wiki/Josiah_Willard_Gibbs) and [Walther Nernst.](https://en.wikipedia.org/wiki/Walther_Nernst) It also led to [a mathematical formulation of the concept of entropy by Clausius and to the introduction of laws of radiant energy by Jožef Stefan. According to Noether's](https://en.wikipedia.org/wiki/Noether's_theorem)



[theorem, the conservation of energy is a consequence of the fact that the laws of physics do not change over time.](https://en.wikipedia.org/wiki/Noether's_theorem)[[3]](#page9) [Thus, since 1918, theorists have understood](https://en.wikipedia.org/wiki/Noether's_theorem) that the law of [conservation of energy](https://en.wikipedia.org/wiki/Conservation_of_energy) is the direct mathematical consequence of the [translational symmetry](https://en.wikipedia.org/wiki/Translational_symmetry) of the quantity [conjugate](https://en.wikipedia.org/wiki/Conjugate_variables) to energy, namely time.



**Units of measure**



In 1843, Joule independently discovered the mechanical equivalent in a series of experiments. The most famous of them used the "Joule apparatus": a descending weight, attached to a string, caused rotation of a paddle immersed in water, practically insulated from heat transfer. It showed that the gravitational [potential energy](https://en.wikipedia.org/wiki/Potential_energy) lost by the weight in descending was equal to the [internal energy](https://en.wikipedia.org/wiki/Internal_energy) gained by the water through [friction](https://en.wikipedia.org/wiki/Friction) with the paddle.



In the [International System of Units](https://en.wikipedia.org/wiki/International_System_of_Units) (SI), the unit of energy is the joule, named after James Prescott Joule. It is a [derived unit.](https://en.wikipedia.org/wiki/SI_derived_unit) It is equal to the energy expended (or [work](https://en.wikipedia.org/wiki/Work_(physics)) done) in applying a force of one newton through a distance of one metre. However energy is also expressed in many other units not part of the SI, such as [ergs,](https://en.wikipedia.org/wiki/Erg) [calories,](https://en.wikipedia.org/wiki/Calorie) [British Thermal Units,](https://en.wikipedia.org/wiki/British_Thermal_Unit) [kilowatt-hours](https://en.wikipedia.org/wiki/Kilowatt-hour) and [kilocalories,](https://en.wikipedia.org/wiki/Kilocalorie) which require a conversion factor when expressed in SI units.



The SI unit of energy rate (energy per unit time) is the [watt,](https://en.wikipedia.org/wiki/Watt) which is a joule per second. Thus, one joule is one [watt-second, and 3600 joules equal one watt-hour. The CGS energy unit is the erg and the imperial and US](https://en.wikipedia.org/wiki/Imperial_and_US_customary_measurement_systems) [customary unit is the](https://en.wikipedia.org/wiki/Imperial_and_US_customary_measurement_systems) [foot pound.](https://en.wikipedia.org/wiki/Foot_pound) [Other energy units such as the](https://en.wikipedia.org/wiki/Imperial_and_US_customary_measurement_systems) [electronvolt,](https://en.wikipedia.org/wiki/Electronvolt) [food calorie](https://en.wikipedia.org/wiki/Food_calorie) [or thermodynamic](https://en.wikipedia.org/wiki/Imperial_and_US_customary_measurement_systems) [kcal](https://en.wikipedia.org/wiki/Kilocalorie) (based on the temperature change of water in a heating process), and [BTU](https://en.wikipedia.org/wiki/British_thermal_unit) are used in specific areas of science and commerce.



[Thomas Young,](https://en.wikipedia.org/wiki/Thomas_Young_(scientist)) the first person to use the term "energy" in the modern sense.



**Scientific use**



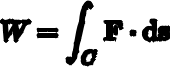
**Classical mechanics**

In classical mechanics, energy is a conceptually and mathematically useful property, as it is a [conserved quantity.](https://en.wikipedia.org/wiki/Conserved_quantity)



Several formulations of mechanics have been developed using energy as a core concept.

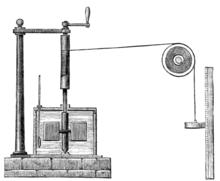
[Work,](https://en.wikipedia.org/wiki/Work_(physics)) a function of energy, is force times distance.



This says that the work () is equal to the [line integral](https://en.wikipedia.org/wiki/Line_integral) of the [force](https://en.wikipedia.org/wiki/Force) **F** along a path *C*; for details see the [mechanical work](https://en.wikipedia.org/wiki/Mechanical_work) article. Work and thus energy is [frame dependent.](https://en.wikipedia.org/wiki/Frame_dependent) For example, consider a ball being hit by a bat. In the center-of-mass reference frame, the bat does no work on the ball. But, in the reference frame of the person swinging the bat, considerable work is done on the ball.



Joule's apparatus for measuring the mechanical equivalent of heat. A descending weight attached to a string causes a paddle immersed in water to rotate.



The total energy of a system is sometimes called the [Hamiltonian,](https://en.wikipedia.org/wiki/Hamilton's_equations) after [William Rowan Hamilton.](https://en.wikipedia.org/wiki/William_Rowan_Hamilton) The classical equations of motion can be written in terms of the Hamiltonian, even for highly complex or abstract systems. These classical equations have remarkably direct analogs in nonrelativistic quantum mechanics.[[4]](#page9)



Another energy-related concept is called the [Lagrangian,](https://en.wikipedia.org/wiki/Lagrangian_mechanics) after [Joseph-Louis Lagrange.](https://en.wikipedia.org/wiki/Joseph-Louis_Lagrange) This formalism is as fundamental as the Hamiltonian, and both can be used to derive the equations of motion or be derived from them. It was invented in the context of [classical mechanics,](https://en.wikipedia.org/wiki/Classical_mechanics) but is generally useful in modern physics. The Lagrangian is defined as the kinetic energy *minus* the potential energy. Usually, the Lagrange formalism is mathematically more convenient than the Hamiltonian for non-conservative systems (such as systems with friction).



