UK Government

Valuation of energy use and greenhouse gas emissions

Background documentation

Department for Energy Security and Net Zero (2026)

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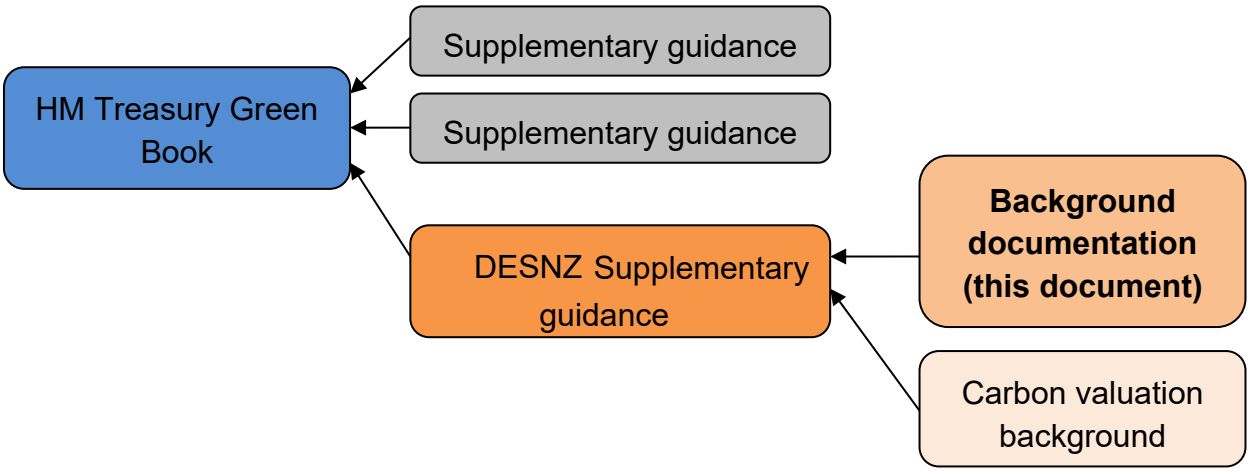
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1. Introduction

1.1. This background document to the HM Treasury Green Book[1] supplement, 'Valuation of Energy Use and Greenhouse Gases (GHG) Emissions for Appraisal and Evaluation'[2], contains auxiliary material aimed at providing further detail on the topics covered in the main guidance. Where the brevity of explanations in the supplementary guidance is insufficient for whatever purpose, analysts should first refer to this background document, although any queries may also be directed to GHGappraisal@energysecurity.gov.uk. For further information on HM Government's approach to carbon valuation, please consult the GOV.UK website[3].



1.2. In the following sections the theory behind the recommended approach to valuing changes in energy use and emissions is presented, and the underlying assumptions and modelling results underpinning the methodology outlined in the main guidance document are given, including the marginal electricity grid emissions factors and the long-run variable costs of electricity supply (LRVCs). This document also covers the valuation of rebound effects, and the valuation of potential cost savings resulting from interactions with existing renewables policies. The various components of energy prices, and their contribution to quantifying LRVCs, are explained. Other issues are considered including indirect tax distortions, assumptions in behaviour change, and security of supply. Finally, details are given on the DESNZ Energy Demand Model (EDM), which is used to produce the Energy and Emissions Projections (EEP)[4], including guidance for policy analysts on how to report impacts of interventions for inclusion within the model.

1.3. Analysts appraising or evaluating policies with impacts on energy and emissions should endeavour to apply sound principles of cost-benefit analysis consistent with the HM Treasury Green Book and DESNZ guidance. Although this background document aims to provide further clarification to analysts, there will be issues unique to the analysis in

[1] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent
[2] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
[3] https://www.gov.uk/government/collections/carbon-valuation--2
[4] https://www.gov.uk/government/collections/energy-and-emissions-projections

question that will require further thought. Further guidance may always be sought by emailing GHGappraisal@energysecurity.gov.uk.

2. Valuing changes in emissions

2.1. This section provides an explanation for the valuation of policies that have impacts on emissions. It will also explain the methodology behind computing emissions factors and any changes from previous versions of the guidance. Emissions factors for each energy type and each year are available in Data Tables 1 and 2.

'Marginal' Policies

2.2. The guidance and its supporting Data Tables provide a framework for use in the valuation of 'marginal' policies or proposals. That is, small impacts that are delivered on top of 'existing' policies (i.e., those already accounted for in the modelling of the price and emissions factor assumptions published alongside this guidance). In other words, the guidance is suitable for assessing projects that change energy use or emissions by an amount that does not lead to wider changes in the market.

2.3. Some proposals are likely to produce material changes to the numbers provided in the Data Tables and should therefore be identified and treated as having non-marginal impacts. For example, a policy that reduces energy demand by a large amount may significantly change the long-run variable cost of marginal electricity supply or the retail electricity price. Whether the expected change is 'significant' is ultimately a question of judgement but may be informed through modelling.

2.4. Rather than using the numbers contained in the guidance, non-marginal policies should be appraised using bespoke analysis. Such analysis should be undertaken in consultation with the relevant experts in DESNZ and other government departments and should use a methodology consistent with the Green Book and the DESNZ Treasury supplementary guidance.

2.5. Some proposals pursue 'transformational change', defined in the HM Treasury Green Book as a radical, permanent and qualitative change in a particular subject, such that the subject has very different properties and behaves in a different way. DESNZ has forthcoming guidance on Risk Opportunity Analysis for policy appraisal in situations of transformational change.

Valuation Methodology

2.6. In order to value the changes in emissions associated with policies that change the consumption of energy, three steps are necessary:

1. Estimate the changes in energy/fuel use by type of energy/fuel.
2. Convert the changes in energy/fuel use into the corresponding changes in CO_2e by multiplying the energy/fuel use by an energy/fuel-specific emissions factor.

3. Multiply estimated changes in CO_2e by the relevant carbon price.

2.7. For most energy sources, the marginal emissions factors used in the second step are those published by DESNZ to support company reporting of greenhouse gas emissions[5]. The emissions factors used for the purpose of the guidance are available in both CO_2 and CO_2e terms and are defined on a gross Calorific Value (CV) basis.

2.8. Marginal emissions factors for petrol, diesel gas and oil, in Data Table 2b, are from DfT and reflect the blending of biofuels into road fuels in accordance with the Renewable Transport Fuel Obligation[6].

Emissions Factors for Electricity

2.9. Unlike other fuels, the emissions associated with a unit of grid electricity can vary greatly depending on the source of electricity generation. It is also important to distinguish between the average and (long-run) marginal electricity emissions factors. Whereas the average emissions factors should be used to account for emissions for the purposes of emissions footprinting, the marginal emissions factor should be used for analysing sustained changes in energy consumption for the purposes of cost-benefit analysis, including policy appraisal. Note that these are emissions factors per unit of electricity consumed (that is, they reflect the emissions from primary fuel use in order to deliver the electricity consumed), taking account of transmission and distribution losses post production. To summarise:

- The average emissions factor is used for reporting emissions associated with electricity use and for calculating the emissions coverage of policies / sectors.
- The marginal emissions factor is used to estimate the change in UK electricity sector emissions associated with policies that lead to sustained marginal changes in the consumption of electricity.
- DESNZ modelling uses illustrative power sector scenarios to analyse the impact of power sector decarbonisation on average and marginal emissions factors[7]. The scenarios are indicative of what a future energy generation mix may look like rather than prescriptive forecasts. There remains much uncertainty, including for example, in the pace of innovation in the market, demand levels in this country as well as abroad, the technical feasibility of some technologies, and the investment decisions of electricity generators. While they should not be considered forecasts given this uncertainty, these scenarios do illustrate the mix of properties required for a power system on the path to meet UK targets including the Carbon Budgets and Net Zero.

[5] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting
[6] https://www.gov.uk/guidance/transport-analysis-guidance-tag
[7] https://www.gov.uk/government/publications/energy-and-emissions-projections-net-zero-strategy-baseline-partial-interim-update-december-2021

Grid Average Emissions Factors for Electricity

2.10. The grid average emissions factor is the annual total greenhouse gas emissions (in kilograms of carbon dioxide equivalent) associated with UK electricity generation, per unit of electricity (in kWh). For past years to 2025 this is reported in the Digest of UK Energy Statistics (DUKES). Future years have been modelled in the power sector model BID3.

2.11. In DUKES (and previous editions of this guidance) the emissions factor is given on a generation basis: that is, averaging over the electricity generated in the UK. There are interconnectors permitting imports and exports with Ireland and continental Europe. For calculating the UK emissions associated with a unit of consumption any imported electricity should also be considered. In Data Table 1 the average emissions are reported on a supply basis. The denominator contains final demand for all UK electricity users and therefore includes net imports. For this reason historic values differ from those published in DUKES.

2.12. BID3 modelled values are the grid average for Great Britain only. The difference between GB-wide and UK-wide values is considered to be within the bounds of modelling error. The numerator contains all GB power sector emissions. The denominator is total final demand, including the effects of consumer-led flexibility (including demand turn-down) but not electricity consumed in the system itself. For example, the denominator does not include electricity used in hydrogen electrolysis.

2.13. The consumption-based series apply a sector-specific factor for losses associated with transmission and distribution between the generator (or interconnector) and the consumer.

Long-run Marginal Emissions Factors for Electricity

2.14. The marginal electricity emissions factor is intended to reflect the change in emissions that would result from a small but sustained change in electricity consumption. The change in electricity consumption is assumed to be predictable in advance, so that it is met by generation bought in the wholesale market, and distributed evenly through the day and year (i.e., the value is a time-weighted average for each year[8]). Marginal factors cannot be observed directly from the system and both past and future values in Data Table 1 are modelled rather than from published statistics.

2.15. The marginal plant(s) refers to what energy source(s) we expect to increase or decrease when there are marginal but sustained changes to energy demand or supply. In an efficient market this will be the most expensive plant generating in any hour. Historically, Combined Cycle Gas Turbine (CCGT) plants have been the long-run marginal electricity generators and thus the marginal emissions factor in 2010 reflected

[8] This is a change in methodology from previous guidance which calculated a volume-weighted average. It is a consequence of changing the model used. Any difference resulting from this is small compared with other uncertainties.

that of a typical CCGT plant (0.357 $kgCO_2e/kWh$ before taking into account distribution and transmission losses). However, as the power sector changes to meet the UK's emissions targets and net zero in 2050, low carbon generation will increase significantly both as a proportion of total and marginal generation, with storage technology playing an increasing role.

