Europe Economics

Impact of Growth of Data Centres on Energy Consumption

Report prepared by Europe Economics

This project has been supported by the Department for Energy Security & Net Zero

Contents

1 Executive Summary

This report by Europe Economics, commissioned by the Department for Energy Security and Net Zero (DESNZ), examines how the growth of digital services, and the data centres that support them, affects energy consumption in the UK. While digitalisation introduces new electricity demand, it can also displace energy-intensive physical activities.

New methodology developed in study

The study developed a new methodology for estimating the total electricity consumption of digital services relative to credible physical alternatives. The approach considers energy use under a representative scenario for the service delivered to the end-user which is the same for both digital and physical approaches to delivery. In this way, the methodology abstracts away from any increase in activity resulting from digitalisation (e.g. due to cost reductions or the redeployment of labour), and thus compares energy use in a hypothetical world in which digitalisation does not lead to economic growth. This allows policy-makers to isolate the direct energy impacts of digitalisation without these being confused with the additional energy consumption associated with economic growth.

Unlike earlier analyses that often focus on carbon emissions or assess individual system components in isolation, this study offers a comparison focused on energy consumption across the full delivery chain. In the digital case, this includes energy used by data centres (both for IT equipment and for supporting infrastructure), transmission networks, and end-user devices. The analysis of physical alternatives captures energy used (where relevant) in manufacturing, transportation, retail operations, office-based service delivery and end-user devices.

For the **digital cases**, the methodology estimates electricity consumption by disaggregating it into three key components, each modelled using activity-based inputs and assumptions tailored to the specific use case:

- Data centre operations: covering both IT energy used directly in tasks such as processing, storage, and streaming, and non-IT supporting energy, such as cooling and lighting, calculated using a Power Usage Effectiveness (PUE) uplift.
- Internet transmission: energy required to transfer data between data centres and end-users, calculated using energy intensity values per gigabyte transmitted via fixed broadband.
- End-user devices: estimated based on device type and active usage time.

The digital methodology makes a distinction between two types of processes. Shared processes, like uploading content or storing data within data centres, have their energy use divided among multiple users. In contrast, user-specific processes, such as streaming or downloading, are attributed entirely to the individual user.

For **physical alternatives**, the methodology differs according to the type of service replaced:

- Manufactured products: UK energy consumption is measured across the delivery chain. We distinguish between UK-based production (in which case, energy use covers all stages from manufacturing to retail) and overseas manufacturing. For overseas manufacturing, the analysis includes only energy consumed within the UK, while energy used in overseas production and non-UK logistics is not included. The analysis accounts for both electricity and fossil-fuel energy, and includes decarbonised scenarios in which fossil fuels are replaced with electricity.
- Office-based services: electricity use is estimated based on the duration of the task and average office energy consumption per worker, incorporating lighting, heating, cooling, and office equipment. Internet transmission and end-user device energy are also included.

We also carry out sensitivity analyses using low, medium and high energy assumptions to explore uncertainty in our estimates (e.g. caused by variations in the energy-efficiency performance of infrastructure).

The methodology is designed to be as generic and widely applicable as possible, thus enabling it to be applied to a wide range of digital use cases in further research.

Selection of Case Studies

To validate the methodology developed in this study, we applied it to three use cases. We selected use cases that are associated with clear and well-defined physical alternatives, allowing for like-for-like energy comparisons. The criteria for selecting these use cases were:

- **Clear Contributor to Growth of Data Centres**: The use cases are representative examples from within a wider category of data centre use which clearly contributes to the growth of data centres.
- **Clear Physical Counterfactual**: Each has a well-defined physical alternative, allowing for direct, like-for-like energy comparisons.
- **Data Availability**: There is sufficient data available for both the digital and physical scenarios.
- **Analytical Tractability**: The selected use cases are feasible to analyse within the project's scope, avoiding unnecessary complexity.
- **AI Inclusion**: At least one use case involves AI, reflecting its growing importance as a driver of data centre energy demand.

Based on these criteria, we selected the following three use cases:

- Video streaming versus Blu-ray discs
- Ebook reading (as an example of electronic publishing) versus printed books
- AI-powered translation (as an example of an AI application) versus human translation

Findings of test cases

For each use case, we calculated energy consumption under low, medium, and high assumptions.

The results show that in all three use cases, the digital option either matches or substantially undercuts the electricity use of the physical alternative:

Video streaming and **Blu-ray** viewing are relatively close in term of electricity consumption. In the central scenario, streaming uses slightly less electricity than a UK-manufactured Blu-ray. However, if the Blu-ray is manufactured overseas, physical delivery results in lower UK energy use, reflecting the fact that much of the production energy is consumed abroad. The use of decarbonised fuels in the physical chain increases electricity use within the UK.

Ebooks consistently consume less electricity than printed books. Even when books are manufactured overseas, UK-based energy use remains 100–200 times higher than that of a typical e-reader download. When books are printed in the UK using decarbonised fuels, overall electricity use in the UK rises further.

AI translation offers the most dramatic contrast. Electricity use for a single AI-powered translation task remains below 0.05 kWh in all scenarios, while the same task carried out by a human translator in an office consumes over 60 kWh in the central case, and more than 120 kWh in the high case.

The table below summarises total UK electricity consumption for each use case under low, medium, and high assumptions, including for both standard and “decarbonised” physical scenarios.

Table 1.1: UK electricity consumption by use case and scenario (KWh)

Use case	Scenario	Low	Medium	High
Video Streaming	Digital	0.65	1.05	1.67
	Physical (UK manufacture)	0.76	1.13	1.69
	Physical (Overseas manufacture)	0.40	0.66	1.13
	Physical (UK, Decarbonised)	0.84	1.23	1.82
	Physical (Overseas, Decarbonised)	0.42	0.69	1.16
ebook	Digital	0.003	0.003	0.005
	Physical (UK manufactured)	3.32	5.16	7.00
	Physical (Overseas manufactured)	0.30	0.60	0.90
	Physical (UK, Decarbonised)	4.48	6.95	9.43
	Physical (Overseas, Decarbonised)	0.38	0.75	1.13
AI Translation	Digital	0.001	0.006	0.021
	Physical (UK-based)	29.40	62.79	121.10

Source: Europe Economics analysis.

Policy implications and recommendations for further research

Our results provide some initial evidence that digitalisation can contribute to achievement of net zero, by reducing electricity consumption in the UK compared with physical counterfactuals for a given level of activity (in the case of ebooks and AI translation).

However, a major limitation of the study for the purpose of drawing policy conclusions is that it only covers three examples out of the many uses cases that exist for data centres. It is unclear to what extent results from our three use cases can be extrapolated to other uses of data centres.

To allow more robust policy conclusions to be drawn, we would therefore recommend that DESNZ extends this research by commissioning further work to apply the methodology that we have developed to a greater number of use cases.

To support this recommendation, we have identified a provisional list of additional digital use cases to analyse. These additional use cases were chosen as representative examples from each of the main categories of current or future data centre usage (as set out in Appendix A). They cover rapidly evolving areas such as AI, as well as more mature technologies like cloud computing and digital media, alongside established applications in telecommunications, financial services, and healthcare. The selection of specific examples within each category of data centre use was based on identifying use cases that have clear physical alternatives, as well as taking account of whether data are likely to be available and whether the use case is likely to be feasible to analyse. Based on these considerations, we propose the following provisional list of additional digital use cases for consideration:

- Cloud gaming
- Online education platforms
- AI for 2D illustrations
- AI customer support
- Software as a service (SaaS) for office workers
- Video conferencing
- Online bank transfers
- Cloud backups for companies
- Digital journal databases
- Virtual doctor’s appointments
- Online tax return
- Smart meters
- Music streaming

2 Introduction

2.1 Objective of Research

Europe Economics has been commissioned by DESNZ to examine the impact of data centre growth on overall energy consumption, considering not only the energy required to deliver digital services, but also the energy avoided by no longer delivering those services through physical means.

In this study, we have developed a methodology for quantifying the net energy implications of digitalisation, by comparing energy use under a digital scenario with that of a credible physical counterfactual. The comparison is based on a representative scenario for the service delivered to the end-user which is the same for both digital and physical approaches to delivery. In this way, the methodology abstracts away from the increased activity that may result from digitalisation (e.g. due to increased demand as the cost of the activity falls, or due to the reallocation of labour to other productive activities). This allows for a clearer assessment of the direct energy implications of digitalisation, separate from its wider impact on economic growth. Whereas previous analyses have typically focused on carbon emissions or examined individual components in isolation, our methodology provides a comprehensive means of comparing energy use across the full delivery chain — spanning data centres, transmission networks, and end-user devices in the digital case, and covering (where relevant) manufacturing, transportation, retail consumption, office-based service delivery and end-user devices in the physical case.

We have tested out our methodology by applying it to three use cases (discussed below). These use cases serve to illustrate how energy demand can be affected by digitalisation. They also demonstrate that our methodology can be applied successfully across a range of digital activities. Looking ahead, the same methodology could be used to evaluate additional use cases to provide a fuller picture of the impact of digitalisation on energy use.

2.2 Our three selected use cases

We selected three use cases that are associated with clear and well-defined physical alternatives, allowing for like-for-like energy comparisons. The criteria for selecting these use cases were:

- **Clear Contributor to Growth of Data Centres**: The use cases are representative examples from within a wider category of data centre use which clearly contributes to the growth of data centres.
- **Clear Physical Counterfactual**: Each has a well-defined physical alternative, allowing for direct, like-for-like energy comparisons.

- **Data Availability**: There is sufficient data available for both the digital and physical scenarios.
- **Analytical Tractability**: The selected use cases are feasible to analyse within the project's scope, avoiding unnecessary complexity.
- **AI Inclusion**: At least one use case involves AI, reflecting its growing importance as a driver of data centre energy demand.

Based on these criteria, we selected the following three use cases:

- Video streaming versus Blu-ray discs
- Ebook reading (as an example of electronic publishing) versus printed books
- AI-powered translation (as an example of an AI application) versus human translation

We briefly outline these use cases below.

Video Streaming versus Blu-ray

Video streaming is one of the most data-intensive and widely adopted uses of data centres, supporting platforms that deliver entertainment and educational content to users on demand. This use case involves the real-time delivery of video over fixed-line broadband to a home television, displacing physical alternatives such as DVDs or Blu-ray discs. It was chosen because it exemplifies high-volume content delivery and provides insight into the relative energy costs of ongoing digital access versus one-off physical distribution.

eBooks versus physical books

The ebooks use case examines the digital consumption of long-form text content, such as a novel, via dedicated e-readers. It was selected as an example of electronic publishing, which is a clear contributor to the growth of data centres. This scenario replaces the purchase or use of a printed book, and hence allows for a clear comparison with traditional, physical media.

AI translation versus human translator

This use case models the use of cloud-based artificial intelligence to translate documents, substituting for translation services provided by human professionals working in office environments. It was selected because it captures the energy use associated with AI workloads, including training and inference, which are expected to account for a growing share of data centre activity. It also represents a use case where the digital alternative may offer substantial efficiency gains, particularly when scaled across many users. The analysis quantifies energy use across data centre processes, transmission, and end-user access, and compares this to the energy associated with office-based translation work.

2.3 Representative scenario approach

This study adopts a **representative scenario approach** as the foundation for estimating and comparing energy consumption across digital services and their physical alternatives. This method involves defining a typical, well-specified instance of service delivery for each use case, based on plausible patterns of use over a realistic period of time. The purpose of this approach is to ensure comparability across digital and physical approaches and thus to provide a meaningful basis for quantifying the impact of digitalisation on energy use.

Rather than relying on aggregated or sector-level data, each scenario reflects the actions of a single user engaging with a specific service under standardised conditions. Parameters such as file sizes, duration of use, number of interactions, and device engagement are explicitly defined and held consistent between digital and physical formats. This ensures that both delivery models are assessed against the same underlying service demand and that energy use is not overstated or understated due to differences in modelling scope or assumptions.

The representative scenarios also establish a fixed analytical timeframe to account for differences in the lifespan and reuse potential of physical products. By applying a uniform time horizon, the analysis captures the cumulative energy impact of both one-off and repeated energy usage.

2.4 Structure of Report

The report is structured as follows:

- Section 3 outlines our methodology for estimating energy consumption in digital use cases. It includes a high-level modelling framework, generic input assumptions applicable across use cases, and specific assumptions for video streaming, ebooks, and AI translation.
- Section 4 sets out our methodology for estimating energy consumption in the physical counterfactuals. It distinguishes between manufactured products (Blu-rays and printed books) and office-based services (human translation), and presents the relevant input assumptions for each.
- Section 5 presents our results, comparing energy consumption across digital and physical scenarios for each of the three use cases. Results are presented for each scenario and use case, followed by a comparative assessment.
- Section 6 summarises insights from stakeholder engagement, including the approach taken and key themes identified through interviews with data centre operators, industry experts, and use-case-specific stakeholders.
- Section 7 provides our preliminary conclusions.

3 Methodology for Modelling Energy Consumption in Digital Use Cases

This chapter outlines the methodology used to model energy consumption for the digital use cases. It begins by presenting the overall structure of the analytical approach, followed by a discussion of the generic input assumptions underpinning the key stages of energy use. The section then sets out the specific assumptions applied to each of the three digital use cases: video streaming, ebooks, and AI translation.

3.1 Overview of the generic modelling framework

This section outlines the approach used to estimate energy consumption for use cases in which a service is delivered via digital means. The framework captures three key components of electricity demand:

- the energy consumed within data centres, covering both IT and supporting non-IT infrastructure;
- the energy required to transmit data over internet networks; and
- the electricity consumed by the end-user's device when accessing the service.

The analysis is grounded in a **representative scenario,** which defines the parameters of the activity under consideration (e.g. the size of the file being processed, the number of times the service is used, and the duration of end-user interaction). These parameters are used consistently across both digital and physical scenarios to ensure comparability.

Data Centre Energy Consumption

Energy consumption within the data centre is estimated by **identifying the relevant IT processes involved in delivering the service,** such as uploading data, storage, AI inference, and content streaming, and multiplying the volume of each process (e.g. gigabytes, CPU-hours, or floating-point operations) by assumed energy intensities. These intensities represent the energy required to complete one unit of each process.

Where applicable, the framework distinguishes between **shared and user-specific processes.** Shared processes (e.g. long-term storage or AI training) are used by multiple users, and only a proportion of the total energy is attributed to the representative user. This proportion is calculated based on the assumed user base. In contrast, user-specific processes (e.g. AI inference or downloading a file) are allocated fully to the representative user.

Once the IT energy is calculated, it is uplifted using standard **Power Usage Effectiveness (PUE)** factors to reflect the additional non-IT energy required to operate the data centre. This includes energy for cooling, power distribution, lighting, and other building services. The result is a combined estimate of IT and non-IT data centre energy attributable to the representative user.

Internet Transmission

Energy used in internet transmission is calculated by applying **fixed energy intensity assumptions (kWh per gigabyte transmitted)** to the volume of data transferred in the representative scenario. As with data centre energy, transmission processes are categorised as either shared or specific. For instance, data uploads may be shared across users in some use cases, while downloads are typically treated as user-specific. Where transmission is shared, only a proportional share of energy is attributed to the representative user.

End-User Device Energy

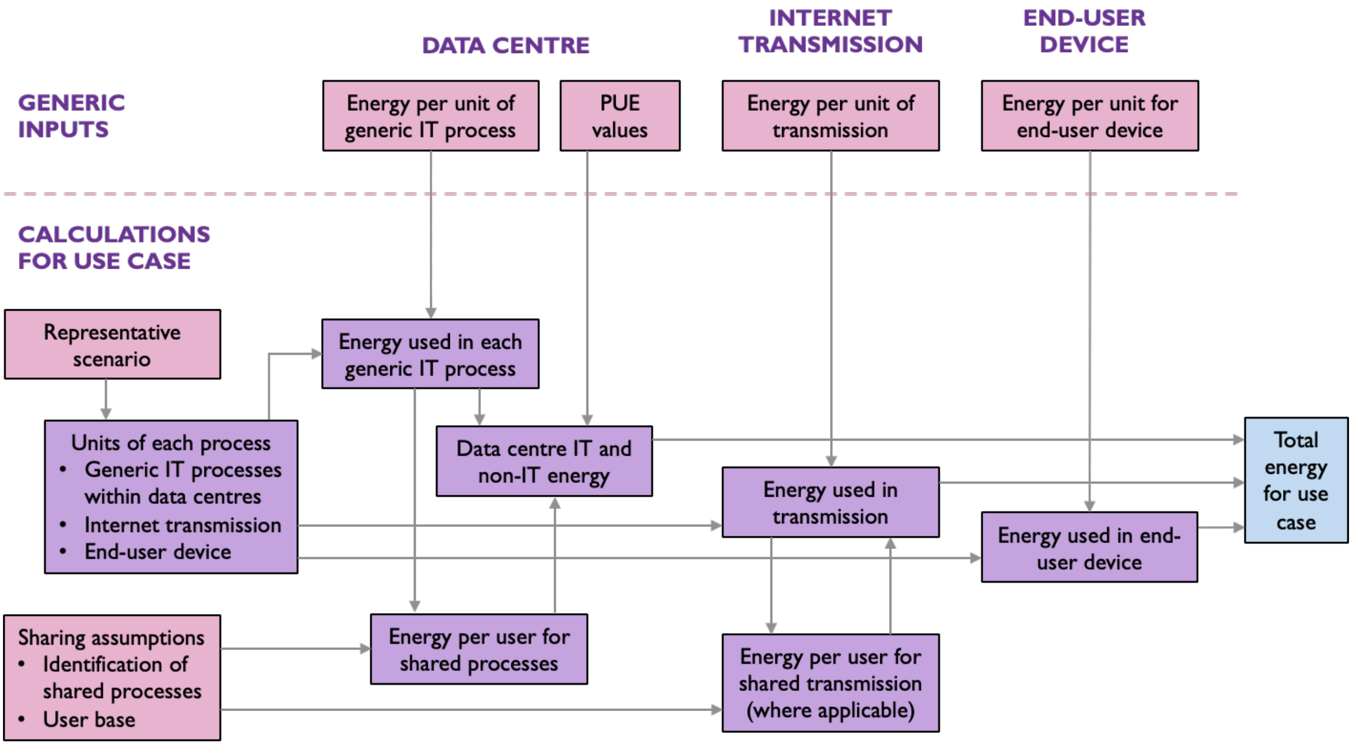
The final component captures the electricity used by the end-user device when interacting with the digital service. This includes the energy consumed when submitting or retrieving data, such as uploading a document or watching a streamed video. The device type (e.g. desktop computer, television, or e-reader) and usage time are defined in the representative scenario. Energy use is then estimated by multiplying the device's power draw by the number of hours (or minutes) of use.

Total Energy Consumption

The total energy consumption for the digital use case is calculated by summing the three components: data centre energy (IT and non-IT), internet transmission, and end-user device consumption. This approach enables a consistent and transparent comparison with the energy demands of physical service delivery (discussed in the next section of this report).

The figure below provides an overview of the overall modelling framework, illustrating how generic inputs and case-specific parameters flow through to produce energy estimates for each digital use case.

Figure 3.1: Modelling framework for estimating energy consumption in digital use cases



In the following sections, we set out the input assumptions that we used in the modelling. In some cases, we identified a source for input assumptions (e.g. from the literature). In cases where we did not find a source, we used artificial intelligence to generate reasonable values to use.[1]

3.2 Generic input assumptions

In this section, we set out the input assumptions underpinning the three main stages of energy consumption in our digital use case modelling: **data centre operations, internet transmission**, and **end-user devices**.

All energy consumption values per process for digital use cases reflect are intended to represent conditions as of 2024, based on the most recent available data. Where necessary, earlier estimates have been extrapolated using efficiency improvement trends specific to each process, to reflect expected conditions as of 2024.

3.2.1 Data Centre

This section sets out the input assumptions for each data centre process relevant to our digital use case modelling. It includes descriptions of the processes involved, the units used to quantify each activity, and the energy intensities applied in our calculations.

[1] This was done by prompting ChatGPT to provide values. Typically, we used the Data Analyst GPT developed by ChatGPT for this purpose, as it has been specifically developed for the purpose of analysing data.

Uploading to Data Centres

This process refers to the initial intake of content into the data centre environment. It involves handling data as it enters the system, verifying and formatting it as needed, and writing it to internal storage for subsequent processing or access. In addition to the computational resources required to manage file handling and storage allocation, this process also consumes energy associated with network interfacing, including routing, switching, and load balancing, to ensure reliable transfer and distribution within the data centre.

We assume a median energy intensity of **0.02 kWh per GB** for uploading data to a data centre, with low and high values of **0.015 kWh per GB** and **0.03 kWh per GB**, respectively.

Video Processing

For use cases involving video content, processing includes tasks such as encoding, decoding, format conversion, compression, and, where applicable, high dynamic range (HDR) enhancement. These processes are necessary to optimise video for delivery and playback across diverse end-user devices and network conditions. They are computationally intensive and typically rely on high-performance graphical processing units (GPUs) and specialised hardware accelerators, such as application-specific integrated circuits (ASICs) and field-programmable gate arrays (FPGAs).

We assume a median energy intensity of **0.4 kWh per GB** for video processing, with low and high values of **0.1 kWh per GB** and **1 kWh per GB**, respectively.

Long-Term Storage

Digital services require the persistent storage of content that may be accessed repeatedly over time or archived for future retrieval. Long-term storage involves writing data to stable, non-volatile systems and maintaining its integrity over extended periods. This process is less computationally demanding than active processing tasks but still contributes significantly to overall energy use due to the sheer volume of stored content and the energy required to keep storage systems powered and cooled. Typical infrastructure includes hard disk drives (HDDs) and solid-state drives (SSDs) arranged in storage arrays, as well as tape drives for deep archival storage where infrequent access is expected.

We estimate the energy cost of long-term data storage based on specifications reported in the **2024 U.S. Data Centre Energy Usage Report**, which provides updated figures on average drive capacities and power consumption for both HDDs and SSDs.[2] To derive annual energy use, we calculate the watts-per-terabyte (W/TB) coefficient for each device type by dividing power draw by storage capacity. For HDDs, a typical 21 TB drive drawing 6.5 W yields a coefficient of 0.31 W/TB, while for SSDs, a 10 TB drive drawing 9 W yields 0.9 W/TB. These values are then converted to annual energy use by multiplying by the number of hours in a year and scaling to per-gigabyte figures. Based on this approach, we estimate the annual energy cost of long-term storage to be **approximately 0.0025 kWh per GB for HDDs (our**

[2] Berkeley Lab (2024) “2024 U.S. Data Centre Energy Usage Report” [online]

low estimate), 0.008 kWh per GB for SSDs (our high estimate), and **0.005 kWh per GB as a central estimate.**

RAM Storage

RAM storage supports high-speed, short-term data retention during active computation. Unlike long-term storage, which focuses on persistence, RAM storage enables fast read/write operations to support real-time processes such as streaming, AI inference, or complex queries. This form of memory is essential for buffering, caching, and holding transient datasets during computation. The primary components involved are dynamic random-access memory (DRAM) modules embedded in servers, alongside high-speed cache memory such as static RAM (SRAM). These systems typically remain powered continuously, and their energy use is closely linked to processing workloads.

To estimate the energy consumption associated with RAM storage, we draw on data referenced by the Cloud Carbon Footprint initiative, which compiles power usage figures from leading memory manufacturers.[3] It is assumed that hyperscale cloud providers predominantly use efficient memory technologies such as DDR4 or DDR5. Two manufacturers, Crucial and Micron, provide indicative power draw estimates for DDR4 memory modules. Crucial reports a usage of 3 watts per 8 GB, equivalent to approximately 0.375 W/GB, while Micron estimates a draw of 0.4083 W/GB. Taking the average of these two values, we adopt a working assumption of 0.392 watts per GB of RAM. Converting this to energy over time, we estimate RAM-related energy use at **0.000392 kWh per GB-hour**. The **low and high estimates** are **0.000375 kWh/GBh** (Crucial) and **0.000408 kWh/GBh** (Micron), respectively.

General Processing

General processing encompasses a broad range of routine computational tasks that are not specific to media encoding or AI applications. These may include metadata handling, indexing, basic logic and arithmetic operations, system monitoring, and background services that maintain the integrity and responsiveness of digital services. These functions are typically handled by general-purpose central processing units (CPUs) hosted in conventional data centre servers. While less specialised than other processes, general processing contributes a significant share of total compute demand, especially in services involving document access, transactions, or coordination between multiple systems.