[Noether's theorem](https://en.wikipedia.org/wiki/Noether's_theorem) (1918) states that any differentiable symmetry of the action of a physical system has a corresponding conservation law. Noether's theorem has become a fundamental tool of modern theoretical physics and the calculus of variations. A generalisation of the seminal formulations on constants of motion in Lagrangian and Hamiltonian mechanics (1788 and 1833, respectively), it does not apply to systems that cannot be modeled with a Lagrangian; for example, dissipative systems with continuous symmetries need not have a corresponding conservation law.



**Chemistry**

In the context of [chemistry,](https://en.wikipedia.org/wiki/Chemistry" \l "Energy) energy is an attribute of a substance as a consequence of its atomic, molecular or aggregate structure. Since a chemical transformation is accompanied by a change in one or more of these kinds of structure, it is invariably accompanied by an increase or decrease of energy of the substances involved. Some energy is transferred between the surroundings and the reactants of the reaction in the form of heat or light; thus the products of a reaction may have more or less energy than the reactants. A reaction is said to be [exergonic](https://en.wikipedia.org/wiki/Exergonic) if the final state is lower on the energy scale than the initial state; in the case of [endergonic](https://en.wikipedia.org/wiki/Endergonic) reactions the situation is the reverse. [Chemical reactions](https://en.wikipedia.org/wiki/Chemical_reaction) are invariably not possible unless the reactants surmount an energy barrier known as the



[activation energy.](https://en.wikipedia.org/wiki/Activation_energy) The *speed* of a chemical reaction (at given temperature *T*) is related to the activation energy *E*, by the Boltzmann's population factor e−*E*/*kT* – that is the probability of molecule to have energy greater than or equal to *E* at the given temperature *T*. This exponential dependence of a reaction rate on temperature is known as the [Arrhenius equation.The](https://en.wikipedia.org/wiki/Arrhenius_equation) activation energy necessary for a chemical reaction can be in the form of thermal energy.



**Biology**

In [biology,](https://en.wikipedia.org/wiki/Biology" \l "Energy) energy is an attribute of all biological systems from the biosphere to the smallest living [organism.](https://en.wikipedia.org/wiki/Organism) Within an organism it is responsible for growth and development of a biological [cell](https://en.wikipedia.org/wiki/Cell_(biology)) or an [organelle](https://en.wikipedia.org/wiki/Organelle) of a biological [organism.](https://en.wikipedia.org/wiki/Organism) Energy is thus often said to be stored by [cells](https://en.wikipedia.org/wiki/Cell_(biology)) in the structures of molecules of substances such as [carbohydrates](https://en.wikipedia.org/wiki/Carbohydrate) (including sugars), [lipids,](https://en.wikipedia.org/wiki/Lipid) and [proteins,](https://en.wikipedia.org/wiki/Protein) which release energy when reacted with [oxygen](https://en.wikipedia.org/wiki/Oxygen) in [respiration.](https://en.wikipedia.org/wiki/Respiration_(physiology)) In human terms, the [human equivalent](https://en.wikipedia.org/wiki/Human_equivalent) (H-e) (Human energy conversion) indicates, for a given amount of energy expenditure, the relative quantity of energy needed for human [metabolism,](https://en.wikipedia.org/wiki/Metabolism) assuming an average human energy expenditure of 12,500 kJ per day and a [basal metabolic rate](https://en.wikipedia.org/wiki/Basal_metabolic_rate) of 80 watts. For example, if our bodies run (on average) at 80 watts, then a light bulb running at 100 watts is running at 1.25 human equivalents (100 ÷ 80) i.e. 1.25 H-e. For a difficult task of only a few seconds' duration, a person can put out thousands of watts, many times the 746 watts in one official horsepower. For tasks lasting a few minutes, a fit human can generate perhaps 1,000 watts. For an activity that must be sustained for an hour, output drops to around 300; for an activity kept up all day, 150 watts is about the maximum.[[5]](#page9) The human equivalent assists



understanding of energy flows in physical and biological systems by expressing energy units in human terms: it provides a "feel" for the use of a given amount of energy.[[6]](#page10)

Sunlight's radiant energy is also captured by plants as *chemical potential energy* in [photosynthesis,](https://en.wikipedia.org/wiki/Photosynthesis) when carbon dioxide and water (two low-energy compounds) are converted into the high-energy compounds carbohydrates, lipids, and proteins. Plants also release oxygen during photosynthesis, which is utilized by living organisms as an [electron acceptor,](https://en.wikipedia.org/wiki/Electron_acceptor) to release the energy of carbohydrates, lipids, and proteins. Release of the energy stored during photosynthesis as heat or light may be triggered suddenly by a spark, in a forest fire, or it may be made available more slowly for animal or human metabolism, when these molecules are ingested, and [catabolism](https://en.wikipedia.org/wiki/Catabolism) is triggered by [enzyme](https://en.wikipedia.org/wiki/Enzyme) action.



Any living organism relies on an external source of energy – radiant energy from the Sun in the case of green plants, chemical energy in some form in the case of animals – to be able to grow and reproduce. The daily 1500–2000 [Calories](https://en.wikipedia.org/wiki/Kilocalorie) (6–8 MJ) recommended for a human adult are taken as a combination of oxygen and food molecules, the latter mostly carbohydrates and fats, of which [glucose](https://en.wikipedia.org/wiki/Glucose) (C6H12O6) and [stearin](https://en.wikipedia.org/wiki/Stearin) (C57H110O6) are convenient examples. The food molecules are oxidised to [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide) and [water](https://en.wikipedia.org/wiki/Water_(molecule)) in the [mitochondria](https://en.wikipedia.org/wiki/Mitochondrion)



C57H110O6 + 81.5O2 → 57CO2 + 55H2O

and some of the energy is used to convert [ADP](https://en.wikipedia.org/wiki/Adenosine_diphosphate) into [ATP.](https://en.wikipedia.org/wiki/Adenosine_triphosphate)