2.16. The marginal emissions factor allows us to conduct policy analysis relative to a baseline which represents a power sector on a trajectory consistent with Net Zero policy. Even in this scenario some greenhouse-gas emitting generation remains on the system (for example, gas CCUS plants have residual emissions) and this is likely to be the marginal source in the hours when it is generating. For this reason the marginal emissions factor remains above zero even in 2050.

2.17. The marginal emissions factors are calculated by DESNZ's power sector models, using the Dynamic Dispatch Model (DDM) for years to 2026 and BID3 thereafter. Technical differences between the models include their representation of battery storage, hydrogen electrolysis and power received over interconnectors, with BID3 preferred.

2.18. For the period to 2026 the emissions factors used for the previous edition of this guidance have been maintained. In a DDM simulation (then, the Net Zero Higher case) the marginal emitter for 2010 was always a gas plant. The simulated mix of marginal emitters in 2029 was used unchanged, and intermediate years are assumed to have a smoothly changing mix between the two. Years 2027-2029 of this series have been superseded by values derived from BID3.

2.19. From 2027 onwards the DESNZ BID3 Net Zero reference case 2025 has been used. The method adds a small amount of demand to each hour of a year, in a simulation of GB and interconnected markets, and looks across the year at which generators respond in the wholesale market. The average emissions from these generators, if they are sited in the UK, give the long-run marginal emissions rate.

2.20. To avoid spurious precision a smoothing power-law curve has been fitted to the raw outputs from BID3 for each year. Beyond 2050 the system is assumed for modelling purposes to remain unchanged.

2.21. For policies affecting total UK electricity demand on a scale large enough to affect the power system as a whole[9], the values in Data Table 1 may not be appropriate and bespoke analysis may be needed. In most cases the marginal emissions factor in the Data Table will be a conservative estimate of the increased emissions from a policy requiring new electrification, and the grid average factor will be a conservative estimate of the emissions savings from a reduction in demand.

[9] As a rule of thumb this might be a sustained increase in consumption of more than 10-20 TWh/year.

Table 2.1: Marginal electricity emissions factor estimation methodology

Period	Marginal Emissions Factor source
2010	CCGT
2011–26	Mix of technologies found from exponential interpolation between 2010 and 2029 simulated years in the DDM.
2027-2050	BID3 Net Zero marginal emissions factor (smoothed curve across all years)
2051 onwards	Constant at 2050 value

Figure 2.1: Generation-Based Marginal Emissions Factors (kgCO_2e/kWh)

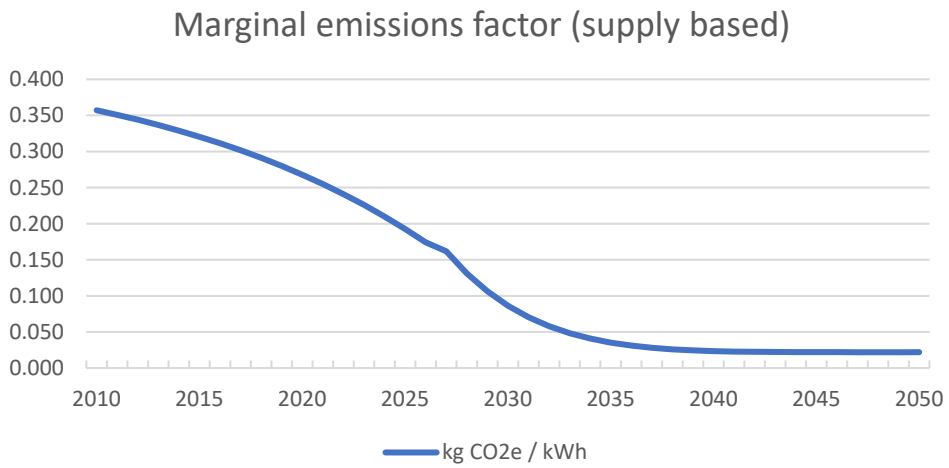


Chart showing generation-based marginal emissions factors declining over time from 0.35 kgCO_2e/kWh in 2010 and the projection out to 2050 shows it will reach 0.02 kgCO_2e/kWh.

3. Valuing improvements in energy efficiency

3.1. This section explains the theory and rationale behind the methodology applied to valuing changes to energy efficiency, which reduces the amount of energy required to provide the same level of energy service. The guidance recommends that the long run variable cost of energy supply (LRVC) is used to value net changes in energy use, and that the retail price of energy is used to value the direct rebound effect (further details on the rebound effect may be found in Chapter 4). Given the scale of uncertainty over LRVCs and future fossil fuel prices, in cases where fossil fuel prices are material to the conclusions of their analysis, analysts should use all the series provided for sensitivity analysis. The overall approach is summarised in Figure 3.1.

Figure 3.1: Valuation of changes in energy consumption

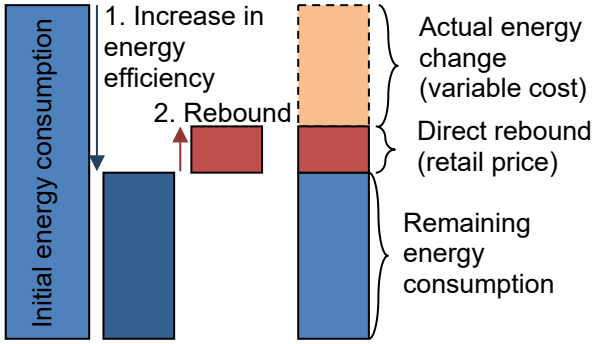


Diagram showing the net energy change is the reduction in energy consumption due to the efficiency improvement, minus the subsequent increase in energy consumption due to the direct rebound effect. The net change in energy consumption should be valued using the long-run variable cost (LRVC) of energy supply and should be used to calculate and value the changes in emissions. The direct rebound should be valued using the retail price.

3.2. Data Tables 4-13 provide assumptions for the annual retail price and long-run variable supply costs for electricity, gas, coal, burning oil, gas oil, diesel, and petrol (which are split by domestic, industrial, and commercial except for diesel and petrol). These should be used for valuation of changes in energy use.

Summary of energy use valuation methodology

3.3. There are two valuations that need to be made: first, a valuation of the net change in energy consumption; and second, a valuation of the increase in welfare through the direct rebound effect. To value net changes in energy use[10], the long run variable cost

[10] If the change results from an improvement in energy-efficiency, then the net change will be the efficiency saving minus any rebound.

of energy supply (LRVC) is used. The steps to calculate the costs/benefits of net changes in energy use in any given year are as follows:

- Estimate the net change in energy use by each type of energy/fuel
- Multiply the net changes in final energy use for each respective energy/fuel by their corresponding long run variable cost of energy supply (LRVC)

3.4. For direct rebound effects (including comfort-taking), the full retail price is applied to the subsequent increase in energy consumption resulting from the rebound effect, and this valuation is used for appraisal. The steps to calculate these costs or benefits are:

- Estimate the change in energy consumption that would result from the change in energy efficiency if no rebound were to occur (Step 1 in the diagram above).
- Estimate the difference between the net change in energy consumption and the results of step 1 (equal to step 2 in the diagram).
- Multiply this quantity of energy by the full retail price of the relevant fuel

3.5. For clarification, a direct rebound effect occurs when consumers use some of the financial savings they have gained from being more efficient in their use of a good or service, to purchase more of the same good or service, as the price of the energy service has fallen. Expenditure of this income on other goods or services is known as the indirect rebound effect. No valuation should be made of the indirect rebound effect in the main appraisal of a policy.

3.6. Annex B of this document contains further details on the rebound effect.

Welfare impacts

3.7. Determining the overall impact on social welfare of a policy that affects energy and/or emissions requires assessing the impacts on individual societal groups and then aggregating these[11]. Three groups are considered here: consumers (households, businesses, or any other energy consumer), energy producers and the exchequer.

3.8. The welfare effects of the net change in energy use and the rebound effect induced by an improvement in energy-efficiency may be analysed graphically, as shown in Figure 3.2. Part 1 shows the effect of energy saving before the rebound effect: the demand line moves from D_a to D_b (point A to B) as the same level of energy service can be achieved at a lower level of energy demand. The yellow box represents the net societal gain from the energy efficiency measure and is valued at the LRVC of energy. The blue box represents the reduction in transfers within the economy, where consumers gain but energy suppliers' margins and the government's taxes fall – a zero net societal effect.

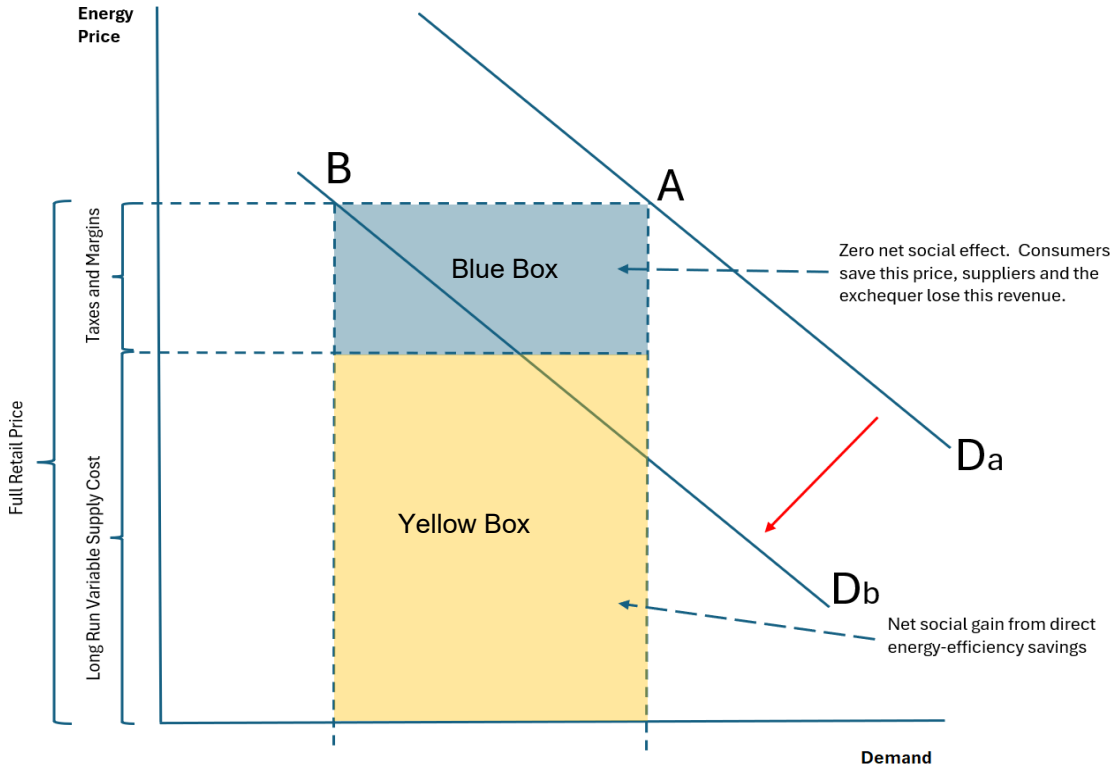
3.9. Part 2 shows the rebound effect. As the effective price of the energy service has fallen, consumers buy more of it. This increases the demand line from D_b to D_c (point B to C).

