

GPG352

Good Practice Guide

An introductory guide to energy performance assessment
Analysing your own performance



Making business sense
of climate change

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1 Introduction

Why is energy efficiency important?

There are numerous reasons for wanting to improve energy efficiency, but perhaps the most compelling one for industry is that wasting energy costs money and this is reflected in the bottom line. In many cases, improvements can be made for low or no cost, involving making slight changes to the way a process or equipment is operated to optimise its performance rather than the purchase of expensive equipment.

Saving energy has many benefits, including:

- Reduced energy costs (increasing profits or releasing resources for other activities)
- Improved environmental performance due to reduced carbon dioxide emissions
- Improved competitiveness of products or services
- Enhanced public image with customers and other stakeholders
- Reduced exposure to Government drivers such as the Climate Change Levy.

Companies in energy-intensive industries have even more incentive to improve performance: members of Climate Change Agreements (CCAs) need to demonstrate improved energy efficiency to continue to qualify for the 80% discount from the Climate Change Levy.

Assessing energy performance

Most companies want to know how well they are managing their energy use – whether their performance is improving through conscious actions that have been taken and whether there is room for further improvement in terms of energy and carbon savings. Performance can be compared ('benchmarked') with either previous performance or that of other organisations (i.e. internal or external benchmarking).

There are two stages to assessing energy performance:

- Establishing how energy use is related to factors such as production levels, product mix, weather conditions, etc. (This allows energy use to be estimated under different conditions such as lower output levels)
- Making meaningful and valid comparisons of performance under equivalent conditions.

Many industrial sectors use specific energy consumption (SEC) as the basic performance indicator. However, many companies have found that using SEC to demonstrate improved energy efficiency is not as straightforward as they thought, primarily because it is affected by more factors than anticipated.

How can this guide help?

This guide is aimed at people who are responsible for managing energy and assessing how their organisation's performance is changing. The guide aims to clarify some of the common problems that are encountered when using SEC as a performance indicator and presents a simple approach to assessing energy performance that allows meaningful comparisons. Examples are used throughout the guide to illustrate this approach.

Following the advice given in this guide will help you to develop a better understanding of where and how energy is being used at your site. This in turn will help you to identify priority areas for making improvements that will result in energy and carbon savings.

This is an introductory guide and deals only with how to assess your own performance. The approach is kept simple and more work may be needed to develop solutions applicable to your site. Further free help may be obtained by calling the Carbon Trust Energy Helpline on 0800 58 57 94.

2 Stage 1: basic energy performance measure

What is energy efficiency?

If a company produces more using the same amount of energy, or uses less energy to achieve the same level of saleable product, then it is said to be using energy more 'efficiently'.

Two simple measures can be used as a basic indicator of performance. The first indicator (energy per unit of production) is specific energy consumption (SEC)¹:

$$\text{Energy per unit of production} = \frac{\text{Energy used}}{\text{Production}}$$

An alternative indicator is:

$$\text{Production per unit of energy} = \frac{\text{Production}}{\text{Energy used}}$$

A change in either of these performance indicators implies that 'energy efficiency' has changed. If your energy per unit of production falls or your production per unit of energy rises, then you are using energy more efficiently. It is best to relate energy to saleable product, as this is where costs can be recovered. Including non-saleable production, scrap, and so on can present an overly optimistic picture.

Industry often uses energy per unit of production or SEC as a performance indicator, because it is so easy to calculate. However it can be misleading and may lead to erroneous assumptions being made. Tables 1 and 2 highlight some of the most common influences on SEC in manufacturing industry, some of which are beyond a company's ability to control. Table 1 shows factors that cause SEC to fall (i.e. reduce energy use and thus improve energy efficiency), and Table 2 shows some common changes that will cause SEC to rise (i.e. increase energy use and thus reduce energy efficiency).

While SEC may show that things have changed, it does not normally allow you to say why. If you want to manage your energy effectively, you need to know how much energy use is due to actions you can control and how much energy use is due to factors outside your control. It is often not appreciated that SEC can rise (i.e. worsen energy efficiency) even if no changes have been made to your plant or practices.

Table 1 Factors that tend to reduce SEC (i.e. improve energy efficiency)

Factor	Comments
Increasing production levels	The market demand for your product may be beyond your ability to control.
Producing components of lower energy intensity	Can you persuade the market to use these components?
Improving plant-running efficiency	You may be able to reduce energy use when the plant is running by making changes, such as adopting more efficient practices, improving insulation and reducing waste.
Reducing the fixed energy component of your plant	Can you reduce the energy used to switch machines on or to hold them at temperature when they are not in use?
Decreasing scrap levels	Avoid making scrap, because it results in unnecessary energy use and other costs.
Mild winters	Winter generally results in increased energy demand; a mild winter lessens the extra energy needed.

¹ Sometimes referred to as Specific Energy Ratio (SER).

Table 2 Factors that tend to increase SEC (i.e. worsen energy efficiency)

Factor	Comments
Falling production levels	It may be difficult to influence market demand in a recession.
Making more energy-intensive components	Customers often demand more complicated items that are intrinsically harder to make. Higher added-value products usually require more energy to produce.
Rising scrap rates	Poor process control can increase scrap rates; however, customer demands for higher quality may result in more rejects despite no changes in the way you operate.
Falling plant efficiency	Poor maintenance and wear can reduce plant efficiency, as can the loss of skilled operators.
Increasing fixed energy levels	For example, you may need to use more energy for extraction fans to comply with legislation.
Poor quality input materials	Lower-grade raw materials are sometimes used because they are cheaper, but they often require considerable extra processing.
Cold winters	In cold weather, space heating demand will rise. The least efficient way to meet heating requirements is to use process heat to compensate for inadequate space heating.

Change of SEC with throughput

SEC is simply a means of assigning energy use to some unit of output. It does not necessarily mean that energy use is related to output (although it often is). However, because SEC is calculated using energy and production, it predisposes people to expect energy use to be related to output. The expectation is thus established that greater production means more energy will be needed or that falling production will automatically mean less energy is used. In some cases, however, some or all of a factory's energy use is independent of production. In such cases, SEC will alter as production alters, but energy use could remain constant.