ADP + HPO42− → ATP + H2O

The rest of the chemical energy in O2[[7]](#page10) and the carbohydrate or fat is converted into heat: the ATP is used as a sort of "energy currency", and some of the chemical energy it contains is used for other [metabolism](https://en.wikipedia.org/wiki/Metabolism) when ATP reacts with OH groups and eventually splits into ADP and phosphate (at each stage of a



[metabolic pathway,](https://en.wikipedia.org/wiki/Metabolic_pathway) some chemical energy is converted into heat). Only a tiny fraction of the original chemical energy is used for work:[note 2]



gain in kinetic energy of a sprinter during a 100 m race: 4 kJ

gain in gravitational potential energy of a 150 kg weight lifted through 2 metres: 3 kJ

Daily food intake of a normal adult: 6–8 MJ

It would appear that living organisms are remarkably [inefficient (in the physical sense)](https://en.wikipedia.org/wiki/Energy_conversion_efficiency) in their use of the energy they receive (chemical or radiant energy), and it is true that most real [machines](https://en.wikipedia.org/wiki/Machine) manage higher efficiencies. In growing organisms the energy that is converted to heat serves a vital purpose, as it allows the organism tissue to be highly ordered with regard to the molecules it is built from. The [second law of thermodynamics](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) states that energy (and matter) tends to become more evenly spread out across the universe: to concentrate energy (or matter) in one specific place, it is necessary to spread out a greater amount of energy (as heat) across the remainder of the universe ("the surroundings").[note 3] Simpler organisms can achieve higher energy efficiencies than more complex ones, but the complex organisms can occupy [ecological niches](https://en.wikipedia.org/wiki/Ecological_niche) that are not available to their simpler brethren. The conversion of a portion of the chemical energy to heat at each step in a metabolic pathway is the physical reason behind the pyramid of biomass observed in [ecology:](https://en.wikipedia.org/wiki/Ecology) to take just the first step in the [food chain,](https://en.wikipedia.org/wiki/Food_chain) of the



estimated 124.7 Pg/a of carbon that is [fixed](https://en.wikipedia.org/wiki/Carbon_fixation) by [photosynthesis,](https://en.wikipedia.org/wiki/Photosynthesis) 64.3 Pg/a (52%) are used for the metabolism of green plants,[[8]](#page10) i.e. reconverted into carbon dioxide and heat.



**Earth sciences**

In [geology,](https://en.wikipedia.org/wiki/Earth_science" \l "earth's_energy) [continental drift,](https://en.wikipedia.org/wiki/Continental_drift) [mountain ranges,](https://en.wikipedia.org/wiki/Mountain) [volcanoes,](https://en.wikipedia.org/wiki/Volcano) and [earthquakes](https://en.wikipedia.org/wiki/Earthquake) are phenomena that can be explained in terms of energy transformations in the Earth's



interior,[[9]](#page10) while [meteorological](https://en.wikipedia.org/wiki/Metereology) phenomena like wind, rain, [hail,](https://en.wikipedia.org/wiki/Hail) snow, lightning, [tornadoes](https://en.wikipedia.org/wiki/Tornado) and [hurricanes](https://en.wikipedia.org/wiki/Tropical_cyclone) are all a result of energy transformations brought about by [solar energy](https://en.wikipedia.org/wiki/Solar_energy) on the [atmosphere](https://en.wikipedia.org/wiki/Atmosphere) of the planet Earth.



Sunlight may be stored as gravitational potential energy after it strikes the Earth, as (for example) water evaporates from oceans and is deposited upon mountains (where, after being released at a hydroelectric dam, it can be used to drive turbines or generators to produce electricity). Sunlight also drives many weather phenomena, save those generated by volcanic events. An example of a solar-mediated weather event is a hurricane, which occurs when large unstable areas of warm ocean, heated over months, give up some of their thermal energy suddenly to power a few days of violent air movement.

In a slower process, [radioactive decay](https://en.wikipedia.org/wiki/Radioactive_decay) of atoms in the core of the Earth releases heat. This thermal energy drives [plate tectonics](https://en.wikipedia.org/wiki/Plate_tectonics) and may lift mountains, via [orogenesis.](https://en.wikipedia.org/wiki/Orogenesis) This slow lifting represents a kind of gravitational potential energy storage of the thermal energy, which may be later released to active kinetic energy in landslides, after a triggering event. Earthquakes also release stored elastic potential energy in rocks, a store that has been produced ultimately from the same radioactive heat sources. Thus, according to present understanding, familiar events such as landslides and earthquakes release energy that has been stored as potential energy in the Earth's gravitational field or elastic strain (mechanical potential energy) in rocks. Prior to this, they represent release of energy that has been stored in heavy atoms since the collapse of long-destroyed supernova stars created these atoms.



**Cosmology**

In [cosmology and astronomy](https://en.wikipedia.org/wiki/Physical_cosmology" \l "Energy_of_the_cosmos) the phenomena of [stars,](https://en.wikipedia.org/wiki/Star) [nova,](https://en.wikipedia.org/wiki/Nova) [supernova,](https://en.wikipedia.org/wiki/Supernova) [quasars](https://en.wikipedia.org/wiki/Quasar) and [gamma-ray bursts](https://en.wikipedia.org/wiki/Gamma-ray_burst) are the universe's highest-output energy transformations of matter. All [stellar](https://en.wiktionary.org/wiki/stellar) phenomena (including solar activity) are driven by various kinds of energy transformations. Energy in such transformations is either from gravitational collapse of matter (usually molecular hydrogen) into various classes of astronomical objects (stars, black holes, etc.), or from nuclear fusion (of lighter elements, primarily hydrogen). The [nuclear fusion](https://en.wikipedia.org/wiki/Nuclear_fusion) of hydrogen in the Sun also releases another store of potential energy which was created at the time of the [Big Bang.](https://en.wikipedia.org/wiki/Big_Bang) At that time, according to theory, space expanded and the universe cooled too rapidly for hydrogen to completely fuse into heavier elements. This meant that hydrogen represents a store of potential energy that can be released by fusion. Such a fusion process is triggered by heat and pressure generated from gravitational collapse of hydrogen clouds when they produce stars, and some of the fusion energy is then transformed into sunlight.



