# Analyzing End-to-End Energy Consumption for Digital Services

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**A collaboration between Guardian News and Media and the University of Bristol provides a model to calculate the overall energy output required for a digital service, from datacenter to end user.**

What is this?

Internet-based digital services enrich our lives in countless ways—expanding interaction with friends and colleagues, facilitating contact with businesses and government, and keeping us entertained and informed as never before imagined. But their growth and increasing ubiquity exact a cost: the considerable energy consumption IT requires, along with the associated emissions of carbon dioxide that contribute to climate change.

Concern over energy consumption has been a key driver behind green IT and has led to significant improvements in datacenter efficiency. What's needed now is a broader perspective that includes IT's overall energy footprint, the total output required to provide a digital service not only at the datacenter level but factoring in network and end-device energy usage as well.

Taking this broader perspective can result in better decision making in areas ranging from Internet architecture design (for example, reducing central server farms by caching data in regional servers that serve as content delivery networks) to business model development (for example, creating and promoting more energy-efficient tablet-based versions for services previously offered primarily in PC format).

Here, we present results of work developed through a partnership between Guardian News and Media (GNM), a London-based content provider, and the University of Bristol that provide insight into the overall energy consumption for a digital service's end-to-end production and delivery. Specifically, we break down how the service's various technical subsystems—networks, third-party servers, end-user devices, and so forth—contribute to its total carbon footprint.

## LIFE-CYCLE ASSESSMENT

Our methodology for determining a digital service's end-to-end energy consumption draws on the life-cycle assessment model. This technique is commonly used to measure the overall, "cradle-to-grave" environmental impact of a consumer product—a packet of crisps, for example—by identifying the share of total inputs and processes involved in its manufacture, distribution, use, and disposal, and then allocating a corresponding share of associated environmental impacts for that product.

Broadly speaking, three factors determine the life-cycle energy consumption associated with a digital service:

- The "source" servers responsible for its production and transmission. Rarely are these located at a single datacenter—for example, *The Guardian* newspaper's homepage comprises

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components served from different content delivery networks, ad networks, and analytics services. Moreover, services based on a P2P architecture will use a share of the client machines as source servers.

- Network transport. This involves the use of core, edge, mobile, and access network equipment to deliver the service to the end user, as well as to transfer data within the delivery architecture (for caching and other purposes).
- End-user equipment. These include not only the devices used specifically to access the service but also any local access equipment such as home Wi-Fi.

Life-cycle assessment for a digital service's energy footprint requires that we determine exactly how much of each of these components it uses and the energy associated with that usage. Several elements can complicate this measurement. While a specified service may fix or constrain some parameters associated with delivery, such as choice of delivery architecture and target device, others will inevitably vary in terms of individual users—the device with which they access the service, their geographic location, and their particular usage pattern.

## A DIGITAL SERVICE ASSESSMENT MODEL

Traditional life-cycle assessment methodology adopts the model of a typical or "average" user to simplify this measurement, but the result is relatively coarse-grained and risks inaccuracy in gauging total impact among all users. However, unlike most consumer products, IT allows rich end-user data to be gathered and quantified straightforwardly and objectively and thus offers the possibility for more detailed and accurate assessment than traditional analytic models.

To measure digital service energy consumption for our analysis, we developed two components:

- a fully parameterizable model for an individual user accessing the service and the resulting energy and carbon consumption, and
- an analytic module that gathers and assesses data regarding users' behavior when accessing GNM news services.

Data from the analytic system regarding actual behavior of individual users (or clusters of similar users) can be parameterized for the individual model.

### Individual user model

The parameters for the individual user model include user access device (phone, laptop, tablet, or desktop), access network technology (3G network, digital subscriber line, cable modem, local Wi-Fi, or corporate LAN), service choice (webpage or video), geographical location, and duration of service access.

The model consists of a set of equations and associated data that can be used to determine energy use across the system for a given choice of user access parameters. Within the model, equation parameters are divided into constants, subsystem variables, and service variables.

Constants are those values that vary only slowly as the Internet evolves, such as energy efficiency for data delivery across a 3G network. Subsystem variables are also fixed values, but these are determined by a user's subsystem choices such as the power consumed by the device or home network setup. Service variables are determined by actual service use and include amount of data transferred and length of user interaction.

As with any model, ours has some uncertainty in terms of the data values used. To handle this, we ran a Monte Carlo analysis over 10,000 iterations; in our analysis we used a spread of values for each equation parameter and randomly sampled from this spread repeatedly to obtain a distribution of outcomes. Details of the model, including the data used, appear elsewhere.[1]

Modelling

### Analytic user behavior module

The analytic module uses data from GNM's analytics system, together with a set of heuristic rules, to determine the likely parameters associated with a given user's access to the service. IP address can help determine likely geographic location, and also whether access is taking place from a residential, campus, or mobile network. Device operating system and screen resolution can help identify the end-user access device.

## ESTIMATING DIGITAL SERVICE ENERGY CONSUMPTION

Together, the individual user model and the analytic behavior module can be used to estimate an individual user's energy consumption for a given service, the service's overall energy consumption, and associated carbon emissions for both.

Figures 1 and 2 show sample analyses of an individual's total energy consumption using two specific digital services: Figure 1 graphs a home user browsing *The Guardian* website with a laptop for 10 minutes, while Figure 2 graphs a smartphone user connected to the site via a 3G network watching a 10-minute news video. Note that in both cases, user parameters have a substantial effect both on the total energy usage and on the relative proportion of consumption attributed to each subsystem responsible for providing the service.