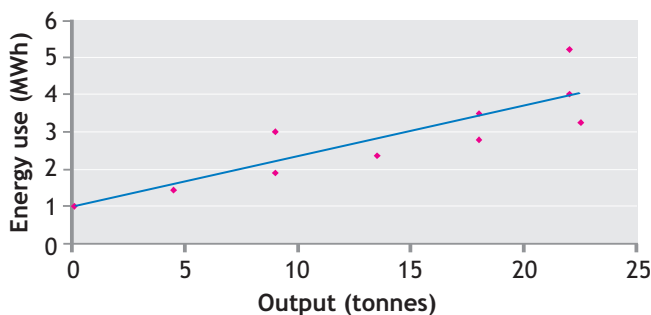
For example, consider a factory that is lit continuously. If this factory has no other energy use, there will be no change to the electricity bill if production increases, but the SEC will fall. Similarly, if production falls and no lights are switched off, energy use will stay constant but SEC will rise.

For many companies, one of the variables most likely to affect SEC is the influence of output/throughput. SEC may well rise by 10% if throughput drops by a similar amount. However, where output has also fallen, using SEC will not help you to demonstrate that a piece of new equipment has made your factory more energy efficient – in fact, the result may indicate the opposite!

Most factories use some energy that is not directly related to making product. This is generally known as the fixed energy component and is often associated with bringing equipment up to temperature or speed, holding material at a fixed temperature (heating or refrigeration), or background heating. It may also include the energy used in an office block for lighting, space heating, etc.

A graph of energy use plotted against production highlights each of these energy components. The graph in Figure 1² shows a common pattern seen in many industries. It is usually found where energy use is determined by the physics of the process (e.g. heating or melting metals, chemical or electrochemical conversion) and is unlikely to apply to largely mechanical processes such as cutting or mixing.

Figure 1 Graph of energy consumption versus production



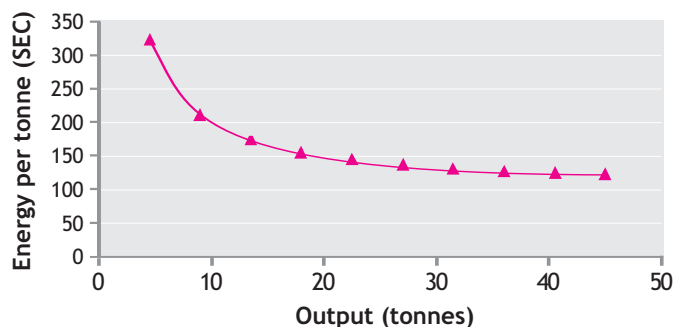
The slope of the straight line in Figure 1 is sometimes called the marginal specific energy consumption (MSEC), expressed in energy per unit of production. It represents the additional energy to produce additional output once the process is up and running, and is a measure of the efficiency of the process. If you can reduce the slope, it means you need less energy for each additional tonne of product. The intercept on the y-axis gives the fixed energy value (i.e. the amount of energy needed to get the process operational but with no associated production). This component includes energy consumption that continues while the process is in operation but which does not contribute to production (e.g. factory lighting or office heating).

The scatter between points on the graph is a measure of how much energy consumption varies at the same level of production. If there is a lot of scatter, it indicates either poor control over the process or the presence of other factors that affect energy use, but which are not related to production. For example, more energy might be used in the winter than in the

summer for the same level of production merely because of higher space heating requirements.

Using the data from Figure 1 to plot energy per tonne (SEC) at a series of production levels results in a graph like the one shown in Figure 2. Figures 1 and 2 show that energy can be linearly related to output, where energy per tonne is not. Even at a high output, the SEC still alters with output.

Figure 2 Graph of energy per tonne versus output



For example, if output fell from 45 tonnes/day to 40 tonnes/day at the company featured in Figure 2, then the SEC would increase by some 2-3%. This represents a change in SEC with no change to the plant (i.e. changes in SEC are not necessarily due to managed actions to improve the process).

It is not generally a good idea to use graphs like Figure 2, because they lead to numerous problems when trying to understand energy use. Working with energy use and output (as in Figure 1) gives you much better information, with fewer ambiguities. It is far better to establish whether a relationship exists between energy use and output (or any other factor that may affect energy use). Once you have determined your energy use, you can easily calculate the SEC.

SEC can change for a number of reasons (as highlighted in Tables 1 and 2), so while this will indicate that something has happened, you may not know what. To be able to manage your energy performance, you will need to know how much of the change is due to actions you have

² This and other examples in this guide are hypothetical and do not relate to any particular company.

taken (e.g. better insulation) and how much is due to factors over which you have no control (e.g. the weather).

Evaluating performance over time demands a valid comparison, which means taking account of the types of factors identified in Tables 1 and 2. For many sites, the first relationship to explore is how changes in output affect energy use (i.e. does energy use depend on throughput?). The less sensitive energy use is to throughput, the more sensitive SEC is to changes in production.

The examples in this section have assumed a very simple relationship, in this case between energy and production. However, energy use can be affected by many variables, making a more complex relationship likely in some cases. The Carbon Trust is working with a number of sectors to develop more industry-specific guidance on getting better models for energy use. For more information, contact the helpline on 0800 58 57 94.

Sustainable or managed energy efficiency

Because SEC can change for reasons you can control and for reasons you cannot, it is necessary to clarify what is meant by energy efficiency. If you introduce changes that reduce either your marginal SEC or your fixed energy component, then this is said to be a *sustainable or managed improvement* to energy efficiency. Although SEC will still vary with output after you have improved the marginal SEC and/or the fixed energy, the SEC will be lower under given conditions than it was before the change.

If, on the other hand, your SEC falls due to a factor you cannot control, such as higher output or milder weather, then the benefit will disappear as soon as throughput falls again or the weather turns colder. In such cases, the improvement in SEC could be *transient* and the SEC will be unaltered under given conditions.

When people talk about managing energy efficiently, they are generally talking about sustainable or managed improvement. To ensure that this has occurred when using SEC as an indicator, you will generally need to adjust it for output. Occasionally, however, an improvement in SEC with increased production is a managed or sustainable improvement (e.g. when production from multiple sites (or process lines) is rationalised into a single site). In this case, it is justifiable to claim that raising throughput has increased energy efficiency.

SEC will change for a variety of reasons. If you want to use SEC to assess performance, then you need to review it in the light of changes in factors such as:

- Output
- Product mix
- Shift patterns
- External temperatures (i.e. the weather).

You should aim to understand the pattern of energy use before trying to interpret SEC figures

3 Stage 2: making comparisons

The process of comparing performance is often called 'benchmarking'. Benchmarking tends to mean different things to different people, so it is important to define what this guide means by benchmarking.