**Quantum mechanics**

In [quantum mechanics,](https://en.wikipedia.org/wiki/Quantum_mechanics) energy is defined in terms of the [energy operator](https://en.wikipedia.org/wiki/Hamiltonian_(quantum_mechanics)) as a time derivative of the [wave function.](https://en.wikipedia.org/wiki/Wave_function) The [Schrödinger equation](https://en.wikipedia.org/wiki/Schrödinger_equation) equates the energy operator to the full energy of a particle or a system. Its results can be considered as a definition of measurement of energy in quantum mechanics. The Schrödinger equation describes the space- and time-dependence of a slowly changing (non-relativistic) [wave function](https://en.wikipedia.org/wiki/Wave_function) of quantum systems. The solution of this equation for a bound system is discrete (a set of permitted states, each characterized by an [energy level)](https://en.wikipedia.org/wiki/Energy_level) which results in the concept of [quanta.](https://en.wikipedia.org/wiki/Quantum) In the solution of the Schrödinger equation for any oscillator (vibrator) and for electromagnetic waves in a vacuum, the resulting energy states are related to the frequency by [Planck's relation:](https://en.wikipedia.org/wiki/Planck's_relation)  (where  is [Planck's constant](https://en.wikipedia.org/wiki/Planck's_constant) and  the frequency). In the case of an electromagnetic wave these energy states are called quanta of light or [photons.](https://en.wikipedia.org/wiki/Photon)



**Relativity**

When calculating kinetic energy [(work](https://en.wikipedia.org/wiki/Mechanical_work) to accelerate a [massive body](https://en.wikipedia.org/wiki/Mass) from zero [speed](https://en.wikipedia.org/wiki/Speed) to some finite speed) relativistically – using [Lorentz transformations](https://en.wikipedia.org/wiki/Lorentz_transformations) instead of [Newtonian mechanics](https://en.wikipedia.org/wiki/Newtonian_mechanics) – Einstein discovered an unexpected by-product of these calculations to be an energy term which does not vanish at zero speed. He called it [rest energy:](https://en.wikipedia.org/wiki/Rest_energy) energy which every massive body must possess even when being at rest. The amount of energy is directly proportional to the mass of the body:



,

where

*m* is the mass of the body,

*c* is the [speed of light](https://en.wikipedia.org/wiki/Speed_of_light) in vacuum,



 is the rest energy.

For example, consider [electron–positron](https://en.wikipedia.org/wiki/Positron) annihilation, in which the rest energy of these two individual particles (equivalent to their [rest mass)](https://en.wikipedia.org/wiki/Invariant_mass) is converted to the radiant energy of the photons produced in the process. In this system the [matter](https://en.wikipedia.org/wiki/Matter) and [antimatter](https://en.wikipedia.org/wiki/Antimatter) (electrons and positrons) are destroyed and changed to non-matter (the photons). However, the total mass and total energy do not change during this interaction. The photons each have no rest mass but nonetheless have radiant energy which exhibits the same inertia as did the two original particles. This is a reversible process – the inverse process is called [pair creation](https://en.wikipedia.org/wiki/Pair_creation) – in which the rest mass of particles is created from the radiant energy of two (or more) annihilating photons.



In general relativity, the [stress–energy tensor](https://en.wikipedia.org/wiki/Stress–energy_tensor) serves as the source term for the gravitational field, in rough analogy to the way mass serves as the source term in the non-relativistic Newtonian approximation.[[10]](#page10)



Energy and mass are manifestations of one and the same underlying physical property of a system. This property is responsible for the inertia and strength of gravitational interaction of the system ("mass manifestations"), and is also responsible for the potential ability of the system to perform work or heating ("energy manifestations"), subject to the limitations of other physical laws.

In [classical physics,](https://en.wikipedia.org/wiki/Classical_physics) energy is a scalar quantity, the [canonical conjugate](https://en.wikipedia.org/wiki/Canonical_conjugate) to time. In [special relativity](https://en.wikipedia.org/wiki/Special_relativity) energy is also a scalar (although not a [Lorentz scalar](https://en.wikipedia.org/wiki/Lorentz_scalar) but a



time component of the [energy–momentum 4-vector)](https://en.wikipedia.org/wiki/Energy–momentum_4-vector).[[10]](#page10) In other words, energy is invariant with respect to rotations of [space,](https://en.wikipedia.org/wiki/Space) but not invariant with respect to rotations of [space-time](https://en.wikipedia.org/wiki/Space-time) (= [boosts)](https://en.wikipedia.org/wiki/Lorentz_boost).



**Transformation**

Some forms of [transfer](https://en.wikipedia.org/wiki/Energy" \l "Energy_transfer) of energy ("energy in transit") from one object or system to another



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Type of transfer** [**process**](https://en.wikipedia.org/wiki/Thermodynamic_process) | | | | | | |  | |  |  | | **Description** | | | | | |
|  |  |  |  |  |  |  |  | |  |  |  | |  |  |  |  |  |
|  | [Heat](https://en.wikipedia.org/wiki/Heat) | | | | | | | that amount of [thermal energy](https://en.wikipedia.org/wiki/Thermal_energy" \l "Differentiation_from_heat) in transit spontaneously towards a lower-[temperature](https://en.wikipedia.org/wiki/Temperature) object | | | | | | | | | |
|  |  |  |  |  |  |  |  | |  |  |  | |  |  |  |  |  |
|  | [Work](https://en.wikipedia.org/wiki/Work_(physics)) | | | | | | | that amount of energy in transit due to a displacement in the direction of an applied [force](https://en.wikipedia.org/wiki/Force) | | | | | | | | | |
|  |  |  |  |  |  |  |  | |  |  |  | |  |  |  |  |  |
| Transfer of material | | | | | | | that amount of energy carried by [matter](https://en.wikipedia.org/wiki/Matter) that is moving from one system to another | | | | | | | | | | |
|  |  |  |  |  |  |  |  | |  |  |  | |  |  |  |  |  |