[11] On the assumption that we value financial benefits in each group equally.

This trade-off of energy is shown in the orange box and is valued at the retail price of energy. The result of the rebound effect is to shrink the size of the yellow and blue boxes, so the societal gain is reduced. The consumer does gain however, as depicted by the green triangle, and more detail on this is given in Annex B. The individual components are presented explicitly in Table 3.1 and further detail on their derivation is given in Annex A.

Figure 3.2: Effects of an increase in energy-efficiency

Part 1:



Part 2:

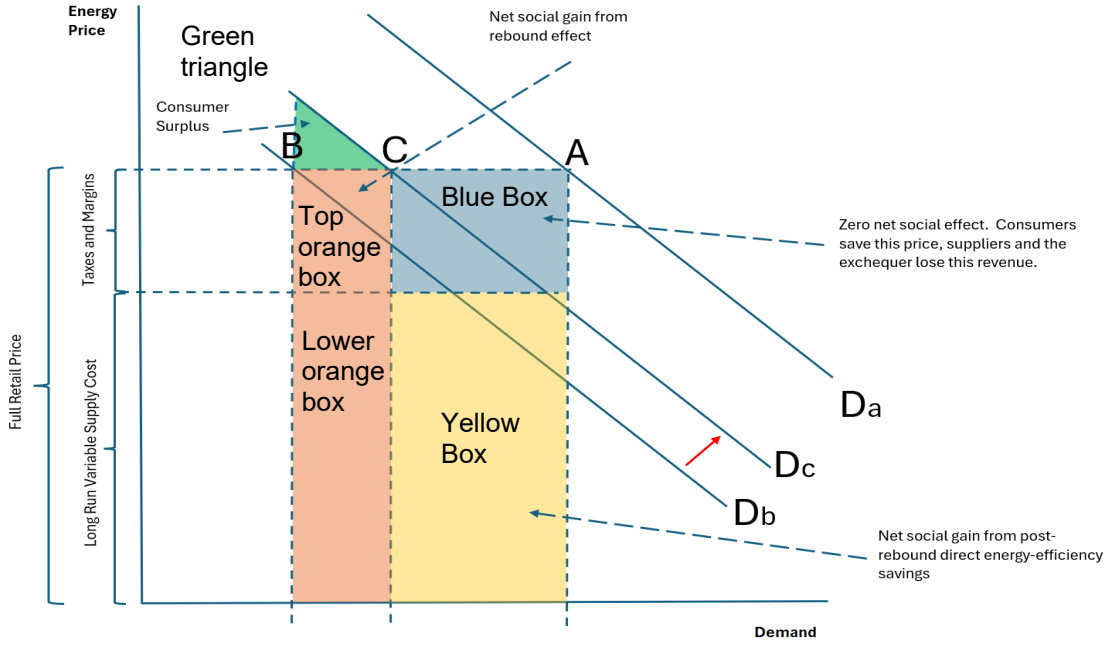


Table 3.1: Societal gains and losses from energy-efficiency installations

Change in energy demand	Consumer Gains	Consumer Losses	Firms & government gains	Firms & government losses	Net societal effect
Part 1: Lower energy demand from efficiency measure	Full retail price of energy saved = blue + yellow boxes		Resource costs of supplying the energy saved = yellow box	Full retail price of energy saved = blue + yellow boxes	Net gain = yellow box
Part 2: Direct rebound effects	Full benefit of comfort, including full retail price = orange boxes + consumer surplus (green triangle)	Full retail price paid = orange boxes	Full retail price paid = orange boxes	Resource costs of supplying the extra energy = lower orange box	Net gain = consumers gain the green triangle; others gain the top orange box

Why does this not double-count some benefits?

3.10. At first glance, it is possible to view this approach as double-counting, or over-counting, welfare benefits relating to the rebound effect. It is possible to overcome this by viewing the valuation approach from another perspective.

3.11. If the consumer just installed a piece of energy-efficiency equipment to maintain their current level of energy services, this would save them the coloured boxes in the Part 1 figure, above, on their bill. The reason the consumer would increase consumption of energy in the rebound effect is to capture more utility. Therefore, by choosing greater consumption of energy through the rebound effect, this must imply the consumer yields greater or equal welfare benefits as before. Spending the orange boxes in the Part 2 figure, above, to capture the orange boxes and green triangle in benefits results in a net gain of the green triangle in addition to the pre-rebound effect benefits.

3.12. The exchequer and energy companies only perceive the final change in energy consumption, and do not notice the pre- and post-rebound consumption levels. Therefore, their only impacts are on this net change in energy consumption, measured at the price of the long-run variable cost of energy supply.

3.13. Consumers' rebound behaviour can only be justified when there is a consumer surplus element. This is the additional price that consumers would have paid for their energy service but, because the price is lower, they receive a benefit for it. However, because this is a theoretical benefit it is difficult to measure or estimate in a typical quantification

of benefits. As a result, the above example would most likely omit quantification of the green triangle.

3.14. The above analysis considers energy-efficiency improvements on the demand-side (improvements in how end consumers use their energy). Energy efficiency improvements may also occur on the supply-side which, although it results in different impacts, may be analysed under the same framework.

4. Rebound Effects

4.1. A brief discussion surrounding rebound effects is useful to explain the current valuation methodology and indicate the limitations of such an approach. For the purposes of this background documentation, an in-depth review of rebound effects and their intricacies is avoided. For more information on rebound effects the UK Energy Research Centre (2007) has published a comprehensive summary of the theory and evidence on rebound effects[12]. Annex B of this document also contains a derivation of the cause of the rebound effect.

Direct vs. indirect rebound effects

4.2. Both the direct and indirect rebound effects affect the aggregate energy demand in an economy. These effects are not always present, but in most cases, there is likely to be some impact.

4.3. For illustration, a household may install wall insulation and receive bill savings from reduced energy consumption necessary to heat the home. How this household chooses to spend this additional money is the core question. The direct rebound effect relates to spending some of the money on energy to raise the temperature of the home (comfort-taking). This will be the result of two effects, the substitution effect (heating the home is relatively cheaper than it was before) and the income effect (more money is available to spend on heating).

4.4. The indirect rebound effect concerns changes in the energy consumption through other goods and services. For example, if the money saved is spent on foreign travel, then this would result in additional energy consumption. On the other hand, consumers may substitute some of their overall consumption, including foreign travel, into heating as the relative price of heating has fallen.

4.5. Given the lack of precedent in appraisal of real-world rebounds beyond the direct rebound effect and the difficulty in their estimation, the guidance recommends that only the direct rebound effect is quantified and valued where necessary, and that this valuation is approximated by the retail price. It is up to the analyst to estimate the size of the rebound that is likely to result from their policy. This approximation means that a small part of the welfare benefit from the direct rebound effect is excluded from the analysis (the green triangle in Figure 3.2, above). If the analyst wishes to make an estimate of this triangle, Annex B gives details on how to account for this additional welfare.

[12] UK Energy Research Centre (UKERC) – Review of Evidence for the rebound effect https://ukerc.ac.uk/publications/ukerc-review-of-evidence-for-the-rebound-effect-technical-report-5-energy-productivity-and-economic-growth-studies/

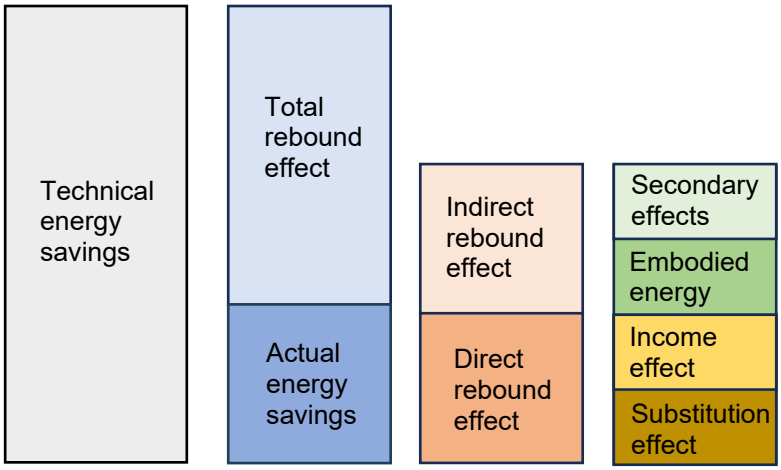
4.6. Analysts should be aware that the unaccounted indirect rebound effects may have implications on estimated total energy and emissions savings, and on the NPV of a policy. In general when considering improvements to energy-efficiency, the indirect rebound effect will mean that the aggregate energy and emissions savings in the economy will be reduced, but that its impact on the NPV of the policy could be positive or negative. This is due to the changes in utility derived from the additional purchased goods and services, offset against any resulting externalities (such as the increase in air quality damages, for example).

Embodied energy-effects

4.7. Figure 4.1 presents the different classifications of the various effects of installing energy-efficiency measures. Direct rebound effects may be disaggregated as described above into income and substitution effects. Indirect effects resulting from both the income and substitution effects may be further disaggregated into secondary effects and embodied energy-effects.

4.8. The secondary effects are the increases in energy consumption resulting from the increases in consumption of all other energy-using services. However, one could take this a step further and consider the differences in energy embodied in the goods and services that are now purchased compared to those goods and services that were purchased before.

Figure 4.1: Classification of rebound effects



4.9. For example, if a consumer purchases a new table as a result of the savings, this table may have required a significant amount of energy to produce and deliver to the household. Furthermore, economy wide rebound effects can take place as efficiency improvements spur economic growth over the long term, taking us to third order effects and beyond. The Oxford Institute of Energy Studies (2011) goes even further and identify a ‘transformational effect’ in which some efficiency measures may give rise to

changes in preferences and the emergence of new goods and services that are more energy intensive[13].