- A benchmark is 'a standard, used for comparison'
- Benchmarking is often described as the 'process of comparing the performance of organisations, functions or processes'.

To demonstrate a sustained or managed change to energy efficiency, you need to compare the current SEC with a relevant SEC under the appropriate conditions. This is particularly important if you are operating against a backdrop of factors that can cause SEC to rise. However, it can also be useful even if you are expecting SEC to fall, because it may highlight that it has not fallen by as much as it should have done and you will therefore be incurring unnecessary energy costs. When comparing your own performance, this is known as *internal benchmarking*.

External benchmarking is more involved and, until you understand internal benchmarking and the factors affecting energy use in your organisation, it is generally unwise to try and draw comparisons with other organisations.

For most companies, the first thing to assess is whether your own performance is improving or deteriorating, and why – but to do this, you need to be able to compare performance and compensate for factors like changes in output.

The importance of valid comparisons

Miles per gallon (mpg) is used as an everyday indicator of a vehicle's energy performance, and is simply production expressed in miles and energy in gallons of fuel (i.e. miles travelled divided by gallons of petrol used). In this case, the performance indicator is given in terms of production per unit of energy rather than energy per unit of production. Hence, any improvement will cause the mpg to rise (i.e. you travel more miles on one gallon of petrol). Can mpg therefore be used to compare performance? If you were asked what mpg you got from your car, you would probably provide more than one answer (say, a figure for around town and one for a long motorway trip), because fuel consumption is affected by how fast you drive and how much stop-start driving you do.

If you wanted to know whether you were using more petrol than necessary in your car, you would need to make a comparison based on similar journeys, because the type of journey affects the mpg; in other words, to make valid internal comparisons you need to use a relevant performance measure. Comparing your value for mpg from a motorway trip with the manufacturer's value would give a reasonable guide to vehicle performance, because you are making a comparison under the same operating conditions. This approach can be used to see if things are changing. For example, the mpg at 70mph on a level stretch of motorway when the car was new and working efficiently would give a base figure for its performance; a subsequent measurement made when, perhaps, the brakes were binding would almost certainly be worse and reveal that something was wrong.

Are things improving?

To show you are managing energy better, you need to make comparisons based on a relevant SEC.

The importance of adjusting for the effect of decreasing output

Suppose you want to compare a plant's performance over two years. In the second year, some good housekeeping measures were adopted and output fell slightly. You want to show that the good housekeeping has been effective (i.e. you are trying to prove you are managing your energy better). Table 3 gives some simple figures about the plant's performance in these two years.

Table 3 Information about plant performance

Year	Energy (kWh)	Production (tonnes)	Unadjusted SEC (kWh/tonne)
1	288.0 million	60,000	4,800
2	270.7 million	55,082	4,913

Did the plant operate better in the second year than in the first year? Simply looking at the two values for SEC suggests that the plant performed less well in the second year, but a calculation of some more relevant values will show what really happened.

The first step is to calculate how much energy would have been used in the second-year had output remained unchanged (i.e. how much energy would have been required to manufacture 60,000 tonnes after the good housekeeping measures had been introduced). Assuming the relationship for energy versus output for the second year is:

Annual energy = 2,755 x production + 120 million kWh

Information on how to calculate such relationships is given in the next section.

Substituting 60,000 tonnes in this equation for production gives a predicted annual energy consumption of 285.3 million kWh. When this

is converted to energy per tonne by dividing by production, SEC comes out at 4,755kWh/tonne.

It is now possible to compare SEC figures adjusted to the same level of output. The actual first-year figure was 4,800kWh/tonne at 60,000 tonnes of production, while the second-year 'adjusted value' is 4,755kWh/tonne for 60,000 tonnes of production. These figures show that, at the same level of output, SEC was lower in the second year, from which you can conclude that the plant was more energy efficient in the second year. In other words, you have proved that you are managing energy more efficiently.

Dealing with more complex processes and changes

Not all plants have a simple one-product process and, consequently, output may not be the only thing that is changing. For example, you may now be making more complex components either on existing machinery or on new lines. However, the same general principle applies – if you want to know if you are managing the process better, you need to compare relevant values. Calculating these values can become more complicated, but the rewards (in terms of identified opportunities for energy and carbon savings) usually outweigh the effort.

In many industry sectors, a method of calculating a relevant value is evolving based on 'Product Mix and Output Algorithms' (PMOAs). An algorithm is a formal name for a set of rules and actions, which, in this case, will allow you to calculate your energy performance in relation to changes in production. Such algorithms often take account of variations in output and can include changes in product mix, effects of changes in ambient temperature, and so on.

It is beyond the scope of this guide to cover every eventuality, but the Appendix describes a user-friendly approach that can be adopted to cover a wide variety of situations.

Comparison with others

Comparing performance with that of other companies can be difficult and is not covered in this guide. But why is it difficult?

The difficulty of comparing performance without knowing all the facts

Returning to the analogy of vehicle mpg, which vehicle is more efficient: vehicle A at 45mpg or vehicle B at 27mpg?

Vehicle A has a better mpg and, based on our definition of energy efficiency, would appear to be more 'efficient'. However, if vehicle A was a small family saloon car and vehicle B was a lorry, it would not be sensible to make a straight comparison.

To decide which is most efficient, it would be more useful to know how the two vehicles compare to similar vehicles under the same operating conditions. For example, if vehicle A achieved 50mpg on a motorway trip, but similar cars achieved 60mpg under the same driving conditions, you might conclude that vehicle A was not performing as well as it might. Likewise, if vehicle B was matching the manufacturer's figures for driving around town, you might conclude it was operating well. To decide which vehicle is more efficient, you need to compare each to a more relevant performance indicator.

To make valid comparisons of vehicle fuel use, it is essential to use a relevant performance measure and compare like with like, under equivalent conditions. The same principle applies to industrial energy performance. To avoid misleading comparisons, you need to compare your performance with that of a similar company. You also need to allow for issues like output levels, etc.

The Carbon Trust is working with certain sectors to address the problems associated with external benchmarking and to provide some more useful values for the purpose of comparison. Please contact the helpline on 0800 58 57 94 for further information.