We assume a median energy intensity of **0.5 kWh per CPU-hour** for general processing, with low and high values of **0.2 kWh per CPU-hour** and **1.5 kWh per CPU-hour**, respectively.

AI Training

AI training is a specialised and highly energy-intensive process involving the development of machine learning models from large datasets. This involves executing complex operations across numerous iterations, requiring prolonged and sustained compute cycles. The infrastructure for this process includes graphics processing units (GPUs), tensor processing units (TPUs), or custom-built high-performance computing (HPC) clusters, often located in AI

[3] Carbon Cloud Footprint "Methodology" [online]

training farms. Due to the scale and intensity of training runs, which can span hours or days, this process typically represents one of the highest energy demands within data centre operations.

To estimate the energy required for AI training, we draw on analysis by Shankar and Reuther (2024), who report energy usage in terms of joules per instruction based on benchmarking data from AI accelerators and supercomputers.[4] For our purposes, we treat this as equivalent to energy per floating-point operation (FLOP), since AI training workloads are dominated by floating-point computations.

The authors provide energy estimates for standard formats including FP16, FP32, and FP64, with reported values ranging from approximately 1×10^{-12} joules per FLOP (for low-precision FP16) to 1×10^{-11} joules per FLOP (for high-precision FP64). Converting to microjoules, this corresponds to a **low estimate of 1×10^{-6} μJ/FLOP, a high estimate of 1×10^{-5} μJ/FLOP,** and **a medium estimate of 5.5×10^{-6} μJ/FLOP,** based on the midpoint of the reported range.

AI Inference

Once a machine learning model has been trained, it can be deployed to perform inference, that is, using new inputs to generate outputs, such as a translated sentence or object detection in a video. While less computationally demanding than training, inference still requires rapid execution and low latency, especially when used in real-time applications. It is typically supported by inference accelerators, including lightweight GPUs, TPUs, or edge computing devices embedded in local or cloud infrastructure.

For the purposes of this study, we assume that the underlying compute operations and associated infrastructure are similar in energy intensity to those used in training. Accordingly, we adopt the same energy-per-FLOP estimates as those used for AI training, drawing on Shankar and Reuther (2024). These are: **1×10^{-6} μJ/FLOP (low), 5.5×10^{-6} μJ/FLOP (medium), and 1×10^{-5} μJ/FLOP (high).**[5]

Downloading / Streaming

Downloading and streaming involve retrieving stored content from data centre storage systems and delivering it to the end user. This process includes internal content access, data routing, and network interfacing tasks that ensure the requested content is assembled and transmitted

[4] Shankar, S., & Reuther, A. (2022, September). Trends in energy estimates for computing in ai/machine learning accelerators, supercomputers, and compute-intensive applications. In *2022 IEEE High Performance Extreme Computing Conference (HPEC)* (pp. 1-8). IEEE. [online]

[5] These figures are supported by our calculations from a separate study on AI model inference, which produced a comparable upper-bound estimate. The analysis considered a typical ChatGPT (GPT-4o) response of 500 tokens. approximately 375 words, which was estimated to require 100 trillion FLOPs, based on 100 billion active parameters and an assumed 2 FLOPs per parameter per token. The energy consumption to generate this response was estimated at 0.3 watt-hours, equivalent to 1,080 joules. Dividing energy by FLOPs yields an energy intensity of 1.08×10^{-11} joules per FLOP, or 1.08×10^{-5} μJ/FLOP. This aligns closely with the upper range of our estimates. It is important to note that this calculation is based on inference using Nvidia H100 GPUs with ~10 per cent utilisation and ~70 per cent of peak power draw, which may be higher than typical inference scenarios. However, as ChatGPT is a high-end deployment of AI inference, we consider it appropriate to benchmark the high end of our range using this approach. [online]

correctly. Although much of the energy cost of transmission lies in external networks, the intra-data-centre activity involved in serving content is non-trivial.

We assume a median energy intensity of **0.015 kWh per GB** for downloading or streaming data from a data centre, with low and high values of **0.01 kWh per GB** and **0.02 kWh per GB**, respectively.

Table 3.1: Energy per unit of generic IT process

Data process	Units	Low	Medium	High
Uploading to Data Centres	kWh per GB uploaded	0.015	0.02	0.03
Video Processing	kWh per GB processed	0.1	0.4	1
Long-term storage	kWh per GB stored per year	0.0025	0.005	0.008
RAM storage	kWh per GB stored in RAM per hour	0.000375	0.000392	0.000408
General processing	kWh per CPU-hour	0.2	0.5	1.5
AI Training	µJ per FLOP	0.000001	0.0000055	0.00001
AI Inference	µJ per FLOP	0.000001	0.0000055	0.00001
Downloading/Streaming	kWh per GB downloaded/streamed	0.01	0.015	0.02

Source: Multiple sources, Europe Economics analysis

Power Usage Effectiveness (PUE) values

PUE is a widely used industry metric that quantifies the ratio between the total energy consumed by a data centre and the energy consumed directly by its IT equipment. It reflects the efficiency of the non-IT infrastructure, such as cooling, lighting, and power conversion systems, and is used to assess how effectively data centres manage their supporting energy loads relative to core computing tasks.

In our modelling, we apply PUE values to uplift the estimated IT energy consumption to derive total data centre energy consumption. Specifically, for each use case and scenario, we multiply the IT energy figures by the relevant PUE value. This ensures that the total energy consumption of data centre reflects not only the direct computational effort, but also the supporting energy services required to maintain operations.

In line with stakeholder input and broader evidence from industry and academic sources, we apply the following PUE values across our low, medium, and high scenarios:

- **Low scenario –1.1**: Reflecting best-in-class performance typically achieved by newly built hyperscale data centres. These centres are often owned and operated by major cloud providers (e.g. AWS, Google, Microsoft) and benefit from extensive in-house optimisation and highly efficient cooling systems. Stakeholders noted that such values are already being achieved by many new hyperscale facilities, and the UK’s moderate climate may make such performance more achievable than in warmer regions.
- **Medium scenario – 1.3**: Represents the industry’s current convergence point, consistent with recent trends and targets. This value reflects the typical performance of

new or recently upgraded data centres that comply with voluntary efficiency standards such as the European Code of Conduct for Data Centre Energy Efficiency or the Carbon Neutral Data Centre Pact.[6] Many stakeholders also highlighted that 1.3 is broadly viewed as a sector-wide target and is increasingly common among large and mid-sized operators.

- **High scenario – 1.5**: Corresponds to less efficient legacy facilities, particularly smaller co-location centres that may not yet have undergone major infrastructure upgrades. These centres often serve a variety of clients with diverse operational needs, making holistic optimisation more difficult. Stakeholders noted that while some older centres still operate at or above this level, there is growing pressure to bring these into alignment with industry targets.

Table 3.2: Ranges of PUE for data centres

	Low	Medium	High
PUE for data centres	1.1	1.3	1.5

Source: Europe Economics analysis of stakeholder views.

3.2.2 Internet Transmission

The next data process is internet transmission, and hence we consider the energy used in moving data from the data centre to the end-user over the internet.

In our modelling, we adopt transmission energy intensity estimates from the Carbon Trust's report on 'The Carbon Impact of Video Streaming', which provides a well-documented approach across fixed and mobile networks.[7] These figures are applied in combination with use case-specific estimates of the data volumes transferred.

The Carbon Trust estimates comprise the total energy use associated with both the core network (which includes national and international backbone infrastructure) and the access network (the local infrastructure connecting users to the internet, such as fibre lines or mobile base stations). These two components are combined into a single aggregate figure for each network type.

For **fixed networks**, we apply an energy intensity of **0.0016 kWh per GB**. This figure is ultimately derived from Aslan et al. (2018), which reviewed a broad range of academic studies and developed a regression model to estimate trends in energy intensity between 2000 and 2015. The Carbon Trust extrapolated these trends forward to 2020 to arrive at the figure used in their analysis, resulting in an energy intensity estimate of 0.0065 kWh per GB. For the purposes of this study, we have further extrapolated these trends to 2024, applying the same rate of annual improvement.

For **mobile networks**, we apply an energy intensity estimate of **0.025 kWh per GB**, also representative of 2024 This is based on Pihkola et al. (2018), which combined reported energy

[6] Interview with Loughborough Business School (February 2025). Loughborough Business School highlighted the Climate Neutral Data Centre Pact, which supports the view that industry is converging towards a PUE of 1.3.
[7] Carbon Trust (2021) "Carbon impact of video streaming" [online]

consumption from Finnish mobile network operators with national data traffic figures. Carbon Trust used regression analysis to estimate the implied energy intensity for mobile networks in 2020, arriving at a figure of 0.1 kWh per GB. For the purposes of this study, we have further extrapolated these trends to 2024, applying the same rate of annual improvement.

In addition to the transmission network, the Carbon Trust includes an estimate for the energy consumed by home Wi-Fi routers, which will only apply in cases in which the end-user uses fixed networks (rather than mobile networks). The figure adopted is **0.025 kWh per GB**, based on the annual energy consumption of a 10W router and average fixed network data consumption per capita in 2019, as published by Ofcom (2020).

We apply median values for energy intensity per GB based on Carbon Trust estimates, with separate figures for fixed and mobile networks. For sensitivity analysis, we assume a **± 20 per cent range** to generate low and high values. These figures are used to estimate transmission-related energy use based on whether data is transferred via fixed or mobile networks. The components and total for each network type are summarised in the table below.

Table 3.3: Energy consumption of transmission (kWh/GB)

Network Type	Component	Low	Medium	High
Fixed	Core + Access	0.00128	0.0016	0.00192
	Home	0.02	0.025	0.03
	Total – Fixed Network	**0.02128**	**0.0266**	**0.03192**
Mobile	**Core + Access**	**0.020**	**0.025**	**0.030**

Source: Carbon Trust (2021), Europe Economics analysis.

3.2.3 End-User device

The final component of energy consumption in digital use cases relates to **end-user devices**, which are responsible for rendering, displaying, or interacting with digital content depending on the nature of the service. These include both primary screen devices, such as TVs, e-readers, laptops, and smartphones, and supporting peripherals, such as set-top boxes. In line with the Carbon Trust's report on the carbon impact of video streaming, we estimate the energy use of these devices based on average hourly power draw, using values that represent typical performance for commonly used models.

We used the Carbon Trust report as a starting point for estimating the energy consumption of end-user devices. The figures in the Carbon Trust report were derived through a review of publicly available technical specifications and industry benchmarks, combining manufacturer data with secondary analysis. Where appropriate, we have reviewed these figures against more recent data for UK consumer devices to ensure they remain representative. Where the Carbon Trust values remain consistent with current device specifications, we retain them; where updated figures indicate a material difference, we apply revised estimates.

For **smartphones**, we retain the Carbon Trust's estimate of an average power draw of **1W**, based on analysis of models such as the Samsung Galaxy S9 and Apple iPhone. For **TVs**, we also retain the Carbon Trust figure of **115W**, based on data from Singh et al. (2019), which captures both the computing device and associated monitor use.

For other devices, such as desktop computers, TVs, set-top boxes, and Wi-Fi routers, we have reviewed available technical specifications for UK consumer devices and apply updated values where needed. Specifically:

- **Laptops** consume between 30W and 70W during active use, depending on the model and workload.[8] We adopt a medium estimate of **50W**, which provides a reasonable benchmark for typical energy consumption. The figure is supported by the Centre for Sustainable Energy, which notes that a typical laptop draws around 50W when in operation. [9]
- **Desktop computers** typically consume more power than laptops. General-purpose desktops tend to draw between 100W and 200W during active use, while energy use ranges from 200W to 500W for larger or gaming-oriented models.[10] We adopt a medium estimate of 140W, which the Centre for Sustainable Energy cites as representative of a typical desktop computer's power draw.
- On average, **set-top boxes** consume between 9.5W and 21.8W when in full operation, depending on the model and activity (e.g. standard viewing, HD/4K streaming, or recording).[11] We use a medium estimate of **15W**, which is the midpoint in this range and reflects typical in-use conditions.
- For **e-readers**, we use an estimate based on the Amazon Kindle Paperwhite. Using Amazon's battery life figures, and assuming low brightness and Wi-Fi off, we estimate average energy use during reading to be **0.26W**. This reflects typical usage patterns such as 30 minutes of reading per day over several weeks.[12]
- For **Blu-ray players**, we assume an average power draw of **40W**, based on data from the Centre for Sustainable Energy. This reflects typical in-use energy consumption when playing physical media.

To reflect uncertainty and variability across device models and user behaviour, we include low and high around the median estimates. These power draw values are then combined with representative usage durations (e.g. time spent streaming) to calculate total device-level energy consumption per scenario

[8] Energysage (2024) "How many watts does a computer use?" [online]
[9] Centre for Sustainable Energy (2025) [online]
[10] Energysage (2024) "How many watts does a computer use?" [online]
[11] BT "Power and energy consumption of the EE TV boxes" [online]
[12] Mirković, Ivana Bolanča, and Zdenka Bolanča. (2024) "Calculation of the carbon footprint of books and E-readers through the stages of the product life cycle." [online]

Table 3.4: Energy consumption for core devices (kWh/hour)

Device type	Low	Medium	High
Smartphone	0.0005	0.001	0.002
Desktop computer	0.1	0.14	0.2
Laptop	0.03	0.05	0.07
TV	0.05	0.1	0.2
ebook reader	0.0001	0.0026	0.0005

Source: Carbon Trust (2021), Europe Economics analysis.

Table 3.5: Energy consumption for additional devices (kWh/hour)

	Low	Medium	High
Set Top Box	0.01	0.015	0.022
Blu-ray player	0.03	0.04	0.05

Source: Carbon Trust (2021), Europe Economics analysis.

3.3 Specific input assumptions for our three cases

This section then sets out the specific assumptions applied to each of the three digital use cases: video streaming, ebooks, and AI translation.

3.3.1 Video-streaming

This digital use-case represents a typical user streaming video content to a television via a fixed-line broadband, without the use of a set-top box.

Network Transmission and End-User Configuration

We assume that streaming takes place over a **fixed-line network**, which determines the relevant energy intensity for data transmission. The viewing device is a **television**, selected to reflect typical behaviour for watching longer-form content such as films or series. No additional hardware (e.g. set-top box) is included in the scenario.

Process Attribution – Shared versus Specific

Most **upstream processes** in the data centre are assumed to be **shared across the user base**, including content uploading, video processing (e.g. encoding, compression), and long-term storage. These processes typically occur once per item of content and benefit from economies of scale as they support multiple users. By contrast, **RAM storage for caching and downloading/streaming are treated as user-specific**, reflecting the per-user nature of these operations.

A similar distinction is made for transmission: upload transmission is considered a shared process (as content is uploaded once), while download transmission is specific to the end-user.

User Base Assumptions for Shared Allocation

To allocate energy use for shared processes, we define the user base in terms of total hours of video content viewed during the period of the representative scenario. For the central case, we assume the content is viewed 1,000,000 times. A larger user base results in a smaller share of upstream energy being attributed to each viewing instance, and hence we assume a larger user base of 5,000,000 views in our low scenario. Conversely, we assume a smaller user base of 500,000 views in our high scenario.

RAM Caching During Playback

We assume that **10 per cent of the video file is cached in RAM during playback**, representing short-term memory buffering typically used in streaming platforms to ensure smooth delivery.

The tables below summarise our input for the video streaming digital use-case.

Table 3.6: Configuration assumptions for the video streaming digital use case

	Assumption
Network type	Fixed-line broadband
End-user device	Television
Use of set-top box?	No
Shared processes	Uploading to data centres, video processing, long-term storage, upload transmission
User-specific processes	RAM storage, downloading/streaming, download transmission

Source: Europe Economics analysis.

Table 3.7: User base and RAM caching assumptions

	Unit	Low	Medium	High
User base for shared allocation (hours of video viewed)	Hours	5,000,000	1,000,000	500,000
RAM catching	Percentage	10	10	10

Source: Europe Economics analysis.

3.3.2 ebook

This scenario represents a user downloading and reading a digital book on a **dedicated ebook reader** over a **fixed-line broadband connection**. No additional hardware (such as a set-top box) is assumed, and the focus is on a standard single-download, single-reader context.

Network and End-User Configuration

We assume that ebook files are downloaded via a fixed-line internet connection and accessed using an ebook reader (e.g. Amazon Kindle). This reflects a common configuration for digital reading, with the device's energy use governed by efficient e-ink display technology optimised for low power consumption during reading. No other devices are assumed to be involved in the process.

Process Attribution – Shared versus Specific

On the data centre side, uploading to the platform and long-term storage of the file are treated as shared processes, occurring once and serving many users over time. By contrast, downloading the file is treated as user-specific, as it represents the transmission of content to each individual reader. Other data centre processes (such as RAM storage, general processing, or AI-related workloads) are not applicable to this scenario.

Similarly, for internet transmission, we assume that upload transmission is shared, while download transmission is user-specific. This reflects the one-time upload of a document by a publisher or author, compared with repeated downloads by individual users.

User Base Assumptions for Shared Allocation

To allocate energy consumption for shared processes, we define the user base in terms of the total number of downloads during the period of the representative scenario. In the central case, we assume 100,000 downloads, with sensitivity ranges of 500,000 (low scenario) and 10,000 (high scenario) downloads. As with other use cases, a higher number of downloads leads to lower per-user energy allocation for shared infrastructure.

Reading Duration and Speed

We assume that the time taken to read the ebook varies with user reading speed and book length. A range of reading speeds is considered, from 150 to 300 words per minute, with a central case of 250 words per minute. Combined with an assumed text length of 90,000 words for the ebook read in our representative scenario, this results in reading durations ranging from 5 to 10 hours, with a central estimate of 6 hours. These values are used to estimate the total energy consumed by the ebook reader during the reading of the ebook.

The tables below summarise our input for the e-book digital use-case.

Table 3.8: Configuration assumptions for the video streaming digital use case

	Assumption
Network type	Fixed-line broadband
End-user device	ebook reader
Shared processes	Uploading to data centres, long-term storage, and upload transmission
User-specific processes	Downloading/streaming, download transmission

Source: Europe Economics analysis.

Table 3.9: User base and RAM caching assumptions

	Unit	Low	Medium	High
User base for shared processes	Number of downloads	500,000	100,000	10,000
Assumed reading speed	Words per minute	150	250	300
Time to read one e-book	Hours	10	6	5

Source: Europe Economics analysis.

3.3.3 AI translation

This scenario reflects the use of an online AI-powered translation service to translate a document via a desktop computer and fixed-line internet connection. The process involves uploading a document, real-time AI inference for translation, and downloading the translated output. It also accounts for the broader infrastructure and training requirements of the underlying AI model.

Network and End-User Configuration

We assume the user accesses the translation tool on a desktop computer over a fixed-line broadband network, without any additional hardware such as a set-top box. The desktop setup reflects typical usage for the translation of documents, where file upload and download are part of the process.

Process Attribution – Shared versus Specific

Within the data centre, the AI model training, long-term storage of the model, and RAM storage of the model are treated as shared processes, since these processes serve a wide user base. In contrast, the actual AI inference (i.e. the real-time processing of the user's translation request), uploading of the document, and downloading of the translated output are considered user-specific processes, tied directly to each instance of translation.

Likewise, for internet transmission, both upload and download transmissions are treated as user-specific, as they occur on a per-user, per-document basis.

User Base Assumptions for Shared Allocation

For the purpose of allocating energy from shared processes (such as model training), the user base is defined in terms of the total number of words translated using a given model over the two-year period of the representative scenario. The central case assumes **104 trillion words**, while the **low and high scenarios assume 208 trillion and 21 trillion words, respectively**. These figures help determine how much of the training and shared infrastructure energy is apportioned per word translated. The low scenario uses the highest user base figure, resulting in the lowest energy attribution per translation.

These figures are based on publicly available data on the scale of Google Translate, which was estimated in 2018 to handle approximately 143 billion words per day. In the absence of more recent definitive data, this figure has been doubled to reflect anticipated growth in online translation activity since 2018.[13] The medium and high scenarios reflect more niche or limited-use models, assumed to process 50 per cent and 10 per cent of the translation volume of Google Translate, respectively.

Translation and Usage Time

The AI translation tool is assumed to process a typical text-only document within 0.75 minutes in the central case, with a range of 0.5 to 1 minute across scenarios. Total user engagement time, including upload and download, is estimated at 1.5 minutes in the central case, with a range from 1 to 2 minutes. These durations determine the extent of energy use for end-user device operation.

AI Model Size and Computational Requirements

For this use case, we assume that the AI translation model is 3 GB in size in the central scenario, with sensitivity values of 1 GB (low) and 5 GB (high). These figures are consistent with models used in large-scale machine translation platforms and reflect the model size hosted within the data centre.

Training the model is assumed to require 5×10^{22} FLOP in the central case, with 1×10^{21} FLOP and 2×10^{23} FLOP used as lower and upper bounds. These values reflect the range of training intensity seen across commonly used AI language models.

For inference, we assume that each translation task requires 30 billion FLOPs in the medium scenario, with a sensitivity range of 10 billion FLOPs (low) to 50 billion FLOPs (high). These estimates are informed by a benchmark calculation based on GPT-4o, which estimates that generating a 500-token response (approximately 375 words) requires around 100 trillion FLOPs. Since a typical translation task is likely to involve less complexity and shorter outputs than a multi-paragraph generative response, we apply a significant downward adjustment to reflect the reduced computational load.

The tables below summarise our input for the translation digital use-case.

Table 3.10: Configuration assumptions for the video streaming digital use case

	Assumption
Network type	Fixed-line broadband
End-user device	ebook reader
Shared processes	Long-term storage, RAM storage, and AI training
User-specific processes	Uploading to data centres, AI inference, downloading, and download transmission

Source: Europe Economics analysis.

[13] Techspot (2018) “One of Google's truly free products remains devoid of ads” [online]

Table 3.11: Input assumptions for digital scenario – AI translation

	Units	Low	Medium	High
User base for shared processes				
User base for shared processes	Trillion words translated	208.8	104.4	20.9
Time to translate				
Time taken by AI translation tool to translate document	Minutes	0.5	0.75	1
Total time taken by user (including upload/download of document)	Minutes	1	1.5	2
AI translation model				
Size of model	GB	1	3	5
Number of FLOP used in training of AI translation model	FLOP	1.0 x 20^{21}	5.0 x 20^{22}	2.0 x 20^{23}
Number of FLOP per word translated during AI inference	FLOP	10,000,000,000	30,000,000,000	50,000,000,000

Source: Europe Economics analysis.

4 Methodology for Modelling Energy Consumption in Physical Counterfactuals

This chapter outlines the methodology used to model energy consumption for the physical counterfactuals. We first consider physical counterfactuals involving a manufactured product (Blu-rays, physical books), and then consider physical counterfactuals involving office-based work (translation). In each case, we begin by presenting the overall structure of the analytical approach, followed by the specific assumptions applied to each physical use case.

4.1 Physical counterfactuals involving manufactured products

This section outlines the approach used to estimate energy consumption for use cases where the physical counterfactual involves manufactured products, that is, where digitalisation replaces a tangible good. It also sets out the specific input assumptions for the Blu-ray and physical book use cases.

4.1.1 Overview of approach

This section outlines the methodology for assessing energy consumption for manufactured products. The approach follows a structured framework that accounts for key stages in the product lifecycle, from raw material production to final consumption. It enables analysis of energy consumption across different manufacturing locations (domestic versus overseas) and for different energy sources (electricity versus all fuels). This methodology could be applied to a range of products, with specific examples being media storage formats (e.g. Blu-rays) and printed materials (e.g. books).

The calculation model consists of three main components:

- **Manufacturing and Storage** – Estimating energy use in raw material processing, product manufacturing, packaging, warehousing, and retail operations.
- **Transportation** – Evaluating energy consumption from road and maritime logistics, including inbound supply chain and retail distribution.
- **End-User Device**– Assessing energy required for product use, considering device operation and consumption profiles where applicable.

The model also consists of two additional considerations:

- **Energy Categorisation** – Summarising energy use by fuel type, distinguishing between estimates for electricity only and for all fuels.
- **Manufacturing Location** – Differentiating between domestic and overseas manufacturing, which will affect the geographical allocation of production energy and the amount of transport energy consumption.

