European Environment Agency

EN19 Efficiency of conventional thermal electricity production

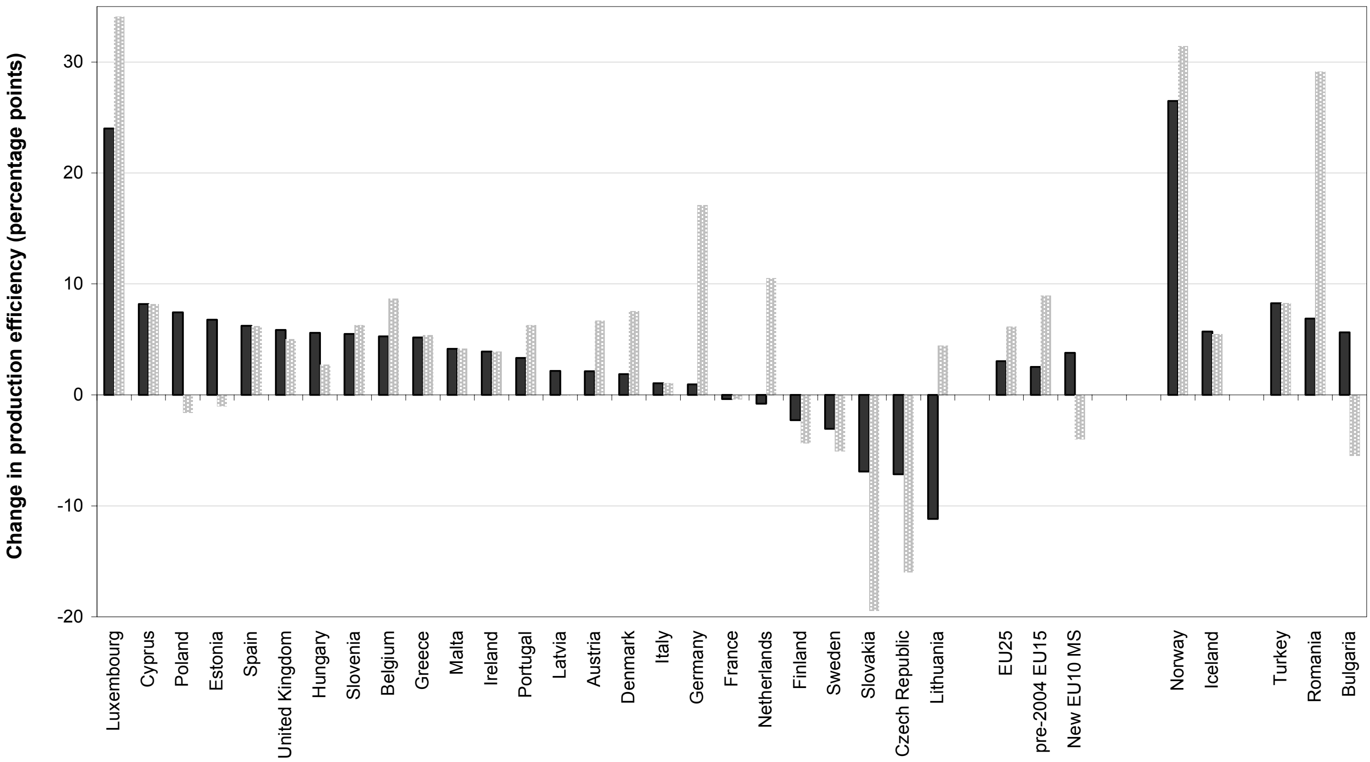
Key message

The efficiency of both electricity, and combined electricity and heat production from conventional thermal power plants improved steadily between 1990 and 2003. This was due to the closure of old inefficient plants, improvements in existing technologies and the installation of new, more efficient technologies, often combined with a switch from coal power plants to more efficient combined cycle gas-turbines. This trend is expected to continue in the future. However, the rapid growth in fossil-fuel based electricity production outweighs some of the environmental benefits of the efficiency improvements.

Rationale

The majority of thermal generation is produced using fossil fuels with associated environmental impacts such as greenhouse gas emissions, but can also include biomass, wastes and geothermal. Whilst the level of environmental impact depends upon factors such as the particular type of fuel and the extent to which abatement technologies are used, all else being equal, the greater the efficiency the lower the environmental impact for each unit of electricity produced.