4 Calculating suitable values for your site

The approach described in this section will allow you to calculate relevant SEC values for your site. It is based on the assumption that energy is linked to production and applies in many, but not all, circumstances – but, because it is the simplest method, it is best to try it first. If it doesn't work, you may need to try a different approach (see the Appendix for other examples). If you try these and are still stuck, contact the helpline for further guidance.

The first stage involves collecting the data needed to produce a graph of energy versus production (like the one shown in Figure 1).

Data collection

Initially you can use information that is already available or which can be compiled using minimal effort. Later it may be necessary to refine your data.

Accurate and relevant data are needed to calculate energy use per unit of production. These can be collected on a monthly, weekly, daily or hourly basis. Weekly data are perhaps more useful, but may not have been collected in the past; however, it does not take long to build up a sensible number of values – say 12 weeks' worth. Monthly data may suffice provided the link between energy and production is strong. Even if monthly data are available, consider compiling weekly data for future use. When collecting data on fuel, bear in mind:

- Although initially you may be able to use data from monthly invoices, these are not the most reliable source of information (especially if estimates are used). When using data from invoices, it is important that the records cover the same period for each fuel

- When using meter readings, the measurements for different fuels should ideally be made on the same day and at the same time
- Collecting data on electricity and gas use is relatively easy since you receive regular bills. Because coal, coke and oil are all stored, the time of purchase does not necessarily equate accurately to time of use
- Different fuels may be recorded in different units (e.g. tonnes of coal and gallons of oil). These values need to be converted to a common unit (e.g. kWh) to allow them to be added together³.

You will also need to collect some production data. This is not always easy, as the data collected will depend on what is required (see the *Common problems* section on page 15). Initially it is best to use the amount of production dispatched.

Data quality

It can be difficult to collect good quality data, but what is important is to make a start – you can improve the systems for data collection gradually with time. It is surprising how quickly you can build up datasets and possibly improve them.

What cannot be overcome is a failure to collect any data. Without sufficient data, you cannot analyse your energy use. If you cannot calculate the relevant values, you cannot assess your performance and thus will fail to identify opportunities to make energy and carbon savings.

³ Conversion factors for common fuels are given in FL132 *Energy and carbon conversions*.

Relating energy to production

Convert energy data into a common unit (say, kWh) and then draw a simple graph (called a scatter graph or a scattergram) with units of production on the x-axis and energy units on the y-axis.

Such graphs show whether energy is related to output in a simple fashion. In many cases, energy use is related to production levels. There is usually an offset (the intersect at the y-axis) due to some 'fixed' energy component, such as bringing a furnace up to temperature or maintaining a refrigerator at temperature overnight. An inevitable consequence of this is that the energy used per tonne (SEC) will increase disproportionately as production falls.

Procedure for plotting the scatter graph

- Collect energy and production data for the plant for a suitable time period (e.g. 12-20 sets of readings). Collate the data in a table, like the one shown in Table 4
- Convert all energy measurements to kilowatt-hours (kWh) or Joules using the conversion factors given in FL132 *Energy and carbon conversions*
- Plot energy use by different fuels against production to obtain a visual impression of which fuels are more related to production and to ensure that the result is roughly what you would expect
- Add up the fuels that show a strong link to production (these will form the basis of your energy to production relationship) to give a table such as Table 5
- Note any fuel that is not related to production. This is C_R (residual fixed component). You will need this value for further analysis of your performance data
- Plot data for total production-related fuel against production data (monthly/weekly) to give a graph such as the one shown in Figure 6.

Computer spreadsheet software can be used to carry out the calculations and produce graphs.

For example, Figure 3 shows weekly electricity and gas use plotted separately against production. In this case, electricity is seen to be constant and independent of production. The gas use shows a lot of scatter, implying it is not related just to production.

Figure 4 shows a graph of gas use versus production based on three years' worth of monthly data from a different company. The line of best fit is used to explore any correlation with production. Some correlation is seen, but there is a lot of scatter, which implies that gas use is driven by factors other than production.

When the data are plotted as a time series (Figure 5), gas use can be seen to be seasonal (the peaks relate to winter and the troughs to summer) with little correlation to production. In this example, gas use is more strongly related to weather than production. To establish the true relationships would require further submetering.

Figure 3 Example of electricity and gas use plotted separately against production

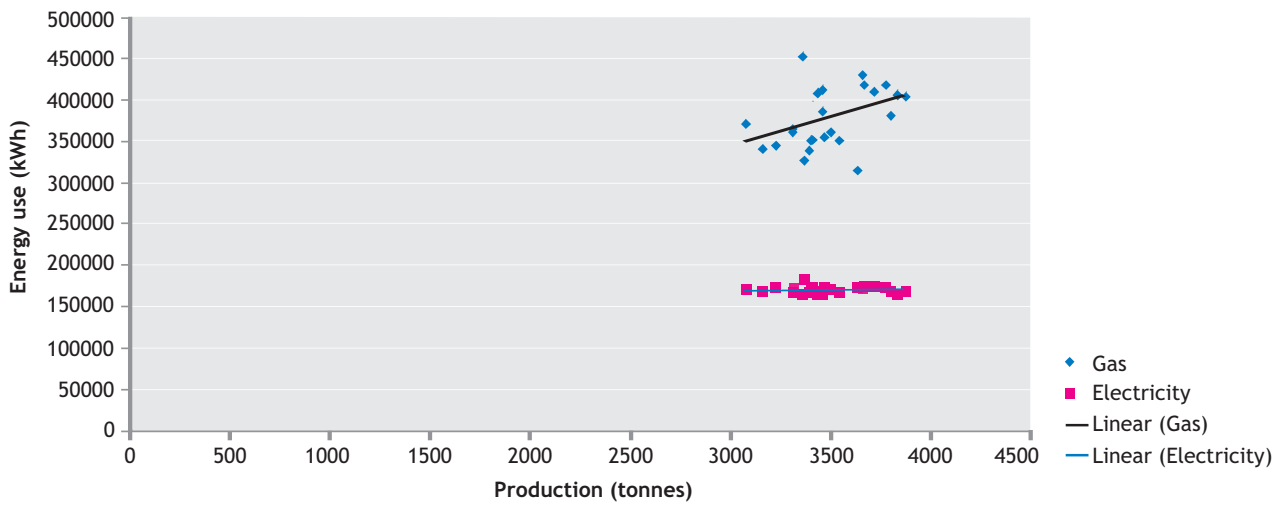


Figure 4 Graph of gas use plotted against production showing considerable scatter