Energy may be [transformed](https://en.wikipedia.org/wiki/Energy_transformation) between different forms at various [efficiencies.](https://en.wikipedia.org/wiki/Energy_conversion_efficiency) Items that transform between these forms are called [transducers.](https://en.wikipedia.org/wiki/Transducer) Examples of transducers include a battery, from [chemical energy](https://en.wikipedia.org/wiki/Chemical_energy) to [electric energy;](https://en.wikipedia.org/wiki/Electric_energy) a dam: [gravitational potential energy](https://en.wikipedia.org/wiki/Gravitational_potential_energy) to [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) of [moving water (and the blades of a turbine) and ultimately to electric energy through an electric](https://en.wikipedia.org/wiki/Electric_generator) [generator; or a](https://en.wikipedia.org/wiki/Electric_generator) [heat engine,](https://en.wikipedia.org/wiki/Heat_engine) [from heat to work.](https://en.wikipedia.org/wiki/Electric_generator)



Examples of energy transformation include generating [electric energy](https://en.wikipedia.org/wiki/Electric_energy) from heat energy via a steam turbine, or lifting an object against gravity using electrical energy driving a crane motor. Lifting against gravity performs mechanical work on the object and stores gravitational potential energy in the object. If the object falls to the ground, gravity does mechanical work on the object which transforms the potential energy in the gravitational field to the kinetic energy released as heat on impact with the ground. Our Sun transforms [nuclear potential energy](https://en.wikipedia.org/wiki/Nuclear_potential_energy) to other forms of energy; its total mass does not decrease due to that in itself (since it still contains the same total energy even if in different forms), but its mass does decrease when the energy escapes out to its surroundings, largely as [radiant energy.](https://en.wikipedia.org/wiki/Radiant_energy)



A [turbo generator](https://en.wikipedia.org/wiki/Turbo_generator) transforms the energy of pressurised steam into electrical energy



[There are strict limits to how efficiently heat can be converted into work in a cyclic process, e.g. in a heat engine, as described by Carnot's theorem and the second](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) [law of thermodynamics. However, some energy transformations can be quite efficient. The direction of transformations in energy (what kind of energy is](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) transformed to what other kind) is often determined by [entropy](https://en.wikipedia.org/wiki/Entropy) (equal energy spread among all available [degrees of freedom)](https://en.wikipedia.org/wiki/Degrees_of_freedom_(physics_and_chemistry)) considerations. In practice all energy transformations are permitted on a small scale, but certain larger transformations are not permitted because it is statistically unlikely that energy or matter will randomly move into more concentrated forms or smaller spaces.



Energy transformations in the universe over time are characterized by various kinds of potential energy that has been available since the [Big Bang](https://en.wikipedia.org/wiki/Big_Bang) later being "released" (transformed to more active types of energy such as kinetic or radiant energy) when a triggering mechanism is available. Familiar examples of such processes include nuclear decay, in which energy is released that was originally "stored" in heavy isotopes (such as [uranium](https://en.wikipedia.org/wiki/Uranium) and [thorium),](https://en.wikipedia.org/wiki/Thorium) by [nucleosynthesis,](https://en.wikipedia.org/wiki/Nucleosynthesis) a process ultimately using the gravitational potential energy released from the [gravitational collapse](https://en.wikipedia.org/wiki/Gravitational_collapse) of [supernovae,](https://en.wikipedia.org/wiki/Supernova) to store energy in the creation of these heavy elements before they were incorporated into the solar system and the Earth. This energy is triggered and released in nuclear [fission bombs](https://en.wikipedia.org/wiki/Fission_bomb) or in civil nuclear power generation. Similarly, in the case of a [chemical explosion,](https://en.wikipedia.org/wiki/Chemical_explosive) [chemical potential](https://en.wikipedia.org/wiki/Chemical_potential) energy is transformed to [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) and [thermal energy](https://en.wikipedia.org/wiki/Thermal_energy) in a very short time. Yet another example is that of a [pendulum.](https://en.wikipedia.org/wiki/Pendulum) At its highest points the [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) is zero and the [gravitational potential energy](https://en.wikipedia.org/wiki/Gravitational_potential_energy) is at maximum. At its lowest point the [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) is at maximum and is equal to the decrease of [potential energy.](https://en.wikipedia.org/wiki/Potential_energy) If one (unrealistically) assumes that there is no [friction](https://en.wikipedia.org/wiki/Friction) or other losses, the conversion of energy between these processes would be perfect, and the [pendulum](https://en.wikipedia.org/wiki/Pendulum) would continue swinging forever.



Energy is also transferred from potential energy ( ) to kinetic energy () and then back to potential energy constantly. This is referred to as conservation of energy. In this closed system, energy cannot be created or destroyed; therefore, the initial energy and the final energy will be equal to each other. This can be demonstrated by the following:



**(*4*)**



The equation can then be simplified further since  (mass times acceleration due to gravity times the height) and  (half mass times



velocity squared). Then the total amount of energy can be found by adding .