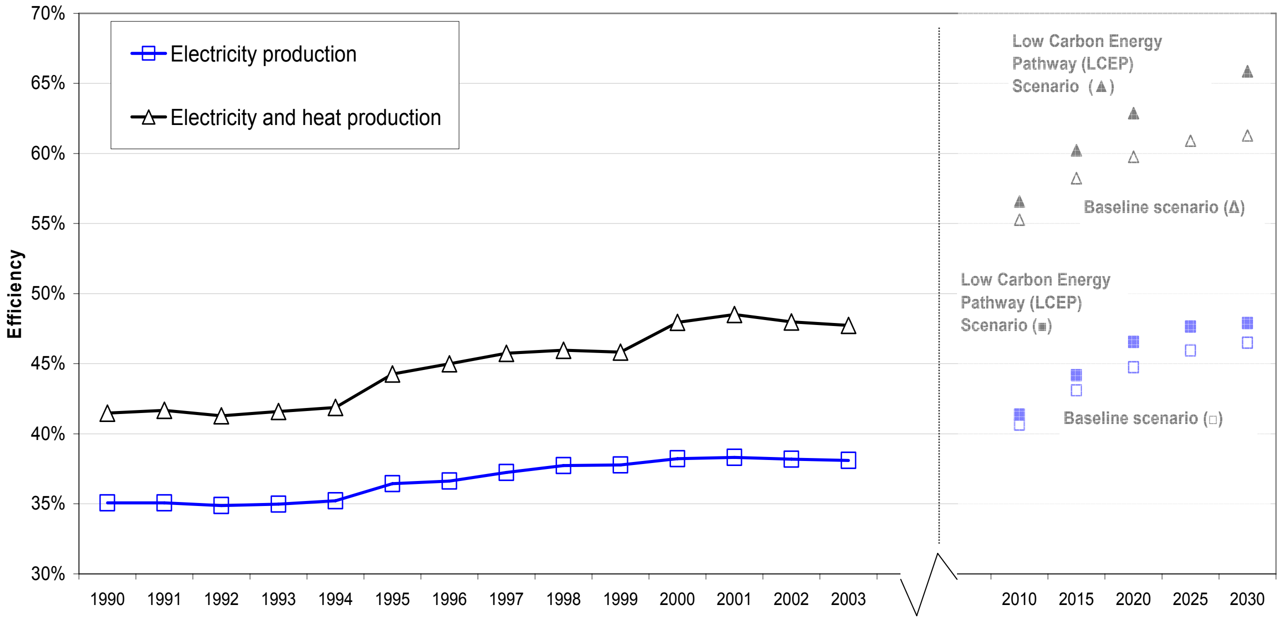
Fig. 1: Average annual percentage change in efficiency of electricity and of electricity and heat production from conventional thermal plants, 1990-2003



Data source: Eurostat.

Notes: Output from conventional thermal power stations consists of gross electricity generation and also of any heat sold to third parties (Combined heat and power plants) by conventional thermal public utility power stations as well as autoproducer thermal power stations. Electricity production from conventional thermal power plants (this includes both public plants and autoproducers) is defined as the process of electricity production using combustible fuel sources (coal, natural gas, oil, waste or biomass) or existing heat sources (geothermal energy). The efficiency of electricity production is calculated as the ratio of electricity output to the total fuel input. However, the input to conventional thermal power plants cannot be separated into input for heat and input for electricity production. Therefore the efficiency rate of electricity and heat production equals the ratio of both electricity and heat production to fuel input (which assumes there is an efficiency rate for heat production).

Fig. 2: Efficiency of conventional thermal electricity and heat production, EU 25



Data source: Eurostat (historical data), EEA (2005) for projections.

Notes: The steep increase between 1999 and 2000 in the efficiency of heat and electricity production is mainly due to an important rise in heat production in Germany**.** EEA baseline projections are consistent with European Commission (2004). The Low-Carbon-Energy Pathway (LCEP) scenario assumes that ambitious future greenhouse gas emission reduction targets will be reached and thus assumes a CO_2 permit price of EUR 30/t CO_2 and EUR 65/t CO_2 in 2020 and 2030, respectively.

1. Indicator assessment

The average energy efficiency of conventional thermal electricity production in the EU-25 improved over the period 1990-2003 by 3.0 percentage points to 38.1 %. Including useful heat, as well as electricity in calculating efficiency, results in an increase of just over 6.3 percentage points to 47.7 % over the same time period.