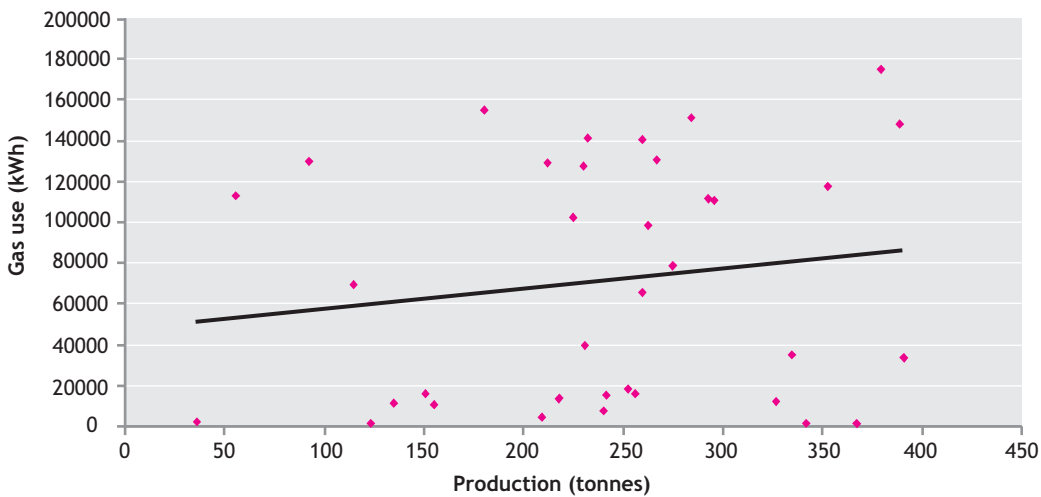
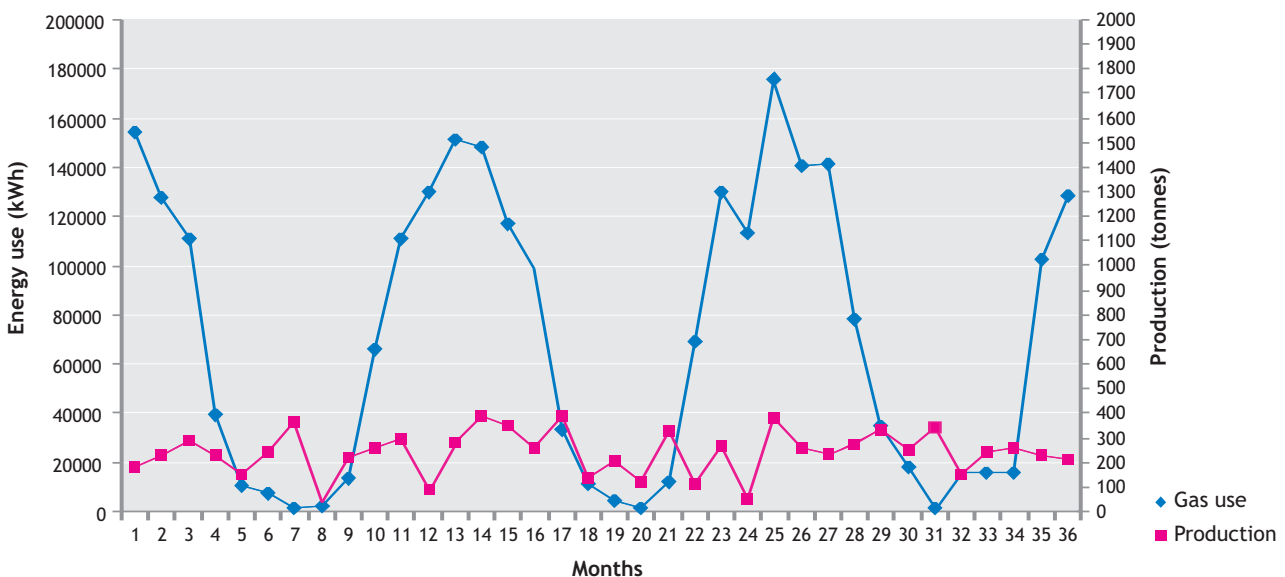


Figure 5 Gas use and production plotted against time



Identifying and plotting production-related energy use

This example is based on data collected from a fictitious factory (see Table 4).

Table 4 Collected energy and production data

Month	Electricity (delivered kWh)	Gas (delivered kWh)	Coke (tonnes)	Other fuels (delivered kWh)	Total (delivered kWh)	Production (tonnes)
1	3,975,262	4,984,493	1,221	0		5,961
2	3,674,562	4,036,115	1,436	0		5,343
3	3,885,752	4,250,028	1,429	0		5,619
4	3,535,781	3,071,560	1,283	0		5,460
5	3,812,427	2,571,317	1,330	0		4,059
6	3,320,800	1,949,450	953	0		3,586
7	3,715,226	2,317,781	1,236	0		4,366
8	2,903,753	1,874,218	809	0		3,369
9	3,520,430	2,646,402	1,273	0		4,201
10	4,021,982	3,504,309	1,244	0		5,376
11	3,949,588	4,499,695	1,195	0		4,789
12	3,207,276	5,077,719	688	0		2,953
Total	43,522,839	40,783,087	14,100	0		55,082

A conversion factor of 1 tonne = 8,278kWh is used to convert coke used into kWh⁴. This allows the different production-related fuels to be added together (the highlighted column in Table 5).