**Conservation of energy and mass in transformation**

Energy gives rise to weight when it is trapped in a system with zero momentum, where it can be weighed. It is also equivalent to mass, and this mass is always associated with it. Mass is also equivalent to a certain amount of energy, and likewise always appears associated with it, as described in [mass-energy equivalence.](https://en.wikipedia.org/wiki/Mass-energy_equivalence) The formula *E* = *mc*², derived by [Albert Einstein](https://en.wikipedia.org/wiki/Albert_Einstein) (1905) quantifies the relationship between rest-mass and rest-energy within the concept of special relativity. In [different theoretical frameworks, similar formulas were derived by J.J. Thomson (1881), Henri Poincaré (1900), Friedrich Hasenöhrl (1904) and others (see Mass-energy equivalence#History for further information).](https://en.wikipedia.org/wiki/Mass-energy_equivalence" \l "History)



Part of the rest energy (equivalent to rest mass) of [matter](https://en.wikipedia.org/wiki/Matter) may be converted to other forms of energy (still exhibiting mass), but neither energy nor mass can be destroyed; rather, both remain constant during any process. However, since  is extremely large relative to ordinary human scales, the conversion of an everyday amount of rest mass (for example, 1 kg) from rest energy to other forms of energy (such as kinetic energy, thermal energy, or the radiant energy carried by light



and other radiation) can liberate tremendous amounts of energy (~ joules = 21 megatons of TNT), as can be seen in nuclear reactors and nuclear

weapons. Conversely, the mass equivalent of an everyday amount energy is minuscule, which is why a loss of energy (loss of mass) from most systems is difficult to measure on a weighing scale, unless the energy loss is very large. Examples of large transformations between rest energy (of matter) and other forms of energy (e.g., kinetic energy into particles with rest mass) are found in [nuclear physics](https://en.wikipedia.org/wiki/Nuclear_physics) and [particle physics.](https://en.wikipedia.org/wiki/Particle_physics)



**Reversible and non-reversible transformations**

Thermodynamics divides energy transformation into two kinds: [reversible processes](https://en.wikipedia.org/wiki/Reversible_process_(thermodynamics)) and [irreversible processes.](https://en.wikipedia.org/wiki/Irreversible_process) An irreversible process is one in which energy is dissipated (spread) into empty energy states available in a volume, from which it cannot be recovered into more concentrated forms (fewer quantum states), without degradation of even more energy. A reversible process is one in which this sort of dissipation does not happen. For example, conversion of energy from one type of potential field to another, is reversible, as in the pendulum system described above. In processes where heat is generated, quantum states of lower energy, present as possible excitations in fields between atoms, act as a reservoir for part of the energy, from which it cannot be recovered, in order to be converted with 100% efficiency into other forms of energy. In this case, the energy must partly stay as heat, and cannot be completely recovered as usable energy, except at the price of an increase in some other kind of heat-like increase in disorder in quantum states, in the universe (such as an expansion of matter, or a randomisation in a crystal).



As the universe evolves in time, more and more of its energy becomes trapped in irreversible states (i.e., as heat or other kinds of increases in disorder). This has been referred to as the inevitable thermodynamic [heat death of the universe.](https://en.wikipedia.org/wiki/Heat_death_of_the_universe) In this heat death the energy of the universe does not change, but the fraction of energy which is available to do work through a [heat engine,](https://en.wikipedia.org/wiki/Heat_engine) or be transformed to other usable forms of energy (through the use of generators attached to heat engines), grows less and less.



**Conservation of energy**



The fact that energy can be neither created nor be destroyed is called the law of [conservation of energy.](https://en.wikipedia.org/wiki/Conservation_of_energy) In the form of the [first law of thermodynamics,](https://en.wikipedia.org/wiki/First_law_of_thermodynamics) this states that a [closed system's](https://en.wikipedia.org/wiki/Closed_system) energy is constant unless energy is transferred in or out by [work](https://en.wikipedia.org/wiki/Work_(thermodynamics)) or [heat,](https://en.wikipedia.org/wiki/Heat) and that no energy is lost in transfer. The total inflow of energy into a system must equal the total outflow of energy from the system, plus the change in the energy contained within the system. Whenever one measures (or calculates) the total energy of a system of particles whose interactions do not depend explicitly on time, it is found that the total energy of the system always remains constant.[[11]](#page10)



While heat can always be fully converted into work in a reversible isothermal expansion of an ideal gas, for cyclic processes of practical interest in [heat engines](https://en.wikipedia.org/wiki/Heat_engine) the [second law of thermodynamics](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) states that the system doing work always loses some energy as [waste heat.](https://en.wikipedia.org/wiki/Waste_heat) This creates a limit to the amount of heat energy that [can do work in a cyclic process, a limit called the available energy. Mechanical and other forms of energy can be transformed in the other direction into thermal](https://en.wikipedia.org/wiki/Thermal_energy)



[energy without such limitations.](https://en.wikipedia.org/wiki/Thermal_energy)[[12]](#page10) [The total energy of a system can be calculated by adding up all forms of energy in the system.](https://en.wikipedia.org/wiki/Thermal_energy)



[Richard Feynman](https://en.wikipedia.org/wiki/Richard_Feynman) said during a 1961 lecture:[[13]](#page10)



There is a fact, or if you wish, a *law*, governing all natural phenomena that are known to date. There is no known exception to this law – it is exact so far as we know. The law is called the [*conservation of energy*](https://en.wikipedia.org/wiki/Conservation_of_energy). It states that there is a certain quantity, which we call energy, that does not change in manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same.



— [*The Feynman Lectures on Physics*](https://en.wikipedia.org/wiki/The_Feynman_Lectures_on_Physics)



Most kinds of energy (with gravitational energy being a notable exception)[[14]](#page10) are subject to strict local conservation laws as well. In this case, energy can only be exchanged between adjacent regions of space, and all observers agree as to the volumetric density of energy in any given space. There is also a global law of conservation of energy, stating that the total energy of the universe cannot change; this is a corollary of the local law, but not vice versa.[[12][13]](#page10)

This law is a fundamental principle of physics. As shown rigorously by [Noether's theorem,](https://en.wikipedia.org/wiki/Noether's_theorem) the conservation of energy is a mathematical consequence of [translational symmetry](https://en.wikipedia.org/wiki/Translational_symmetry) of time,[[15]](#page10) a property of most phenomena below the cosmic scale that makes them independent of their locations on the time coordinate. Put differently, yesterday, today, and tomorrow are physically indistinguishable. This is because energy is the quantity which is [canonical conjugate](https://en.wikipedia.org/wiki/Canonical_conjugate) to time. This mathematical entanglement of energy and time also results in the uncertainty principle - it is impossible to define the exact amount of energy during any definite time interval. The uncertainty principle should not be confused with energy conservation - rather it provides mathematical limits to which energy can in principle be defined and measured.