Each component is structured to accommodate product-specific variations while maintaining a generalised approach suitable for application across a wide range of products.

The **manufacturing and storage component** includes the energy used to process raw materials such as plastics, metals, paper, and ink; the energy used during manufacturing activities such as moulding or printing; the energy associated with producing and assembling packaging; and the energy used in warehousing and retail settings, such as lighting, climate control, and shelving systems. For each stage, we apply energy intensity values drawn from the literature that we have reviewed or from other sources.

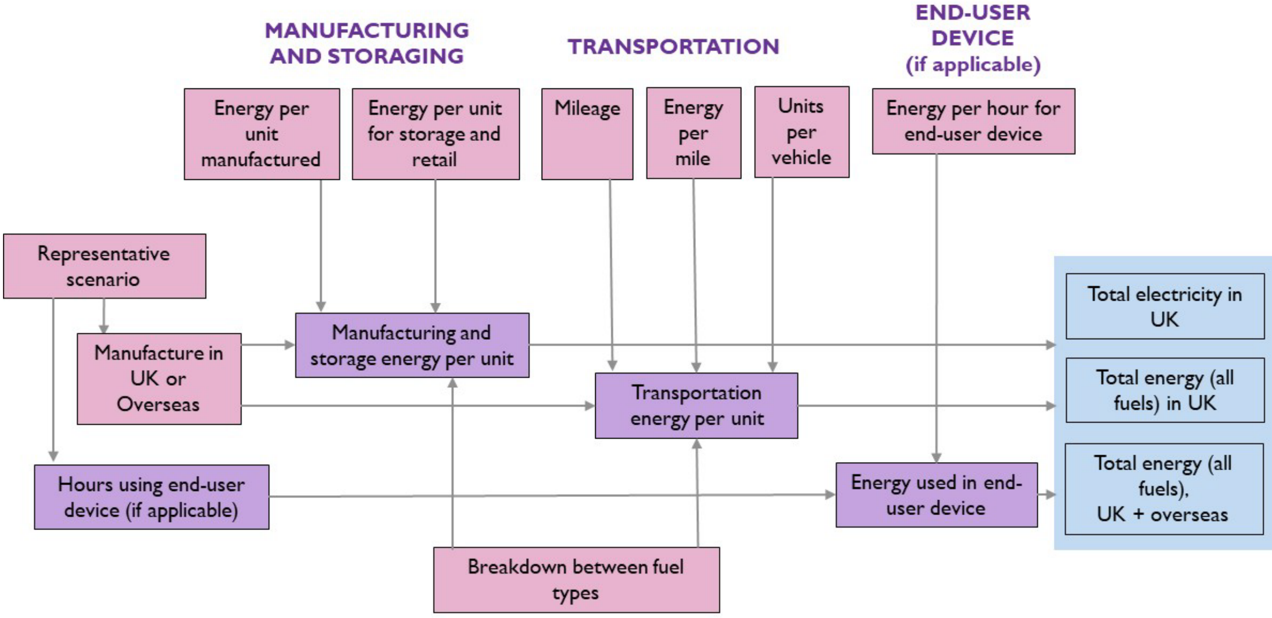
Transportation energy is calculated using a bottom-up approach, based on fuel consumption intensities and transport distances. For domestic manufacturing, energy consumption is attributed to road transport from the production site to a warehouse and onward to retail outlets. For overseas manufacturing, the model includes additional transport stages: road transport from the overseas factory to a port, ferry transport to the UK, and road transport from the UK port to the warehouse and retail store.

Where relevant, the model also includes the **energy used by end-user devices**. For example, in the case of Blu-ray discs, we account for the electricity required to operate both the Blu-ray player and a television. In contrast, physical books do not require electronic devices for use, so no end-user device energy is included in that scenario.

We produce two types of estimates of energy: electricity-only and all-fuels. The electricity-only estimate captures energy drawn directly from the UK electricity grid, while the all-fuels estimate includes contributions from gas, diesel, and marine fuels, enabling a more complete view of total energy use across the supply chain.

Finally, the model allows the determination of whether the product is manufactured in the UK or overseas. When a product is manufactured domestically, the energy consumed in all stages of the lifecycle is taken into account, including energy consumed in manufacturing, packaging, storage, transportation and retail. For overseas manufacturing, only energy consumed within the UK (such as warehousing, retail operations, and the UK portion of transportation) is included, while energy used in overseas stages (such as manufacturing and non-UK transportation) is excluded. This ensures that estimates of UK energy demand reflect only the stages of the product lifecycle occurring within UK borders. This approach means that products manufactured overseas may have lower reported UK energy consumption, as significant portions of their lifecycle energy use occur outside the UK.

Figure 4.1: Modelling framework for estimating energy consumption involving manufactured products



Decarbonised Counterfactual Scenario

To reflect the expected evolution of the UK energy system under 2050 Net Zero targets, we have included a decarbonised counterfactual in our analysis. This scenario assumes that all processes currently reliant on fossil fuels, such as diesel or gas, are instead powered by low-carbon electricity, either directly (e.g. through electrification) or indirectly (e.g. via energy carriers such as green hydrogen).

For road and marine transport, we have developed dedicated decarbonised estimates that reflect the specific energy profiles of low-carbon alternatives: electric heavy goods vehicles (HGVs) and hydrogen-powered vessels. These estimates consider the differing energy conversion efficiencies of electric drivetrains and hydrogen fuel cells compared to diesel-based systems. The assumptions underpinning these estimates are detailed in the corresponding transport modelling sections (see section 4.1.2 Input assumptions for Blu-ray).

For other fossil fuel processes, we assume a direct substitution with electricity, holding total KWh energy consumption constant. In the case of space heating, where gas is commonly used, we model the switch to electric resistive heating with no change in total energy use. Although electric heating systems can be more efficient, we do not apply a downward adjustment due to the lack of specific evidence on energy demand from heat pump deployment in these settings.

Similarly, for forklift operations, typically powered by diesel in packaging and warehousing environments, we assume unchanged energy consumption in kWh terms under electrification. While electric forklifts are generally more energy efficient, available evidence on energy use per task is limited and context-specific. Given the relatively small share of overall energy attributed to forklift activity, and in the absence of robust data, we maintain an assumption of no change in energy demand.

In the following sections, we set out the input assumptions that we used in the modelling for Blu-rays and books. In some cases, we identified a source for input assumptions (e.g. from the literature). In cases where we did not find a source, we used artificial intelligence to generate reasonable values to use.[14]

All energy consumption values for the physical counterfactual involving manufactured products are intended to represent conditions as of 2024. Where recent data was unavailable, earlier estimates were retained, as most processes are mature and not expected to have improved significantly in efficiency.

4.1.2 Input assumptions for Blu-ray

This scenario reflects the viewing of a movie using a Blu-ray disc. Energy consumption metrics are assumed across three components: manufacturing and storage, transportation, and end-user device usage. In addition, we account for the type of fuel used at each stage, distinguishing between electricity, gas, diesel, and marine fuel, and consider how energy consumption varies depending on whether the product is manufactured domestically or overseas.

Fuel Type

In order to differentiate the fuel types associated with each step of energy consumption and to isolate electricity, we multiply the percentage allocation of each fuel type by the energy consumption of each step. This approach allows us to quantify the contribution of each fuel type across the Blu-ray production and distribution process, ensuring a clear distinction between electricity use and consumption of other types of fuel.

Manufacture of Raw Materials

It is assumed that 80 per cent of the energy used in the production of raw materials such as plastic is from electricity. This reflects the use of large-scale electrically powered machinery for polymerisation, chemical processing, and refining. The remaining 20 per cent is attributed to gas, primarily for heating and other thermal processes.

Manufacture of Blu-ray Discs

The manufacturing process—including injection moulding, stamping, and cooling, is assumed to be 90 per cent electricity-based, due to its reliance on high-precision automated machinery. The remaining 10 per cent is attributed to gas use for heating applications in specific manufacturing steps.

Burning of Video onto Blu-ray

This stage is assumed to be fully powered by electricity (100 per cent), as laser burning and encoding rely entirely on electrically operated optical drives.

[14] This was done by prompting ChatGPT to provide values. Typically, we used the Data Analyst GPT developed by ChatGPT for this purpose, as it has been specifically developed for the purpose of analysing data.

Packaging

Packaging is assumed to use a mix of energy sources: 70 per cent electricity, supporting automated assembly lines; 20 per cent gas, for processes such as heat sealing; and 10 per cent diesel, reflecting the use of fuel-powered forklifts or material handling equipment within packaging facilities.

Warehouse Operations and Retail Store

Warehouse energy consumption is assumed to be 80 per cent electricity and 20 per cent gas. Electricity supports lighting, conveyors, and cooling systems, while gas is used for space heating, particularly in colder climates.

Transportation fuel

All road-based transport, covering inbound logistics, ferry-port transfers, and retail distribution, is assumed to be powered entirely by diesel. For overseas manufacturing, ferry segments are assumed to use marine diesel exclusively, consistent with typical fuel use by roll-on/roll-off freight vessels.

Table 4.1: Share of energy consumption by fuel type for various activities (%)

Activity	Electricity	Gas	Diesel	Marine Diesel
Manufacture of raw materials	80	20	0	0
Manufacture of Blu-ray	90	10	0	0
Burning of video onto Blu-ray	100	0	0	0
Packaging	70	20	10	0
Warehouse Operations	80	20	0	0
Retail store energy	80	20	0	0
Transportation – road	0	0	100	0
Transportation – ferry	0	0	0	100
Retail Distribution	0	0	100	0

Source: Europe Economics analysis.

Manufacturing and Storage

According to research on the energy consumption associated with media production and distribution, the manufacture and storage of Blu-ray discs involve multiple stages, including raw material processing, disc manufacturing, video burning, packaging, and warehousing, and retail operations. Each step contributes to the overall energy footprint, with variations depending on production efficiency, material sourcing, and location of manufacturing.

Energy Manufacturing Raw Material – Case and Sleeve

The energy consumption values for manufacturing the Blu-ray case and sleeve have been derived from Shehabi et al. (2014).[15] Specific data for Blu-ray cases were unavailable;

[15] Shehabi et al. (2014), The energy and greenhouse-gas implications of internet video streaming in the United States [online]

however, due to the similarity in materials used for both DVD and Blu-ray cases (primarily polycarbonate and polypropylene), it is reasonable to assume comparable energy requirements. According to Shehabi et al. (2014), the energy consumption for manufacturing a **DVD case is approximately 0.05004 kWh per unit**. Similarly, the energy required for the **sleeve is approximately 0.03614 kWh per unit**. To account for variations in manufacturing conditions and material processing efficiency, a ±20 per cent adjustment has been applied to derive the low and high values.

Manufacturing Energy per Disc

The energy required to manufacture a Blu-ray disc itself has also been sourced from Shehabi et al. (2014), using DVD manufacturing data as a proxy. Both DVDs and Blu-rays share similar production processes, including injection moulding and metallisation. The study estimates that the energy consumption for **manufacturing a DVD is approximately 0.3753 kWh per disc**. A ±20 per cent range has been introduced to reflect potential differences in efficiency, material wastage, and process optimisations across different manufacturers.

Burning of Video onto Blu-ray

The energy consumption for burning video onto a Blu-ray disc has been estimated based on the power consumption of SATA Blu-ray drives, which operate at 25 to 30 W during the burning process.[16] Given that Blu-ray burning typically takes around 0.5 hours per disc, **the total energy consumption ranges from 0.0125 kWh** (low, at 25 W) to **0.015 kWh** (high, at 30 W). **The medium value is calculated as 0.01375 kWh**, derived from the average of the low and high estimates.

Packaging – Shrink Wrapping, Cardboard Boxes, and Pallet Shrink Wrapping

For the energy associated with packaging materials and processes, no directly applicable references were found. Instead, values have been estimated based on assumptions about material energy intensity and the typical energy cost of shrink-wrapping, corrugated cardboard production, and pallet wrapping. The medium values reflect typical industry practices, while the low and high values account for variations in material thickness, production efficiency, and automation levels.

Shrink wrapping is assumed to require 0.03 kWh per Blu-ray (medium value), with a low estimate of 0.015 kWh and a high estimate of 0.045 kWh.[17] **Cardboard boxes**, used for bulk transport and retail display, have an estimated **energy requirement of 0.025 kWh per Blu-ray** (medium value), ranging from 0.018 to 0.032 kWh. We assume that **pallet shrink wrapping**, which is required for bulk shipping, has a **medium energy estimate of 0.01 kWh per Blu-ray**, with a range of 0.007 to 0.014 kWh.

[16] Power Consumption of PC Components in Watts [online]

[17] This estimate is based on general energy values for shrink film production (typically 2–4 MJ/kg) and heat-sealing. Assuming 10–15 g of film per Blu-ray, material use contributes approximately 0.005–0.01 kWh, while sealing adds around 0.001–0.002 kWh.

Warehouse Storage Energy per Disc

The storage energy consumption per Blu-ray has been derived from Seetharam et al. (2010),[18] which analyses energy usage in warehouse operations. The study estimates that the energy consumption **for storing a DVD in a warehouse is approximately 0.026 kWh per disc**. A ±20 per cent variation has been applied to derive the low and high values, accounting for differences in warehouse efficiency, climate control energy usage, and storage density.

Retail Store Energy (Lighting, Heating, ventilation, and air conditioning (HVAC), Shelving)

To estimate the energy consumed in retail environments attributable to Blu-ray disc sales, we draw on industry data on commercial energy intensity and make assumptions about typical store operations and product distribution. The calculation begins with figures from the U.S. Energy Information Administration (EIA), which reports an average annual electricity consumption of approximately 13.5 kWh per square foot (equivalent to around 145 kWh per square metre) for retail stores.[19]

To estimate the retail energy use associated with Blu-ray sales, we assume that a dedicated media section of 10 square metres is used to display and sell Blu-ray discs. If this area supports the sale of 10,000 discs per year, this implies 0.001 m² of floor space per unit sold. We apply an energy intensity of 145kWh per square per year. This yields an estimated retail energy use of 0.145 kWh per Blu-ray sold. To provide a conservative estimate, we round this figure down to **0.1 kWh per disc**. To accommodate uncertainty in parameters such as store size, layout, lighting efficiency, HVAC operation, and product turnover, a ±20 per cent range is applied around this central estimate.

Table 4.2: Manufacturing and Storage energy (kWh/blu-ray)

Category	Low	Medium	High	Location
Manufacture of raw materials	0.069	0.086	0.103	UK/Overseas
Case	*0.04*	*0.05*	*0.06*	
Sleeve	*0.029*	*0.036*	*0.043*	
Manufacture of Blu-ray	0.3	0.375	0.45	UK/Overseas
Burning of video onto Blu-ray	0.011	0.0138	0.0165	UK/Overseas
Packaging	0.04	0.065	0.091	UK/Overseas
Shrink wrapping	*0.015*	*0.03*	*0.045*	
Cardboard boxes	*0.018*	*0.025*	*0.032*	
Pallet shrink wrapping	*0.007*	*0.01*	*0.014*	
Warehouse Operations	0.022	0.026	0.031	UK
Retail store energy	0.08	0.1	0.12	UK

Source: Europe Economics analysis

[18] Seetharam et al. (2010), Shipping to Streaming: Is this shift green? [online]
[19] EIA (2016), Electricity consumption totals and conditional intensities by building activity subcategories, 2012 [online]

Transportation

This section outlines the key assumptions used to estimate transportation energy consumption. The calculation framework accounts for multiple transportation stages, including inbound logistics (from the manufacturing facility to a distribution warehouse) and retail distribution (from the warehouse to retail stores). Key parameters include distance (km), fuel consumption intensity (L/km), energy content per litre (kWh/L), and the number of units transported per vehicle (units/truck and trucks/ferry).

To determine the transportation energy per unit, the following formula is applied:

$$kWh\ per\ unit = \left(Distance\ (km)\ \times Fuel\ Consumption\ \left(\frac{l}{km}\right) \times Energy\ content\ per\ litre\ \left(\frac{kWh}{l}\right)\right) \div\ Number\ of\ units\ per\ vehicle$$

Distance

Inbound Logistics (Manufacture to Warehouse)

Inbound logistics can be classified into two scenarios: (1) when manufacturing occurs within the UK, and (2) when manufacturing takes place outside the UK (e.g., in Germany). Each scenario involves different transportation routes and distances. All our assumptions for distance are captured in Table 4.3.

UK Manufacturing - Road to Warehouse

For Blu-rays produced in the UK, we assume they are transported from the manufacturing site to a warehouse for national retail distribution via road. The distance depends on the location of the factory and the position of the warehouse within the UK. A **low estimate of 100 km** is applied where both the manufacturing site and warehouse are within the same region, such as in the Midlands. A **medium estimate of 150 km** is applied for a typical route, such as from Enfield (North London) to a warehouse in the Midlands (e.g. Daventry or Milton Keynes). A **high estimate of 200 km** accounts for longer domestic transport, such as when manufacturing occurs in northern England or Scotland, requiring greater distances to reach distribution centres in the Midlands.

Overseas Manufacturing (Factory to Warehouse via Ferry)

For Blu-rays manufactured overseas, the supply chain involves multiple transport stages: (A) overland transport from the factory to a ferry port, (B) a ferry crossing to the UK, and (D) final road transport from the UK port to a distribution warehouse.

Overseas Road (Factory to Ferry Port)

Before shipping to the UK, Blu-rays must first be transported from the factory to the nearest ferry port in Europe. The distance depends on the factory location and its proximity to a major port. A **low estimate of 300 km** applies when the factory is near a major port, such as in western Germany with access to Rotterdam. **A medium estimate of 500 km** accounts for typical transport distances from central Germany to a ferry port. A **high estimate of 700 km** is used when manufacturing is farther east, such as in Poland or the Czech Republic, requiring a longer overland journey before reaching the ferry port.

Ferry Distance (Cross-Channel)

The ferry distance depends on the port of departure in Europe and the UK port of entry. The shortest and most common ferry route, Dover-Calais, **is 35 km, which applies as the low estimate**. A **medium estimate of 150 km accounts for longer ferry crossings** such as Rotterdam to Harwich or Zeebrugge to Hull. The **high estimate of 300 km represents significantly longer sea routes**, such as Hamburg to Immingham or Liverpool, used when shipments take a North Sea route instead of the English Channel.

UK Road (Ferry Port to Warehouse)

Once the shipment arrives in the UK, it must be transported by truck from the ferry port to a distribution warehouse. The distance depends on which UK port is used and the warehouse location. **A low estimate of 100 km** applies when the warehouse is near the port, such as in South East England. The **medium estimate of 200 km** accounts for a typical transport route to a Midlands warehouse, such as in Daventry or Milton Keynes, which are central logistics hubs. A **high estimate of 300 km** represents longer distances, such as when the shipment is transported from Dover to a warehouse in Manchester or Leeds.

Retail Distribution (Warehouse to Store)

Once the Blu-rays have arrived at the warehouse, they are distributed to retail stores within the UK. The distance varies depending on store locations, warehouse networks, and regional demand. A **low estimate of 20 km** represents a case in which the retail store is near the warehouse, typically in urban areas. The **medium estimate of 50 km** assumes that stores are located in regional retail hubs with regular delivery routes. The **high estimate of 100 km accounts for longer distribution routes**, such as deliveries to rural locations or smaller towns.

Table 4.3: Assumed transport distances for Blu-ray discs

Category	Unit	Low	Medium	High
Inbound Logistics (Manufacture to Warehouse)				
UK Manufacturing				
UK Road (Factory to Warehouse)	km	100	150	200
Overseas Manufacturing				
Overseas Road (Factory to Ferry Port)	km	300	500	700
Ferry Distance (Cross-Channel)	km	35	150	300
Percentage of ferry fuel allocated to UK	percent	0.4	0.5	0.6
UK Road (Ferry Port to Warehouse)	km	100	200	300
Retail Distribution (Warehouse to Store)				
UK Road (Warehouse to Store)	km	20	50	100

Source: Europe Economics analysis.

Fuel consumption intensity

To estimate the energy use associated with transportation, the model draws on fuel consumption intensity (FCI) values for both road and maritime modes. These represent the amount of fuel consumed per kilometre travelled and are a critical input for calculating transport energy per product unit

For **road freight**, the central estimate is taken from the International Council on Clean Transportation (ICCT), which reports that a typical long-haul tractor-trailer in Europe consumes approximately 32.6 litres of diesel per 100 kilometres (L/100 km). [20] **Converted to a per-kilometre basis, this equates to 0.326 L/km**. To reflect variability in vehicle efficiency, road conditions, and driving behaviour, a ±20 per cent adjustment is applied. This yields a lower bound of 0.2608 L/km for more efficient operations and an upper bound of 0.3912 L/km for less efficient scenarios.

For **ferry transport**, the model uses data from ARUP (2014), which provides typical fuel consumption values for roll-on/roll-off (Ro-Ro) freight vessels operating on cross-channel routes. [21] **The medium case assumes a fuel consumption intensity of 5.54 L/km**, based on reported averages for these vessels. Again, a ±20 per cent range is applied to account for variations in vessel type, sea conditions, and operational practices. This results in a low estimate of 4.432 L/km for high-efficiency or optimally loaded ferries, and a high estimate of 6.648 L/km for older vessels or less efficient operations.

[20] ICCT(2018), Comparison of fuel consumption and emissions for representative heavy-duty vehicles in Europe [online]
[21] ARUP (2014), Cost of Emissions for NSW Ferry Networks [online]

Table 4.4: Fuel consumption intensity (l/km)

Category	Low	Medium	High
Truck energy fuel consumption intensity	0.2608	0.326	0.3912
Ferry energy fuel consumption intensity	4.432	5.54	6.648

Source: Europe Economics analysis.

Energy content per litre

To convert fuel consumption into energy use, the model draws on the lower calorific value (LCV) of diesel and marine diesel fuels. These values represent the amount of usable energy released during combustion and are expressed in kilowatt-hours per litre (kWh/L).

For road diesel, the Oak Ridge National Laboratory (ORNL, 2022) reports an LCV of 38.6 megajoules per litre (MJ/L).[22] Using the standard conversion factor of 1 MJ = 0.2778 kWh, this equates to an **energy content of 10.72 kWh/L**.

For marine diesel, the International Maritime Organization (IMO) provides a lower calorific value of 42,700 kilojoules per kilogram (kJ/kg), alongside a typical fuel density of 0.8744 kilograms per litre (kg/L).[23] Multiplying these gives a volumetric energy content of 37.35 MJ/L, which converts to **10.38 kWh/L** using the same MJ-to-kWh factor.

These energy content values are used to convert fuel consumption intensity (FCI, in litres per kilometre) into energy intensity (EI, in kilowatt-hours per kilometre):

$$EI\left(\frac{kWh}{km}\right) = FCI\left(\frac{L}{km}\right) \times Energy\ content\left(\frac{kWh}{L}\right)$$

Table 4.5: Energy content per litre (kWh/L)

	Energy content per litre
Diesel Energy Content per litre	10.72
Marine Diesel Energy Content per litre	10.68

Source: ORNL (2022), IMO (2016)

Decarbonised scenario

To estimate the energy consumption in the decarbonised scenario, the model adopts the following assumptions for road and marine transport, reflecting the expected performance of electric HGVs and hydrogen-powered vessels based on emerging real-world data.

For **electric HGVs**, we use data from the UK's Battery Electric Truck Trial (BETT, 2024) to model energy use for electric HGVs.[24] The trial, based on 287,000 km of real-world fleet data, reported an average efficiency of **1.08 km per kWh (0.93 kWh/km),** which we adopt as our medium estimate. Urban stop-start driving reduced efficiency to **0.90 km per kWh (1.11**

[22] ORNL (2022), Transportation Energy Data Book [online]
[23] IMO's MEPC.281(70) Report [online]
[24] Cenex (2024) "BETT: Battery Electric Truck Trial Final Report" [online]

kWh/km, high case), while rural routes achieved **1.20 km per kWh (0.83 kWh/km, low case).** While higher efficiency figures have been reported in test-cycle and idealised conditions, we consider that the BETT trial offers the most robust dataset for UK fleet use. We therefore consider that these figures provide a representative basis for modelling energy consumption under a decarbonised transport scenario.