4.10. It is not recommended that these additional impacts are included in an NPV estimate for a policy. However, where these impacts could be large, the analyst should make some consideration of them.

[13] The Oxford Institute for Energy Studies – 'Energy-efficiency – Should we take it seriously' http://www.oxfordenergy.org/wpcms/wpcontent/uploads/2011/12/SP_24.pdf

5. The long-run variable cost of energy supply (LRVC)

5.1. As the previous section explains, changes in energy consumption should be valued by using the long-run variable cost of energy supply. To calculate this, one must identify the parts of the retail price that represent actual costs to society that vary according to the level of consumption. Other price components are fixed or will only result in transfers between groups in society (which are of no net social benefit). The disaggregation of the price into its elements is the focus of this chapter. What is defined as a variable cost will depend on the fuel/energy type. Therefore, the cost estimates that are provided alongside this guidance are calculated in different ways.

5.2. The following section explains the different components of retail energy prices and identifies which should be considered variable in the long-run. Further down, an explanation is given on how each of the cost series published in the Data Tables is calculated as well as providing the underlying assumptions.

Components of the retail price

5.3. The retail price of energy that consumers pay is made up of a number of components relating to costs of provision, in addition to taxation and profits. These components are described below in Table 5.1. Some components will contain both variable and non-variable elements, while others will only be one or the other. The components will vary depending on the fuel type being analysed.

Table 5.1: Components of energy prices

Non-variable cost components and societal transfers	Long-run variable components
Government policies with fixed costs	Carbon costs (measured and valued separately)
Taxes (e.g. VAT, CCL)	Variable costs of transmission and distribution
Energy supplier profits	Primary fuel (including long-run variable capital costs of plant (electricity)) and other variable operating costs
Other fixed energy company costs	Government policies to support generation (electricity)
Fixed costs of transmission, distribution and metering	

Wholesale energy cost (primary fuel)

5.4. In this context, the wholesale energy cost is the cost of energy on the wholesale market. This includes the cost of operation and raw material (fuel) inputs, and some capital costs. The wholesale cost of energy would also include any margins made by the firms involved in the supply of wholesale energy.

5.5. The wholesale price will include some non-variable costs incurred upstream in the supply chain such as the fixed costs and margins. For estimating the true cost to society, these transfers should ideally be removed from the LRVC.

Transmission, distribution, and metering (TD & M)

5.6. Distribution charges are costs associated with the building, running and maintenance of gas pipes and power lines/wires that deliver gas and electricity to the end user and the costs of distributing petroleum and other energy products. Transmission charges are costs associated with the building, running and maintenance of high-pressure gas and high voltage transmission networks.

5.7. There will generally be a per unit cost for transmission and distribution of energy as well as a fixed cost of operating and maintaining networks.

Other supplier costs and margins

5.8. There are additional running costs incurred by energy suppliers which relate to business activities such as sales, customer service and billing. In addition, the retail price of energy may include energy supplier profits, which will be where the price is beyond the cost of the energy sold. Some of these margins will go to cover the fixed and sunk costs of the business, while the rest will become pure profits for the energy producer. When energy consumption changes, the impact on societal welfare will depend on the variable supplier costs.

Energy and climate change policies

5.9. Certain government policies will affect the price of energy. Some policies will be invariant to changes in consumption levels. Particular examples of this include Smart Metering, since the cost of smart meters is not affected by the energy consumption of users. Instead, it depends on the number of users. Other policies may vary when consumption levels change. An example of this would be the renewable transport fuel obligation (RTFO) which requires suppliers to source a minimum proportion of their fuels from renewables.

Indirect taxation

5.10. Indirect taxes such as VAT[14] and road fuel duty for example, are included in the retail price but would not normally be associated with direct social costs because they are considered to be a transfer between consumers/businesses and government. Therefore, indirect taxes would not form part of the LRVC.

Estimating the LRVC

Electricity

5.11. The variable supply cost for electricity is given by the following equation:

$LRVC_{Electricity}$ = *Wholesale prices (adjusted for demand profiles, carbon costs, balancing costs and transmission & distribution losses) + Policy support costs (RO, CfDs and Capacity Payments) + Variable distribution costs + Variable transmission costs*

5.12. Within the estimated price series, the LRVC of electricity supply is taken as being the adjusted wholesale price plus the cost of government policies that support generation costs plus variable transmission and distribution costs.

5.13. Estimated wholesale energy prices are derived from DESNZ's Dynamic Dispatch Model (DDM) and are published in DESNZ's Energy and Emissions Projections[15]. The wholesale price is adjusted to exclude the traded cost of carbon, which is valued separately, and the exchequer revenues from the Carbon Price Support which, as a tax, is a transfer between consumers/energy firms and the government. However, Carbon Price Support costs that result in increased revenue for generators through higher wholesale prices, rather than tax revenue for the exchequer, are included[16] as these represent a payment from consumers to generators to cover generation costs. These costs are calculated by subtracting the average emissions factor from the marginal price-setting emissions factor and multiplying by the Carbon Price Support rate.

5.14. Further adjustments are made to account for the demand profiles of different types of users, balancing costs and transmission and distribution losses. The residential electricity supply costs have been constructed by uplifting the wholesale prices discussed above to account for the additional costs of meeting the residential sector's

[14] VAT on energy bills is payable at a rate of 5% on the final energy price for residential customers though is reducing to 0% from October 2026 for a limited time. Businesses are typically charged the standard rate of VAT on energy (20% as of March 2021). However, those businesses that are registered for VAT may claim back any VAT that they have paid on their energy consumption.

[15] See https://www.gov.uk/government/collections/energy-and-emissions-projections. The residential sector has its electricity costs increased because the average price (in terms of wholesale prices) of meeting the residential load shape is higher than the base-load price. Residential electricity has a higher resource cost because demand comes in peaks and troughs.

[16] It should be noted that the Carbon Price Support will be removed from Apr-28 though the LRVCs do not factor this in currently.

load shape. The uplift is estimated based on the 5-year average historic difference between actual lagged wholesale prices and wholesale cost estimates consistent with those published by Ofgem as part of their Supply Market Indicators analysis[17]. This uplift will account for distribution losses, seasonal consumption profiling[18] and shaping costs. Long-run variable transmission and distribution costs have then been added.

5.15. A similar approach is used to calculate the variable costs of electricity to industry and commercial/public sectors, except that industrial customers and the commercial/public sector are assumed not to face the wider uplift on the wholesale price that the residential prices reflect. Losses on the local distribution network are also included. For the commercial/public sector, losses are assumed equal to the grid average[19]. For the industrial sector they are assumed to be 2 percentage points lower, to reflect the fact that some demand is direct from the transmission network.

5.16. Certain assumptions are made surrounding the proportion of transmission and distribution costs that are fixed and variable. 90% of transmission costs are assumed to be variable in the long-term. By contrast, only 10% of distribution costs are assumed to be variable in the long-term. However, if a policy requires linking new users to distribution networks, 100% of distribution costs should be included in the LRVC. In these circumstances, it is the responsibility of the analyst to ensure that they make an appropriate assessment of these costs.

5.17. Although in the short-term Combined Cycle Gas Turbine (CCGT) plants typically drive the wholesale price, it is reasonable to expect in the future low carbon generators will set the wholesale price. It is therefore necessary to augment the wholesale price with estimates of Renewables Obligation (RO) support costs and Electricity Market Reform (EMR), specifically Contracts for Differences (CfDs) and Capacity Payments. Modelling of illustrative demand reduction scenarios indicates that sustained reductions in demand will result in both less low carbon capacity and less conventional generation capacity being built and operated. It is therefore necessary to reflect these costs in the estimate of the long run variable costs of energy supply.

5.18. Other supplier costs are excluded from the LRVC of electricity because most do not vary according to levels of energy consumption (although they may vary according to numbers of customers). Similarly, suppliers' margins are excluded from the LRVC of energy because these are payments between consumers and firms, and do not reflect a change in societal welfare.

Gas

5.19. The long-run variable supply cost for gas is calculated using the following equation:

[17] Available online at: https://www.ofgem.gov.uk/news-and-insight/data/data-portal/wholesale-market-indicators
[18] For example, households tend to consume more gas in winter when it is colder and the wholesale price of gas tends to be higher.
[19] Figures are available in the electricity chapter of the Digest of UK Energy Statistics, available online at: https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes.

$LRVC_{Gas}$ = *Wholesale price (adjusted for distribution losses) + Variable local distribution costs + Variable local transmission costs*

5.20. The wholesale price for gas reflects the fossil fuel prices published in the supporting data. However, since the wholesale price in this context is the cost of supplying the marginal unit of gas to the transmission and local distribution networks, it is necessary to apply an uplift factor to the fossil fuel price to take account of the additional local transportation losses that result from each unit increase in gas demand. The rate of physical losses on the local gas distribution network is estimated to be 0.5%. The rate of losses on the transmission system is likely to be much smaller than in the distribution network because there are relatively few joints and vulnerable points, so in the LRVC series provided, the losses on the transmission network are ignored.

5.21. 90% of the transmission costs of gas are assumed to be variable in the long-run, in contrast with only 10% of distribution costs.

Non-transport oil products and coal

5.22. The variable supply cost is estimated by adding non-fuel variable costs and subtracting estimated average fixed costs from the wholesale price.

5.23. The equation for long-run variable supply cost for non-transport oil products and coal is:

LRVC = *Wholesale price + Non-fuel costs – Fixed costs*

5.24. Transmission, distribution, and metering costs are not measured for other fuels as they do not require the infrastructure assets relevant to the supply of electricity and gas. Furthermore, the wholesale prices of other fuels do not require adjustments for balancing costs and losses as is required for electricity. As such, the calculation is less complicated.

5.25. The wholesale price is based on adjusting the underlying fossil fuel price series to reflect the costs of producing each product.

5.26. Non-fuel costs include expenses beyond those of procuring the ownership rights or production of fuel. Any costs involved in physically moving the fuel from the wholesale point of sale to the retail point of sale will come under non-fuel costs. Fixed costs relate to costs that do not vary with respect to energy use.

5.27. Average fixed costs are estimated and subtracted from non-fuel costs to find the variable non-fuel costs. Variable non-fuel costs are assumed to vary between sectors.