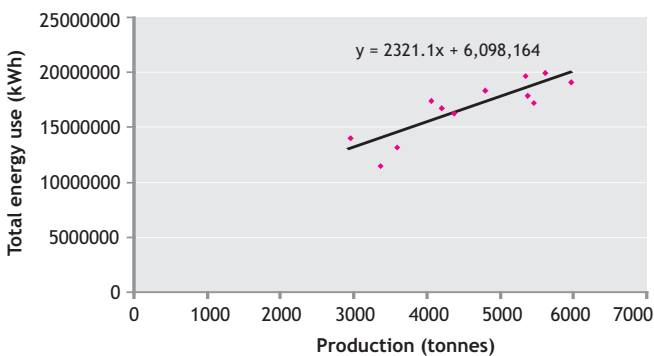
Table 5 Total energy use

Month	Electricity (delivered kWh)	Gas (delivered kWh)	Coke (kWh)	Other fuels (delivered kWh)	Total (delivered kWh)	Production (tonnes)
1	3,975,262	4,984,493	10,107,636	0	19,067,391	5,961
2	3,674,562	4,036,115	11,886,336	0	19,597,013	5,343
3	3,885,752	4,250,028	11,831,148	0	19,966,928	5,619
4	3,535,781	3,071,560	10,620,792	0	17,228,133	5,460
5	3,812,427	2,571,317	11,008,368	0	17,392,112	4,059
6	3,320,800	1,949,450	7,889,028	0	13,159,278	3,586
7	3,715,226	2,317,781	10,238,340	0	16,271,347	4,366
8	2,903,753	1,874,218	6,701,520	0	11,479,491	3,369
9	3,520,430	2,646,402	10,543,512	0	16,710,344	4,201
10	4,021,982	3,504,309	10,300,752	0	17,827,043	5,376
11	3,949,588	4,499,695	9,895,032	0	18,344,315	4,789
12	3,207,276	5,077,719	5,698,812	0	13,983,807	2,953
Total	43,522,839	40,783,087	116,721,276	0	201,027,202	55,082

⁴ See FL132 *Energy and carbon conversions*.

The energy versus production graph for this factory is shown in Figure 6. Because monthly data have been used, this graph shows the relationship between total monthly energy use and monthly production. The graph shows that, in this example, energy is strongly related to production.

Figure 6 Energy use versus production graph



Using energy versus production graphs for energy management

When there is a lot of scatter about the line of best fit drawn on the energy versus production graphs, the implication is that energy use is driven by variables other than production. However, the scatter may be due to poor data collection or an inappropriate measure of production.

In the example, all fuels showed a good link to production and therefore C_R was zero. Improved production efficiency and control may therefore offer potential energy savings. If C_R is *not* zero for your company, you need to identify the factors driving energy use (e.g. weather) – they may provide scope for significant energy savings.

The line of best fit (as determined in Figure 6 using a computer spreadsheet) gives an equation that underpins all further work. This equation is in the form:

$$\text{Energy} = (\text{Production} \times M) + C$$

where: M is the slope of the graph

C is a constant (the intercept on the y-axis).

Once you have determined your site's values for M and C , you can use this equation to calculate how much energy is needed for a given level of production.

In the example shown in Figure 6, M is 2,321kWh/tonne and C is 6.1 million kWh. The amount of energy needed to produce say, 8,000 tonnes/month, is therefore:

$$\begin{aligned} \text{Energy} &= (2,321 \times 8,000) + 6,100,000 \\ &= 18,568,000 + 6,100,000 \\ &\approx 24.7 \text{ million kWh} \end{aligned}$$

Dividing the equation relating energy to production by production gives an equation for energy per unit of production (i.e. SEC).

$$\frac{\text{Energy}}{\text{Production}} = \frac{(\text{Production} \times M)}{\text{Production}} + \frac{C}{\text{Production}}$$

or

$$\frac{\text{Energy}}{\text{Production}} = M + \frac{C}{\text{Production}}$$

In the example, production was measured in tonnes. Hence:

$$\text{Energy per tonne} = M + (\text{tonnes produced})$$

Energy per unit of production (SEC) is only independent of production if ' C ' is zero, but this is very rare. In all other cases, energy per unit output will rise if production falls. Although this change could be plotted as a graph, care is needed when using it for energy management purposes. An example of such a graph is given in Figure 2; the graph is normally a curve and you should not attempt to fit the data to a straight line. Such graphs usually show that as production falls, the energy per tonne increases (i.e. energy efficiency worsens). There are a few special cases where C is zero: only in these cases will a graph of SEC versus production be a straight line.

Plotting SEC versus output gives you much less useful information compared with the simpler plot of energy versus output.

Using monthly data for annual projections

To compare year-on-year performance and your progress in improving energy efficiency, you need to have a target based on annual values. Companies seldom have the necessary energy and production data to allow them to calculate an annual value directly. However, monthly (or weekly) data can be used to establish the relationship.

As in the example shown in Table 5 and Figure 6, you can determine the values of M and C from your monthly data. These values can be substituted in the following equation to predict energy use on an annual basis:

$$\text{Annual energy use} = M \times \text{Annual production} + (12 \times C) + C_R$$

A similar approach can be applied to weekly data, but in this case, the weekly fixed energy, C, is multiplied by 52.

C_R is the annual total of fuels (energy streams) that show no relationship to output. This energy may be weather-related; weather-related variables are discussed in more detail in the *Common problems* section on page 15 and the Appendix.

Adjusting SEC for different production levels

The following equation allows you to derive the energy per unit of production for different outputs on an annual basis. This equation is the one above divided by production (P_A = annual production):

$$\text{Energy per tonne} = M + \frac{(12 \times C)}{P_A} + \frac{C_R}{P_A}$$

This allows you to convert energy per unit of production (SEC) in different years to a fixed level of production, thereby producing a relevant SEC. You can now compare SECs that are corrected for changes in production levels and determine whether or not energy efficiency is improving.

How sensitive is SEC to output?

Table 6 shows how energy per tonne has altered at six companies when production has fallen. For many of these companies, SEC has risen by about 10% for a 10% drop in production.

In most of these companies, SEC is sensitive to changes in output. This is because the fixed energy components are being distributed over more or less production (i.e. the fixed costs (energy) are being spread over less production and hence the energy per unit (cost) rises). If the fixed energy component is trivial or zero, then SEC will not be very sensitive to output changes – but this is seldom the case. Company F is one where C is very small (virtually zero) and hence its SEC is unaffected by changing output level.

Table 6 Industry examples of how SEC varies as output falls

Company	SEC (kWh/tonne)		
	At 100% production	With 10% drop in production	With 20% drop in production
A	1,573	1,679	1,813
B	2,280	2,409	2,569
C	4,840	5,241	5,741
D	3,826	4,048	4,326
E	3,521	3,654	3,821
F	2,193	2,200	2,208

5 Common problems

Energy is not always solely linked to production

Energy consumption may not only be determined by production. Other factors, such as the weather, can cause energy use to change. If that is the case, then trying to relate energy use solely to output is doomed to failure.

For example, more energy will be needed for space heating in a cold winter. This can be corrected for by applying a technique known as 'degree day correction', which effectively alters the 'fixed' energy component for that year. Degree day figures allow you to account properly for the effect of weather on energy consumption. A fact sheet, FSSB013 *How and why to use degree day information*, is available from the Carbon Trust through the helpline on 0800 58 57 94 or via the website (www.thecarbontrust.co.uk/energy).

