4E Electronic Devices & Networks Annex EDNA

Addendum Report for the

Total Energy Model V2.0 for Connected Devices

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Technology Collaboration Programme
by iea

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Total Energy Model V2.0 for Connected Devices

Report Prepared for IEA 4E EDNA

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Electronic Devices & Networks Annex
EDNA

The Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E TCP), has been supporting governments to co-ordinate effective energy efficiency policies since 2008.

Fifteen countries have joined together under the 4E TCP platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However, the 4E TCP is more than a forum for sharing information: it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Members of 4E find this an efficient use of scarce funds, which results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions.

The 4E TCP is established under the auspices of the International Energy Agency (IEA) as a functionally and legally autonomous body.

Current members of 4E TCP are: Australia, Austria, Canada, China, Denmark, the European Commission, France, Japan, Korea, Netherlands, New Zealand, Switzerland, Sweden, UK and USA.

Further information on the 4E TCP is available from: **www.iea-4e.org**

The EDNA Annex (Electronic Devices and Networks Annex) of the 4E TCP is focussed on a horizontal subset of energy using equipment and systems - those which are able to be connected via a communications network. The objective of EDNA is to provide technical analysis and policy guidance to members and other governments aimed at improving the energy efficiency of connected devices and the systems in which they operate.

EDNA is focussed on the energy consumption of network connected devices, on the increased energy consumption that results from devices becoming network connected, and on system energy efficiency: the optimal operation of systems of devices to save energy (aka intelligent efficiency) including providing other energy benefits such as demand response.

Further information on EDNA is available at: **edna.iea-4e.org**

This report was commissioned by the EDNA Annex of the 4E TCP. It was authored by Paul Ryan of EnergyConsult Pty Ltd, Terence Smith of Mississippi Consulting Pty Ltd, and Anson Wu of Hansheng Ltd. The views, conclusions and recommendations are solely those of the authors and do not state or reflect those of EDNA, the 4E TCP or its member countries.

Electronic Devices & Networks Annex
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Glossary

AEC_{Region_id}	Regionalised Annual Energy Consumption is the product of power consumed over a year measured in terawatt-hours per annum (TWh pa).
AV	Audio-visual
BAU	Business-As-Usual
CDN	A Content Delivery Network is used by video streaming service providers to meet quality of service requirements.
Core Network	A Core Network is a network or set of networks at the centre of the Internet consisting of IP service providers' networks.
DC	Data Centre
Digital Voice Assistant	A Digital Voice Assistant is a connected device which responds to voice commands which may be intended to control household equipment such as lighting, heating/cooling, audio visual equipment, act as a VoIP device or respond to general interest queries.
Downstream	In the scope of this study, downstream energy use includes all energy use of edge devices and Local Area Network (LAN) equipment.
Edge Network	An Edge Network is a mobile wireless broadband, WLAN or LAN on the periphery of the Internet or other heterogenous network.
EI	Energy Intensity, in the context of this report, refers to the energy consumed in generating data traffic and is measured in kilowatt hours per giga byte (kWh/GB).
FAN	Fixed Area Network
HDD	Hard Disk Drive storage device
ICT	Information and Communications Technology is the term used by the ITU-T to what was previously referred to as Information Technology (IT).
ITU-D	International Telecommunications Union Telecommunications Development Bureau, it fosters international cooperation on telecommunication and ICT development issues
LPWA	Low Power Wide Area.
LTE-M	Long Term Evolution Machine Type Communication is an Internet of Things (IoT) LPWA network 3rd Generation Partnership Project (3GPP) standard for 4G and 5G mobile networks
NB-IoT	Narrowband Internet of Things is an IoT LPWA network 3GPP standard for mobile networks
Network Active	Network active is a condition in which a device is communicating with another device on a network.
Network Standby	Network standby is a condition which allows a device to resume its main function upon a receiving a remotely initiated trigger via a network connection.
Over the Top (OTT)	Over the Top describes a service delivered over a network shared with other services. It is commonly used to describe an Internet video streaming service.
RAN	Radio Area Network
Smart TV	A Smart TV is a television with a network interface and ability to run software applications enabling use the interface for data retrieval and/or receiving streaming media..
SSD	Solid State Drive storage device.
STB	Set top Box
Streaming Media	Streaming media is a condition in which audio-visual content data is being transmitted over the network to a Smart TV, Casting Stick or similar entertainment device and is energy use includes the that used in fulfilling its main function.
UEC	Unit Energy Consumption is product of the power consumed and time measured in hours, the units are watt-hours (Wh) or kilowatt-hours (kWh)
Upstream	In the scope of this study, upstream energy use includes all energy use of DC and WAN, including the access network.
VoIP	Voice over Internet Protocol.