Road Transport Fuels

5.28. The long-run variable supply cost is estimated using assumptions on fixed costs provided by the Department for Transport and is calculated by adding non-fuel costs and subtracting fixed costs from the wholesale price.

5.29. The equation for the variable supply cost of road transport fuel is:

$$LRVC_{Transport\ fuels} = \text{Wholesale price} + \text{Non-fuel costs} - \text{Fixed costs}$$

5.30. The fixed costs are essentially the long-term costs of refining infrastructure and capital investment. The assumptions for fixed costs are based on modelling and industry estimates.

Additional costs of energy supply

5.31. The analysis in the previous sections shows that the LRVC should be used to value net changes in energy use. The LRVC of energy represents the opportunity cost to society of an additional unit of energy produced or supplied. However, the LRVC does not include the impact on air quality, carbon costs, or any other wider impacts. Analysts should calculate the value of carbon costs and air quality impacts separately.

6. Other considerations in appraisal of energy and emissions policies

Behaviour Change Assumptions

6.1. Behaviour change is often a key goal for energy and climate change policies. Behaviour change is "a challenging and complex process, requiring theories, methods and evidence from many academic disciplines" (UCL Centre for Behaviour Change)[20].

6.2. Implicit in policy appraisal may be a number of assumptions about human and organisational behaviour including assumptions relating to the likely take up of new products and technologies, and effectiveness with which people put new technologies to use over time. Analysts should consider hidden or implicit assumptions about human and organisational behaviours and ensure at the minimum that all such assumptions are given consideration and clearly stated. For example, human and consumer behaviours may be motivated by preconceived beliefs or patterns of action that complicate engagement with interventions or change. These assumptions, in particular those that are not evidenced, can then be explored during policy development using existing or new research, and can be examined at the evaluation stage as far as possible. Attention should be given to the key evaluation questions, including those about behaviour change, at the policy design stage. The way a policy is formulated or implemented can have significant impacts on the ability to evaluate it rigorously.

6.3. The following questions and examples in Table 6.1 are used to illustrate what analysts should endeavour to consider:

Table 6.1: Considerations for behavioural change

Questions	Examples
Are there implicit assumptions that behaviours will change in response to policy and are these realistic?	Where a policy involves installing solar water heating; some people do not achieve the theoretical potential energy savings because they prefer to take a power shower in the morning rather than showering in the evening when hot solar heated water is available. In this case it is not realistic to assume that behaviours have changed to deliver the full potential energy savings of the policy.

[20] For an overview of behaviour change models, see: GSR (2008) Practice Guidance: An overview of behaviour change models and their use (http://webarchive.nationalarchives.gov.uk/20140305122816/http://www.civilservice.gov.uk/wp-content/uploads/2011/09/Behaviour-change_practical_guide_tcm6-9696.pdf)

Have assumptions been made that certain behaviours will not change in response to policy and are they realistic?	As houses become draught-proofed, some consumers may respond by opening more windows. As consumers accumulate more energy-efficient products, they may change their preferences towards energy intensive products.
Are estimates of the effectiveness of technologies based upon laboratory experiments rather than pilots of how they have been used in practice? If so, did the experiments account for the role of human behaviours when assessing the potential impact of technologies, and if not, have potential limitations of the analysis been clearly stated? Put another way, what is the quality of the evidence base to support the assumptions?	A policy which requires new energy-efficiency light-bulbs to be installed in buildings may not deliver carbon savings envisaged from lab experiments because consumers choose to change the lights and fittings before the technical life of the bulbs for aesthetic reasons
Does the analysis assume for instance that consumers have read a manual or have been trained in the effective use of technologies? Or does the analysis assume that training is not necessary for the effective use of technologies?	The policy involves fitting new heating controls to commercial buildings, but the building managers are not trained in how to use them so projected carbon savings might not transpire.
Have assumptions been clearly stated about the effectiveness with which technologies are used, particularly relating to new and relatively untested technologies?	Stating assumptions behind a policy on carbon capture and sequestration.

6.4. When conducting subsequent evaluations, analysts should aim to measure the impact of human behaviours and test the assumptions made at the appraisal stage. A good starting point is to map the intervention logic. Logic mapping or logic models are a structured way of setting out the assumptions, and evidence on which they are based to describe the relationship between an intervention's inputs, activities, outputs, outcomes and impacts. They are the representation of the causal theory underlying the impact of the associated intervention. This can then be tested in the evaluation. For further details on evaluation, see HM Treasury's Magenta Book[21].

Energy Security and Resilience

6.5. DESNZ understands energy security to be achieved by having secure, affordable supply and a system resilient enough to mitigate and withstand shocks, so that energy reaches

[21] https://www.gov.uk/government/publications/the-magenta-book

people, businesses and critical services with minimal disruption. This comprises a secure supply, ensuring enough energy is available to meet demand at an affordable price; and resilience, ensuring the energy system can anticipate, prevent, withstand, and recover from disruption.

6.6. For appraisal, analysts should consider this through three dimensions: supply security, whether sufficient energy sources and infrastructure capacity are available to meet normal and peak demand; price exposure, the system's vulnerability to international and geopolitical price shocks; and resilience, the ability of the system to anticipate, prevent, withstand, and recover from disruption. Any policy that has an impact on the supply of or demand for energy or energy services, including by affecting the way energy markets function, could therefore affect the UK's energy security and resilience.

6.7. Analysts should first consider whether the policy could plausibly affect any of the three dimensions. Where no material impact is expected, the basis for this conclusion should be recorded briefly; where impacts could be material, analysts should assess the relevant factors below and consider whether quantitative analysis or specialist advice is required.

6.8. Policies may affect energy security and resilience directly or indirectly through changes to energy supply, infrastructure or investment; changes to the level or profile of demand; or a combination of supply and demand-side effects. This may include policies whose primary objectives relate to decarbonisation, industrial development, or wider infrastructure rather than energy security and resilience itself.

6.9. This section sets out a conceptual framework for appraising the energy security and resilience impacts of policies and provides factors for policymakers and analysts to consider when assessing options.

Qualitative assessment

6.10. A qualitative assessment should identify how a policy could affect the three dimensions of energy security: supply security, price exposure, and resilience. This assessment should consider national, regional, or local impacts and, where relevant, how impacts may differ over time. It should also consider material consequences that are not fully captured by quantitative indicators or monetised estimates, including disruption to essential services, impacts on vulnerable consumers and wider welfare effects.

6.11. Energy markets in the UK are used as a key instrument for: balancing supply and demand, supporting investment and enabling a response to changing conditions. Analysts should therefore consider how a policy affects: market functioning, competition, price signals, investment incentives, and the ability of markets and consumers to respond. However, markets may not fully reflect the wider social value of energy security and resilience, particularly where the benefits are dispersed, impacts are uncertain, or investments protect against high-impact, low-likelihood events. This may

result in capacity, flexibility, redundancy, or other resilience measures being underprovided without government intervention.

6.12. Analysts should firstly consider how a policy may affect the 'physical' characteristics of the energy system. This includes: the availability and deliverability of energy, infrastructure capacity, demand, flexibility, diversity, reliability, protection against disruption, and the ability to restore supply. Analysts should also consider relevant dependencies on: digital and data systems, workforce capability, supply chains, international relationships, and other critical sectors.

6.13. The following factors may help analysts identify relevant effects within the three dimensions. They are not exhaustive and will not all be relevant to all policies, with several factors potentially affecting more than one dimension:

- Supply security
    - Available supply and infrastructure capacity
    - Reliability
    - Responsiveness and flexibility
    - Diversity
    - Levels and profiles of demand
    - Consumer-led flexibility
- Price exposure
    - Exposure to international markets and price shocks
    - Concentration and diversity of supply chains
    - Ability to respond to price shocks and market functioning
- Resilience
    - Anticipation and prevention
    - Ability to absorb and withstand disruption
    - Concentration / dispersion of infrastructure
    - Preparedness, response, and recovery
    - Dependencies and cascading impacts

6.14. For policies with complex, indirect or cross-sector effects, systems mapping may help to identify dependencies, feedback effects, and potential cascading impacts. Analysts should focus on the factors that are plausible and material to the policy and seek advice where significant impacts or complex system interactions are identified. Further guidance on these factors is set out below. Table 6.2 summarises issues an analyst may wish to consider when assessing a policy's impact across the three dimensions.

Supply Security

6.15. In assessing supply security, analysts should consider whether a policy could affect the availability of energy, the capacity to deliver it, or the ability of supply and demand to

adjust to changing conditions. The following characteristics may be relevant when assessing these impacts.

Availability of supply and infrastructure capacity

6.16. Analysts should consider whether sufficient energy and infrastructure capacity are expected to be available to meet demand and deliver energy to consumers. This should reflect capacity likely to be available in practice, including de-rating where appropriate, rather than maximum theoretical capacity alone. Across sectors, analysts should distinguish between infrastructure capacity and access to the underlying commodity, including where imports depend on availability and competing demand in connected or international markets, and consider constraints that may limit delivery nationally, regionally, or locally.

6.17. For electricity, relevant factors may include: available generation, storage, electricity interconnector flows, and transmission and distribution capacity. For gas: domestic production, storage, pipeline and interconnector capacity, LNG import infrastructure and the physical availability of gas from European and LNG markets may be considered. For oil and refined products, the factors to consider could include: domestic production and refining, imports, stocks[22] and the infrastructure needed to transport and distribute fuels.

6.18. Where relevant, analysts should also consider whether a policy affects investment in, or the timing of, new or replacement supply and infrastructure, including the risk that existing capacity becomes unavailable before alternatives are operational.

Reliability

6.19. Analysts should consider whether energy sources and the infrastructure needed to produce, import, store, transmit, and distribute energy are likely to perform as required and be available when needed. This may include the expected availability and operating characteristics of generation technologies, including variable and weather-dependent generation and sources capable of generating when required. Furthermore, analysts should consider the risk of planned or unplanned outages, technical failure or underperformance, and whether a policy changes the reliability of individual assets or the wider system, including transmission and distribution infrastructure. Analysts should also consider whether assets and supply arrangements are expected to remain reliable as operating conditions and external risks change over time, including where relevant because of climate change, such as wetter and warmer winters or hotter and drier summers, or geopolitical developments, such as conflict, trade restrictions, or disruption to international supply routes.