Many sites make more than one type of component and thus energy is related to more than one production variable.

Appendix 1 describes a simple approach that takes account of:

- Degree days
- Cases where there is a range of output units and process lines.

Data collection issues

Table 7 summarises the surprisingly large number of issues that can cause problems when compiling energy and production data.

Conversion factors

When assessing your energy performance, it is essential to work in consistent units.

Factors for use when converting different fuels to common units are widely available. Conversion factors for common fuels are given in FL132 *Energy and carbon conversions*, or in the Expert Info section of the Carbon Trust's website (www.thecarbontrust.co.uk/energy).

Primary versus supplied energy

To assess your own performance, you can work in 'as supplied' units. However, if you want to calculate how much carbon dioxide is emitted due to your energy consumption, you need to work in primary terms. For example, the inefficiency in conventional electricity production means that a modern generating plant uses about 2.6 times as much energy in fuel as the electricity it delivers to the point of use. In other words, it requires 2.6kWh of energy in other fuels to deliver 1kWh of electricity at the point of use.

Table 7 Common issues with data collection

Area	Issue
Production data	If there are non energy-intensive processes downstream of production that reduce output (e.g. scrap or waste is generated), then energy may not be simply related to output but may be better related to throughput at some point upstream.
Monthly data	Not all months have the same number of days or weekends. Monthly data are likely to give misleading results if there is a strong production-independent component to energy use. For example, a cluster of four points in a given year with noticeably higher energy and production values may be due to five-week months. This can lead to a strong but potentially false correlation between energy and production because the fixed energy component is different for four-week and five-week datasets. Use of monthly data is therefore inappropriate in such cases.
Energy use based on purchase instead of use	Some fuels, such as oil and coke, can be stored and, in such cases, there may be no link between energy purchase and production.
Using process input rather than output as the basis for calculating energy	This can be very misleading. It is much better to relate energy to output, as that is ultimately where costs are recovered. A lower SEC based on input may mask deteriorating performance.
Production figures not synchronised with energy figures	If the energy and production data are not recorded at the same time, it will be virtually impossible to establish a relationship between them.
Changing calorific value of fuel	Some fuels, such as coke, have a variable calorific value. In some cases, changes in SEC may be due to changing fuel grade and the use of inappropriate conversion factors.
Data errors	It is worth checking that energy use has been correctly recorded. Common errors include misreading meters (typically being out by a factor of ten).
Scrap (returns)	If components are returned from customers in a different month, you need to record the return against the month in which they were produced and not the one in which they were returned.

6 Further information

Free help from the Carbon Trust

For further advice on benchmarking energy efficiency to account for changes in production and so on, and for information about cost-effective measures to reduce energy use in your company, please contact the Carbon Trust.

The Carbon Trust provides free, independent advice and information to UK businesses and public sector organisations to help them cut their energy costs. It offers an extensive library of free publications; a number of free services, such as site surveys; and interest-free loans to encourage businesses to improve energy efficiency and cut carbon emissions.

Relevant publications from the Carbon Trust include:

- GPG231 *Introducing information systems for energy management*
- GPG310 *Degree days for energy management – a practical introduction*
- FSSB013 *How and why to use degree day information (fact sheet)*
- FL132 *Energy and carbon conversions*
- GPG112 *Monitoring and targeting in large companies⁵*
- GPG125 *Monitoring and targeting for small and medium sized companies⁵*

To find out more about the Carbon Trust's services or to obtain free copies of these and other publications, call the helpline on 0800 58 57 94 or visit the energy website (www.thecarbontrust.co.uk/energy).

⁵ These guides contain much useful information, but are highly technical and are primarily intended for use by energy consultants and technical experts.

Appendix: dealing with multiple products and compensating for external factors

This appendix describes a method for applying a more complicated analysis to compensate for factors such as:

- Multiple products
- Weather
- Different units of production.

It also explains how to derive marginal specific energy consumptions for multiple products.

This approach provides a relatively easy way to calculate the relevant value for SEC once you have established the energy and production relationships for your various products.

Dealing with multiple products

One approach is to consider the energy used to produce each product, product group or products through a particular process route, and combine the results.

This is best explained using an example that considers gas consumption in a factory making four different products.

This method can also cope with dissimilar units of production (see below).

Note: In this example, the effects of weather for the year have been averaged out to a weekly figure included in the value for fixed energy consumption.

Deriving SEC for multiple, but similar, products

A study has been carried out at the factory to establish the sensitivity of gas use to the output of the various products in a particular year, which is taken as the base year for comparative purposes. This study produced the marginal SEC values shown in italics in Table A1, which also shows the factory's fixed energy component. The marginal SEC is the energy used per additional unit of production. Thus, a variation of one tonne in the output of Product A causes gas consumption to vary by 200kWh.

The figures in bold in Table A1 are the measured values (i.e. actual gas used, actual product outputs and the number of weeks). Each row of the table shows the kWh attributed to one of these driving factors and, by definition, the total equals what was actually used. Total production of all four products adds up to 1,580 tonnes and total gas use is calculated to be 3,633,600kWh. Provided the four products are similar, it is valid to say the SEC equals 3,633,600 divided by 1,580 (i.e. 2,300 kWh/tonne).

Table A1 Base-year gas consumption

Component of demand	Marginal SEC			Quantity		Total gas use (kWh)
Fixed weekly consumption	66,692	kWh/week	x	52	weeks	= 3,468,000
Product A	<i>200</i>	kWh/tonne	x	350	tonnes	= 70,000
Product B	<i>100</i>	kWh/tonne	x	460	tonnes	= 46,000
Product C	<i>400</i>	kWh/tonne	x	90	tonnes	= 36,000
Product D	<i>20</i>	kWh/tonne	x	680	tonnes	= 13,600
Total consumption						= 3,633,600

Correcting for the weather

To account for the weather, it is necessary to have a weekly or monthly figure that acts as an index of demand for heating or cooling. Such a measure is called the 'degree day' value. Regional monthly degree day data (calculated from daily air temperatures) are available from many sources including:

- The free monthly journal, *Energy Resource Environmental & Sustainable Management*, published by the Department for Environment, Food and Rural Affairs
- The website <http://vesma.com/ddd/history.htm>

The recorded degree day count can simply be treated as another energy consumption driver, analogous to product output volume. It should be extracted from the fixed energy component.