WAN	The Wide Area Network (WAN) referred to in this report is the network comprising the Core network, associated with data centre interconnection, and the Access network providing the connection between the Core and network connected devices, the Access network is considered to include mobile broadband networks.
	Units
GB	Gigabyte, 10^9 bytes,
W	Watt, a unit of power.
Wh	Watt-hour, a unit of energy, equivalent to a power consumption of one Watt for one hour.
TWh	Terawatt-hour or, 10^{12} Watt-hours, a unit of energy.

Executive Summary

In June 2019 IEA 4E Electronic Device and Network Annex (EDNA) published the original Total Energy Model, TEM1.0. The purpose in developing TEM1.0 was to provide "*a quantitative model of the 'total energy use' of connected devices, globally*." TEM1.0 was developed as a flexible tool which could be updated as additional data became available, and expanded to encompass new network technologies and devices associated with the rapidly evolving range of services over the Internet. The overall purpose of the model was to provide a reputable source of energy use information for connected devices for use by energy efficiency policy makers in all jurisdictions. Subsequently 4E EDNA commissioned an expanded version of TEM1.0, the TEM2.0.

The TEM1.0 and 2.0 model the energy use by edge network connected devices; wireless and fixed network equipment made up of wired and wireless Local Area Networks and mobile networks; as well as Data Centres and Wide Area Networks. In TEM2.0 uses identical device categories to TEM 1.0: ICT, entertainment, automation and security, and the same sectors: residential, business and public.

The TEM1.0 was intended to model the energy use of network connected devices by region however, because of insufficient data being available, the TEM1.0 was limited to a global model. For TEM2.0 regional product sales/stock data was obtained from external sources to EDNA (purchased from Juniper Research). Updated population, household numbers, and fixed broadband data by economy were available from the United Nations and used to match the eight regions characterised in data from Juniper Research.

The TEM2.0 expands the conditions of energy consumption. In TEM1.0 energy use was separated into network standby and network active conditions. TEM2.0 introduces streaming media as a third condition, it is the energy consumption associated with streaming video services, and includes the energy consumed by the device used to view the video.

New devices are introduced in TEM2.0 increasing the model's scope, these include: Casting Sticks, Digital Voice Assistants (DVA)-Video Display and DVA-Speaker. Casting Sticks, also referred to as Digital Media Adapters, directly connect to a television for viewing streamed video. Digital Voice Assistants, which are available in two forms, with and without a video display, and often referred to as "smart speakers" and "smart displays", provide voice control of a range of connected appliances, including Casting Sticks and televisions (which includes Smart TVs and, indirectly, ordinary TVs).

The TEM2.0 model provides the ability to evaluate energy consumption scenarios related to policy making in the many TEM2.0 regional jurisdictions. It provides a credible and transparent tool to policy makers to assess the impact of potential voluntary and regulatory measures. The TEM2.0 forecast timeframe is to 2030, the same as used in TEM1.0.