Responsiveness and flexibility

6.20. For each energy market the infrastructure, demand-side resources, and supply sources available must be able to adjust sufficiently and in time to changing conditions. This may

[22] Or, *in extremis*, from oil stocks. However, note that mandated oil stocks are different from gas or electricity storage in that they are not part of the normal commercial operation of the market and are only used to boost supply under certain (emergency) conditions.

include increasing or reducing supply, drawing on or feeding into storage, redirecting energy through available infrastructure, substituting between energy sources, or shifting or reducing demand. Where suitable incentives and arrangements are in place, greater flexibility may be used to help maintain the balance between supply and demand and reduce the risk of market tightness or interruption to supply.

Diversity

6.21. Analysts should consider whether a policy changes the range and concentration of energy sources, technologies, infrastructure, suppliers or import routes on which the system depends. Greater diversity can reduce exposure to the failure or disruption of a particular asset, technology or source of supply, provided that credible alternatives are available when required. Analysts should also consider dependencies within critical energy supply chains, including on particular countries, suppliers, materials, components or specialist services needed to build, operate, and maintain energy infrastructure.

Level and profile of demand

6.22. Analysts should consider whether a policy changes the level, timing or location of energy demand, including normal, peak, and seasonal demand. Reductions in demand may increase available headroom and reduce pressure on energy infrastructure, while increases may create additional supply, capacity, or operability requirements, particularly where markets and infrastructure cannot adjust sufficiently or in time. Impacts across energy systems should also be considered, as a policy may reduce demand for one energy source while increasing demand for another. However, where changes in demand are anticipated and fully reflected in market decisions, supply and infrastructure may adjust over time, limiting the longer-term effect on supply security. Time lags, market imperfections and the long operating lives of existing infrastructure should therefore be considered when assessing this impact. Analysts should consider whether changes in demand, embedded generation or storage affect the visibility and predictability of net demand and the ability to forecast and balance the system.

Consumer-led flexibility

6.23. Analysts should consider the extent to which consumers can adjust, shift, or reduce demand in response to changing prices, incentives, or system conditions. In the short term, demand side response can help the system manage supply shortages and maintain the balance between supply and demand, particularly for electricity. Policies may also support longer-term reductions in peak or overall demand through energy efficiency, technology choices, and sustained behavioural change.

Price exposure

6.24. In assessing price exposure, analysts should consider whether a policy could affect the energy system’s vulnerability to international and geopolitical price shocks, including the extent to which those shocks may be transmitted across energy markets and to

consumers. The following characteristics may be relevant when assessing these impacts.

Exposure to international markets and price shocks

6.25. Analysts should consider whether a policy changes exposure to price shocks arising from international energy markets or geopolitical events. This may include changes in reliance on internationally traded energy, the extent to which domestic prices are linked to global or regional markets, and whether price movements in one energy source could affect costs elsewhere in the energy system. Exposure to international prices should not be assessed solely by considering the level of energy imports. Domestically produced energy may still be affected by international prices, while imports from a diverse range of markets may reduce dependence on any single source of supply. Analysts should also consider whether exposure is concentrated across particular countries, markets, suppliers or supply routes, including, where material, markets for critical materials, components or technologies needed for energy infrastructure.

Ability to respond to price shocks and market functioning

6.26. Analysts should consider whether markets, market participants and consumers can respond effectively to price shocks. Relevant factors may include competition, liquidity, price formation, market design, and investment incentives, alongside the availability of storage, flexibility, substitution, energy efficiency or demand reduction. Analysts should also consider whether a policy transfers price exposure or costs between consumers, sectors or parts of the energy system.

Resilience

6.27. In assessing resilience, analysts should consider whether a policy could affect the ability of the energy system and relevant organisations to anticipate, prevent, absorb and recover from disruption. This should include short-term disruptions and longer-term stresses, including those arising from climate change, and interactions with other systems and sectors. Relevant risks may include natural hazards and severe weather, technical failures, accidental damage, cyber and physical attacks, geopolitical instability and market or supply chain disruption. The following characteristics may be relevant when assessing these impacts.

Anticipation and prevention

6.28. Analysts should consider whether a policy affects the ability of the energy system and relevant organisations to identify, assess, and monitor threats, hazards, and vulnerabilities. The ability to take proportionate action to prevent or reduce disruption should also be considered. This may include access to timely information, threat intelligence, risk assessment, preparedness, and planning, and measures to address vulnerabilities before they result in disruption. The assessment should consider relevant risks, including natural hazards and severe weather, physical and cyber attacks, and geopolitical instability and market disruption.

Ability to absorb and withstand disruption

6.29. Analysts should consider whether a policy affects the ability of the energy system to continue operating or limit the consequences when disruption occurs. For investments in new or existing infrastructure, analysts should consider whether assets and networks are designed or adapted to remain resilient under changing conditions, including the increasing frequency or severity of relevant climate-related hazards. This may include the adequacy and proportionality of protection for energy infrastructure, assets, and networks, as well as redundancy, spare capacity, alternative supply routes, or operating arrangements, and the avoidance of single points of failure. The assessment should consider whether essential energy services can be maintained during disruption and the ability to withstand natural hazards and severe weather, physical and cyber attacks, and geopolitical instability and market disruption.

Preparedness, response, and recovery

6.30. Analysts should consider whether a policy affects the ability of the energy system and relevant organisations to respond to disruption, manage its consequences, and restore supplies safely and effectively. Relevant factors may include emergency plans and procedures, coordination and communications, access to skilled personnel, equipment and replacement components, and the time and resources required to restore affected infrastructure and services. The assessment should also consider arrangements for maintaining the balance between supply and demand during disruption, including the use of storage, alternative supplies, demand reduction, and, where necessary, controlled disconnection or load shedding. Analysts should consider how quickly different consumers and services could be restored and whether recovery arrangements appropriately account for critical services and vulnerable consumers.

Dependencies and cascading impacts

6.31. Analysts should consider whether a policy creates or changes dependencies within the energy system or between energy and other critical sectors. This may include dependencies on other energy sources, telecommunications, digital and data services, transport, water, workforce capability, and supply chains. The assessment should consider whether disruption to these supporting systems could affect energy supply, and whether disruption within the energy system could cause wider or cascading impacts on consumers, businesses, public services, or other infrastructure. Particularly, analysts should focus on dependencies that are capable of creating single points of failure or are difficult to substitute.

Table 6.2: Issues to consider in a qualitative assessment of energy security and resilience

Energy security dimension	Characteristic of the energy system	Issue to consider

Supply security	Availability of supply and infrastructure capacity	Consider effects on the practical availability and timely delivery of energy, storage and infrastructure capacity, including imports, de-rating where appropriate, geographical constraints and the timely delivery of replacement capacity.
	Reliability	Consider whether energy sources and infrastructure are likely to perform and remain available when required, including the risk of outages, technical failure or underperformance.
	Responsiveness and flexibility	Consider whether supply, storage, infrastructure and demand can adjust sufficiently and in time to changing conditions, including through redirection or substitution.
	Diversity	Consider changes in dependence on particular energy sources, technologies, assets, suppliers, import routes or critical supply-chain inputs, and the availability of credible alternatives.
	Level and profile of demand	Consider changes in the level, timing, location or predictability of demand, including peak demand and transfers between energy sources.
	Consumer-led flexibility	Consider consumers' ability to shift or reduce demand in the short or longer term through price signals, incentives, energy efficiency, technology or behavioural change.
Price exposure	Exposure to international markets and price shocks	Consider changes in exposure to internationally driven price shocks, how these may be transmitted across energy markets and to consumers, and the ability to respond. Consider whether concentration across countries, suppliers, markets, routes or critical materials, components and technologies increases exposure.
Resilience	Anticipation and prevention	Consider the ability to identify, assess and monitor threats, hazards and vulnerabilities, and to address them before disruption occurs.
	Ability to absorb and withstand disruption	Consider whether infrastructure is designed or adapted to withstand relevant threats and hazards, and whether protection, redundancy and alternative arrangements enable essential energy services to continue and limit single points of failure during disruption.

	Preparedness, response, and recovery	Consider whether emergency arrangements support effective supply-demand management and the safe and timely restoration of services, including for critical services and vulnerable consumers.
	Dependencies and cascading impacts	Consider whether dependencies on other energy sources, infrastructure, sectors, workforce or supply chains could cause or amplify disruption across systems, services or locations.

Quantitative approach

6.32. Where proportionate and supported by evidence, a quantitative assessment should estimate the energy security and resilience impacts of a policy against an appropriate counterfactual. This may include impacts on energy supply, demand or other relevant characteristics of the energy system, as well as changes in the likelihood or consequences of disruption. Where the policy could create, prevent or mitigate energy disruption, analysts should identify the relevant scenarios and assess how the policy could affect them.

6.33. Energy security and resilience impacts may be more apparent under stressed conditions than during normal operation. Where relevant, analysts should therefore compare the policy and counterfactual across a range of plausible scenarios, such as severe weather, infrastructure failure or international market disruption. The assessment should consider both the likelihood and potential impacts of relevant scenarios. Potential impacts may reflect the duration and scale of disruption and the resulting consequences for consumers, businesses and essential services. Robust probabilities may be difficult to establish. Where this is the case, analysts should consider a range or distribution of plausible outcomes and, where appropriate, calculate the probability at which the expected benefits of the policy would equal or exceed its costs, applying the Green Book guidance on sensitivity analysis and switching values[23].

6.34. For example, analysts may estimate the expected cost of an interruption by combining likelihood with the volume of unmet demand and the value of resulting impacts. Depending on the policy and available evidence, estimation methods may be used to assess the resulting economic and welfare impacts. These may include Value of Lost Load (VoLL); Quality-Adjusted Life Years (QALYs), where there are material health impacts; and modelling of output losses or supply-chain effects, including through input-output analysis, to estimate the resulting financial losses to producers. Where these methods are used together, analysts should establish which impacts are captured by each method and avoid double counting overlapping impacts. Where relevant, potential

[23] HM Treasury (2026). The Green Book: UK government guidance on appraisal, paragraphs 6.60 to 6.77 and 6.102 to 6.105.
https://assets.publishing.service.gov.uk/media/698dbcd17da91680ad7f4308/The_Green_Book_2026.pdf

macroeconomic effects should be reported separately from the welfare appraisal and should not be included in the policy's net present social value. The costs and benefits should be assessed over the appraisal period and discounted in accordance with Green Book guidance[24]. Assumptions, uncertainties, and impacts that cannot be monetised should be clearly presented.