Adjusting data to account for the weather

In the example multi-product factory, each degree day variation in the weather induces a 500kWh change in gas consumption. Removing this energy gives a fixed weekly demand for the base year of 46,500kWh. The marginal SECs for the four products are the same. When multiplied by the corresponding actual production quantity (in bold), they yield a value for kWh that would have been used if all the processes had been operating at base-year efficiencies. Table A2 shows base-year gas consumption corrected for the weather.

Table A2 Base-year gas consumption corrected for weather variations

Component of demand	Marginal SEC			Quantity			Total gas use (kWh)
Fixed weekly consumption	46,500	kWh/week	x	52	weeks	=	2,418,000
Weather	500	kWh/deg-day	x	2,100*	deg-days	=	1,050,000
Product A	200	kWh/tonne	x	350	tonnes	=	70,000
Product B	100	kWh/tonne	x	460	tonnes	=	46,000
Product C	400	kWh/tonne	x	90	tonnes	=	36,000
Product D	20	kWh/tonne	x	680	tonnes	=	13,600
Total consumption						=	3,633,600

*Annual degree-days for the region in this year.

Performance in any subsequent year can be compared against this base-year scenario.

For example, base-year gas consumption figures are given in Table A1. Table A3 illustrates how to calculate gas consumption for a year with different weather and different product outputs. Essentially the table enables the energy use at base-year efficiency to be predicted for a different level of production and different weather conditions. This calculated value can then be compared with the actual energy use figure, to see if any improvement in energy efficiency has been made.

In Table A3, the predicted energy use is calculated at 3,600,600kWh. Suppose that actual gas consumption in this year was 3,567,000kWh. This would imply that that company had made energy savings of $3,600,600 - 3,567,000 = 33,600\text{kWh}$ (or just under 1%) adjusted for product mix, output and weather.

This method gives a figure for the energy saved in absolute kWh and thus, if required, in percentage terms. The base-year SEC for gas can be calculated from Table A1 at 2,300kWh/tonne, based on production of 1,580 tonnes and energy use of 3.6 million kWh. Total production in the subsequent year is 1,670 tonnes (see Table A3). At base-year efficiencies, gas consumption would be 3,600,600kWh/year, giving an SEC of 2,156kWh/tonne. However, based on the measured gas consumption of 3,567,000kWh, the actual SEC is 2,135kWh/tonne, showing that a sustainable improvement in energy efficiency has been achieved.

Table A3 Gas consumption for plant used in Table A1 in a subsequent year

Component of demand	Marginal SEC		Quantity		Total gas use (kWh)
Fixed weekly consumption	46,500 kWh/week	x	52 weeks	=	2,418,000
Weather	500 kWh/deg-day	x	1,900* deg-days	=	1,050,000
Product A	200 kWh/tonne	x	210 tonnes	=	42,000
Product B	100 kWh/tonne	x	640 tonnes	=	64,000
Product C	400 kWh/tonne	x	290 tonnes	=	116,000
Product D	20 kWh/tonne	x	530 tonnes	=	10,600
Total consumption				=	3,600,600

*Annual degree days for the region in this year.

Diverse units of measurement

Table A4 illustrates the method with products X, Y and Z reckoned in m³, tonnes and thousand-pieces, respectively: any subsequent comparisons are made on the basis of total energy use, rather than SEC.

The example in Table A4 also shows how to allow for the plant being closed for five weeks of holidays per year.

Table A4 Benchmark gas consumption with diverse units of measurement

Component of demand	Marginal SEC			Quantity		Total gas use (kWh)
Fixed consumption (working weeks)	51,000	kWh/week	x	47 weeks	=	2,397,000
Fixed consumption (shut weeks)	4,200	kWh/week	x	5 weeks	=	21,000
Weather	230	kWh/deg-day	x	1,900* deg-days	=	437,000
Product X	30	kWh/m ³	x	2,100 m ³	=	63,000
Product Y	75	kWh/tonne	x	700 tonnes	=	52,500
Product Z	25	kWh/thousand	x	320 thousand-pieces	=	8,000
Total expected consumption at base-year efficiencies						= 2,978,500

*Annual degree days for the region in this year.

Deriving marginal SECs for multiple products

It is important to allocate an appropriate marginal specific energy consumption (MSEC) to each product or category of product. The consequence of error is not significant when variations in product mix, output and weather are slight, but when substantial shifts occur over time, inaccurate MSECs will cause the correction algorithm to yield incorrect results. This could give a misleading impression of performance.

The various methods of deriving MSECs depending on particular circumstances are summarised in Table A5. Once you have obtained relevant values, you can make a meaningful comparison to decide whether you are achieving managed energy efficiency.

Where there is another method of estimating a particular MSEC, this can be used in preference to applying one of the methods in Table A5 to the residual consumption attributable to other driving factors. Possible methods include:

- A given product's MSEC might be known reliably from another plant where it is the sole product
- It might be possible to model energy requirements analytically from first principles
- It might be possible to devise tests or experiments.

Independent assessment of one or more MSECs in this way is likely to improve the reliability of any inferential techniques (e.g. multiple regression analysis) used to derive other MSECs.

Table A5 *Methods of deriving marginal SECs*

Circumstances	Method
A single processing facility makes different products one at a time in sustained production campaigns.	Energy and output data can be analysed for each product during any campaign when it is being made. Provided there is a reasonable variation in output from week to week, only a few weeks' data are needed to estimate the MSEC. Data for a particular product can be collected whenever there is a whole week devoted to its production. In some industries, daily data might be an option.
Separate processing facilities are dedicated to particular products.	Permanent or temporary sub-metering can be used. An evaluation period of a few weeks might suffice to estimate each MSEC.
Product categories are differentiated only by yield and share common preliminary processing steps applied to the same raw material.	The MSECs for saleable production will vary in inverse proportion to relative yields.
A common facility makes diverse products simultaneously or in short campaigns.	A statistical technique called multiple regression analysis can be used (with caution) to estimate the sensitivity of demand to changes in the output of each product.
Weeks of very low production occur in summer or winter.	Any residual demand during such weeks will be mainly attributable to standing loads and climate-related consumption. The MSEC for space heating or air conditioning can be estimated from the variation in residual demand during such periods relative to corresponding degree day values. The lowest observed consumption indicates the level of fixed background consumption. Note: Beware of unrepresentative operation during complete shutdowns.

Notes

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