For **maritime transport**, we assume the use of hydrogen-powered vessels based on published specifications of commercially piloted models.[25] We assume the use of a hydrogen-powered 64.5m vessel with two 240 kW fuel cells and a 380 km range per refill. Operating at full power, this yields **a medium estimate of 12.6 kWh/km**. We assume **9.5 kWh/km for the low case** (slower cruising or higher efficiency) and **16.8 kWh/km for the high case** (less efficient operation or longer trip duration). These estimates are based on early-stage hydrogen vessel designs suited to short-haul freight.

Table 4.6: Energy efficiency for decarbonised scenario (kWh/km)

Category	Low	Medium	High
Electric HGVs	0.83	0.93	1.11
Green hydrogen vessels	9.5	12.6	16.8

Source: Global Times (2024), Cenex (2024)

Number of Blu-ray DVDs per truck

To determine transport energy per Blu-ray disc, it is necessary to estimate the number of units that can be transported within a standard freight vehicle. In the case of ferry transport, it is also necessary to estimate the number of freight vehicles that can be transported on a ferry. A 40-foot lorry typically offers an internal cargo volume of 67.7 cubic metres. Given that a standard Blu-ray case occupies approximately 0.00035 cubic metres, this implies a theoretical maximum capacity of around 193,000 units per lorry.

However, practical constraints such as palletisation, stacking inefficiencies, and space reserved for manoeuvring and packaging reduce the usable volume significantly. Assuming that only 50 per cent of the internal space is effectively utilised, the capacity falls to 96,500 Blu-rays per lorry. After applying a further downward adjustment to account for additional packing inefficiencies, a rounded central estimate of 90,000 Blu-rays per lorry is adopted.

For ferry transport, the model assumes a large roll-on/roll-off (Ro-Ro) ferry capable (in the medium scenario) of accommodating 120 lorries. This is consistent with specifications from major ferry operators such as DFDS, Stena Line, and P&O Ferries. A typical large Ro-Ro ferry includes three to five decks and offers a total lane length of between 2,000 and 3,500 metres. Given that a 40-foot lorry occupies approximately 17 metres of lane length, the assumed capacity of 120 lorries per vessel aligns with real-world configurations after accounting for manoeuvring space and deck utilisation.

[25] Global Times (2024) “China launches hydrogen-powered container ship, capable of sailing 380 kilometers” [online]

To reflect uncertainties in loading efficiency, pallet dimensions, and real-world constraints, a sensitivity range is introduced: the number of Blu-rays per lorry is assumed to vary between 70,000 and 110,000, while the number of lorries per ferry is assumed to vary between 100 and 140. This variation is important for energy calculations, as a lower number of units per lorry and lorries per ferry results in higher transport energy per Blu-ray, and vice versa.

Table 4.7: Number of Blu-Rays

Category	Low	Medium	High
Blu-rays per truck	110,000	90,000	70,000
Trucks per ferry	140	120	100

Source: Europe Economics analysis.

End-user device

We have a similar end-user device setup for the physical case as in the digital case, with a TV and no set-top box. However, for physical media, a Blu-ray player is assumed to be used for every viewing session, adding to the energy consumption.

4.1.3 Input assumptions for book

This scenario reflects the reading of a printed paperback book. Energy consumption metrics are assumed across three components: manufacturing and storage, transportation, and retail operations. We also consider the fuel types used at each stage, primarily electricity, gas and diesel, and we distinguish between books manufactured in the UK and those produced overseas, to capture differences in energy attribution and transport requirements.

Fuel Type

Manufacture of Raw Materials (Paper, Ink, Binding)

The production of raw materials, such as paper pulp, ink, and binding components, is assumed to be primarily electricity-based (around 70 per cent), reflecting the extensive use of electrically powered equipment for pulping, chemical processing, and ink formulation. The remaining 30 per cent is attributed to gas, which is typically used for high temperature drying and certain chemical treatments.

Printing of Books

The book printing process is highly electricity-intensive, with electricity assumed to represent 85 per cent of energy use. Gas makes up the remaining 15 per cent, primarily for heat-based drying and curing.

Binding and Finishing

Binding and finishing processes, such as cutting, folding, and gluing, are assumed to be powered mostly by electricity, which accounts for 90 per cent of energy use. Gas is assumed to make up the remaining 10 per cent, used in heat-based glue application.

Packaging

Packaging operations are assumed to use 60 per cent electricity, 30 per cent gas, and 10 per cent diesel. Electricity powers shaping and assembly equipment; gas supports heat-sealing and thermoplastic processes; and diesel is used by on-site logistics equipment such as forklifts.

Warehouse Operations and Retail Store

Energy use in warehouses is assumed to consist of 80 per cent electricity and 20 per cent gas. Electricity is used for lighting and climate control systems, while gas is used for space heating.

Table 4.8: Share of energy consumption by fuel type for various activities (%)

Activity	Electricity	Gas	Diesel
Manufacture of raw materials	70	30	0
Printing of books	85	15	0
Binding and finishing	90	10	0
Packaging	60	30	10
Warehouse Operations	80	20	0
Retail store energy	80	20	0

Source: Europe Economics analysis.

Manufacturing and Storage

A study by Gard & Keoleian (2002)[26] provides a useful starting for thinking about the energy consumption associated with printed materials. Although their study focused specifically on academic journals and is now over two decades old, we use it as a conceptual reference point to inform the structure of our own estimates. Our focus is on the energy consumption of physical books—specifically a typical 300-page book—we develop separate estimates to reflect differences in format, as well as likely improvements in production efficiency and technological advancements since the original study. The following sections outline these adjustments across various stages of the production process.

Manufacture of raw materials (Paper, Ink, Binding)

According to the study by Gard & Keoleian (2002), the manufacture of raw materials (paper, ink, and binding) consumed approximately 43 kWh per journal. This was largely due to the energy-intensive process of pulping, refining, and drying paper, as well as the production of ink and binding materials. However, for books, we assume to be approximately 3–6 kWh per book for several reasons. Firstly, book-grade paper production has become more efficient, with a higher percentage of recycled content and reduced chemical usage. Additionally, paperweight per unit varies, and books, unlike journals, are often printed in bulk runs, benefiting from economies of scale. Advances in ink formulation and precision printing technologies also

[26] Gard & Keoleian (2002), Digital versus Print: Energy Performance in the Selection and Use of Scholarly Journals [online]

contribute to lower ink-related energy demands. A ±20 per cent range accounts for differences in book size, paper type, and advancements in paper manufacturing efficiency.

Printing of books

For the printing process, Gard & Keoleian (2002) estimated journal printing energy at 4.8 kWh per unit, based on traditional offset printing techniques. However, book printing differs in terms of scale, speed, and ink coverage. We assume an adjusted range of 0.8–1.5 kWh per book reflects the transition to more energy-efficient printing technologies, such as digital and offset lithography, which optimise ink application and reduce wastage. Additionally, printing processes have improved significantly since the study, incorporating better drying methods and reduced energy consumption per printed page. The adjusted values also consider that books are typically printed in bulk, whereas journals are often produced in smaller, periodic runs, which increases per-unit energy demand.

Binding and finishing

In terms of binding and finishing, Gard & Keoleian (2002) estimated journal binding energy at 5.1 kWh per unit. Journals often undergo post-production manual binding, which requires separate transportation and additional processing energy. In contrast, books are typically bound inline, within the same printing process, thus we assume a significantly lower energy requirement of 0.2–0.5 kWh per book. The adjusted values also factor in modern mechanised binding, where automated gluing, stitching, and trimming have become more energy-efficient.

Packaging

The packaging process in Gard & Keoleian (2002) included journal delivery and protective materials, accounting for 1.4 kWh per journal. However, for books, we assume the energy intensity to be lower, with an adjusted range of 0.1–0.3 kWh per book. This reduction is primarily due to the bulk shipping and streamlined logistics of book distribution. Unlike journals, which are often shipped individually or in small batches, books are typically packaged in pallets or large cartons, optimising transportation efficiency and reducing per-unit packaging waste. Additionally, the use of lighter, recyclable materials in packaging has further contributed to energy savings.

Warehouse Operations

Gard & Keoleian (2002) originally estimated warehouse operations to account for a significant energy burden, with 92 kWh per journal copy, largely due to long-term storage in climate-controlled library buildings. However, books typically spend less time in storage, and warehouses operate with higher turnover rates compared to library archives. Thus, we assume an adjusted estimate of 0.3–1 kWh per book reflects modern warehouse efficiencies, including the use of LED lighting, improved HVAC systems, and automated material handling. Unlike library collections, where books are stored indefinitely, retail warehouses function on a rapid inventory cycle, ensuring a lower per-unit energy allocation.

Retail store energy (lighting, HVAC)

We apply the same estimate of **0.1 kWh per unit for** the retail energy use associated with physical book sales as used for Blu-ray discs. As outlined in the Blu-ray section above, this estimate is based on a dedicated media area of 10 square metres supporting the sale of 10,000 units annually, combined with an energy intensity of 145 kWh per square metre per year. This approach is considered reasonable for books, as they occupy similar shelf space, are sold through comparable retail formats, and involve broadly similar display and handling requirements.

Table 4.9: Manufacturing and Storage energy (kWh/book)

	Low	Medium	High	Location
Manufacture of raw materials	3	4.5	6	UK/Overseas
Printing of books	0.8	1.15	1.5	UK/Overseas
Binding and finishing	0.2	0.35	0.5	UK/Overseas
Packaging	0.1	0.2	0.3	UK/Overseas
Warehouse Operations	0.3	0.65	1	UK
Retail store energy	0.08	0.1	0.12	UK

Source: Europe Economics analysis.

Transportation

For books, we assume that transportation follows the same logistics model as Blu-rays, both in terms of manufacturing location and product size. This means that books can be either manufactured within the UK or imported from overseas, affecting transport stages and energy consumption. The transport process includes inbound logistics (factory to warehouse), potential ferry transport for imports, and retail distribution (warehouse to store). Given that books and Blu-rays are similar in volume and weight, we assume comparable truck and ferry loading capacities, ensuring that per-unit transport energy calculations remain consistent across both product types.

End-user device

For physical books, we assume there is no dedicated end-user device required for consumption. While lighting may be used for reading, it is excluded from the comparison because it applies equally to both the physical and digital cases (as one may need lighting to read an ebook on an e-reader). As lighting is not an inherent part of either format's energy footprint, being dependent on external factors such as time of day, it is not considered in the analysis.

4.2 Physical counterfactuals involving office-based work

4.2.1 Overview of approach

This section outlines our approach to estimating energy consumption for use cases in which the service would, under a physical alternative, be delivered by a professional working in an office environment. The calculation draws on three components:

- the electricity consumption attributable to the office space occupied by the service provider;
- the energy used to transmit electronic files between the client and the provider; and
- the electricity consumed by the client's end-user device to access the service.

The analysis is grounded in the same representative scenario used for the digital use case, which sets the parameters of the activity under consideration.

Office Energy Consumption

The primary energy contribution in this scenario is the electricity required to support the working environment and computer equipment of the person delivering the service. This is estimated using a bottom-up approach:

- We apply a **standard electricity energy use intensity (EUI)** for commercial office buildings, measured in kilowatt-hours per square metre per year (kWh/m²/year).
- This is multiplied by an assumption for **average office space per worker** (in m²), yielding an estimate of **annual energy use per office worker**.

The EUI figures used are all-inclusive: they represent the total annual metered electricity demand of the premises and therefore encompass all forms of energy use within the building. This includes energy for IT and computing equipment, lighting, heating and cooling, ventilation, and other building services. As such, they already incorporate the energy used by the office-based worker's device and supporting infrastructure.

We then scale this annual figure based on the **time required to perform the specific task**. This provides an estimate of the **energy consumed during the performance of the activity**, covering lighting, heating or cooling, IT equipment, and other infrastructure associated with an occupied office space.

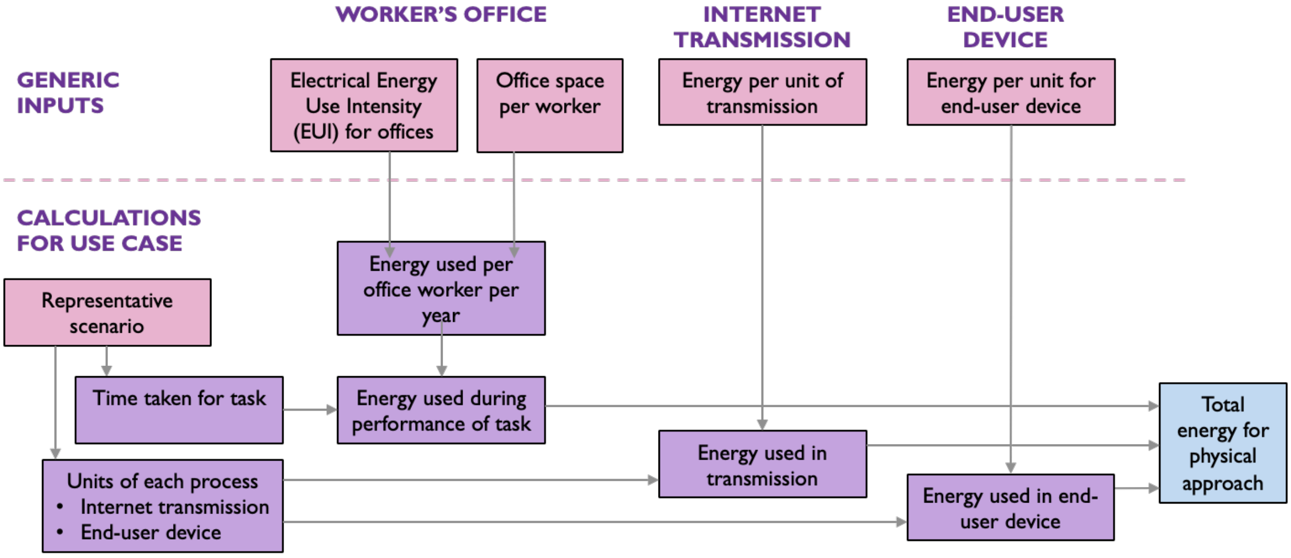
Internet Transmission

Although the core service is carried out by a human being, we include the energy associated with sending and receiving electronic files, for example, transmitting a document to the provider and receiving the completed version. These activities are treated as discrete data transfers and modelled using fixed energy intensity values per gigabyte transmitted, consistent with the digital approach.

End-User Device Energy

The final component reflects the energy used by the end-user's device, typically a desktop computer, to send the document to the service provider and receive the final output. This is considered separately from the provider's device, which is already captured within the office energy calculation.

Figure 4.2: Modelling framework for estimating energy consumption involving office-based work



In the following sections, we set out the input assumptions that we used in the modelling for human translation. All energy consumption values for the physical counterfactual involving office-based work are intended to represent conditions as of 2024.

4.2.2 Input assumptions for translator

This scenario reflects the physical delivery of a translation service, in which a professional translator completes the task while working in an office. In line with the approach described above, energy consumption is estimated across three components: the translator's office, internet transmission, and the client's device.

Network and End-User Device Configuration

It is assumed that the client accesses the service via a desktop computer connected to a fixed-line broadband network.

Task Duration – Human Translation Speed

The time required to complete the task is based on assumptions about the speed of human translators, expressed in words per hour. The central estimate is 500 words per hour, with a lower bound of 600 and an upper bound of 400.[27] These figures reflect typical productivity in professional translation.

Office Energy Consumption

The electricity consumption associated with the translator's office is estimated using two key parameters: the EUI of commercial office buildings and the floor area allocated per translator.

The EUI represents the total annual metered electricity demand of office premises, expressed in kilowatt-hours per square metre per year (kWh/m²/year). It is an all-inclusive figure that

[27] Training For Translators (2011) "Webinar question: how many words per day?" [online]

captures electricity consumption from all major end-uses, including office IT equipment, lighting, heating, cooling, and ventilation. In the central case, we assume an EUI of 79.5 kWh/m²/year, with sensitivity ranges of 67 kWh/m²/year (low) and 92 kWh/m²/year (high).[28]

The second input is the office space per translator, reflecting the average amount of floor area occupied by the worker. In the central case, this is assumed to be 15 square metres, with a lower bound of 10 m² and an upper bound of 20 m² to capture differences across office types and working arrangements.

Internet Transmission

The model includes the energy required to send the source document to the translator and to receive the completed version. We assume the same energy intensity values per GB of transmission as used in the digital scenario, with file size parameters aligned to ensure consistency between the two approaches.

End-User Device Energy

The energy consumption of the end-user is based on the time spent emailing the document, assumed to be 1.5 minutes in the central case, with a range from 1 to 2 minutes across scenarios. The relevant device power draw, typically a desktop computer, is applied to this duration to estimate the total energy for this component.

Table 4.10: Input assumptions for human translation

Component	Unit	Low	Medium	High
Translation speed	Words per hour	600	500	400
EUI (office)	kWh/m²/year	67	79.5	92
Office space per worker	m²	10	15	20
End-user device use	Time spent emailing (minutes)	1	1.5	2

Source: Europe Economics analysis.

[28] See Annex 2 at DESNZ (2024) “Non-Domestic Building Stock in England and Wales” [online]

5 Results for Test Cases

In this section of the report, we present the results of our calculations for our three use cases, in each case comparing energy consumption under the digital approach with energy consumption under the physical counterfactual.

5.1 Video streaming versus Blu-ray

This use case assesses the energy consumption associated with watching a movie using either a digital streaming platform (in the digital scenario) or a Blu-ray disc (in the physical counterfactual).

The analysis is grounded in a **representative scenario** that defines the parameters of video delivery and viewing, ensuring consistency between both approaches. The scenario assumes a **two-hour video**, with **a streaming-optimised data rate of 3.5 GB per hour**, resulting in a **total file size of 7 GB** per viewing. The video is assumed to be watched **twice over a five-year period**, based on the premise that a Blu-ray disc, had it been purchased instead, would typically be owned and usable for around five years. Over this period, a total of 14 GB of data is transmitted for the digital use case.

The viewer accesses the content using a **TV connected to a fixed-line broadband network**.

Digital scenario

This section sets out the estimated energy use associated with video streaming using a digital platform. The analysis includes energy use from three main sources: (i) data centre energy consumption, including both IT and non-IT processes, (ii) internet transmission, and (iii) the end-user's device.

Data centre

The delivery of streaming content involves several IT processes within data centres, including the uploading and processing of video content, long-term and RAM storage, and final downloading/streaming to the user. Each of these processes is characterised by a defined activity level and energy intensity, with some processes classified as shared across users (e.g. uploading, processing, long-term storage) and others as user-specific (e.g. downloading/streaming, RAM usage).

The table below presents the activity volumes for each process under low, medium and high scenarios, along with their classification as shared or specific.

Table 5.1: Activity volumes and process classification for IT processes

Data Process	Units	Low	Medium	High	Shared/ Specific	Basis of Estimate
Uploading to Data Centres	GB uploaded	7	7	7	Shared	*File size of a 2hr movie (from representative scenario)*
Video Processing	GB processed	7	7	7	Shared	*File size of a 2hr movie (from representative scenario)*
Long-term storage	GB stored per year	7	7	7	Shared	*File size of a 2hr movie (from representative scenario)*
RAM storage	GB-hours	2.8	2.8	2.8	Specific	*Size of video × % cached in RAM × number of viewings × video length*
General Processing	CPU-hours	0	0	0	-	-
AI Training	FLOP	0	0	0	-	-
AI Inference	FLOP	0	0	0	-	-
Downloading/ Streaming	GB downloaded /streamed	14	14	14	Specific	*Total file size of movie streamed over representative scenario (file size × number of viewings)*

Source: Europe Economics analysis.

Using these activity volumes and corresponding energy intensities (Table 3.1), the total energy consumption associated with each IT process is calculated. These figures represent the total energy usage, prior to accounting for user attribution.

Table 5.2: Energy used in each IT process - Video Streaming (kWh)

Data Process	Low	Medium	High
Uploading to Data Centres	0.105	0.14	0.21
Video Processing	0.7	2.8	7
Long-term storage	0.0875	1.75	0.35
RAM storage	0.001	0.001	0.001
Downloading/Streaming	0.14	0.21	0.28
Sub-total	1.034	3.326	7.771

Source: Europe Economics analysis.

To estimate the energy attributable to the representative user, we apply allocation factors for shared processes (e.g. uploading to data centres, video processing, and long-term storage), based on the assumed user base.[29] For specific processes such as RAM storage and downloading/streaming, the full energy is allocated to the user. The table below presents these user-level allocations.

[29] The percentage attributable to user for shared processes, over the period of the representative scenario, is calculated as (total viewing time per user) / (total hours of viewing of video (all users))

Table 5.3: IT energy attributable to each user (kWh)

IT Process (attributable to user)	Low	Medium	High
Uploading to Data Centres	8.4×10^{-8}	5.6×10^{-7}	1.7×10^{-6}
Video Processing	5.6×10^{-7}	1.1×10^{-5}	5.6×10^{-5}
Long-term storage	7.0×10^{-8}	7.0×10^{-6}	2.8×10^{-6}
RAM storage	0.001	0.001	0.001
Downloading/Streaming	0.14	0.21	0.28
Total IT energy	0.141	0.211	0.281

Source: Europe Economics analysis.

In addition to the IT energy, we include an allocation for non-IT energy used to support data centre operations. This is calculated by applying a proportional uplift to each IT process (Table 3.2) in line with its share of total data centre activity.

The table below summarises both IT and non-IT energy components to give the total data centre energy attributable to the user.

Table 5.4: Summary of data centre energy consumption (kWh)

Component	Low	Medium	High
IT energy	0.141	0.211	0.281
Non-IT energy	0.014	0.063	0.141
Total data centre energy	**0.155**	**0.274**	**0.421**

Source: Europe Economics analysis.

Internet Transmission

Energy is consumed in transmitting the video content between the data centre and the end-user. This includes both the initial upload of content to the platform (e.g. by a content producer) and the streaming of the video to the user. **Upload transmission is considered a shared process, while download transmission is specific to the user**. Therefore, only a small proportion of the upload energy is attributed to the representative user, while the full energy for download is allocated.

Table 5.5: Transmission energy attributable to each user (kWh)

Component	Low	Medium	High
Upload transmission	1.2×10^{-7}	7.4×10^{-7}	1.7×10^{-6}
Download transmission	0.2979	0.3724	0.4469
Total transmission	**0.2979**	**0.3724**	**0.4469**

Source: Europe Economics analysis.

End-User Device Energy

The end-user is assumed to watch the video using a television connected via a fixed-line broadband connection, with no set-top box involved. Energy consumption is estimated by multiplying the TV's assumed power draw (Table 4.10) by the total hours of use — in this case, 4 hours (2 hours × 2 viewings).

Table 5.6: Energy used in end-user devices (kWh)

Units	Low	Medium	High
Energy used in device	0.2	0.4	0.8
Energy used in set-top box	0	0	0
Total device energy	**0.2**	**0.4**	**0.8**

Source: Europe Economics analysis.

Summary of Energy Use

This section consolidates the estimated energy consumption associated with streaming a 2-hour video twice over a five-year period. The total energy use accounts for data centre operations (both IT and non-IT), internet transmission, and energy consumed by the end-user device.

As shown in the table below, internet transmission and end-user device usage each contribute a sizeable share of the overall energy, particularly in the low and medium scenarios.

Table 5.7: Total energy consumption for representative scenario (kWh)

Component	Low	Medium	High
IT energy (data centres)	0.14	0.21	0.28
Non-IT energy (data centres)	0.01	0.06	0.14
Internet transmission	0.3	0.37	0.45
End-user device	0.2	0.4	0.8
Total	**0.65**	**1.05**	**1.67**

Source: Europe Economics analysis.

It is also useful to express energy consumption on a per-hour-of-viewing basis. Given that the user watches a total of 4 hours of video in this scenario (2 viewings of a 2-hour film), the following table shows the energy footprint per viewing hour.

Table 5.8: Total energy consumption for representative scenario (kWh)

Component	Low	Medium	High
IT energy (data centres)	0.04	0.05	0.07
Non-IT energy (data centres)	0	0.02	0.04
Internet transmission	0.07	0.09	0.11
End-user device	0.05	0.1	0.2
Total	**0.16**	**0.26**	**0.42**

Source: Europe Economics analysis.

To illustrate the relative contributions of each component, the table below presents the percentage breakdown of total energy consumption across the three scenarios.