Each of the basic forces of nature is associated with a different type of potential energy, and all types of potential energy (like all other types of energy) appears as system [mass,](https://en.wikipedia.org/wiki/Mass) whenever present. For example, a compressed spring will be slightly more massive than before it was compressed. Likewise, whenever energy is transferred between systems by any mechanism, an associated mass is transferred with it.



In [quantum mechanics](https://en.wikipedia.org/wiki/Quantum_mechanics) energy is expressed using the Hamiltonian [operator.](https://en.wikipedia.org/wiki/Operator_(physics)) On any time scales, the uncertainty in the energy is by

which is similar in form to the [Heisenberg Uncertainty Principle](https://en.wikipedia.org/wiki/Heisenberg_Uncertainty_Principle) (but not really mathematically equivalent thereto, since *H* and *t* are not dynamically conjugate variables, neither in classical nor in quantum mechanics).



In [particle physics,](https://en.wikipedia.org/wiki/Particle_physics) this inequality permits a qualitative understanding of [virtual particles](https://en.wikipedia.org/wiki/Virtual_particles) which carry [momentum,](https://en.wikipedia.org/wiki/Momentum) exchange by which and with real particles, is responsible for the creation of all known [fundamental forces](https://en.wikipedia.org/wiki/Fundamental_forces) (more accurately known as [fundamental interactions)](https://en.wikipedia.org/wiki/Fundamental_interactions). [Virtual photons](https://en.wikipedia.org/wiki/Virtual_photons) (which are simply lowest quantum mechanical [energy state](https://en.wikipedia.org/wiki/Energy_state) of [photons)](https://en.wikipedia.org/wiki/Photon) are also responsible for electrostatic interaction between [electric charges](https://en.wikipedia.org/wiki/Electric_charge) (which results in [Coulomb law),](https://en.wikipedia.org/wiki/Coulomb_law) for [spontaneous](https://en.wikipedia.org/wiki/Spontaneous_fission) radiative decay of exited atomic and nuclear states, for the [Casimir force,](https://en.wikipedia.org/wiki/Casimir_force) for [van der Waals bond forces](https://en.wikipedia.org/wiki/Van_der_Waals_force) and some other observable phenomena.



**Energy transfer**



**Closed systems**

Energy transfer can be considered for the special case of systems which are [closed](https://en.wikipedia.org/wiki/Closed_system) to transfers of matter. The portion of the energy which is transferred by [conservative forces](https://en.wikipedia.org/wiki/Conservative_force) over a distance is measured as the [work](https://en.wikipedia.org/wiki/Work_(thermodynamics)) the source system does on the receiving system. The portion of the energy which does not do work



[during the transfer is called heat.[note 4] Energy can be transferred between systems in a variety of ways. Examples include the transmission of electromagnetic](https://en.wikipedia.org/wiki/Electromagnetic_energy) [energy via photons, physical collisions which transfer](https://en.wikipedia.org/wiki/Electromagnetic_energy) [kinetic energy,](https://en.wikipedia.org/wiki/Kinetic_energy)[[note 5]](https://en.wikipedia.org/wiki/Electromagnetic_energy) and the conductive transfer of [thermal energy.](https://en.wikipedia.org/wiki/Thermal_energy)



Energy is strictly conserved and is also locally conserved wherever it can be defined. In thermodynamics, for closed systems, the process of energy transfer is described by the [first law:](https://en.wikipedia.org/wiki/First_law_of_thermodynamics)[note 6]



**(*1*)**



where  is the amount of energy transferred,  represents the work done on the system, and  represents the heat flow into the system. As a simplification, the heat term, , is sometimes ignored, especially when the [thermal efficiency](https://en.wikipedia.org/wiki/Thermal_efficiency) of the transfer is high.



**(*2*)**



This simplified equation is the one used to define the [joule,](https://en.wikipedia.org/wiki/Joule) for example.



**Open systems**

Beyond the constraints of closed systems, [open systems](https://en.wikipedia.org/wiki/Thermodynamic_system" \l "Open_system) can gain or lose energy in association with matter transfer (both of these process are illustrated by fueling an auto, a system which gains in energy thereby, without addition of either work or heat). Denoting this energy by , one may write



**(*3*)**



**Thermodynamics**



**Internal energy**

[Internal energy](https://en.wikipedia.org/wiki/Internal_energy) is the sum of all microscopic forms of energy of a system. It is the energy needed to create the system. It is related to the potential energy, e.g., molecular structure, crystal structure, and other geometric aspects, as well as the motion of the particles, in form of kinetic energy. Thermodynamics is chiefly concerned with changes in internal energy and not its absolute value, which is impossible to determine with thermodynamics alone.[[16]](#page10)



**First law of thermodynamics**

The [first law of thermodynamics](https://en.wikipedia.org/wiki/First_law_of_thermodynamics) asserts that energy (but not necessarily [thermodynamic free energy)](https://en.wikipedia.org/wiki/Thermodynamic_free_energy) is always conserved[[17]](#page10) and that heat flow is a form of energy transfer. For homogeneous systems, with a well-defined temperature and pressure, a commonly used corollary of the first law is that, for a system subject only to [pressure](https://en.wikipedia.org/wiki/Pressure) forces and heat transfer (e.g., a cylinder-full of gas) without chemical changes, the differential change in the internal energy of the system (with a *gain* in energy signified by a positive quantity) is given as



 ,

where the first term on the right is the heat transferred into the system, expressed in terms of [temperature](https://en.wikipedia.org/wiki/Temperature) *T* and [entropy](https://en.wikipedia.org/wiki/Entropy) *S* (in which entropy increases and the change d*S* is positive when the system is heated), and the last term on the right hand side is identified as work done on the system, where press

This equation is highly specific, ignoring all chemical, electrical, nuclear, and gravitational forces, effects such as [advection](https://en.wikipedia.org/wiki/Advection) of any form of energy other than heat and pV-work. The general formulation of the first law (i.e., conservation of energy) is valid even in situations in which the system is not homogeneous. For these cases the change in internal energy of a *closed* system is expressed in a general form by



where  is the heat supplied to the system and  is the work applied to the system.