6.35. VoLL is one approach to estimating the economic and welfare costs of energy not supplied during a disruption. The VoLL value used should reflect the context of the assessment (including the energy source, consumer group, and interruption characteristics, such as timing, duration, frequency, season and whether it is planned, unplanned or involves rolling disconnections).

6.36. Conducting this analysis for each of the years of the lifetime of a policy, and comparing this to the 'business as usual' counterfactual case, would provide a Net Present Value of security benefits that could be compared to the costs of delivering reductions in the probability of interruptions. Assessing the impact that a policy may have on the probability of an interruption to supply (or on the likelihood of prices spiking) is however very complex.

6.37. The Energy Networks Association (ENA) 2025 study[25] provides the most recent research and suggestions of electricity VoLL values. Some assessments may continue to use the London Economics 2013 study[26], particularly where consistency with an existing methodology is required. For gas interruptions, the London Economics 2011 study[27] provides VoLL estimates for domestic, SME, industrial, and commercial gas users. When utilising such studies, analysts should consider any relevant energy system or societal changes that may mean the values would be different today. Furthermore, analysts should explain why the selected source and values are appropriate.

6.38. VoLL may be less suitable where the disruption being assessed is not comparable with the interruption scenarios used to derive the selected values, or where impacts are not closely related to the volume of unmet energy demand. This may include significant health or wider welfare impacts, disruption to essential services such as hospitals or clean-water supply, indirect or supply-chain effects, or policies that principally affect price exposure or broader system resilience. In these cases, analysts should use another proportionate method or combine VoLL with additional analysis.

[24] HM Treasury (2026). The Green Book: UK government guidance on appraisal, paragraphs 6.9 to 6.14 and 6.52 to 6.59. https://assets.publishing.service.gov.uk/media/698dbcd17da91680ad7f4308/The_Green_Book_2026.pdf
[25] ENA (2025). Value of Lost Load Study in Great Britain. https://www.energynetworks.org/publications/value-of-lost-load-study-in-great-britain
[26] London Economics (2013). The Value of Lost Load (VoLL) for Electricity in Great Britain. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/224028/value_lost_load_electricty_gb.pdf
[27] London Economics (2011). Estimating Value of Lost Load (VoLL). https://www.ofgem.gov.uk/sites/default/files/docs/2011/11/london-economics%2C-estimating-value-of-lost-load---final-report-to-ofgem.pdf

6.39. Any relevant macroeconomic effects should be considered separately from the appraisal steps outlined above. Where the appropriate method is unclear, analysts should engage with DESNZ for further input.

6.40. For policies that principally affect energy demand, analysts should consider whether the change can be accommodated by existing or planned supply and infrastructure, including during the period before the energy system can adjust. This may include effects on system operation, investment requirements or demand for other energy sources. Where impacts may be material at system level, including for sector-wide policies like industrial strategy decisions, or wholesale decarbonisation of transport or housing, analysts should engage with DESNZ on whether further modelling is required.

6.41. Sector-specific standards, indicators, and modelling may be used to assess the likelihood and scale of supply capacity impacts. For electricity, this may include Loss of Load Expectation (LOLE)[28], a probabilistic measure of the expected frequency of periods when available supply may be insufficient to meet demand[29], and the de-rated capacity margin, which measures expected available capacity above peak demand after accounting for the likely availability of different capacity types. For the gas sector, assessments may consider whether relevant security of supply standards would continue to be met, including the N-1 infrastructure standard, which assesses whether sufficient capacity remains available following the loss of the single largest item of gas infrastructure to meet demand under defined severe conditions.

6.42. Analysts should focus on the factors that are plausible and material to the policy and seek further advice from DESNZ where significant impacts or complex system interactions are identified, including whether further quantitative analysis is required.

6.43. Further advice on a case-by-case basis can be sought from GHGappraisal@energysecurity.gov.uk.

[28] Department of Energy and Climate Change (2013). Annex C: Reliability Standard Methodology. https://assets.publishing.service.gov.uk/media/5a7c52eaed915d338141e0ce/emr_consultation_annex_c.pdf

[29] LOLE does not represent the expected duration of consumer disconnections. The three-hour reliability standard is a long-term probabilistic planning standard, and mitigating actions may be taken before controlled disconnection is required.

7. Measuring the impact of policies on energy demand for DESNZ's Energy Demand Model

Reporting requirement for additional policy savings inclusion in the DESNZ Energy Demand Model

7.1. All UK energy or emissions saving policy is included within the DESNZ Energy Demand Model (EDM) baseline projections, the Energy and Emissions Projections (EEP)[30], when it is implemented, or planned where the level of funding has been agreed and the design of the policy is near final, i.e. where there are no outstanding decisions on intervention design or funding that might materially affect their impact.

7.2. The following fuel impact information is a reporting requirement for all non-transport and non-power generation policy meeting this threshold. Transport and power generation policy inclusions in the DESNZ EDM may require specialised information and policy analysts are asked to please contact the EEP modelling team directly at emissionsprojections@energysecurity.gov.uk.

7.3. Fuel saved by the additional policy must be reported, in TWh, separately for each affected sector of the following: domestic, commercial, public, industry, and agriculture. Within each sector, savings must be reported separately for each affected fuel of the following: electricity, gas, oil, solid fuels, and biofuels. For each fuel, savings must be reported for each year from 2000 to 2060. Impacts may be zero in some years, e.g. before implementation.

7.4. For policies that abate emissions without affecting fuel use, the emissions impact in $MtCO_2e$ should be provided instead of the fuel impact in TWh, in the same sector breakdown and disaggregated by GHG instead of fuel.

7.5. An example format of the required information is demonstrated in the table below.

Table 7.1: Total sector saving (Please complete one table for each relevant sector)

TWh	2000	2001	2002	……	2060
Electricity					
Gas					
Oil					

[30] https://www.gov.uk/government/collections/energy-and-emissions-projections

Solid Fuels

Biofuels

7.6. *Please note*: figures can be positive (indicating a reduction in fuel use) or negative (indicating an increase in fuel use). For example, if a policy reduces electricity use but increases gas use, the figures for the energy impact may be +3.4 TWh of electricity, -2.8 TWh of gas saved in year 2026.

7.7. It is also essential that policy overlaps have been accounted for, and that the methodology used by the analyst is explained clearly.

7.8. For further information, or for any clarification on the latest projections please contact the DESNZ EEP team: emissionsprojections@energysecurity.gov.uk.

8. Annex A: Analysis of energy-efficiency improvements

Linkages between energy markets and demand for energy services

8.1. Consumers demand energy for the services (e.g. heating, lighting, etc) the energy can provide. An energy-efficiency measure improves the efficiency through which these services can be delivered, which in turn reduces the amount of energy needed to provide these services. This relationship is demonstrated in Figure A1 and is explained below.

8.2. While consumers of energy ultimately care only about their consumption of energy services, we cannot readily observe this consumption. Instead, it is the purchase of energy that can be observed and measured. Therefore, it is useful to link the energy services market (top-left) with the energy market (top-right) in Figure A1.

8.3. The quantity of energy services is related to the quantity of energy through the energy efficiency converter (bottom-left). The slope of this curve determines how efficiently energy can be used to provide energy services. The steeper the curve, the less efficient the conversion, and the higher the energy requirement to provide energy services. Within this framework, we assume that any demand changes are small, and so they do not impact on the market price for energy. This is represented by a flat supply curve for energy and energy services. Nevertheless, it is fairly straightforward to extend this analysis to non-marginal changes in energy demand.

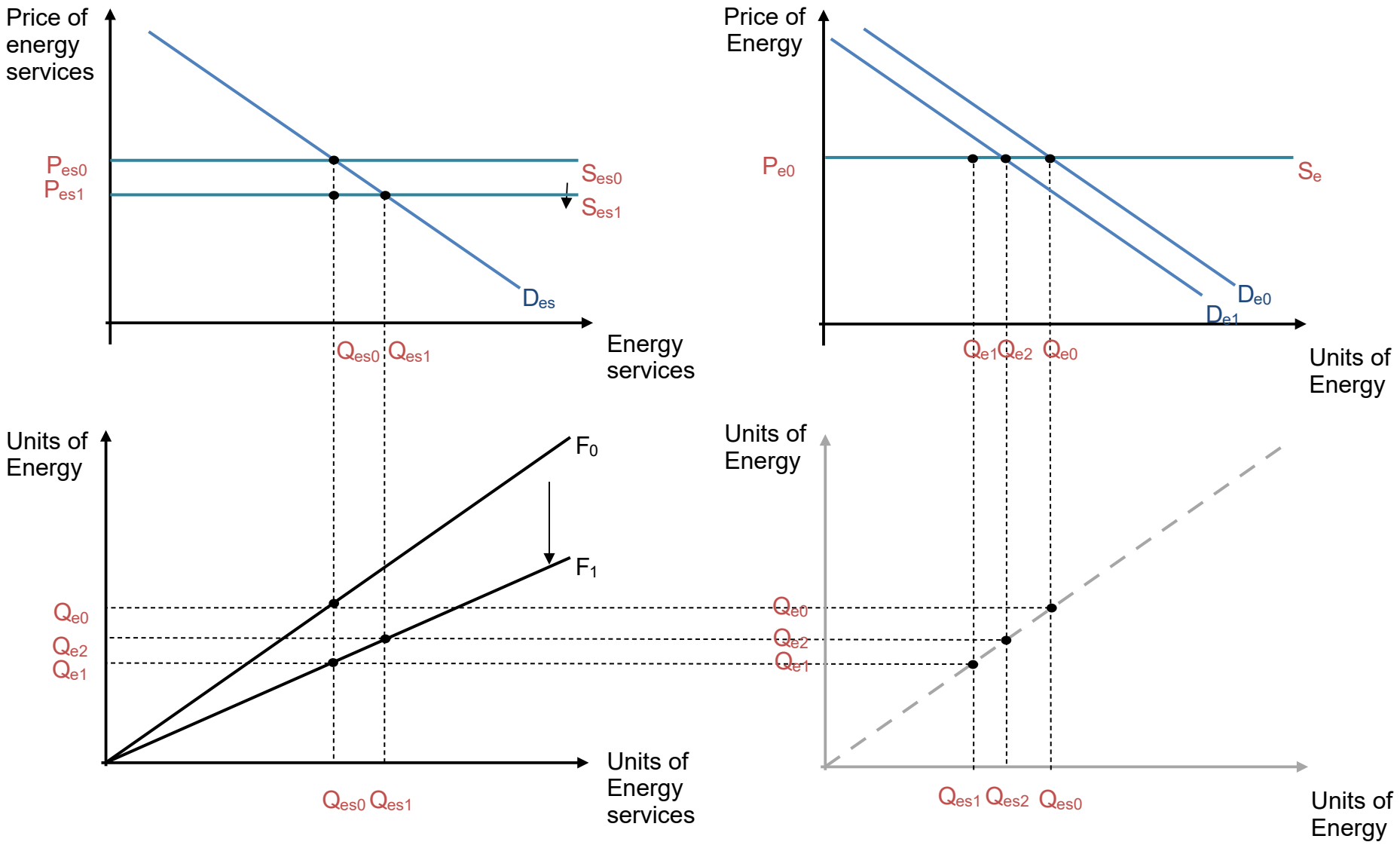
Initial equilibrium

8.4. The initial equilibrium price and quantity of energy services is P_{es0} and Q_{es0} respectively in Figure A1. At the initial energy-efficiency, F_0, this is equivalent to Q_{e0} units of energy. Using the 45 degree line for energy (bottom-right), the equilibrium in the energy market can be depicted where the initial demand for energy, D_{e0}, intersects with the supply of energy, S_e. This yields the initial price and quantity for energy, P_{e0} and Q_{e0}.