Table 5.9: Breakdown of energy consumption (%)

Component	Low	Medium	High
IT energy (data centres)	22	20	17
Non-IT energy (data centres)	2	6	8
Internet transmission	46	36	27
End-user device	31	38	48
Total	**100**	**100**	**100**

Source: Europe Economics analysis.

It can be more challenging for an electricity network to supply power to a single, central location than to supply power to decentralised locations. For video streaming, we treat electricity consumed within the data centre as centralised, while electricity used for transmission and end-user devices is decentralised. Thus, the share of electricity consumed in centralised locations ranges from **24 to 26 per cent.**

Physical counterfactual

This section sets out the estimated energy use associated with watching a film using a Blu-ray disc. The analysis includes energy used in the manufacturing, packaging and storage, and transportation of the Blu-ray product. Range estimates are presented reflecting variations in production processes, packaging energy, and transportation distances from manufacturing sites to end users.

UK Manufacturing

For products manufactured within the UK, all energy-intensive processes, including raw material processing, manufacturing, packaging, warehousing, and retail operations, contribute to the UK's energy consumption footprint. Transportation energy is also fully accounted for, covering road transport from the manufacturing facility to warehouses and from warehouses to retail stores. Since all stages of production occur domestically, the analysis captures the energy consumption associated all stages of production.

Manufacturing and Storage

The energy consumption for manufacturing and storage is determined using figures for the energy use for each stage of production, allocated across fuel types using an assumed percentage breakdown by type of fuel. In this way, the results distinguish between electricity use and other fuel types (gas and diesel) when assessing the energy footprint of Blu-ray production.

Table 5.10 sets out the electricity consumption for manufacturing and storage when Blu-rays are produced within the UK. The majority of electricity consumption comes from Blu-ray manufacturing, followed by raw material processing and retail store energy use. Warehousing and packaging contribute a smaller share.

Table 5.10: Energy Consumption for Manufacturing and Storage (Manufactured with Electricity within the UK) – Electricity (kWh/blu-ray)

	Low	Medium	High
Manufacture of raw materials	0.055	0.069	0.083
Manufacture of Blu-ray	0.27	0.0.338	0.405
Burning video onto Blu-ray	0.011	0.014	0.017
Packaging	0.028	0.046	0.064
Warehouse Operations	0.017	0.021	0.025
Retail store energy	0.064	0.08	0.096
Total	**0.445**	**0.567**	**0.689**

Source: Europe Economics analysis.

Table 5.11 presents the energy consumption from other fuel sources, including gas and diesel. Gas is primarily used in raw material processing, manufacturing, and packaging, particularly for heating and chemical processes, while diesel consumption is minimal, appearing only in packaging operations. In total, consumption of other fuels is very small compared with consumption of electricity.

Table 5.11: Energy Consumption for Manufacturing and Storage (Manufactured within the UK) – other fuel (kWh/blu-ray)

	Low	Medium	High
Gas			
Manufacture of raw materials	0.0138	0.0172	0.0207
Manufacture of Blu-ray	0.03	0.0375	0.045
Burning of video onto Blu-ray	-	-	-
Packaging	0.008	0.013	0.0182
Warehouse Operations	0.0041	0.0052	0.0062
Retail store energy	0.016	0.02	0.024
Diesel			
Packaging	0.004	0.0065	0.0091
Total	**0.076**	**0.099**	**0.123**

Source: Europe Economics analysis.

Transportation

Table 5.12 presents the energy consumption for transportation when Blu-rays are manufactured within the UK. The transportation energy is calculated by multiplying the distance travelled (km) by the fuel consumption intensity per kilometre (L/km) and the energy content per litre of fuel (kWh/L), then dividing by the number of Blu-rays transported per vehicle to obtain the per-unit energy consumption.

For UK-manufactured Blu-rays, all transportation occurs by road, with no marine transportation involved. The total transport energy consists of inbound logistics (from the factory to the warehouse) and retail distribution (from the warehouse to stores). We have assumed that all road transport relies on diesel, meaning that all transport energy in this scenario is attributed to diesel consumption.

The results show that transportation energy per Blu-ray is minimal, particularly when compared to the energy required for manufacturing and storage. This is because the high number of Blu-rays transported per vehicle significantly reduces per-unit transport energy. Inbound logistics from the factory to the warehouse contributes the largest share of transportation energy, while retail distribution has a smaller impact due to shorter distances.

Table 5.12: Energy Consumption for Transportation (Manufactured within the UK) – other fuel (kWh/blu-ray)

	Low	Medium	High
Inbound Logistics			
Factory to Warehouse	0.0025	0.0058	0.0119
Retail Distribution			
Warehouse to Store	0.0005	0.0019	0.006
Total			
Total Road transportation inside UK (Diesel)	**0.003**	**0.0078**	**0.018**
Marine transportation inside UK (Marine Diesel)	**0**	**0**	**0**

Source: Europe Economics analysis.

In the decarbonised scenario, all road transport is assumed to be carried out by electric trucks. The transportation energy is calculated by multiplying the distance travelled (km) by the energy efficiency of electric trucks (kWh/km), then dividing by the number of Blu-rays transported per vehicle to obtain the per-unit energy consumption.

Table 5.13: Energy Consumption for Transportation (Manufactured within the UK) – Decarbonised (kWh/blu-ray)

	Low	Medium	High
Inbound Logistics (Factory to Warehouse)	0.00075	0.0016	0.0032
Retail Distribution (Warehouse to Store)	0.00015	0.0005	0.0016
Total - road	**0.0009**	**0.0021**	**0.0048**

Source: Europe Economics analysis.

End-User Device

Similarly to the digital case, the energy consumption for end-user devices is calculated by multiplying the power draw of the television and Blu-ray player (in Table 3.4) by the total hours of use (4 hours). Unlike the digital case, where only the TV is used, the physical case includes additional energy consumption from the Blu-ray player, increasing the total energy use. The set-top box is assumed to be absent in both cases.

The results show that the Blu-ray player adds between 0.12 kWh and 0.2 kWh to the total energy consumption, leading to a higher overall device energy use compared to digital viewing. The total energy use ranges from 0.32 kWh (low) to 1 kWh (high), depending on device efficiency. This highlights that while the Blu-ray player contributes additional energy demand, its impact varies based on power draw and efficiency.

End-user device energy consumption remains the same regardless of whether the Blu-ray was manufactured in the UK or overseas and is assumed to be entirely electricity-based.

Table 5.14: Energy Consumption for End-User Device - Electricity (kWh)

Units	Low	Medium	High
Energy used by device	0.2	0.4	0.8
Energy used by blu-ray player (if used)	0.12	0.16	0.2
Total device energy	**0.32**	**0.56**	**1.0**

Source: Europe Economics analysis.

Summary of Energy Use

Electricity

We will only consider the energy consumption within the UK, and will consider a scenario in which the Blu-ray is manufactured domestically or and a scenario in which it is manufactured overseas.

Since all transportation energy is assumed to be diesel or marine diesel, the electricity consumption in this scenario includes only the manufacturing and storage energy consumption (for UK manufacturing with the relevant electricity apportioning) and the end-user device energy consumption.

Electricity consumption for the representative scenario (Table 5.15) ranges from 0.77 kWh to 1.69 kWh, with manufacturing, packaging, and storage making up a significant share in the low and medium estimates. However, in the high scenario, end-user device consumption becomes the dominant factor, reflecting the variability in device energy efficiency.

Table 5.15: Total energy for representative scenario (kWh) - (Manufactured within the UK) - Electricity

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing	0.445	0.567	0.689
Energy for end-user device	0.32	0.56	1
Total energy for representative scenario	**0.765**	**1.127**	**1.689**

Source: Europe Economics analysis.

When distributed over 4 hours of assumed viewing, electricity use per hour of viewing ranges from 0.19 kWh to 0.42 kWh (Table 5.16). End-user device energy contributes a significant share, increasing with higher power draw assumptions.

Table 5.16: Energy per hour of video watching - (Manufactured within the UK) - Electricity

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing	0.1112	0.1417	0.1723
Energy for end-user device	0.08	0.14	0.25
Total energy per hour of video watching	**0.1912**	**0.2817**	**0.4223**

Source: Europe Economics analysis.

Table 5.17 presents the percentage breakdown of electricity consumption. At lower estimates, manufacturing, packaging, and storage contribute a larger share (58 per cent), while at higher estimates, end-user device consumption dominates (59 per cent). The variation is due to the assumed power draw of the Blu-ray player and TV, highlighting that playback efficiency influences total electricity consumption.

Table 5.17: Breakdown of energy consumption (%) - (Manufactured within the UK) - Electricity

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing	58	50	41
Energy for end-user device	42	50	59

Source: Europe Economics analysis.

In the UK manufacturing scenario, we classify electricity used in production, warehousing, and retail as centralised and electricity for end-user devices as decentralised. Thus, the share of electricity consumption occurring in centralised locations ranges from **41 to 58 per cent**.

All fuel

The *"all fuel"* scenario accounts for all fuel types (electricity, gas, diesel, and marine diesel) consumed across manufacturing, storage, transportation, and end-user device usage. All transportation energy is assumed to be diesel or marine diesel, the manufacturing and storage energy includes electricity, gas and diesel consumption, while end-user device energy remains entirely electricity-based.

Table 5.18 presents the total energy consumption, which ranges from 0.84 kWh to 1.82 kWh, with electricity remaining the dominant energy source. Gas contributes to manufacturing and storage processes, but its share is relatively small compared to electricity. Diesel is mainly used for road transportation, making its impact minor due to the high number of Blu-rays transported per vehicle. Marine diesel consumption is zero, as UK manufacturing does not involve maritime shipping.

Table 5.18: Total energy for representative scenario (kWh) - (Manufactured within the UK) – All Fuel

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing - electricity	0.445	0.5667	0.6892
Energy for manufacturing, packaging, storage, and retailing - other fuel	0.076	0.0994	0.1233
Energy for transportation - road - other fuel	0.003	0.0078	0.018
Energy for transportation - marine - other fuel	0	0	0
Energy for end-user device - electricity	0.32	0.56	1
Total energy for representative scenario	**0.844**	**1.234**	**1.8304**

Source: Europe Economics analysis.

Table 5.19 shows energy consumption per hour of video watching, derived by dividing the total energy by the assumed 4-hour viewing period. Electricity from manufacturing and storage remains the largest contributor, while other fuel energy remains minimal. End-user device energy consumption is significantly higher in the high-energy scenario, making it a key driver of total energy use.

Table 5.19: Energy per hour of video watching (kWh) - (Manufactured within the UK) – All Fuel

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing - electricity	0.1112	0.1417	0.1723
Energy for manufacturing, packaging, storage, and retailing - other fuel	0.0189	0.0248	0.0308
Energy for transportation - road - other fuel	0.0008	0.0019	0.0046
Energy for end-user device- electricity	0.08	0.14	0.25
Total energy per hour of video watching	**0.211**	**0.3085**	**0.4576**

Source: Europe Economics analysis.

Table 5.20 provides a breakdown of energy consumption across different components. Electricity remains the dominant energy source, accounting for over 90 per cent of total energy consumption, including both manufacturing, storage, and end-user device use. Other fuels (mainly gas) used in manufacturing and storage account for only 6–9 per cent, highlighting their limited role. Diesel for road transport remains negligible (0–1 per cent), reinforcing that logistics have a minor impact on the total energy footprint.

Table 5.20: Breakdown of energy consumption (%) - (Manufactured within the UK) - All Fuel

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing - electricity	53	46	38
Energy for manufacturing, packaging, storage, and retailing - other fuel	9	8	7
Energy for transportation - road - other fuel	0	1	1
Energy for end-user device- electricity	38	45	55

Source: Europe Economics analysis.

Under the UK manufacturing scenario (all fuel), we classify energy used in production, warehousing, and retailing as centralised. Transport fuel and end-user device electricity are treated as decentralised. The proportion of total energy consumption that occurs in centralised locations ranges from **44 to 62 per cent**.

Decarbonised scenario

In the decarbonised case, all processes, including transport and heating, are assumed to be powered by low-carbon electricity. As a result, all energy consumption is reported in kWh of electricity, regardless of whether it would previously have been diesel or gas. The figures below therefore reflect the total grid-relevant energy demand under a fully electrified supply chain.

Table 5.21 presents total energy consumption under the decarbonised scenario, which ranges from 0.84 kWh to 1.82 kWh. Manufacturing energy is the largest contributor. Transportation adds minor energy consumption, with road transport accounting for more than marine transport.

Table 5.21: Total energy for representative scenario (kWh) - UK Manufactured - Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	0.521	0.666	0.812
Energy for transportation - road	0.001	0.002	0.005
Energy for end-user device	0.32	0.56	1
Total energy for representative scenario	**0.8419**	**1.2283**	**1.8172**

Source: Europe Economics analysis.

Table 5.22 shows energy consumption per hour of video watching, derived by dividing total energy by the assumed 4-hour viewing period.

Table 5.22: Energy per hour of video watching (kWh) - (UK Manufactured) – Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	0.1302	0.1666	0.2031
Energy for transportation - road	0.0002	0.0005	0.0012
Energy for end-user device	0.08	0.14	0.25
Total energy for representative scenario	**0.2105**	**0.3071**	**0.4543**

Scenario: Europe Economics analysis.

To illustrate the relative contributions of each component, the table below presents the percentage breakdown of total energy consumption across the three scenarios.

Table 5.23: Breakdown of energy consumption (%) - (UK Manufactured) - Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	62	54	45
Energy for transportation - road	0	0	0
Energy for end-user device	38	46	55
Total energy for representative scenario	**100**	**100**	**100**

Source: Europe Economics analysis.

Under the UK manufacturing decarbonised scenario, we classify energy used in production, warehousing, and retailing as centralised. Transport fuel and end-user device electricity are treated as decentralised. The proportion of total energy consumption that occurs in centralised locations ranges from **45 to 62 per cent**.

Overseas Manufacturing

For products manufactured overseas, we **only consider the energy consumption directly associated with UK-based activities** in the analysis. This consists of warehousing, retail operations, and the domestic portion of transportation, which includes road freight from the UK port to warehouses and final retail distribution. Additionally, the energy from maritime transport is allocated between the UK and overseas. The energy used in raw material processing, manufacturing, and packaging are excluded as it remains outside the UK's energy footprint, as these processes occur abroad.

Manufacturing and Storage

For Blu-rays manufactured overseas, the UK energy consumption for manufacturing and storage is limited to warehouse operations and retail store energy use, as all other production processes occur outside the UK.

Electricity consumption (Table 5.24) is primarily from retail store operations, driven by lighting, HVAC, and shelving systems, while warehouse operations consume less energy.

Table 5.24: Energy Consumption for Storage and Retailing (Manufactured Overseas) – Electricity (kWh/blu-ray)

	Low	Medium	High
Warehouse Operations	0.01664	0.0208	0.02496
Retail store energy	0.064	0.08	0.096
Total	**0.0806**	**0.1008**	**0.121**

Source: Europe Economics analysis.

Gas consumption follows a similar pattern, with retail store heating accounting for the majority and warehouse operations using a smaller share for climate control (Table 5.25)

Table 5.25: Energy Consumption for Storage and Retailing (Manufactured Overseas) – gas (kWh/blu-ray)

	Low	Medium	High
Warehouse Operations	0.00416	0.0052	0.00624
Retail store energy	0.016	0.02	0.024
Total	**0.02016**	**0.0252**	**0.03024**

Source: Europe Economics analysis.

Transportation

The transportation energy consumption is calculated using the same methodology across all transport stages, with energy derived from the distance travelled, fuel consumption intensity, energy content per litre of fuel and the number of Blu-rays transported per vehicle. For ferry transport, energy consumption is calculated using marine diesel, factoring in ferry fuel consumption intensity, energy content per litre and the number of lorries per ferry. The results are presented in Table 5.26.

- The UK allocation of **marine transportation energy (marine diesel)** represents the share of ferry fuel attributed to the UK. It is calculated as the total ferry energy consumption multiplied by the proportion allocated to the UK. Due to the high cargo capacity of ferries, the per-unit energy consumption is low.
- **Road transportation inside the UK (diesel)** includes transport from the UK ferry port to the warehouse and final retail distribution to stores. Since UK distances are generally shorter than overseas transport, this component contributes less to the total footprint.

The results show that UK road transport contributes the most to the total UK transport energy consumption, as it includes both inbound logistics from the UK port to the warehouse and final retail distribution to stores. Marine transport energy allocated to the UK has a minimal per-unit energy impact, as the ferry energy consumption is allocated across large cargo shipments.

Table 5.26: Energy Consumption for Transportation (Manufactured Overseas) - other fuel (kWh/blu-ray)

	Low	Medium	High
Inbound Logistics			
Ferry (Cross-Channel)	0.0001	0.0008	0.0029
UK Road (Ferry Port to Warehouse)	0.0025	0.0078	0.018
Retail Distribution			
Warehouse to Store	0.0005	0.002	0.006
Total			
Marine transportation allocated to the UK (Marine Diesel)	**0.0000418**	**0.0004**	**0.0018**
Road transportation inside UK (Diesel)	**0.003**	**0.0097**	**0.024**

Source: Europe Economics analysis.

In the decarbonised scenario, all road transport and marine transport are assumed to be carried out by electric trucks and hydrogen powered vessels. The transportation energy is calculated by multiplying the distance travelled (km) by the energy efficiency of electric trucks or hydrogen powered vessels (kWh/km), then dividing by the number of Blu-rays transported per vehicle to obtain the per-unit energy consumption.

Table 5.27: Energy Consumption for Transportation (Manufactured Overseas) – Decarbonised (kWh/blu-ray)

	Low	Medium	High
Inbound Logistics			
Ferry (Cross-Channel)	$2.15*10^{-5}$	0.00018	0.0007
UK Road (Ferry Port to Warehouse)	0.00075	0.0021	0.0048
Retail Distribution			
Warehouse to Store	0.00015	0.0005	0.0016
Total			
Marine transportation allocated to the UK	**$8.63*10^{-6}$**	**0.00009**	**0.00043**
Road transportation inside UK	**0.00009**	**0.0026**	**0.0063**

Source: Europe Economics analysis.

End-User Device

End-user device energy consumption is the same for the UK manufacturing case (see Table 5.14).

Summary of Energy Use

Electricity

Since all transportation energy is assumed to be diesel or marine diesel, the electricity consumption in this scenario includes only the storage (such as warehousing) and retail energy, with the relevant apportionment to electricity) energy consumption and the end-user device energy consumption.

Electricity consumption for the representative scenario (Table 5.28) ranges from 0.40 kWh to 1.12 kWh, with end-user device consumption making up the dominant share across all scenarios.

Table 5.28: Total energy for representative scenario (kWh) - (Manufactured Overseas) - Electricity

Component	Low	Medium	High
Energy for storage and retailing	0.0806	0.1008	0.121
Energy for end-user device	0.32	0.56	1
Total energy for representative scenario	**0.4006**	**0.6608**	**1.121**

Source: Europe Economics analysis.

When distributed over 4 hours of assumed viewing, electricity use per hour ranges from 0.10 kWh to 0.28 kWh (Table 5.29). As seen in the UK manufacturing case, end-user device energy is the primary driver of electricity use, while storage energy remains a minor contributor.

Table 5.29: Energy per hour of video watching (kWh) - (Manufactured Overseas) - Electricity

Component	Low	Medium	High
Energy for storage and retailing	0.0202	0.0252	0.0302
Energy for end-user device	0.08	0.14	0.25
Total energy per hour of video watching	**0.1002**	**0.1652**	**0.2802**

Source: Europe Economics analysis

Table 5.30 presents the percentage breakdown of electricity consumption. Across all scenarios, end-user device consumption dominates, contributing between 80 per cent and 89 per cent of the total electricity use. Storage accounts for only 11–20 per cent.

Table 5.30: Breakdown of energy consumption (%) - (Manufactured Overseas) - Electricity

Component	Low	Medium	High
Energy for storage and retailing	20	15	11
Energy for end-user device	80	85	89

Source: Europe Economics analysis.

In the non-UK manufacturing scenario, we classify electricity used in warehousing, and retail as centralised, while electricity for end-user devices is decentralised. Thus, the share of electricity consumption occurring in centralised locations ranges from **11 to 20 per cent.**

All fuel

The *“all fuel”* scenario accounts for all fuel types (electricity, gas, diesel, and marine diesel) consumed across storage, transportation, and end-user device usage. All transportation energy is assumed to be diesel or marine diesel, the storage energy includes electricity, gas, and diesel consumption, while end-user device energy remains entirely electricity-based.

Table 5.31 presents the total energy consumption, which ranges from 0.42 kWh to 1.18 kWh. Similar to the electricity-only scenario, end-user device energy remains the largest contributor. Transportation adds minor energy consumption, with road transport accounting for more than marine transport.

Table 5.31: Total energy for representative scenario (kWh) – (Manufactured Overseas) – All Fuel

Component	Low	Medium	High
Energy for storage and retailing- electricity	0.0806	0.1008	0.121
Energy for storage and retailing- other fuel	0.0201	0.0252	0.0302
Energy for transportation - road - other fuel	0.003	0.0097	0.024
Energy for transportation - marine - other fuel	4.18×10^{-05}	0.0004	0.0018
Energy for end-user device- electricity	0.32	0.56	1
Total energy for representative scenario	**0.4239**	**0.6961**	**1.1769**

Source: Europe Economics analysis.

Table 5.32 shows energy consumption per hour of video watching, derived by dividing total energy by the assumed 4-hour viewing period.

Table 5.32: Energy per hour of video watching (kWh) – (Manufactured Overseas) – All Fuel

Component	Low	Medium	High
Energy for storage and retailing- electricity	0.0202	0.0252	0.0302
Energy for manufacturing and storage - other fuel	0.005	0.0063	0.0076
Energy for transportation - road - other fuel	0.0008	0.0024	0.006
Energy for transportation - marine - other fuel	1.05×10^{-5}	9.98×10^{-5}	4.4×10^{-4}
Energy for end-user device- electricity	0.08	0.14	0.25
Total energy per hour of video watching	**0.106**	**0.174**	**0.2942**

Source: Europe Economics analysis.

Table 5.33 highlights the dominance of end-user device electricity consumption, which accounts for 75 per cent to 85 per cent of total energy use across all scenarios. This confirms that the primary driver of UK energy consumption when manufacturing is carried out overseas is the playback device itself. Storage contributes just 14 per cent or less of total energy use, with other fuels making up a marginal share (3 to 5 per cent), indicating limited reliance on non-electric energy sources. Transport energy is negligible, with road fuel contributing only 1 to 2 per cent, while marine diesel has virtually no impact.

Table 5.33: Breakdown of energy consumption (%) - (Manufactured Overseas) - All Fuel

Component	Low	Medium	High
Energy for manufacturing, storage and retailing- electricity	19	14	10
Energy for manufacturing, storage and retailing- other fuel	5	4	3
Energy for transportation - road - other fuel	1	1	2
Energy for transportation - marine - other fuel	0	0	0
Energy for end-user device - electricity	75	80	85

Source: Europe Economics analysis.

In the non-UK manufacturing case (all fuels), only UK-based warehousing and retail operations contribute to centralised energy use, while domestic transport and end-user devices represent decentralised consumption. Thus, the centralised share of total UK-attributable energy use (all fuels) ranges from **13 to 24 per cent**.

Decarbonised scenario

In the decarbonised case, all processes, including transport and heating, are assumed to be powered by low-carbon electricity. As a result, all energy consumption is reported in kWh of electricity, regardless of whether it would previously have been diesel, marine fuel, or gas. The figures below therefore reflect the total grid-relevant energy demand under a fully electrified supply chain.

Table 5.34 presents the total energy consumption, which ranges from 0.42 kWh to 1.16 kWh. As with the electricity-only scenario, end-user device energy remains the largest contributor. Transportation adds minor energy consumption, with road transport accounting for more than marine transport.

Table 5.34: Total energy for representative scenario (kWh) - Manufactured Overseas - Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	0.1008	0.126	0.1512
Energy for transportation - road	0.0009	0.0026	0.0063
Energy for transportation - marine	8.63×10^{-6}	0.00009	0.00043
Energy for end-user device	0.32	0.56	1
Total energy for representative scenario	**0.4217**	**0.6887**	**1.158**

Source: Europe Economics analysis.

Table 5.35 shows energy consumption per hour of video watching, derived by dividing total energy by the assumed 4-hour viewing period.