## ESTIMATING OVERALL CARBON FOOTPRINT

The model we've described so far allows us to determine a given user's energy consumption for a specific

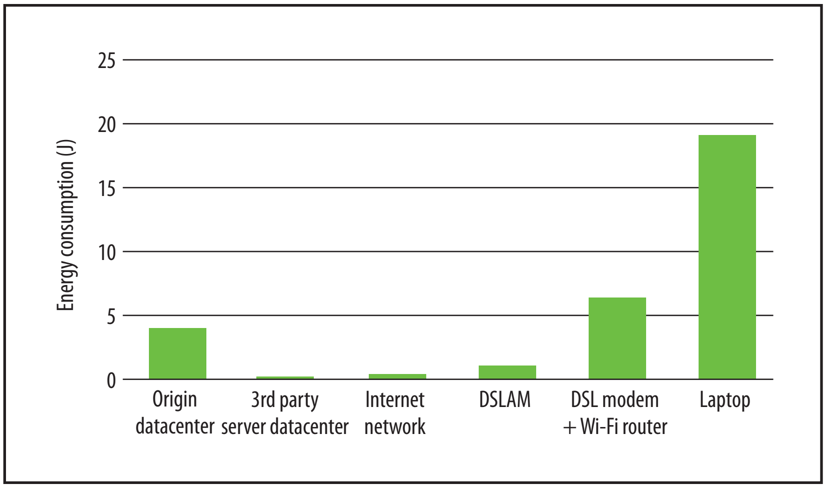


**Figure 1. Typical energy consumption (in joules) for a home user browsing *The Guardian* website for 10 minutes using a laptop.**

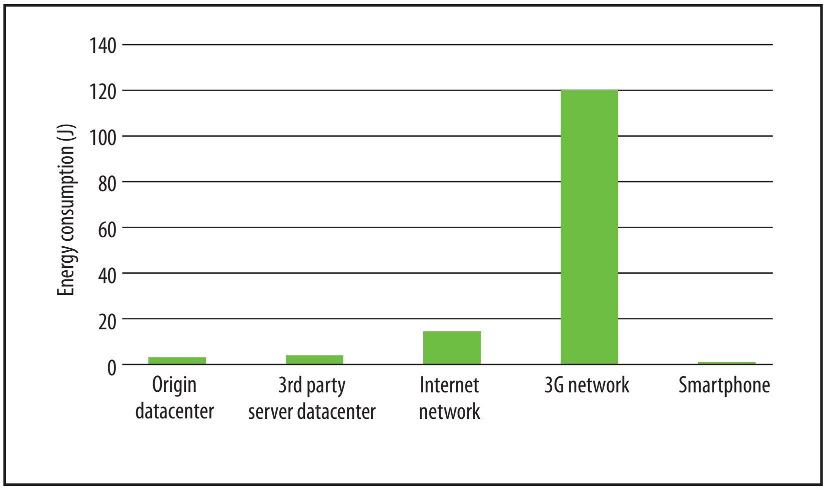


**Figure 2. Typical energy consumption (in joules) for a smartphone user watching a 10-minute video on *The Guardian* website.**

service. To derive the corresponding overall carbon footprint, we combine this with data about average carbon emissions per unit of energy (tCO$_2$e/kWh)—that is, the emissions factor.

This emissions factor varies significantly from country to country, as the mix of different energy generation technologies varies. For a given user, our site analytics software infers country of access based on IP address and a geolocation database; we assume that both end-device and access-network electricity consumption occur in this country. We can't locate with a similar degree of precision either the edge and core networks or most of the content delivery network servers involved in a given interaction. For these we use the average global emissions factor of Organization for Economic Cooperation and Development (OECD) member countries. Finally, because the GNM datacenter is located in the UK, we use the UK emissions factor for our calculation. Together, these provide the basis for converting the model's energy consumption figures into an overall carbon footprint.

Table 1 estimates the total energy consumption and carbon footprint broken down for each subsystem involved in delivery of GNM's online news services over a 12-month period. As the table makes clear, user devices and access networks are the dominant contributors. This is partly because GNM services are primarily text- and image-based, with relatively little video streaming. In services offering other operating characteristics, the dominating subsystems may differ. model

Elsewhere,[2] we've elaborated on our approach and results more fully, including the impact of alternative architectures and business models on digital service energy consumption.

The work described here has provided GNM with detailed insight into the end-to-end energy and carbon footprint of its digital services and allowed GNM to become the first organization to include such findings in its annual sustainability report. We hope our work will inspire other organizations to identify the overall environmental impact of their digital services and explore approaches for reducing energy consumption. ■

## References

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2. D. Schien et al., "A Model for Green Design of Online News Media Services," *Proc. 22nd Int'l Conf. World Wide Web* (WWW 13), 2013, pp. 1111–1122.

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**Table 1. Electrical energy output and carbon footprint for Guardian News & Media digital services over a 12-month period.**

| Subsystem | Energy (MWh) | Carbon ($tCO_2e$) | Percentage of $CO_2e$ |
|---|---|---|---|
| Origin data center | 369 | 199 | 2.59 |
| Shared networks | 111 | 60 | 0.78 |
| Third-party servers | 29 | 15 | 0.20 |
| Access networks | 3,049 | 1,681 | 21.86 |
| Users | 10,475 | 5,736 | 74.57 |
| **Total** | **14,033** | **7,691** | **100** |

**Carbon footprint is measured in tons of carbon dioxide equivalent ($tCO_2e$). The carbon dioxide equivalent ($CO_2e$) allows greenhouse gases to be compared on a like-for-like basis relative to one unit of $CO_2$. MWh: megawatt hours.**


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