This energy efficiency improvement has been due to a combination of factors including the closure of old inefficient plants, improvements in existing technologies, installation of new, more efficient technologies, often combined with a switch to fuels with a better generating efficiency, such as from coal power plants to high-efficiency combined cycle gas-turbines. Environmental regulation has also been important in encouraging improvements and fuel switching towards more efficient fuels. However, the main factor in the choice of new electricity production plant during the period 1990-2003 was economic, as the costs of electricity produced from gas-fired plants have generally been less than for coal or oil fired plants, which has led to gas being the more desirable fuel for new plants.

The growth in the use of combined cycle gas turbine plants (CCGT) has been an important factor in the improving efficiency seen in the pre-2004 EU-15 Member States. CCGT plants can achieve conversion efficiencies in the order of 60 %, with the prospect of even higher efficiencies in future plants. The liberalisation of the power production markets stimulated the uptake of gas for electricity production, combined with policies in certain Member States that favoured the use of gas, as well as a low gas price in the 1990s, improved gas technologies and improved infrastructure for the delivery of gas in some Member States. However, continued improvements have also been made in conventional coal generation with plant capable of efficiencies in the range 40-45 %, and further advances that may allow this to exceed 50 % (IEA, 2005).

Although overall improvements in electricity generation efficiency have been seen over the period 1990 to 2003, in recent years, from approximately 2001 onwards, a marginal decline in efficiency has been observed. This has been due primarily to a combination of a recent increase in the relative price of gas to coal, as well as a sizeable drop in hydro electricity production due to low rainfall, both of which have subsequently led to increased utilisation of existing lower efficiency coal plant (see EN-27 for more details).

It should also be noted that positive impacts on the environment overall, due to reduced emissions, from increased efficiency in electricity production may be offset by the high rate of increase in electricity consumption, which is growing at an average rate of 1.8 % per year (see EN18), especially considering that over half of this electricity (54.6 % in 2003) is produced from fossil fuels (see EN27)[1]. There is also a potential tension between environmental legislation requiring the reduction of other air pollutants (for example the Large Combustion Plant Directive 2001/80/EC) such as SO_2, whereby retrofitting flue-gas desulphurisation technology incurs an energy penalty thus reducing overall efficiency. However, future coal technologies such as IGCC (Integrated Gasification Combined Cycle) can operate at higher efficiencies and also allow the sulphur, nitrogen compounds and particulates to be removed prior to combustion (OECD, 2005).

Fig. 3 Fossil-fuelled electricity production capacity by technology, EU-25

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
Steam turbines	92%	87%	84%	84%	82%	81%	78%	77%	75%	73%
Gas turbines (single cycle)	6%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Gas turbines (combined cycle)	1%	5%	7%	7%	9%	10%	13%	14%	15%	18%
Oil and gas engines	1%	1%	2%	2%	2%	2%	2%	2%	3%	3%

Data source: Eurostat (historical data), EEA (2005) for projections.

Note: No data for Slovakia available for all years; no data was available for Germany in 2002 and 2003; for the purpose of the above calculation it was assumed that capacities in Germany in 2002/3 were the same as in 2001.

At the beginning of the 1990s, the electricity sectors of the new EU Member States were characterised by low efficiencies of production mainly due to obsolete plant technology. However, in the second half of the 1990s, the privatisation of the electricity production industry in many of these countries stimulated the need to cut costs and thus investments were made to improve performance of existing plants. Many of the New Member States had used substantial amounts of low quality brown coal as it was readily available, and another significant trend was a switch from coal to gas in new and reconstructed fossil fuelled heat and power plants. This also contributed to an increase in generating efficiency due to the higher efficiency of gas combined cycle technologies. The growth in the use of gas has been supported by environmental regulation, government support (as high-efficiency electricity production from gas is seen as a low-pollution option) and programmes to finance enlargement of the gas networks. The efficiency in electricity generation thus increased at a higher rate in the EU-10 (+3.7%) than in the pre-2004 EU-15 Member States (+2.5% between 1990 and 2003)[2]. Despite this converging trend, the electricity conversion efficiency is still 6.9 Percentage points lower in the new MS on average, but the gap has decreased from 8.1 percentage points in 1990.