Table 5.35: Energy per hour of video watching (kWh) - (Manufactured Overseas) - Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	0.0252	0.0315	0.0378
Energy for transportation - road	0.0002	0.0006	0.0016
Energy for transportation - marine	0.000002	0.000022	0.000108
Energy for end-user device	0.08	0.14	0.25
Total energy for representative scenario	**0.1054**	**0.1722**	**0.2895**

Source: Europe Economics analysis.

To illustrate the relative contributions of each component, the table below presents the percentage breakdown of total energy consumption across the three scenarios.

Table 5.36: Breakdown of energy consumption (%) - (Manufactured Overseas) - Decarbonised

	Low	Medium	High
Energy for manufacturing, packaging and storage	24	18	13
Energy for transportation - road	0	0	1
Energy for transportation - marine	0	0	0
Energy for end-user device	76	81	86
Total energy for representative scenario	**100**	**100**	**100**

Source: Europe Economics analysis.

In the non-UK manufacturing decarbonised case, only UK-based warehousing and retail operations contribute to centralised energy use, while domestic transport and end-user devices represent decentralised consumption. Thus, the centralised share of total UK-attributable energy use ranges from **13 to 24 per cent**.

Comparison of energy consumption

Video streaming using a digital platform against the physical alternative of watching a Blu-ray disc differ significantly in how and where energy is consumed. Both scenarios are assessed using the same representative case: a two-hour video watched twice over a five-year period. This provides a total of four hours of viewing time and a basis for consistent comparison across the digital and physical delivery formats.

Total Energy Use Across Scenarios (Electricity Only)

The table below presents the electricity-only energy use for each scenario under low, medium, and high assumptions. These figures represent **only the electricity consumption attributable to the UK,** excluding electricity use in overseas manufacturing (in the scenario in which manufacture happens overseas), or energy consumption from other fuel types.

The results show that electricity consumption from video streaming is slightly lower to that of UK-manufactured Blu-rays. For Blu-rays manufactured overseas, electricity use in the UK is lower across all scenarios, as significant stages of the lifecycle, including production, take place abroad.

Table 5.37: Total electricity consumption attributable to the UK (kWh)

	Low	Medium	High
Streaming (Digital)	0.65	1.05	1.67
Blu-ray (UK manufactured)	0.77	1.13	1.69
Blu-ray (Overseas manufactured)	0.4	0.66	1.12
Blu-ray (UK manufactured, Decarbonised)	0.84	1.23	1.82
Blu-ray (Overseas manufactured, Decarbonised)	0.42	0.69	1.16

Source: Europe Economics analysis.

Total Energy Use (All Fuels)

The table below includes electricity and other fuels (gas, diesel, marine diesel) used across all lifecycle stages. Again, these values represent **only energy consumption occurring within the UK**, aligned with the study's objective of assessing domestic energy implications.

These results show that once other fuels are included, energy use in the physical scenarios is higher, particularly for UK-manufactured Blu-rays where gas and diesel are used in manufacturing and transport. However, the difference between streaming and physical formats remains relatively modest. For overseas-manufactured Blu-rays, total energy consumption remains below that of the digital alternative, as significant portions of the lifecycle energy use are not included in the UK total.

Table 5.38: Total energy consumption attributable to the UK (All Fuels, kWh)

Scenario	Low	Medium	High
Streaming (Digital)	0.65	1.05	1.67
Blu-ray (UK manufactured)	0.84	1.23	1.83
Blu-ray (Overseas manufactured)	0.42	0.7	1.18
Blu-ray (UK manufactured, Decarbonised)	0.84	1.23	1.82
Blu-ray (Overseas manufactured, Decarbonised)	0.42	0.69	1.16

Source: Europe Economics analysis.

Electricity versus Other Fuels

It is also important to distinguish between electricity and other fuel types. In the streaming scenario, all energy use, including data centre activity, transmission, and end-user device usage, is assumed to be electricity-based. In the Blu-ray scenario, while the end-user device remains electricity-driven, energy used in manufacturing, storage, and transportation includes gas, diesel, and marine diesel. As a result, total energy consumption in the Blu-ray case includes a mix of fuels, with electricity typically accounting for around 80 to 90 per cent of the total.

UK versus Overseas Energy Use

Another key distinction relates to where the energy is consumed. In the digital scenario, electricity demand is largely driven by data centre operations, which are assumed to take place inside the UK. The physical counterfactual also involves energy consumption within the UK, including for retail operations, warehousing, and the end-user device. However, for Blu-rays manufactured overseas, the significant amount of energy used in production is excluded from energy consumption within the UK, though domestic warehousing and transport still contribute.

Energy Use Per Hour of Viewing

To standardise comparisons, the total energy use is divided by the four hours of viewing time. This metric highlights the per-hour energy footprint of each delivery method. Again, these values reflect energy consumption within the **UK only**.

These results reinforce the earlier findings: the differences in energy consumption between formats are modest if the Blu-ray is manufactured within the UK. However, when the Blu-ray is manufactured overseas, UK energy consumption is lower under the physical approach.

Table 5.39: Energy use per hour of video viewing attributable to the UK (electricity, kWh/hour)

Scenario	Low	Medium	High
Streaming (Digital)	0.16	0.26	0.42
Blu-ray (UK manufactured)	0.21	0.31	0.46
Blu-ray (Overseas manufactured)	0.1	0.17	0.28
Blu-ray (UK manufactured, decarbonised)	0.21	0.3	0.45
Blu-ray (Overseas manufactured, decarbonised)	0.11	0.17	0.29

Source: Europe Economics analysis.

Decarbonisation Readiness

We also investigate the proportion of total energy consumption supplied in the form of electricity, which we refer to as a “Decarbonisation Readiness Index” (DRI). This index is calculated as the share of electricity within total energy use (including electricity, gas, and liquid fuels) and provides an indication of how readily each scenario could benefit from electricity grid decarbonisation. For Blu-rays manufactured in the UK, the DRI ranges from 90.6 to 92.3 per cent across scenarios. Where manufacturing occurs overseas, UK-attributable electricity use accounts for an even higher share of total energy consumption, with a DRI ranging from 94.5 to 95.2 per cent. In both cases, electricity represents the dominant energy source, though some residual use of gas and diesel remains in UK-based manufacturing, warehousing, or transport.

By contrast, the digital video streaming scenario is entirely electricity-based, resulting in a DRI of 100 per cent. This indicates that digitalisation not only reduces overall energy use in many cases, but also increases decarbonisation readiness, as all energy demand can be directly aligned with a decarbonised electricity grid.

Table 5.40: DRI for Blu-ray streaming (% of energy from electricity)

	Low	Medium	High
Streaming (Digital)	100	100	100
Blu-ray (UK manufactured)	90.6	91.3	92.3
Blu-ray (Overseas manufactured)	94.5	94.9	95.2

Source: Europe Economics analysis.

5.2 Ebook versus physical book

This use case evaluates the energy consumption associated with reading a book in either a digital format (e-book scenario) or as a physical paperback (physical counterfactual). The analysis is based on a representative scenario that establishes the parameters of book access and consumption, ensuring consistency between both cases.

The scenario assumes an adult fiction book with a total word count of 90,000 words and a file size of 0.001 GB when stored as an EPUB e-book without images. Over a 15-year period, the book is read twice. The total reading time (which is relevant when calculating the energy consumption of the e-reader under the digital approach) varies depending on the reader's assumed reading speed:

- 150 words per minute → (90,000 / 150) × 2 = 1,200 minutes = 20 hours
- 250 words per minute → (90,000 / 250) × 2 = 720 minutes = 12 hours
- 300 words per minute → (90,000 / 300) × 2 = 600 minutes = 10 hours

The analysis considers the energy use associated with digital reading devices, data storage, and e-book downloads in the e-book scenario, compared to the energy consumption of book printing, distribution, and storage in the physical counterfactual. The 15-year timeframe reflects the typical lifespan of a paperback book, allowing for a fair comparison of energy use across both scenarios.

Digital Scenario

This section sets out the estimated energy use associated with downloading an ebook. The analysis includes energy use from three main sources: (i) data centre energy consumption, including both IT and non-IT processes, (ii) internet transmission, and (iii) the end-user's device.

Data centre

The downloading of an ebook involves several IT processes within data centres, including uploading the ebook to the cloud, long-term storage, and final downloading/streaming to the user. Each of these processes is characterised by a defined activity level and energy intensity, with some processes classified as shared across users (e.g. uploading, long-term storage) and others as user-specific (e.g. downloading/streaming).

The table below presents the activity volumes for each process under low, medium and high scenarios, along with their classification as shared or specific.

Table 5.41: Activity volumes and process classification for IT processes

Data Process	Units	Low	Medium	High	Shared/ Specific	Basis of Estimate
Uploading to Data Centres	GB uploaded	0.001	0.001	0.001	Shared	*File size of an ebook (from representative scenario)*
Video Processing	GB processed	0	0	0	-	-
Long-term storage	GB stored per year	0.001	0.001	0.001	Shared	*File size of an ebook (from representative scenario)*
RAM storage	GB-hours	0	0	0	-	-
General Processing	CPU-hours	0	0	0	-	-
AI Training	FLOP	0	0	0	-	-
AI Inference	FLOP	0	0	0	-	-
Downloading/ Streaming	GB downloaded/ streamed	0.002	0.002	0.002	Specific	*Total GB downloaded under representative scenario (file size × number of readings)*

Source: Europe Economics analysis.

Using these activity volumes and corresponding energy intensities (Table 3.1), the total energy consumption associated with each IT process is calculated. These figures represent the gross energy usage, prior to accounting for user attribution.

Table 5.42: Energy used in each IT process – Video Streaming (kWh)

Data Process	Low	Medium	High
Uploading to Data Centres	0.000015	0.00002	0.00003
Long-term storage	0.0000375	0.000075	0.00012
Downloading/Streaming	0.00002	0.00003	0.00004
Sub-total	**0.00007**	**0.00012**	**0.00019**

Source: Europe Economics analysis.

To estimate the energy attributable to the representative user, we apply allocation factors for shared processes (e.g. uploading to data centres and long-term storage), based on the assumed user base.[30] For downloading/streaming, the full energy is allocated to the user. The table below presents these user-level allocations.

Table 5.43: IT energy attributable to each user (kWh)

IT Process (attributable to user)	Low	Medium	High
Uploading to Data Centres	6.0×10^{-11}	4.0×10^{-10}	6.0×10^{-9}
Long-term storage	1.5×10^{-10}	1.5×10^{-9}	2.4×10^{-8}
Downloading/Streaming	0.00002	0.00003	0.00004
Total IT energy	**0.00002**	**0.00003**	**0.00004**

Source: Europe Economics analysis.

In addition to the IT energy, we include an allocation for non-IT energy used to support data centre operations. This is calculated by applying a proportional uplift to the energy consumed by each IT process (Table 3.2) based on the assumed PUE value. The table below summarises both IT and non-IT energy components to give the total data centre energy attributable to the user.

Table 5.44: Summary of data centre energy consumption (kWh)

Component	Low	Medium	High
IT energy	0.00002	0.00003	0.00004
Non-IT energy	0.000002	0.000009	0.00002
Total data centre energy	**0.00002**	**0.00004**	**0.00006**

Source: Europe Economics analysis.

Internet Transmission

Energy is consumed in transmitting the ebook between the data centre and the end-user. This includes both the initial upload of the ebook to the platform (e.g. by the publisher or the writer) and downloading of the ebook by the user. **Upload transmission is considered a shared process**, while **download transmission is specific to the user**. Therefore, only a small proportion of the upload energy is attributed to the representative user, while the full energy for download is allocated.

Table 5.45: Transmission energy attributable to each user (kWh)

Component	Low	Medium	High
Upload transmission	8.5×10^{-11}	5.3×10^{-10}	6.4×10^{-9}
Download transmission	0.00004	0.00005	0.00006
Total transmission	**0.00004**	**0.00005**	**0.00006**

Source: Europe Economics analysis.

[30] The percentage attributable to user for shared processes, over the period of the representative scenario, is calculated as (number of downloads per user) / (total number of downloads (all users))

End-User Device Energy

The end-user is assumed to read the ebook using an eReader via a fixed-line broadband connection for download. Energy consumption is estimated by multiplying the e-reader's assumed power draw (Table 3.4) by the total hours of use (20 hours in the medium case, based on 10 hours × 2 readings).

Table 5.46: Energy used in end-user devices (kWh)

	Low	Medium	High
e-reader energy consumption	**0.002**	**0.003**	**0.005**

Source: Europe Economics analysis.

Summary of Energy Use

The table below brings together the energy consumed across all stages of digital delivery and reading of an ebook. Across all scenarios, the end-user device is the dominant contributor to total energy use, accounting for more than 97 per cent of the total. Internet transmission and data centre energy represent only a very small share of total consumption.

Table 5.47: Total energy consumption for representative scenario (kWh)

Component	Low	Medium	High
IT energy (data centres)	0.00002	0.00003	0.00004
Non-IT energy (data centres)	0.000002	0.000009	0.00002
Internet transmission	0.00004	0.000053	0.000064
End-user device	0.002	0.003	0.005
Total	**0.002**	**0.003**	**0.005**

Source: Europe Economics analysis.

To illustrate the relative contributions of each component, the table below presents the percentage breakdown of total energy consumption across the three scenarios.

Table 5.48: Breakdown of energy consumption (%)

Component	Low	Medium	High
IT energy (data centres)	1.0	0.9	0.8
Non-IT energy (data centres)	0.1	0.3	0.4
Internet transmission	2.1	1.7	1.2
End-user device	96.9	97.1	97.6
Total	**100**	**100**	**100**

Source: Europe Economics analysis.

For ebooks, we classify electricity consumed within the data centre as centralised, while electricity used for transmission and end-user devices is considered decentralised. Across the low, medium, and high scenarios, the share of electricity consumed in centralised locations ranges from 1.1 to 1.2 per cent.

Physical counterfactual

This section sets out the estimated energy use associated with reading a physical book. The analysis includes energy used in the manufacturing, packaging and storage, and transportation of a physical book. Range estimates are presented reflecting variations in manufacturing and packaging energy, and distances covered for the transportation of a physical book.

UK Manufacturing

For books manufactured within the UK, all energy-intensive processes—including raw material processing, printing, binding, packaging, warehousing, and retail operations—contribute to the UK's energy consumption footprint. Transportation energy is also fully accounted for, covering road transport from the manufacturing facility to warehouses and from warehouses to retail stores. Since all stages of production occur domestically, the analysis captures the complete energy consumption associated with the production and distribution of these products within the UK.

Unlike digital media (e.g. e-books or video watching), books do not require an end-user device that consumes additional energy during use.

Manufacturing and Storage

The energy consumption for manufacturing and storage is determined using figures for the energy use for each stage of production, allocated across fuel types using an assumed percentage breakdown by type of fuel. In this way, the results distinguish between electricity use and other fuel types (gas and diesel) when assessing the energy footprint of book production.

Table 5.49 presents the electricity consumption for manufacturing and storage when books are produced within the UK. The highest electricity consumption comes from raw material production (including paper, ink, and binding), followed by the printing process. Binding and finishing, packaging, and warehousing operations contribute a smaller share. Retail store energy use, including lighting and HVAC, is also significant.

Table 5.49: Energy Consumption for Manufacturing and Storage (Manufactured within the UK) – Electricity (kWh/book)

	Low	Medium	High
Manufacture of raw materials	2.1	3.15	4.2
Printing of books	0.68	0.9775	1.275
Binding and finishing	0.18	0.315	0.45

	Low	Medium	High
Packaging	0.06	0.12	0.18
Warehouse Operations	0.24	0.52	0.8
Retail store energy	0.064	0.08	0.096
Total	**3.32**	**5.16**	**7**

Source: Europe Economics analysis.

Table 5.50 presents the energy consumption from other fuel sources, including gas and diesel. Gas is primarily used in raw material processing, printing, and packaging, while diesel consumption is minimal and appears only in packaging operations.

Table 5.50: Energy Consumption for Manufacturing and Storage (Manufactured within the UK) – other fuel (kWh/book)

	Low	Medium	High
Gas			
Manufacture of raw materials	0.9	1.35	1.8
Printing of books	0.12	0.1725	0.225
Binding and finishing	0.02	0.035	0.05
Packaging	0.03	0.06	0.09
Warehouse Operations	0.06	0.13	0.2
Retail store energy	0.016	0.02	0.024
Diesel			
Packaging	0.01	0.02	0.03
Total	**1.16**	**1.7875**	**2.419**

Source: Europe Economics analysis.

Transportation

Transportation energy per book is assumed to be the same as for Blu-ray discs (as shown in Table 5.12 and Table 5.13), based on the same assumptions regarding transportation distances, volume, weight, and energy intensity per unit.

Similarly, for UK-manufactured books, all transportation occurs by road, with no marine transportation involved. The total transport energy consists of inbound logistics (from the factory to the warehouse) and retail distribution (from the warehouse to stores). All road transport is assumed to use diesel.

Summary of Energy Use

Only energy consumption within the UK is considered, regardless of whether the book is manufactured domestically or overseas.

Electricity

Electricity consumption includes only the manufacturing and storage energy consumption (100 per cent).

Table 5.51: Total energy for representative scenario (kWh) - (Manufactured within the UK) – Electricity

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing	**3.32**	**5.16**	**7.00**

Source: Europe Economics analysis.

All electricity consumption is attributable to centralised activities, specifically manufacturing, packaging, warehousing, and retailing. There is no decentralised electricity use associated with transportation or end-user devices. As a result, the share of electricity consumed in centralised locations is **100 per cent** across all scenarios.

All fuel

The All-Fuel scenario accounts for electricity, gas, diesel, and marine diesel consumption across manufacturing, storage, and transportation. Manufacturing and storage dominate total energy use (more than 99 per cent), with transportation contributing less than 1 per cent. Electricity is the largest energy source (74–75 per cent), mainly due to power-intensive raw material processing (paper production) and printing. Gas contributes 25–26 per cent, primarily for heating and drying in manufacturing and warehouse operations. Diesel use is minimal, appearing only in packaging and road transportation, while marine transport is not used given in this scenario we are assuming the book is produced in the UK.

Table 5.52: Total energy for representative scenario (kWh) - (Manufactured within the UK) – All Fuel

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing - electricity	3.32	5.16	7.00
Energy for manufacturing, packaging, storage, and retailing - other fuel	1.15	1.79	2.419
Energy for transportation - road - other fuel	0.003	0.008	0.0180
Energy for transportation - marine - other fuel	0	0	0
Total Energy	**4.48**	**6.96**	**9.44**

Source: Europe Economics analysis.

Table 5.53: Breakdown of energy consumption (%) - (Manufactured within the UK) – All Fuel

Component	Low	Medium	High
Energy for manufacturing, packaging, storage, and retailing - electricity	74	74	74
Energy for manufacturing, packaging, storage, and retailing - other fuel	26	26	26
Energy for transportation - road - other fuel	0	0	0
Energy for transportation - marine - other fuel	0	0	0

Source: Europe Economics analysis.

Under the UK manufacturing scenario (all fuel), we classify energy used in production, packaging, warehousing, and retailing as centralised. Transport fuel is treated as decentralised. The proportion of total energy consumption that occurs in centralised locations is approximately **100 per cent**.

Decarbonised scenario

In the decarbonised case, all processes, including transport and heating, are assumed to be powered by low-carbon electricity. As a result, all energy consumption is reported in kWh of electricity, regardless of whether it would previously have been diesel or gas. The figures below therefore reflect the total grid-relevant energy demand under a fully electrified supply chain.

Table 5.54 presents the total energy consumption, which ranges from 4.48 kWh to 9.43 kWh. Manufacturing energy is the largest contributor. Transportation adds minor energy consumption, with road transport accounting for more than marine transport.

Table 5.54: Total energy for representative scenario (kWh) – UK Manufactured– Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	4.480	6.950	9.420
Energy for transportation - road	0.001	0.002	0.005
Total energy for representative scenario	**4.481**	**6.952**	**9.425**

Source: Europe Economics analysis.

To illustrate the relative contributions of each component, the table below presents the percentage breakdown of total energy consumption across the three scenarios.

Table 5.55: Breakdown of energy consumption (%) - (UK Manufactured) – Decarbonised

	Low	Medium	High
Energy for manufacturing, packaging and storage	100	100	100
Energy for transportation - road	0	0	0
Total energy for representative scenario	**100**	**100**	**100**

Source: Europe Economics analysis.

Under the UK manufacturing decarbonised scenario, we classify energy used in production, packaging, warehousing, and retailing as centralised. Transport fuel is treated as decentralised. The proportion of total energy consumption that occurs in centralised locations is approximately **100 per cent**.

Overseas Manufacturing

For books manufactured overseas, **only the energy consumption directly associated with UK-based activities is included** in the analysis. This consists of warehousing, retail operations, and the domestic portion of transportation, including road freight from the UK port to warehouses and final retail distribution. Additionally, some of the maritime transport energy is allocated to the UK. The energy used in raw material processing, printing, binding, and packaging remains is consumed outside the UK and is therefore excluded from our figures, as these processes occur abroad.

Manufacturing and Storage

Table 5.56 presents electricity consumption for UK-based warehousing and retail operations.

Table 5.56: Energy Consumption for Storage and Retailing (Manufactured Overseas) – Electricity (kWh/book)

	Low	Medium	High
Warehouse Operations	0.24	0.52	0.8
Retail store energy	0.064	0.08	0.096
Total	**0.30**	**0.60**	**0.90**

Source: Europe Economics analysis.

Table 5.57 presents gas consumption, which follows a similar pattern.

Table 5.57: Energy Consumption for Storage and Retailing (Manufactured Overseas) – other fuel (kWh/book)

	Low	Medium	High
Gas	**0.08**	**0.15**	**0.22**
Warehouse Operations	0.06	0.13	0.2
Retail store energy	0.016	0.02	0.024

Source: Europe Economics analysis.

Transportation

Transportation energy per book is assumed to be the same as for per Blu-ray discs (as shown in Table 5.26 and Table 5.27), based on the same assumptions regarding transportation distances, size, weight, and energy intensity per unit. The UK road transport contributes the most to the total UK transport energy consumption, as it includes both inbound logistics from the UK port to the warehouse and final retail distribution to stores.

Summary of Energy Use

Electricity

Since all transportation energy is attributed to diesel or marine diesel, the electricity consumption scenario includes only UK-based warehouse and retail store energy use (100 per cent).

Table 5.58 Total energy for representative scenario (kWh) - (Manufactured Overseas) – Electricity

	Low	Medium	High
Total Energy (Electricity)	**0.304**	**0.6**	**0.896**

Source: Europe Economics analysis.

All electricity consumption is attributable to centralised activities, specifically warehousing and retailing. There is no decentralised electricity use associated with transportation or end-user devices. As a result, the share of electricity consumed in centralised locations is **100 per cent** across all scenarios.

All fuel

The All-Fuel scenario accounts for electricity, gas, diesel, and marine diesel consumption across UK-based manufacturing, storage, and transportation. Electricity is the largest contributor, accounting for around 80 per cent, as electricity for UK warehouse and retail store operations drive most of the energy use. Gas contributes around 20 per cent, primarily for retail heating and warehouse climate control. Diesel and marine transport energy remain minimal, making up only 1 per cent of total energy consumption due to efficient bulk transport and short domestic distances.

Table 5.59: Total energy for representative scenario (kWh) - (Manufactured Overseas) – All Fuel

	Low	Medium	High
Energy for storage and retailing - electricity	0.304	0.6	0.896
Energy for storage and retailing - other fuel	0.076	0.15	0.224
Energy for transportation - road - other fuel	0.003	0.0097	0.024
Energy for transportation - marine - other fuel	0.00004	0.0004	0.0018
Total Energy	**0.38**	**0.76**	**1.15**

Source: Europe Economics analysis.

Table 5.60: Breakdown of energy consumption (%) - (Manufactured Overseas) – All Fuel

	Low	Medium	High
Energy for storage, and retailing - electricity	89	79	78
Energy for storage, and retailing - other fuel	20	20	20
Energy for transportation - road - other fuel	1	1	2
Energy for transportation - marine - other fuel	0	0	0

Source: Europe Economics analysis.