Impact of an improvement in energy-efficiency

8.5. An improvement in energy-efficiency reduces the amount of energy required to deliver the same level of energy services. Graphically, this can be represented by a fall in the steepness of the energy-efficiency curve from F_0 to F_1. This is equivalent to a reduction in the price of energy services from P_{es0} to P_{es1} given by a shift in the supply of energy services from S_{es0} to S_{es1} (note that energy suppliers do not actually change their supply curves for energy: Se stays the same). Any increase in the equilibrium consumption of energy services stems from the energy-efficiency measure and the shift in the demand curve.

Figure A1: Relationship between energy services/energy with a demand side energy-efficiency measure



8.6. If consumers do not adjust their consumption of energy services following the improvement in energy-efficiency, thus remaining at Q_{es0}, they can enjoy the same level of energy services at a lower price, P_{es1}. Consuming at this level of energy and at this price (Q_{e1}, P_{e0}), however, is not a point on the consumer's new demand curve, D_{e1}[31].

8.7. The fall in the price of energy services results in a move along the demand curve for energy services from Q_{es0} to Q_{es1}. The final energy demand, post-installation of the energy-efficiency measure, can be found at Q_{e2}. The demand curve for energy has shifted from D_{e0} to D_{e1}. Given the flat supply curve for energy, the price of energy, P_e, remains the same throughout.

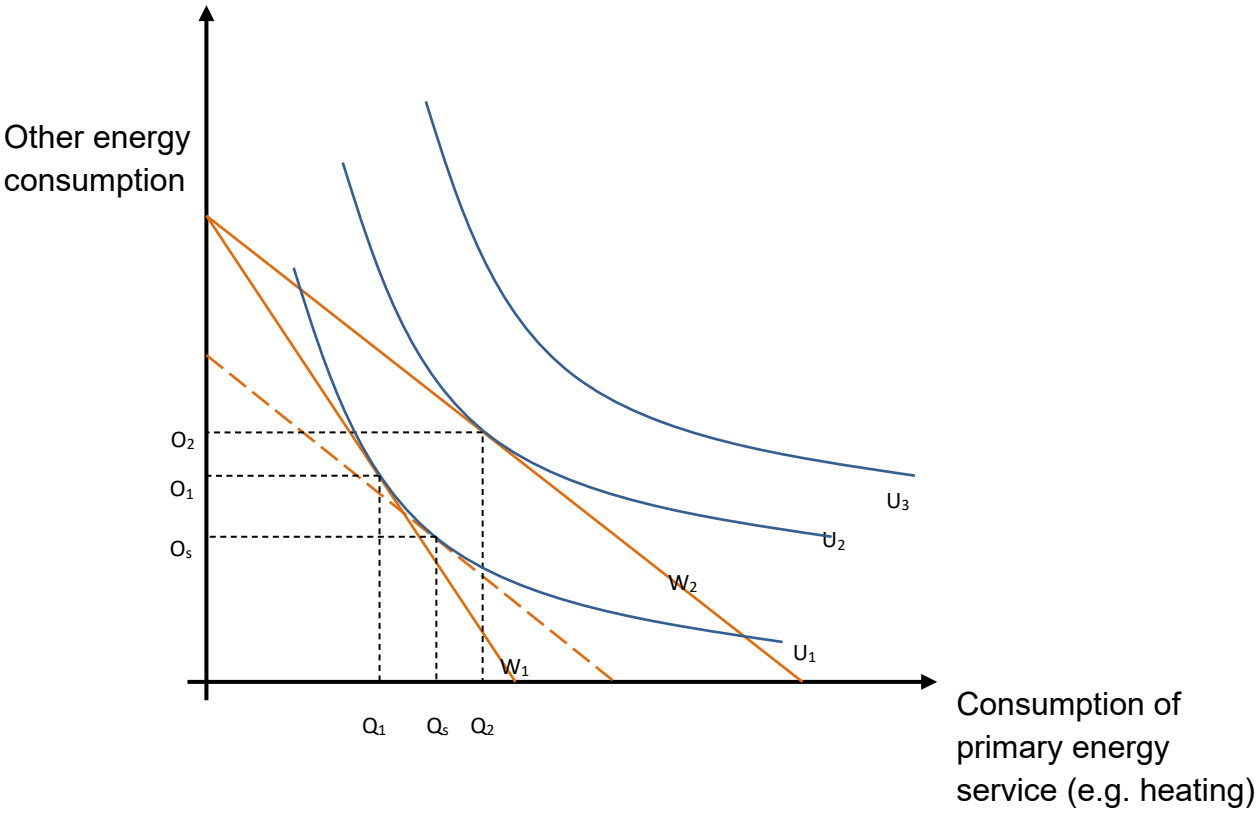
[31] There is no demand curve going through this point because it is not an optimal consumption choice for consumers. A rebound effect due to the change in price of energy services means that consumers will choose to consume more at this price of energy. The only circumstance under which the new demand curve for energy would run through this point is if the demand for energy *services* is completely inelastic. However, we would expect this to be unlikely in most situations.

9. Annex B: Further analysis of rebound effects

The cause of rebound effects

9.1. Figure B1 depicts the direct and indirect rebound effects. Prior to the energy-efficiency installation being made, energy consumption is in equilibrium at (Q_1, O_1). This is the point where the relevant indifference curve[32], U_1, is tangential to the budget constraint W_1. This maximises the representative consumer's utility and is the theoretical optimal choice. Subsequent to the installation being made, two effects occur. First, there is a change in the relative prices of heating services and all other energy-consuming services. This results in a tilt to the budget constraint (the dotted line), and a subsequent substitution effect between heating services and all other energy-related services. This substitution effect comprises two parts: an increase in demand for heating services to Qs and a fall in demand for all other energy-related services to O_s.

Figure B1: Direct and indirect rebound effects



[32] At points on an indifference curve, the consumer is indifferent between the different consumption bundles of goods represented by the curve.

9.2. With the income effect from bill savings, the representative consumer's budget constraint pushes out to W_2. The indifference curve tangent to W_2 is now U_2, giving us a theoretical optimal choice at Q_2, O_2. The overall change in demand for other energy-related services depends on the shape of the indifference curves and the relative prices of the two energy-related services. It is possible that in some circumstances the substitution effect will dominate and the consumption of other energy-related services will fall. Overall, however, this is unlikely to be the case as most energy services are not obvious substitutes.

9.3. In summary, the effects represented in Figure B1 are as follows:

- **Direct rebound effect:** Q_1 to Q_s (substitution effect) to Q_2 (income effect)
- **Indirect rebound effect:** O_1 to O_s (substitution effect) to O_2 (income effect)

9.4. The impact of the indirect rebound effects can be viewed under the same framework as for direct rebound effects. The differences are in the drivers of the rebound and the energy/emissions intensity of the goods consumed. While the income effect will drive both types of rebound effects, the substitution effect induces both direct and indirect rebound effects, which work in opposite directions. If the energy intensity of the good that has fallen in price, which consumers substitute consumption towards, is greater than the energy intensity of the basket of goods that consumers substitute away from, the net effect would be an increase in aggregate energy consumption. As for the income effect, the greater the elasticity of energy demand with respect to income, the greater both types of rebound effects will be, and the further to the right the resulting energy demand curve will be.

Measuring the full impact of the direct rebound effect on consumer surplus

9.5. In practical terms, it is necessary to draw limits when assessing rebound effects. Referring to Figure 3.2, the direct rebound effect is measured for consumers according to their willingness to pay (orange box and green triangle) as approximated by the retail price of energy (orange box). By using the retail price, this excludes a valuation of the consumer surplus (green triangle), which also represents a further improvement in consumer welfare.

9.6. To avoid over-complicating the process, the consumer surplus area (green triangle) can be approximated using the elasticity of the demand curve and the size of the rebound

effect[33]. There are a number of studies that estimate the size of both of these[34], and could be used to inform assumptions made in policy appraisal. In most circumstances however, it is unlikely to be proportionate to quantify this triangle in an appraisal.

9.7. It should be noted that direct rebound effects are not limited to only domestic consumers. For example, energy consuming firms will have a demand curve for energy that reflects the energy consumption level that maximises profit at a given energy price. By installing energy-efficiency measures, firms may produce the existing level of output using less energy. However, they may wish to expand their output to take advantage of the lower input costs. The increase in profit that they would experience would be represented by the area underneath their energy demand curve, which would include the equivalent triangle.

[33] The area of the triangle may be approximated as follows: $A = \frac{1}{2} base \times height = \frac{1}{2}\Delta e \times \Delta p$. The base is equal to the size of the rebound. This may be used with the elasticity of the energy demand curve to estimate the height of the triangle, by rearranging the formula for the elasticity n itself. $n = \frac{\%\Delta e}{\%\Delta p} = \frac{p\Delta e}{e\Delta p}$ (where e is the energy consumption, p is the prevailing energy price, Δe represents the base of the green triangle (or width of the orange box) in Figure 3.2. Therefore, the height of the triangle may be calculated as follows: $\Delta p = n^{-1}\frac{p}{e}\Delta e$

[34] See, for example, Espey and Espey (2004); Madlener and Hauertmann (2011); and Wirl (1997).

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