Individual Member States show marked differences in the extent to which their efficiency of conventional thermal power production has improved and in some cases differences depending on whether just electricity or both electricity and heat is considered. Amongst the larger countries, that tend to dominate the overall trend, large improvements have been seen in the United Kingdom and Spain. In the United Kingdom, efficiency improvements have been largely due to the fuel switch to gas prompted by the liberalisation of the United Kingdom energy market. Similarly, liberalisation in Spain has also increased efficiency via a rapid penetration of CCGT. In Germany the efficiency of electricity production has improved only slightly over the period whereas the efficiency of heat and electricity production has improved significantly.

Amongst other countries, particularly significant improvements in the efficiency of electricity production have been seen in Luxembourg and Cyprus. In the case of Luxembourg, the construction of a new CCGT has significantly increased both electricity production in the country (at the expense of imports) while also dramatically increasing the overall efficiency of conventional thermal production. Cyprus has also seen rapidly increasing electricity production (mostly from oil), with new more efficient plant being built. Significant decreases in the efficiency of electricity production have been seen in Lithuania and the Czech Republic between 1990 and 2003, but closer examination of the trend shows a sharp fall in efficiencies in the early 1990s during the period of economic collapse due to low utilisation of plants, followed by steadily increasing efficiencies in more recent years due to higher load factors on existing plants, refurbishment and new investment. Large differences can be seen in the improvement in efficiency for electricity production compared to electricity and heat production for countries such as Denmark and the Netherlands, which have shown a large increase in combined heat and power since 1990 (see EN20). With more 'waste' heat being utilised, the efficiency of heat and electricity production has increased more sharply than the efficiency of electricity production alone, see the cross-country comparison in Figure 1 for more details.

The trend in increasing efficiency is expected to continue into the future, as new more efficient technologies are introduced, in particular with the increased market penetration of combined cycle gas turbine technologies, and following the closure of older less efficient plants. Both the baseline and Low Carbon Energy Pathway (LCEP) suggest that the bulk of new capacity comes from CCGT plants (with a larger increase under the LCEP scenario). This is because these plants are more efficient and cost-

[1] Specific details of emission levels from electricity generating plants can be obtained for a variety of pollutants at the European Pollutant Emission Register.

[2] However, due to the decreasing use of heat, the efficiency in electricity and heat generation fell by 3.6% in the EU10, while it increased in the EU15.

effective, than existing power stations and new advanced coal technologies, with the added cost advantage relative to coal under the LCEP scenario, due to the increasing CO_2 permit price.

The rise in efficiency in the LCEP scenario is faster than the baseline due primarily to the introduction of a carbon tax which speeds the transfer to less carbon intensive natural gas (and hence CCGT generation) from the relatively more carbon intensive coal generation. Even though the difference in the conversion efficiency between the two scenarios appears small (1.9 percentage points) it accounts for an emissions reduction of around 60 $MtCO_2$ due to the significant proportion of emissions from the power production sector (EEA, 2005)

2. Indicator rationale

2.1 Environmental context

Changes in the efficiency of electricity production from conventional thermal power production provides an indication of their environmental impact, as the majority of fuel used for thermal generation uses fossil fuels with their associated environmental impacts such as greenhouse gas emissions and the release of other pollutants such as NO_x, SO_2 and particles. However, the overall environmental impact has to be seen in the context of the type of fuel (see EN27) and the extent to which abatement technologies are used (see EN06). All else being equal, the greater the efficiency of thermal power generation the lower the environmental impacts for each unit of electricity produced, as less input fuel is required to produce it.

2.2 Policy context

The recent Green Paper on energy efficiency (COM(2005)265 final) highlights the importance of improving the efficiency of thermal generation as the expected increase in demand for electricity is likely to require over 500GW of new capacity to be installed up to 2030. The paper specifies the need to ensure that: the most efficient CCGT technology is used; research is expanded to improve the efficiency of coal generation; the use of distributed generation is expanded particularly to make greater use of waste heat, and that in combination with this a greater use of combined heat and power (cogeneration) technology is realised.

Efficiency has a direct impact on certain environmental issues, such as greenhouse gas emissions (the power generation sector was responsible for approximately 33 % of EU-25 emissions in 2003). The overall Kyoto target for the pre-2004 EU-15 Member States requires an 8 % reduction in greenhouse gases by 2008-2012 from base-year levels (1990 for most greenhouse gases), while most new Member States have individual targets under the Kyoto Protocol.