In the non-UK manufacturing case (all fuels), only UK-based warehousing and retail operations contribute to centralised energy use, while domestic transport accounts for decentralised consumption. Thus, the centralised share of total UK-attributable energy use (all fuels) ranges from **98 to 99 per cent**.

Decarbonised case

In the decarbonised case, all processes, including transport and heating, are assumed to be powered by low-carbon electricity. As a result, all energy consumption is reported in kWh of electricity, regardless of whether it would previously have been diesel, marine fuel, or gas. The figures below therefore reflect the total grid-relevant energy demand under a fully electrified supply chain.

Table 5.61 presents the total energy consumption, which ranges from 0.38 kWh to 1.13 kWh. Similar to the electricity-only scenario, end-user device energy remains the largest contributor. Transportation adds minor energy consumption, with road transport accounting for more than marine transport.

Table 5.61: Total energy for representative scenario (kWh) - Manufactured Overseas – Decarbonisation

	Low	Medium	High
Energy for manufacturing, packaging and storage	0.380	0.750	1.120
Energy for transportation - road	0.001	0.003	0.006
Energy for transportation - marine	8.63×10^{-6}	0.00009	0.00043
Total energy for representative scenario	**0.381**	**0.753**	**1.127**

Source: Europe Economics analysis.

To illustrate the relative contributions of each component, the table below presents the percentage breakdown of total energy consumption across the three scenarios.

Table 5.62: Breakdown of energy consumption (%) - (Manufactured Overseas) – Decarbonised

	Low	Medium	High
Energy for manufacturing, packaging and storage	100	100	99
Energy for transportation - road	0	0	1
Energy for transportation - marine	0	0	0
Total energy for representative scenario	**100**	**100**	**100**

Source: Europe Economics analysis.

In the non-UK manufacturing decarbonised case, only UK-based warehousing and retail operations contribute to centralised energy use, while domestic transport represents decentralised consumption. Thus, the centralised share of total UK-attributable energy use ranges from **99 to 100 per cent**.

Comparison of energy consumption

This section compares the energy consumption associated with reading a book using an e-reader (digital scenario) versus a printed paperback book (physical counterfactual). As explained earlier, both scenarios are assessed using a consistent representative scenario involving a 90,000-word book read twice over a 15-year period.

Total Energy Use Across Scenarios (Electricity Only)

The table below presents electricity consumption in the UK in each scenario. For ebooks, this includes electricity used by data centres, internet transmission, and the e-reader device. For physical books, it includes electricity consumed during manufacturing, packaging, warehousing, and retail operations.

Electricity use in the ebook scenario remains minimal under all assumptions, reflecting the low energy demands of e-reader devices and associated digital infrastructure. In contrast, UK-manufactured physical books result in significantly higher electricity use, driven by energy-intensive processes such as paper production, printing, and in-store retail. For books produced overseas, only energy consumed within the UK, such as warehousing and retail is considered, resulting in considerably lower reported UK electricity consumption than for UK manufacture. Nonetheless, even when the book is manufactured overseas, UK electricity consumption is still much higher for a physical book than for an ebook.

Table 5.63: Total electricity consumption attributable to the UK – ebook versus Physical Book (kWh)

Scenario	Low	Medium	High
ebook (Digital)	0.002	0.003	0.005
Book (UK manufacture)	3.324	5.1625	7.001
Book (Overseas manufacture)	0.304	0.6	0.896
Book (UK manufactured, Decarbonised)	4.48	6.95	9.43
Book (Overseas manufactured, Decarbonised)	0.38	0.75	1.13

Source: Europe Economics analysis.

Total Energy Use Across Scenarios (All Fuels)

The table below includes electricity as well as other fuels such as gas and diesel. While energy consumption in the digital scenario is entirely electricity-based, physical book production involves a broader mix of fuels, particularly in manufacturing and transport.

As in the electricity-only scenario, ebooks have the lowest energy consumption across all assumptions. The inclusion of non-electric fuels raises the total energy consumption for printed books, particularly where books are manufactured domestically. For overseas-manufactured books, substantial energy use takes place outside the UK and is therefore excluded, resulting in a lower figure for UK energy consumption than when the book is manufactured in the UK. Even so, UK energy consumption is much greater for a physical book than for an ebook, even when production takes place outside the UK.

Table 5.64: Total energy consumption attributable to the UK (All Fuels, kWh)

Scenario	Low	Medium	High
ebook (Digital)	0.002	0.003	0.005
Book (UK manufactured)	4.48	6.96	9.44
Book (Overseas manufactured)	0.38	0.76	1.15
Book (UK manufactured, Decarbonised)	4.48	6.95	9.43
Book (Overseas manufactured, Decarbonised)	0.38	0.75	1.13

Source: Europe Economics analysis.

Conclusion

Under all scenarios, ebooks exhibit the lowest energy consumption. This reflects the energy efficiency of e-reader devices and the relatively low operational demands of digital infrastructure. By contrast, printed books involve energy-intensive supply chains and retail operations, which drive up electricity and total energy use. While overseas manufacturing can reduce the energy consumption within the UK for physical books, UK energy consumption is still considerably higher for a physical book than for digital alternatives.

Decarbonisation Readiness

We also investigate the DRI for manufacturing physical books. For physical books manufactured in the UK, the DRI is approximately 74 per cent across scenarios, reflecting the significant role of electricity in manufacturing and retail, alongside a persistent share of gas and diesel use. In the scenario in which books are manufactured overseas, only UK-based warehousing and retail operations are included in the calculation, resulting in a DRI ranging from 78 to 79 per cent.

By comparison, the digital scenario is fully electricity-based, resulting in a DRI of 100 per cent. This reinforces the pattern seen across use cases: digitalisation increases decarbonisation readiness, as all energy demand is directly compatible with a low-carbon electricity system.

Table 5.65: DRI for physical books (% of energy from electricity)

	Low	Medium	High
ebook (Digital)	100.00	100.00	100.00
Book (UK manufactured)	74.20	74.17	74.16
Book (Overseas manufactured)	79.35	78.94	78.20

Source: Europe Economics analysis.

5.3 AI translation versus human translator

This use case assesses the energy consumption involved in translating a document using either an AI-based translation tool (digital scenario) or a human translator working from an office (physical counterfactual). The analysis is grounded in a **representative scenario** that defines the parameters of the task, ensuring that both approaches are assessed on a consistent basis.

The scenario assumes a **document containing 50,000 words**, submitted digitally in Word or PDF format with a file size of approximately **0.0015 GB**. The client accesses the service using a **desktop computer over a fixed-line broadband connection**. The AI translation model is assumed to have a useful life of two years before it needs to be retrained.

Digital scenario

This section sets out the estimated energy use associated with delivering a translation task using a digital AI-based translation tool. The analysis includes energy use from three main sources: (i) data centre energy consumption, including both IT and non-IT processes, (ii) internet transmission, and (iii) the end-user's device.

Data Centre

The AI translation process draws on several IT processes within data centres. These include uploading and downloading the document, long-term and RAM storage of the AI translation model, and compute-intensive operations such as AI training and inference. The energy required for each process is determined by both the scale of activity (e.g. file size, duration, number of floating point operations or FLOP) and whether the process is shared across multiple users or is specific to the representative user.

The table below summarises the IT processes involved, the units used to quantify each activity, the assumed volumes under low, medium, and high scenarios, and whether the energy for that process is treated as shared or specific to the user. A final column outlines the basis of each estimate.

Table 5.66: IT processes within data centre – AI translation

Data Process	Units	Low	Medium	High	Shared/ Specific	Basis of Estimate
Uploading to Data Centres	GB uploaded	0.0015	0.0015	0.0015	Specific	*File size of Word/PDF document (from representative scenario)*
Video Processing	GB processed	0	0	0	-	-
Long-term storage	GB stored per year	1	3	5	Shared	*Size of AI model (Table 3.11)*
RAM storage	GB-hours	17,532	52,596	87,660	Shared	*Storage of AI model for the period of representative scenario*
General Processing	CPU-hours	0	0	0	-	-
AI Training	FLOP	1.0×10^{21}	5.0×10^{22}	2.0×10^{23}	Shared	*Energy consumed for training AI model*
AI Inference	FLOP	5.0×10^{14}	1.5×10^{15}	2.5×10^{15}	Specific	*Number of FLOP per word translated during AI inference * 50,000 words (representative scenario)*
Downloading/ Streaming	GB downloaded	0.0015	0.0015	0.0015	Specific	*File size of Word/PDF document (from representative scenario)*

Source: Europe Economics analysis.

Using these activity volumes and corresponding energy intensities (Table 3.1), the total energy consumption associated with each IT process is calculated. These figures represent the total energy usage, prior to accounting for user attribution.

Table 5.67: Energy used in each IT process – AI translation (kWh)

Data Process	Low	Medium	High
Uploading to Data Centres	0.0000225	0.00003	0.000045
Long-term storage	0.005	0.03	0.08
RAM storage	6.5745	20.617632	35.76528
AI Training	278	76,389	555,556
AI Inference	0.000139	0.00229	0.0069
Downloading/Streaming	0.000015	0.0000225	0.00003
Sub-total	**284**	**76,409**	**555,591**

Source: Europe Economics analysis.

To estimate the energy attributable to the representative user, we apply allocation factors for shared processes (e.g. RAM storage, long-term storage, and AI training), based on the assumed user base.[31] For specific processes such as AI inference and document transmission, the full energy is allocated to the user. The table below presents these user-level allocations.

Table 5.68: IT energy attributable to each user (kWh)

IT Process (attributable to user)	Low	Medium	High
Uploading to Data Centres	0.0000225	0.00003	0.000045
Long-term storage	1.20×10^{-12}	1.44×10^{-11}	1.91×10^{-10}
RAM storage	1.57×10^{-9}	9.88×10^{-9}	8.56×10^{-8}
AI Training	6.65×10^{-8}	3.65×10^{-5}	1.33×10^{-3}
AI Inference	0.000139	0.00229	0.0069
Downloading/Streaming	0.000015	0.0000225	0.00003
Total IT energy	**0.00017**	**0.0024**	**0.0084**

Source: Europe Economics analysis.

In addition to the IT energy, we include an allocation for non-IT energy used to support data centre operations (e.g. cooling, lighting, and power supply systems). This is calculated by applying a proportional uplift to each IT process (Table 3.2) using our assumed PUE values.

The final table below summarises both IT and non-IT energy components to give the total data centre energy attributable to the user.

Table 5.69: Summary of data centre energy consumption (kWh)

[31] The percentage attributable to user for shared processes is calculated as (Number of words in a document) / (number of words translated over the two-year period of analysis)

Component	Low	Medium	High
IT energy	0.0002	0.0024	0.0084
Non-IT energy	0.00002	0.00071	0.00418
Total data centre energy	**0.0002**	**0.0031**	**0.0125**

Source: Europe Economics analysis.

Internet Transmission

Energy is also consumed when the user uploads the document to the translation tool's cloud platform and downloads the translated version using a fixed line network. As this transmission is user-specific, the **entire energy consumption is attributed directly to the representative user**. This energy is calculated using an assumed energy intensity per GB of data transferred (Table 3.3), applied to the file size of 0.0015 GB (as specified in the representative scenario).

Table 5.70: Transmission energy attributable to each user (kWh)

Component	Low	Medium	High
Upload transmission	0.00003192	0.0000399	0.00004788
Download transmission	0.00003192	0.0000399	0.00004788
Total transmission	**0.00006384**	**0.0000798**	**0.00009576**

Source: Europe Economics analysis.

End-User Device Energy

The end-user is assumed to interact with the AI platform using a desktop computer connected to a fixed-line broadband network. The device is assumed to be used for a few minutes to submit the document and retrieve the output. The total energy is estimated by multiplying the assumed power draw of the device (Table 3.4) by the number of minutes spent using it (Table 3.11).

Table 5.71: Energy used in end-user devices

Units	Unit	Low	Medium	High
Time spent uploading and downloading	Hours	0.0167	0.0250	0.0333
Energy used in end-user device	kWh	0.0017	0.0035	0.0067
Total end-user energy	**kWh**	**0.0017**	**0.0035**	**0.0067**

Source: Europe Economics analysis.

Summary of Energy Use

The table below combines the three components of energy use. As expected, data centre IT operations, particularly AI inference and training, account for the largest share of total consumption in most scenarios. End-user device and transmission energy are modest in comparison.

Table 5.72: Total energy for representative scenario (kWh)

Component	Low	Medium	High
Data centre IT energy	0.00018	0.00238	0.00835
Data centre non-IT energy	0.00002	0.00071	0.00418
Internet transmission	0.00006	0.00008	0.00010
End-user device	0.0017	0.0035	0.0067
Total energy use	**0.00192**	**0.00667**	**0.01929**

Source: Europe Economics analysis.

Percentage Breakdown of Energy Use

The table below shows the percentage contribution of each component of total energy use across the three scenarios. The relative importance of IT versus non-IT energy varies with the assumed intensity of model training. End-user device energy accounts for a significant percentage in the low scenario, while becoming negligible in the high case.

Table 5.73: Breakdown of energy consumption (%)

Component	Low	Medium	High
Data centre IT energy	9.2	35.7	43.3
Data centre non-IT energy	0.9	10.7	21.6
Internet transmission	3.3	1.2	0.5
End-user device	86.6	52.4	34.6
Total	**100**	**100**	**100**

Source: Europe Economics analysis.

For AI translation, we treat electricity consumed within the data centre as centralised, while electricity used for transmission and end-user devices is considered decentralised. Across the low, medium, and high scenarios, the share of electricity consumed in centralised locations ranges from **10 to 65 per cent**.

Physical counterfactual

This section sets out the estimated energy use associated with delivering a translation task using a human translator operating from an office environment. The analysis includes energy used in the translator's office, internet transmission of documents, and the energy consumption of the end-user's device (i.e. the device of the person requesting the translation). Range estimates are presented to reflect variations in task duration, office energy intensity, and device use.

Task Duration and Office Energy Consumption

The time required to complete the translation by a human translator is calculated by dividing the total word count (50,000 words, as defined in the representative scenario) by assumed translation speeds (Table 4.10). This defines the total number of hours required to complete the task, which is then converted into working days based on a 7.5-hour workday.

Table 5.74: Time required to translate document

	Units	Low	Medium	High
Number of hours required for translation	Hours	83.3	100.0	125.0
Number of working days required	Working days	11.1	13.3	16.7

Source: Europe Economics analysis.

Electricity consumption in the translator's office is calculated by multiplying the assumed EUI (kWh/m²/year) by office space per worker (m²) to derive an annual electricity consumption per translator per year. This annual figure is then scaled to reflect the number of working days spent completing the task, assuming 253.25 working days per year.

Table 5.75: Electricity consumed in translator's office

	Units	Low	Medium	High
Electricity per translator per year	kWh/year	670	1,192.5	1,840
Electricity per working day	kWh/day	2.65	4.71	7.27
Electricity used during translation	**kWh**	**29.40**	**62.78**	**121.09**

Source: Europe Economics analysis.

Internet Transmission

Although the translation is carried out by a human translator, the exchange of documents is still assumed to occur digitally. Energy is used to transmit the original document to the translator and to transmit the completed translation back to the end-user. As with the digital scenario, this energy is calculated using an assumed energy intensity per GB of data transferred (Table 3.3), applied to the file size of 0.0015 GB (as specified in the representative scenario).

Table 5.76: Transmission energy attributable to each user (kWh)

Component	Low	Medium	High
Upload transmission	0.00003192	0.0000399	0.00004788
Download transmission	0.00003192	0.0000399	0.00004788
Total transmission	**0.00006384**	**0.0000798**	**0.00009576**

Source: Europe Economics analysis.

End-User Device Energy

The end-user is assumed to interact with the translator by emailing the original document and receiving the translated version back by email. This interaction is assumed to occur on a desktop computer over a fixed-line network. As the digital scenario, the total energy is estimated by multiplying the assumed power draw of the device (Table 3.4) by the number of minutes spent using it (Table 4.10).

Table 5.77: Energy used in end-user devices

Units	Unit	Low	Medium	High
Time spent emailing	Hours	0.0167	0.0250	0.0333
Energy used in end-user device	kWh	0.0017	0.0035	0.0067
Total end-user energy	**kWh**	**0.0017**	**0.0035**	**0.0067**

Source: Europe Economics analysis.

Summary of Energy Use

The tables below sums the components of energy use for the full delivery of the translation task. Electricity use in the translator's office remains the dominant factor, with transmission and device energy contributing marginal amounts.

Table 5.78: Total energy consumption for representative scenario (kWh)

Component	Low	Medium	High
Translator's office	29.40	62.78	121.09
Internet transmission	0.000064	0.000080	0.00010
End-user device	0.0017	0.0035	0.0067
Total energy use	**29.40**	**62.79**	**121.10**

Source: Europe Economics analysis.

Table 5.79: Breakdown of energy consumption (%)

Component	Low	Medium	High
Translator's office	99.994	99.994	99.994
Internet transmission	<0.001	<0.001	<0.001
End-user device	0.006	0.006	0.006

Source: Europe Economics analysis.

We classify electricity consumed in the translator's office as decentralised, given that an office will typically have a much lower energy intensity than a factory (and certainly a much lower energy intensity than a data centre). Electricity used for internet transmission and the client's end-user device also represent decentralised consumption. Thus, the share of electricity consumption occurring in decentralised locations is **100 per cent**.

Comparison of energy consumption

AI-based translation and human translation differ significantly in how and where energy is consumed. This comparison is based on a consistent representative scenario involving the translation of a 50,000-word document, allowing for a like-for-like assessment of the two approaches. Energy use in both scenarios includes core service delivery (data centre or office), internet transmission, and end-user device activity.

Total Energy Use Across Scenarios

The table below summarises the total energy consumption for the task across low, medium, and high input assumptions. Our calculations show that human translation requires substantially more energy than its AI-based counterpart. Under medium assumptions, the human scenario results in over 62 kWh of electricity consumption - more than 10,000 times higher than the 0.007 kWh associated with the AI translation.

Table 5.80: Total energy consumption – AI versus Human Translation (kWh)

Scenario	Low	Medium	High
AI Translation	0.002	0.007	0.019
Human Translation	29.40	62.79	121.10

Source: Europe Economics analysis.

The scale of difference is largely explained by office energy use in the human translation scenario. Translation is performed manually over a number of working days in an office setting with consistent electricity demand for lighting, heating, and computing. Even in the lowest scenario, energy use for human translation exceeds 29 kWh.

Relative Contributions of Energy Components

In the physical counterfactual, more than 99 per cent of energy use comes from the office environment. The contributions from internet transmission and end-user devices are negligible by comparison.

In the digital scenario, energy use is comprised of several components. Data centre operations represent the bulk of consumption, driven primarily by AI inference and, under high case assumptions, model training. Internet transmission and end-user device usage contribute less than 0.01 kWh each in the medium scenario.

Energy use in the AI case is **especially sensitive to how AI training energy** is allocated. In the low scenario, the model is assumed to serve a very large user base, spreading the training energy thinly across users. In the high scenario, the same training effort is attributed to far fewer users, substantially raising per-task energy consumption. Even under this high assumption, however, total energy use remains much less than 1 kWh, and is still a fraction of the physical alternative.

Quality differences

A caveat to our analysis is that at the current time AI-produced translations are of lower quality than translations produced by a human translator. The extent to which this matters will depend on the purpose of the translation. If the end-user simply wants to understand the gist of a document, an AI-produced translation may be sufficient for the purpose. However, if the end-user wants to be able to publish the translated document or use if for legal purposes (e.g. a contract), then a human translation will probably still be required at the current time.

It is worth noting that the quality of AI-produced translations has been getting better through time, and hence it is possible that in the future AI-produced translations may become as good as translations produced by a human translator.

Energy Consumption Associated with Food Intake

The energy estimates for human translation reflect the direct electricity used in office environments, covering lighting, heating, and computing over the course of a typical workday. They would include electricity used in the office to make hot drinks (e.g. boiling a kettle) or to heat a worker's lunch (e.g. the use of a microwave in a staff kitchen). However, these estimates do not include the indirect energy associated with producing the translator's food, which also contributes to their overall energy footprint. Including this additional input would be to likely increase the total energy required for human translation, further widening the gap between digital and physical alternatives, particularly for work that takes a significant period of time to carry out.

Conclusion

AI-based translation offers a markedly lower electricity footprint than human translation across all scenarios. While digital translation relies on data centre infrastructure, including compute-heavy processes like AI training, its overall energy demand remains significantly lower due to high-speed processing. By contrast, human translation involves time-intensive work conducted in energy-consuming office environments, leading to consistently higher energy use for an equivalent task.

6 Insights from Stakeholder Engagement

This chapter presents a summary of the stakeholder engagement conducted to inform our modelling approach. Through a series of targeted interviews with data centre operators, industry experts, academics, and specialists in the selected use cases, we gathered insights to validate key input assumptions, refine our methodology, and ensure the analysis reflects current practices and emerging trends.

6.1 Overview of engagement methodology

We conducted 11 online interviews (each lasting up to an hour) with key stakeholders including data centre operators and industry experts, as well as stakeholders specific to the selected use cases. In addition to qualitative insights, these discussions helped to validate our modelling assumptions, improve our understanding of both digital and non-digital approaches to our use cases, and identify practical insights that were not evident in the literature alone.

Interviews with data centres. We conducted four interviews with data centres to gain an overview of their views on our modelling approach, as well as their insights on the trends and forecasts of the energy efficiency of UK data centres over time. These interviews enabled us to gather views from data centre experts with practical experience of the industry, providing a broader view than the interviews with academics and industry experts.

Interviews with academics and industry experts. We held seven interviews with academics and industry experts from leading research institutions to gather evidence across the research questions. The aim was to gather views on the specifics of our methodology, including insights on the disaggregated energy consumption of data centres (e.g. information on IT and non-IT energy). We also obtained their views on realistic input assumptions to use for our selected use-cases, and suggestions of sources we can quote to support our input assumptions.

6.2 Key themes emerging from discussions

General comments

Most stakeholders indicated that energy consumption can **vary across different processes**. Other stakeholders emphasised that factoring in how **individual users interact with data** (via different devices, networks, and usage patterns) adds complexity to measuring energy consumption consistently.

Stakeholders generally agreed that data processes (e.g. internet transmission, video processing, and long-term storage) can be **measured in kilowatt hours** (kWh) per gigabyte (GB), but some noted that microjoules or joules provide a more precise measure. Different energy metrics (kWh, watts, or joules) may be used depending on which elements of the data chain are being assessed and how the system boundaries are defined. One stakeholder shared a paper which examines different measures of energy consumption.[32]

Most stakeholders agreed that no significant data processes within our use cases were overlooked. A stakeholder suggested that one way to estimate energy use for IT processes is by looking at **hardware specifications**, such as HDD and SSD power consumption for long-term storage.

The issue of the **boundaries to what is included in our analysis** emerged as a key factor for consideration. A study recommended by stakeholders examined system boundaries, assumptions, and the analysis period, all of which can significantly affect estimates of internet transmission networks' energy consumption.[33]

The concept of **dematerialisation** was flagged as potentially leading to higher overall usage rather than a reduction in resource consumption due to 'rebound effects' (i.e. increased activity levels). Despite efficiency gains, digitalisation may lead to more transactions and interactions.

One stakeholder pointed out the increasing focus on **water consumption and carbon emissions** in data centres, noting that the two metrics are often closely linked. Companies are now required to report on these metrics as part of comprehensive environmental reporting. It was suggested that these factors should be included in any broader analysis of data centre efficiency, given their growing importance in sustainability efforts.