**Equipartition of energy**

The energy of a mechanical [harmonic oscillator](https://en.wikipedia.org/wiki/Harmonic_oscillator) (a mass on a spring) is alternatively [kinetic](https://en.wikipedia.org/wiki/Kinetic_energy) and [potential.](https://en.wikipedia.org/wiki/Potential) At two points in the oscillation [cycle](https://en.wikipedia.org/wiki/Frequency) it is entirely kinetic, and at two points it is entirely potential. Over the whole cycle, or over many cycles, net energy is thus equally split between kinetic and potential. This is called [equipartition principle;](https://en.wikipedia.org/wiki/Equipartition_principle) total energy of a system with many degrees of freedom is equally split among all available degrees of freedom.



This principle is vitally important to understanding the behaviour of a quantity closely related to energy, called [entropy.](https://en.wikipedia.org/wiki/Entropy) Entropy is a measure of evenness of a



[distribution](https://en.wikipedia.org/wiki/Distribution_(mathematics)) of energy between parts of a system. When an isolated system is given more degrees of freedom (i.e., given new available [energy states](https://en.wikipedia.org/wiki/Energy_state) that are the same as existing states), then total energy spreads over all available degrees equally without distinction between "new" and "old" degrees. This mathematical result is called the [second law of thermodynamics.](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) The second law of thermodynamics is valid only for systems which are near or in [equilibrium state.](https://en.wikipedia.org/wiki/Equilibrium_state) For non-



[equilibrium systems, the laws governing system's behavior are still debatable. One of the guiding principles for these systems is the principle of maximum entropy](https://en.wikipedia.org/wiki/Principle_of_maximum_entropy) [production.](https://en.wikipedia.org/wiki/Principle_of_maximum_entropy)[[18][19]](#page10) [It states that nonequilibrium systems behave in such a way to maximize its entropy production.](https://en.wikipedia.org/wiki/Principle_of_maximum_entropy)[[20]](#page10)



**See also**



[Combustion](https://en.wikipedia.org/wiki/Combustion)



[Index of energy articles](https://en.wikipedia.org/wiki/Index_of_energy_articles)



[Index of wave articles](https://en.wikipedia.org/wiki/Index_of_wave_articles)



[Mattergy](https://en.wikipedia.org/wiki/Hybrid_word" \l "English_examples)



[Orders of magnitude (energy)](https://en.wikipedia.org/wiki/Orders_of_magnitude_(energy))



[Power station](https://en.wikipedia.org/wiki/Power_station)



[Transfer energy](https://en.wikipedia.org/wiki/Spaceflight" \l "Transfer_energy)



**Notes**



* The [second law of thermodynamics](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) imposes limitations on the capacity of a system to transfer energy by performing work, since some of the system's energy might necessarily be [*consumed*](https://en.wikipedia.org/wiki/Waste_heat) in the form of [heat](https://en.wikipedia.org/wiki/Heat) instead. See e.g. Lehrman, Robert L. (1973). "Energy Is Not The Ability To Do Work". *The Physics Teacher*. **11** (1): 15–18. [Bibcode](https://en.wikipedia.org/wiki/Bibcode):[1973PhTea..11...15L (https://ui.adsabs.harvard.edu/abs/1973PhTea..11...15L)](https://ui.adsabs.harvard.edu/abs/1973PhTea..11...15L). [doi](https://en.wikipedia.org/wiki/Digital_object_identifier):[10.1119/1.2349846 (https://doi.org/10.1119%2F1.2349846)](https://doi.org/10.1119%2F1.2349846). [ISSN](https://en.wikipedia.org/wiki/International_Standard_Serial_Number) [0031-921X (https://www.worldcat.org/issn/0031-921X)](https://www.worldcat.org/issn/0031-921X).
* These examples are solely for illustration, as it is not the energy available for work which limits the performance of the athlete but the [power](https://en.wikipedia.org/wiki/Power_(physics)) output of the sprinter and the [force](https://en.wikipedia.org/wiki/Force_(physics)) of the weightlifter. A worker stacking shelves in a supermarket does more work (in the physical sense) than either of the athletes, but does it more slowly.
* [Crystals](https://en.wikipedia.org/wiki/Crystal) are another example of highly ordered systems that exist in nature: in this case too, the order is associated with the transfer of a large amount of heat (known as the [lattice energy](https://en.wikipedia.org/wiki/Lattice_energy)) to the surroundings.
* Although heat is "wasted" energy for a specific energy transfer,(see: [waste heat](https://en.wikipedia.org/wiki/Waste_heat)) it can often be harnessed to do useful work in subsequent [interactions. However, the maximum energy that can be "recycled" from such recovery processes is limited by the second law of](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics) [thermodynamics.](https://en.wikipedia.org/wiki/Second_law_of_thermodynamics)
* The mechanism for most macroscopic physical collisions is actually [electromagnetic](https://en.wikipedia.org/wiki/Electromagnetism), but it is very common to simplify the interaction by ignoring the mechanism of collision and just calculate the beginning and end result.
* There are several [sign conventions for this equation](https://en.wikipedia.org/wiki/First_law_of_thermodynamics" \l "Description). Here, the signs in this equation follow the IUPAC convention.



ure is *P* and volume *V* (the negative sign results since compression of the system requires work to be done on it and so the volume change, d*V*, is negative when work is done on thesystem).

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