A number of EU policies have also had an impact on the changes in the efficiency of electricity and heat production. For example, the Directives concerning common rules for the internal market in electricity (2003/54/EC) and gas (2003/55/EC) establish common rules for the transmission, distribution, supply and storage of electricity and gas and the organisation and functioning on the sectors. The main impact of the directives, in terms of efficiency of conventional thermal generation, is that they have led to the progressive introduction of competition in the electricity supply industry, both within and between Member States. It is expected that these new market structures will encourage switching to cheaper and more efficient technologies, in particular gas technologies (although this is also likely to lead to reduced energy prices for final energy consumers, which may stimulate demand (see EN31).

Another important policy is the Directive establishing a scheme for greenhouse gas emission allowance trading within the Community (2003/87/EC), which is intended to contribute to the European Union fulfilling its commitments under the Kyoto Protocol. Under the Directive, Member States have to draw up a National Allocation Plan that will include setting caps on CO^2 emissions from all thermal electricity generating plant greater than 20 MW. A shift to less carbon intensive fuels for electricity generation, such as gas, and improvements in efficiency are important options to help generators meet their requirements under the directive.

Other relevant policies include: the Directive on the promotion of high-efficiency cogeneration (2004/8/EC); the Large Combustion Plant Directive (2001/80/EC) which aims to control emissions of SOx NOx and particulate matter from large (>50MW) combustion plants and hence favours the use of higher efficiency CCGT as opposed to coal plants; and plants covered under the IPPC Directive (96/61/EC) of <20MW are required to meet a set of basic energy efficiency provisions, whilst for larger plants energy efficiency is covered by the plants participation within the EU emissions trading scheme.

References

COM (2005) 265 final – Green Paper on energy efficiency, or doing more with less, European Commission
http://europa.eu.int/comm/energy/efficiency/doc/2005_06_green_paper_text_en.pdf

Council Decision 2002/358/EC to ratify the Kyoto Protocol under the United Nations Framework Convention on Climate Change

Directive 96/61/EC concerning integrated pollution prevention and control

Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants

Directive 2003/54/EC concerning common rules for the internal market in electricity and repealing Directive 96/92/EC

Directive 2003/55/EC concerning common rules for the internal market in natural gas and repealing Directive 98/30/EC

Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC

Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market amending Directive 92/42/EEC.

EEA (2005) Climate change and a low-carbon European energy system, European Environment Agency report No 1/2005

IEA (2005) Reducing Greenhouse Gas Emissions The Potential of Coal, International Energy Agency

European Commission (2003) European energy and transport, Trends to 2030, Directorate General for Energy and Transport.

European Commission (2004) European energy and transport – scenarios on key drivers, Directorate General for Transport and Energy

OECD (2005) International Energy Technology Collaboration and Climate Change Mitigation, Case Study 4: Clean Coal Technologies

UNFCCC (1997) Kyoto Protocol to the United Nations Framework Convention on Climate Change; adopted at COP3 in Kyoto, Japan, on 11 December 1997

Meta data

Technical information

1. Data source:
   Fuel input to, and electricity and heat output from conventional thermal power stations: Eurostat (historical data) http://europa.eu.int/comm/eurostat/. There were important corrections for the year 1990 in the energy balance. These changes for Latvia have been taken into account as much as possible. However, the EU-10 and EU-25 aggregates could not be updated. Changes to the EU aggregates are likely to be limited as in 1990 the total energy consumption in Latvia represented approximately 3 % and 0.5 % of the total energy consumption in the EU-10 and EU-25, respectively.
   Projection data: European Environment Agency (2005) – baseline projections are consistent with European Commission (2004)

2. Description of data/Indicator definition:
   Output from conventional thermal power stations consists of gross electricity generation and also of any heat sold to third parties (Combined heat and power plants) by conventional thermal public utility power stations as well as autoproducer thermal power stations. The energy efficiency of conventional thermal electricity production (which includes both public plants and autoproducers) is defined as the ratio of electricity production to the energy input as a fuel. As thermal power stations also produce heat as well as electricity, more of which is now being used rather than wasted, another measure of efficiency is to divide the sum of electricity and useful heat produced by the fuel input. Fuels include solid fuels (i.e. coal, lignite and equivalents, oil and other liquid hydrocarbons, gas, thermal renewables (industrial and municipal waste, wood waste, biogas and geothermal energy) and other non-renewable waste.
   Units: Fuel input and electrical and heat output are measured in thousand tonnes of oil equivalent (ktoe)
   Efficiency is measured as the ratio of fuel output to input (%)
   The PRIMES model was used by the EEA to analyse possible future developments of the European energy sector, including a baseline scenario without a permit price and the low carbon energy pathway (LCEP) scenario. It describes the least-cost response of the EU-25 energy system to the introduction of a carbon permit price that rises to EUR 65/t CO^2-equivalent by 2030.