PUE values

Stakeholders generally confirmed that our approach of applying PUE values to account for non-IT energy consumption was appropriate and widely-used, but noted the importance of accounting for country-specific factors such as temperature when considering PUE values for UK-based data centres. It was also emphasised that any estimates of PUE should encompass a range of values to account for differing data centre designs and operating conditions. Stakeholders also recommended factoring in energy efficiency targets and planned investments by data centres, as these could significantly impact future trends. A few stakeholders suggested we refer to a publication produced by Lawrence Berkeley National Laboratory (LBNL) which outlines the energy use of data centres from 2014 to 2028.[34]

Stakeholders also widely acknowledged the broader trend of PUE values dropping significantly until 2013 (from around 2.5 in 2007 to 1.65 in 2013). Stakeholders attributed the decline in PUE values overtime **to advances in technology** (e.g. improved cooling systems and server optimisation), and the introduction of **initiatives** such as the Carbon Neutral Data Centre Pact which has put pressure on the industry to bring existing and new data centres within a target PUE range.[35] One stakeholder further noted that, as data volumes have grown, shared cooling

[32] Jackson and Hodgkinson (2024) "Debate: The data threat to 2050 net zero—public administrations' responsibility for the 'data-scape'" [link]
[33] Aslan et al (2017) "Electricity Intensity of Internet Data Transmission: Untangling the Estimates" [link]
[34] Shehabi et al (2024) "2024 United States Data Centre Energy Usage Report" [link]
[35] The Pact has set a target of a PUE value of 1.3 for new and legacy sites in the UK (in comparison to 1.4 internationally).

and infrastructure systems have continued to lower per-unit energy consumption. Additionally, over the past decade, chip designs have evolved to tolerate higher temperatures, enabling data centres to operate at warmer conditions which reduces cooling requirements. However, since 2013 PUE values have largely stabilised in the range of 1.3 to 1.6, indicating that the rate of improvement has slowed down. While a range of 1.1 to 1.6 was deemed suitable for the UK, it was also noted by some stakeholders that a PUE of 1.2 would be a reasonable target for the UK going forward. Stakeholders pointed us towards a study by the European Commission on the trends in data centre energy consumption under the European Code of Conduct for data centre energy efficiency. The study has found that average PUE values fall for data centres participating in the programme year after year.[36]

Stakeholders also highlighted that PUE values can vary depending on a **range of factors**, such as the specific type of facility. For example, large hyperscale data centres (typically owned by providers like Google, AWS, or Microsoft) tend to have more control over the optimisation of their IT facilities and can generally reach lower PUE values of around 1.1 to 1.2. On the other hand, co-location centres (i.e. those that are owned by a third party which host a variety customers) can be affected by differing IT requirements and operating conditions specified by their customers. For instance, some customers can run at a high load by precisely matching capacity to current requirements, whereas others may plan for future growth, which can result in underutilised space. Although the UK currently has more co-location centres, the number of hyperscale data centres is expected to grow, and the country may also achieve lower PUE values than other regions of the world due to reduced cooling requirements.

Stakeholders generally agreed that there is a priority going forward of bringing both new and existing data centres within a target PUE range. However, some warned that further reductions will be limited unless IT technology itself becomes more efficient. One issue raised by stakeholders is that older data centres are still operating at their original efficiency levels, meaning any shift toward lower PUE values will require upgrades to their existing infrastructure.

Artificial Intelligence

Overall, stakeholders confirmed that our approach was plausible, though it was noted that AI workloads (particularly training and inference) are highly variable. Most stakeholders noted the importance of accounting for both the energy required in both the **training** and **inference** of models (which was widely agreed to be suitably measured in microjoules per FLOP).

A number of stakeholders shared a seminal paper on the cost of AI deployment, which compares the energy required for a number of different inference processes.[37] It was suggested that we could obtain insights from this paper to understand more about how much energy a trained model consumes on a server (in kWh per GB). However, stakeholders also warned that precise data on this training and inference remains unclear, as companies do not publicly disclose detailed energy consumption figures. As a result, existing research and

[36] Bertoldi et al (2017) “Trends in data centre energy consumption under the European Code of Conduct for Data Centre Energy Efficiency” [link]
[37] Luccioni et al (2023) “Power Hungry Processing: Watts Driving the Cost of AI Deployment?” [link]

estimates in academic papers are largely based on informed assumptions rather than concrete data.

It was also noted that energy consumption does **not always have a linear** relationship with user numbers, and can vary depending on the workload type. AI training, for instance, is significantly more energy-intensive than execution tasks due to its computational demands. The general view among stakeholders was that training a model requires more energy consumption than inference, however even trained models with long-term storage require energy use each time a user attempts to access it. The energy consumption associated with usage may therefore surpass the energy required for training over time.

Additionally, a number of stakeholders noted the **growing demand for AI** is expected to influence PUE trends. The high processing demand of AI GPUs generates more heat and power, which in turn requires more cooling and could drive PUE values upward. Other stakeholders noted that improvements in liquid and immersive cooling systems may help to offset increased cooling requirements and keep PUE values from rising. Overall, it was acknowledged that AI will likely reshape how data centres are designed and operated, though the scale and direction of its impact on energy efficiency remains uncertain.

Stakeholders also explained that **dynamic load balancing** is key to optimising energy use. By managing when and how tasks are processed, workloads can be handled more efficiently. Centralised workload management offers significant benefits over distributed systems and can reduce energy consumption by up to 50 per cent when implemented effectively. It was also explained that AI workloads tend to be more energy-intensive than traditional IT workloads. The challenge lies in accounting for wide variations within and between workloads, particularly when comparing AI to traditional IT tasks.

Stakeholders also agreed that the energy use of **generative AI models** is significantly greater than more straight-forward platforms (e.g. Google Translate) due to the fundamentally different logical processes involved. Stakeholders also mentioned that the energy use associated with AI is expected to reduce as models improve. However, it was noted that the limited transparency regarding where AI models are being trained makes it difficult to accurately assess their energy footprint.

E-book Production

Stakeholders confirmed that our proposed methodology for capturing the stages of energy consumption for e-books was reasonable. One stakeholder highlighted that a key challenge lies in determining what constitutes “the data”. Multiple copies of the same data may exist, raising questions about how to account for their storage and processing.

One stakeholder recommended incorporating the **embodied energy** of data infrastructure (e.g. cabling networks) and cautioned that **system boundary issues** might arise. The stakeholder suggested beginning with available life cycle assessment (LCA) studies to understand what has been included or excluded in prior models. Additionally, a stakeholder highlighted that there is uncertainty in estimating the energy consumption of downloading and reading e-books versus reading a physical book.

Stakeholders also highlighted that digital e-books require energy every time they are used, with most energy consumption originating from the **downloading of the file** rather than storage. On the other hand, the production of a physical book requires more energy upfront and that the average energy consumed per reading of the book will diminish with the number of people that share a copy of the book. A stakeholder mentioned that a few seconds of CPU time might be required for authentication when an ebook is downloaded.

Video Streaming

Stakeholders made a number of comments related to the video streaming use case. For instance, the energy consumption associated with video streaming will be affected by how far the person streaming the video is located from the data centre.

One stakeholder mentioned in cases where there is a continuous stream of data (such as streaming a movie), the energy consumption associated with the downloading and transmission of data can become significant. However, energy consumption may decrease in the case of videos which are cached or stored on RAM and shared among a wide range of users (i.e. popular movies).

Stakeholders noted that video processing (e.g. converting videos to specific formats such as HDR) has traditionally relied on CPUs. However, more complex tasks involving computer generation and rendering demand a higher computational intensity, similar to AI workloads. In the future, such processes may shift to GPU-based solutions to increase speed and efficiency, particularly in film production. AI-driven filmmaking could entail higher energy consumption due to the large volume of required calculations.

Overall, stakeholders confirmed that our methodology for capturing energy consumption in video streaming was plausible. However, stakeholders cautioned that the energy-efficiency of video streaming will depend on the preferred device for streaming (e.g. streaming on a 70-inch TV will be different to streaming on an iPad). A number of stakeholders pointed us towards a study by the Carbon Trust on the carbon impact of video streaming to help with the development of the methodology for the use case.[38]

[38] Carbon Trust (2021) "Carbon Impact of Video Streaming" [link]

7 Conclusions

This study has developed a framework for assessing the electricity consumption associated with digital services by comparing them with plausible physical alternatives, under the assumption that digital substitution does not alter the overall scale of economic activity. It has then examined the energy implications of digitalisation by comparing the energy consumption of three digital services — video streaming, ebooks and AI-based translation — with their physical counterparts: Blu-ray discs, printed books and human translation.

The results of our modelling and analysis show that our methodology can produce comparable energy estimates for digital and physical approaches across diverse digital activities. Our three use cases serve both as illustrative applications and as a test of the practicality of our methodology. In future work, the same framework could be extended to other digital services.

This chapter first sets out our findings for our three use case cases based on our modelling and analysis. Below, we present in turn our results for total electricity consumption, the percentage of that electricity which is consumed in a centralised location, and our decarbonisation readiness index. We then discuss other use cases to which our methodology could be applied in further research.

Electricity Consumption

The table below summarises the total electricity consumption in the UK across the three use cases under low, medium, and high assumptions.

Table 7.1: Total electricity consumption (kWh) in the UK

Use case	Scenario	Low	Medium	High
Video Streaming	Digital	0.65	1.05	1.67
	Physical (UK manufacture)	0.76	1.13	1.69
	Physical (Overseas manufacture)	0.40	0.66	1.12
	Physical (UK, Decarbonised)	0.84	1.23	1.82
	Physical (Overseas, Decarbonised)	0.42	0.69	1.16
ebook	Digital	0.002	0.003	0.005
	Physical (UK manufactured)	3.32	5.16	7.00
	Physical (Overseas manufactured)	0.30	0.60	0.90
	Physical (UK, Decarbonised)	4.48	6.95	9.43
	Physical (Overseas, Decarbonised)	0.38	0.75	1.13
AI Translation	Digital	0.002	0.007	0.019
	Physical (UK)	29.40	62.79	121.10

Source: Europe Economics analysis.

These results show particularly large differences between the digital and physical approaches in the case of AI translation, where electricity use for the digital scenario remains below 0.05 kWh even in the high case, compared with over 120 kWh for the human translation scenario. For ebooks, the digital alternative consistently consumes less electricity than printed books, whether manufactured domestically or overseas. Electricity use for video streaming is broadly comparable to electricity use for a Blu-ray if the Blu-ray is manufactured in the UK. For scenarios involving overseas manufacturing, the lower electricity consumption reflects the exclusion of energy used in overseas manufacturing and transportation, which is not included in the UK totals.

The study distinguishes between total energy consumption and electricity use. The physical counterfactuals often rely on a mix of fuels, including gas and diesel, whereas digital services are entirely electricity-based. We have also modelled the physical alternatives under a decarbonised scenario in which all of the energy consumed is electricity.

Centralised Electricity Use

A further distinction has been made between centralised electricity use (e.g. data centres, warehousing, retail outlets) and decentralised use (e.g. offices, end-user devices, road freight, internet transmission). This distinction is important for understanding how the digital and physical approaches to different use cases may place demands on the electricity system.

Table 7.2 presents the estimated share of electricity consumption that is centralised versus decentralised across use cases. In digital scenarios, data centre operations are centralised, while internet transmission and device usage are decentralised. In physical scenarios, manufacturing, warehousing and retail energy are treated as centralised, whereas offices, freight transportation and in-home consumption are treated as decentralised.

These results show that physical use cases involving a manufactured product generally exhibit a higher share of centralised electricity consumption, particularly where manufacturing and storage occur within the UK. In contrast, digital use cases tend to have a more decentralised energy profile, with a significant share arising from end-user devices and data transmission. Among digital cases, AI translation displays the widest range, reflecting a wide range for the energy used in AI training and inference. The ebook use case is almost entirely decentralised (reflecting the energy consumed by end-user devices), while physical books are fully centralised from the UK's energy perspective. By contrast, the physical translation case is entirely decentralised, as energy use arises solely from end-user activity (e.g. office electricity consumption).

Table 7.2: Centralised Electricity Consumption by use-case (%)

Use case	Scenario	Centralised energy (%)
Video Streaming	Digital	24-26
	Physical (UK manufacture)	41-58
	Physical (Overseas manufacture)	11-20
	Physical (UK, Decarbonised)	45-62
	Physical (Overseas, Decarbonised)	13-24
ebook	Digital	1.1-1.2
	Physical (UK manufactured)	100
	Physical (Overseas manufactured)	100
	Physical (UK, Decarbonised)	~100

Use case	Scenario	Centralised energy (%)
	Physical (Overseas, Decarbonised)	99-100
AI Translation	Digital	10-65
	Physical (UK)	0

Source: Europe Economics analysis.

Decarbonisation Readiness

While digital use cases are already fully electrified, physical alternatives vary in how easily their energy inputs can be decarbonised. Some partially rely on fossil fuels (e.g. diesel for freight, gas for heating or manufacturing), while others are already largely electricity-based. We assess decarbonisation readiness based on whether the current energy sources can be feasibly replaced with low-carbon electricity or energy carriers using commercially available technologies.

Table 7.3 summarises the estimated share of current UK-attributable energy use in each physical scenario that could be decarbonised through electrification using commercially available technologies. The figures reflect technical feasibility rather than jurisdictional control (i.e. overseas emissions are included where relevant to UK consumption).

Table 7.3: Decarbonisation Readiness (%)

Use case	Scenario	Decarbonisation Readiness (%)
Video Streaming	Digital (video streaming)	100.0
	Physical (UK manufactured)	90.6-92.3
	Physical (Overseas manufactured)	94.5-95.2
ebook	Digital (ebook)	100.0
	Physical (UK manufactured)	74.1-74.2
	Physical (Overseas manufactured)	78.2-79.4
AI Translation	Digital (AI translation)	100.0
	Physical (UK-based)	100.0

Source: Europe Economics analysis.

These results show that most UK-attributable energy use in physical cases is electricity, particularly for video streaming, where end-user devices and storage already account for a high share of electricity consumption. For printed books, a larger share of energy comes from gas and diesel use in warehousing and transport, leading to a lower overall electricity share. The human translation use case is already fully electrified in its physical form, resulting in a 100 per cent score for decarbonisation readiness.

Policy Implications

Our results provide some initial evidence that digitalisation can contribute to achievement of net zero, by reducing electricity consumption in the UK compared with physical counterfactuals for a given level of activity (in the case of ebooks and AI translation) and by increasing decarbonisation readiness (in the case of video streaming and ebooks).

We also note that the potential for digitalisation to reduce electricity consumption for a given level of activity may increase through time. This is because ongoing advances in relation to IT equipment, data centre operations and transmission networks are driving improvements in the energy efficiency of digital approaches over time. By contrast, it seems reasonable to assume that the energy consumption associated with physical processes such as book printing and Blu-ray manufacturing is unlikely to decline significantly over time, given that the processes and technologies involved are relatively mature.

However, a major limitation of the study for the purpose of drawing policy conclusions is that it only covers three examples out of the many uses cases that exist for data centres. While two of these selected use cases (ebooks and translation) show that significant reductions in electricity consumption can be achieved by digitalisation and the other use case (video streaming) shows comparable levels of energy consumption for the digital and physical approaches, it is unclear to what extent these results can be extrapolated to other uses of data centres.

To allow more robust policy conclusions to be drawn, we would therefore recommend that DESNZ extends this research by commissioning further work to apply the methodology that we have developed to a greater number of use cases. This will provide a more extensive evidence base on the impact that digitalisation has on electricity consumption in the UK.

Suggested Use Cases for Future Research

To support such a future extension of this analysis, we propose a provisional list of additional digital use cases for consideration. These have been selected based on three key criteria: (i) they contribute meaningfully to data centre demand, now or in the near future; (ii) they replace a well-defined physical alternative; and (iii) the use case is sufficiently tractable to allow for robust modelling. In addition, as set out in the appendix in the next section, they have been selected so that together they cover all major categories of data centre usage. The use cases are presented in a suggested order of priority.

- **Cloud gaming** is one of the most compute- and bandwidth-intensive emerging digital applications. It replaces local gaming on dedicated consoles, which themselves involve significant energy consumption for hardware, display, cooling, and local processing. As a digital alternative, cloud gaming consolidates compute into data centres.
- **Online education platforms** replace physical attendance at short-term educational programmes such as bootcamps, summer schools, or crash courses. These typically involve temporary access to facilities, residential accommodation, and travel by both students and instructors. By focusing on these short-term formats rather than full-time education, the comparison is more like-for-like in terms of educational quality and structure.
- **AI for 2D illustrations** involves generating digital images using AI models such as DALL·E or Midjourney. It replaces work previously carried out by human illustrators using professional software and high-performance computing equipment. The counterfactual includes energy use associated with local rendering, editing, and

hardware operation. As generative AI becomes more common in design workflows, this use case is likely to become increasingly relevant.

- **AI customer support** replaces traditional human-operated call centres with automated chatbots and voice-based agents. The physical counterfactual includes both telephone-based and online live chat support delivered by staff working in office environments, involving energy use from computing equipment, lighting, heating, and telephony systems.
- **Software as a service (SaaS)** for office workers involves running applications hosted in data centres rather than installed locally on users' devices. The physical counterfactual includes the energy use associated with local computing resources, including desktop PCs or laptops, and associated local infrastructure.
- **Video conferencing** has become a widespread substitute for in-person meetings across the workplace, education, and healthcare sectors. The physical counterfactual involves individuals travelling, often by car, rail, or even air, to meet face-to-face, and then using physical venues for meetings (e.g. offices, conference centres).
- **Online bank transfers** substitute for traditional banking processes such as depositing physical cheques at local branches. The physical alternative would involve energy use in a cheque being sent through the post, the recipient of the cheque travelling to a bank branch, and branch operations.
- **Cloud backups for companies** involve storing data remotely in data centres instead of using physical backup media such as tapes or drives stored locally. The physical alternative involves local server backups and secure transportation and storage of backup media.
- **Digital journal databases** replace physical libraries holding print collections of academic journals. The physical alternative involves energy use from printing journals, transportation to libraries, library lighting and heating, and user travel.
- **Virtual doctor's appointments** replace in-person medical consultations. The physical counterfactual includes travel by patients and staff, as well as energy consumption from building management systems (lighting, heating, cooling).
- **Submitting an online tax return** replaces the completion and submission of paper tax forms via postal services. The physical counterfactual involves energy use from producing the paper forms, postal logistics and administrative processing at government offices.
- **Smart meters** substitute traditional "dumb" electricity or gas meters by automatically transmitting energy usage data digitally. The physical counterfactual involves manual meter readings requiring travel by field staff and associated administrative processing.
- **Music streaming** substitutes for the production, distribution, and playback of physical music media such as CDs. The counterfactual includes the energy associated with manufacturing discs and packaging, operating retail outlets, and consumer transport. Streaming also involves end-user energy use and backend infrastructure for content

delivery. While per-unit energy use is relatively low, the global scale of music streaming means aggregate demand is substantial.

8 Appendix A: Additional Use Cases for Further Research

The table below identifies 11 broad categories of data centre use that we consider are together likely to cover the majority of data centre usage. Categories that we understand to be larger in scale (or growing rapidly in scale, in the case of AI) are shown at the top of the table. The table then shows how the provisional list of additional use cases that we have suggested for further research would ensure coverage of all of these categories, with at least one specific use case within each category. We have suggested covering two or three use cases for the first three categories given the importance of these categories as current and future sources of demand for data centres.

We note that our suggestions of further use cases to consider are provisional, and more detailed work to identify the best use cases could form an initial phase of the additional research project. For example, this first stage of work might include an initial review of data availability to check that it is feasible to model each additional use case.

Table 8.1: How our suggested additional use cases cover all major categories of data centre usage

Data Centre Usage Category	Use cases covered in this study	Suggested additional use cases (with physical counterfactuals)
Cloud Computing and Hosting Services	–	Online education platform (short residential course) Cloud gaming (gaming on own computer)
Artificial Intelligence, Machine Learning, and Big Data Analytics	AI translation	AI for 2D illustrations (human artist) AI customer support (human in call centre)
Internet and Digital Media Delivery	Video streaming ebook	Music streaming (music CD)
Enterprise IT and Internal Operations	–	Use of software as a service by office worker (software on worker’s local device)
Telecommunications and Network Infrastructure	–	Video conferencing (in-person meetings)
Financial Services and Trading	–	Bank transfer (paying in cheque in local bank branch)
Backup, Disaster Recovery, and Archival Storage	–	Cloud back-up by company (server back-up onto physical media)

Data Centre Usage Category	Use cases covered in this study	Suggested additional use cases (with physical counterfactuals)
Scientific Research and Supercomputing	–	Journal database (library of journals)
Healthcare and Life Sciences	–	Virtual doctor's appointment (in-person doctor's appointment)
Government and Public Sector Operations	–	Online tax return (paper tax return)
Industrial IoT and Smart Infrastructure	–	Smart meters (dumb meters)

9 Appendix B: Clarifications on Issues Raised by DESNZ

This appendix addresses two points raised by DESNZ regarding how certain types of energy use are treated in our modelling. Specifically, it covers (a) whether the energy consumed by corporate (non-data-centre) staff should be included in estimates of data centre energy use, and (b) the approach used to estimate energy consumption under the human translation counterfactual.

9.1 Treatment of head office energy consumption

A question arises as to whether energy consumed by corporate staff not directly involved in data centre operations — such as employees in finance, HR, or senior management — should be accounted for in the modelling of data centre energy use. These roles are typically located in separate head office facilities and are not involved in the day-to-day running of IT infrastructure. In contrast, energy consumption related to personnel who work on-site at the data centre, such as engineers or facility staff, is already embedded within the overhead components of PUE, which captures all non-IT energy used to support computing loads, including lighting, cooling, and building services. Since head office energy use falls outside the scope of this metric, it raises the question of whether it should be separately accounted for in our modelling.

To assess whether this form of energy use warrants separate inclusion in our modelling, we considered a representative comparison. A modern hyperscale data centre with a nameplate power draw of 100 MW,[39] operating at a typical load factor of between 50 and 75 per cent, would consume between 438,000 and 657,000 MWh of electricity per year. When applying a conservative PUE estimate of 1.3, this implies IT-related energy use in the range of **337,000 to 505,000 MWh annually**.

Against this, a head office employing 50 corporate staff, with average annual per-employee energy use of **1,200 kWh** (a figure derived from our human translation counterfactual scenario, where we calculate the energy consumed per translator per year), would consume just **60 MWh per year**. This represents between **0.012 and 0.018 per cent** of the IT energy consumption of the data centre, depending on operating assumptions.

Given the very limited magnitude of this contribution, we consider it immaterial in the context of our analysis. The scale of energy use at data centres dwarfs any associated head office consumption. As such, this category of energy use is not modelled explicitly. However, if there were a desire to incorporate it, the simplest and most proportionate method would be to apply a modest upward adjustment to the assumed PUE (e.g. from 1.30 to 1.3002). This would have

[39] IEA (2024) “What the data centre and AI boom could mean for the energy sector” [online]

a negligible effect on the results presented and is within the rounding range typically seen in reported values for PUE.

9.2 Estimating energy consumption for human translation

In our representative counterfactual for AI-powered translation, we estimate the energy consumption of human translators by drawing on data for the Electrical Energy Use Intensity (EUI) of office buildings, combined with assumptions about the typical office space occupied per translator. This allows us to capture the energy directly attributable to the workplace environment needed to carry out translation tasks, including lighting, heating, and the powering of IT equipment within that defined area. This approach is consistent with the broader structure of our modelling, which is focused on estimating the marginal energy requirements of specific activities that are displaced by digital alternatives.

An alternative method would start with an estimate of average energy consumption per person and thus also include energy consumed by the translator at home. However, we consider that energy consumed at home is not part of the energy required to deliver translation services and hence we consider that this approach would be conceptually incorrect. Further, inclusion of the energy consumed as a result of people's incomes would make the analysis intractable – for example, for consistency it would require us to include within the digital calculations the additional energy consumed by investors who gain extra investment income from data centres.

That said, we have designed the model to be flexible. If a different assumption is preferred, the user can modify cells in row 70 and 71 in sheet **'Inputs – translation'** to reflect an alternative estimate of energy per person.

We acknowledge that travel to work may introduce additional energy consumption and that this could legitimately be included as part of the energy consumption associated with human translation. Our representative scenario assumes that the translator walks or cycles to their office, which implies zero commuting energy. In practice, some employees may use electric vehicles or trains, which would introduce additional electricity use. We recognise this as a limitation of the current assumptions.

10 Appendix C: List of Stakeholders

As part of this study, we conducted a series of stakeholder interviews to inform our understanding of current practices, validate our modelling approach, and refine input assumptions. We gratefully acknowledge the input received from stakeholders through these interviews. Below, we have listed those organisations represented in the interviews which have agreed to be named in this appendix.

- Cyrus one
- Imperial College London
- Kings College London
- Loughborough Business School[40]
- Microsoft
- University of Sussex
- Uptime Institute

[40] We acknowledge the input received from Loughborough Business School during an interview in February 2025, which assisted us in in validating our assumption that new data centres are converging towards a PUE of 1.3, as supported by the Climate Neutral Data Centre Pact.