3. Geographical coverage:
   The Agency had 31 member countries at the time of writing of this fact sheet. These are the 25 European Union Member States and Bulgaria, Romania and Turkey, plus Iceland, Norway and Liechtenstein. On 1 April 2006, Switzerland joined the EEA, bringing its number of member countries to 32.
   No energy data available for Switzerland and Liechtenstein. No projection data are available for Iceland, Liechtenstein.

4. Temporal coverage: 1990-2003, projections to 2030 in 5 year intervals.

5. Methodology and frequency of data collection:
   Data collected annually.
   Eurostat definitions for energy statistics http://forum.europa.eu.int/irc/dsis/coded/info/data/coded/en/Theme9.htm
   Eurostat metadata for energy statistics http://europa.eu.int/estatref/info/sdds/en/sirene/energy_base.htm

6. Methodology of data manipulation:
   Average annual rate of growth calculated using: [(last year / base year) ^ (1/number of years) –1]*100
   Efficiency of electricity production = electrical output/fuel input
   Efficiency of electricity and heat production = (electrical output + heat output)/fuel input
   The coding (used in the Eurostat New Cronos database) and specific components of the indicator are:
   Numerator:
   a) Electricity output from conventional thermal power stations 101101 (6000 electrical energy) OR
   b) Electricity output from conventional thermal power stations 101101 (6000 electrical energy) + Heat output from conventional thermal power stations 101101 (5200 derived heat)
   Denominator: Input to conventional thermal power stations 101001 (0000 all products)

Qualitative information

7. Strengths and weaknesses (at data level)
   Data have been traditionally compiled by Eurostat through the annual Joint Questionnaires, shared by Eurostat and the International Energy Agency, following a well established and harmonised methodology. Methodological information on the annual Joint Questionnaires and data compilation can be found in Eurostat's web page for metadata on energy statistics.
   http://europa.eu.int/estatref/info/sdds/en/sirene/energy_sm1.htm

8. Reliability, accuracy, robustness, uncertainty (at data level):

   Indicator uncertainty (historic data)
   The efficiency of electricity production is calculated as the ratio of electricity output to the total fuel input. However, the input to conventional thermal power plants cannot be disaggregated into separate input for heat and input for electricity production. Therefore the efficiency rate of electricity and heat production equals the ratio of both electricity and heat production to fuel input, which assumes there is an efficiency rate for heat production.
   Also, electricity data (unlike that for overall energy consumption) for 1990 refers to the western part of Germany only, so there is a break in the series from 1990-1992.
   There are also slight differences in the calculation of efficiencies between the historical and projected data. In contrast to the Eurostat data, the projections take into account non-marketed steam, i.e. steam generated - either in boilers or in CHP plants - and used on site by industrial consumers.The calculation of projected efficiencies therefore takes into account both the non-marketed steam generated in CHP units as well as the corresponding fuel input whereas the calculation of historical efficiencies excludes both these components.

   Indicator uncertainty (scenarios/projections)
   Scenario analysis always includes many uncertainties:
   - uncertainties related to future socioeconomic developments (e.g. GDP) and human choices;
   - uncertainties in the underlying statistical and empirical data (e.g. on future technology costs and performance);
   - uncertainties in the choice of indicators (representativeness);
   - uncertainties in the dynamic behaviour of systems and its translation into models;
   - uncertainties in future fuel costs and the impact on low carbon technologies.

   The LCEP scenario uses relatively optimistic assumptions on economic growth, compared with other scenarios. The same level of carbon prices as in the LCEP scenario would lead to higher CO2 emission reduction when simulated with other models (e.g. TIMER), which may partly result from the fact, that carbon capture and storage was not included in the PRIMES LCEP scenario.

9. Overall scoring - historical data (1 = no major problems, 3 = major reservations):

Relevance: 1
Accuracy: 2
Comparability over time: 2
Comparability over space: 1