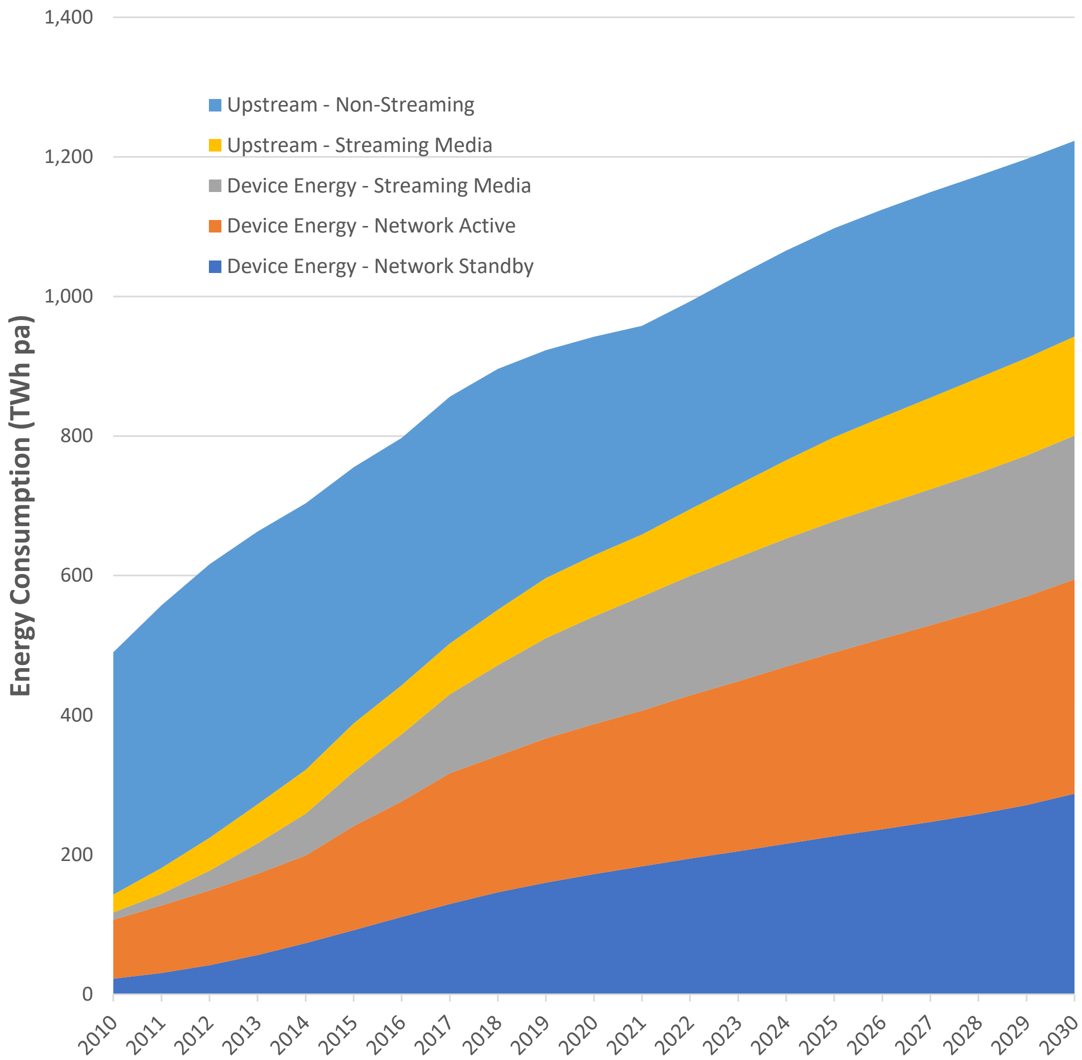
The TEM2.0 outputs include the web-based graphical display of the model results, to be publicly accessed on the EDNA website (see https://www.iea-4e.org/edna/charts/).

The expanded TEM2.0 methodology employs the same approach for calculating the network-connected energy use of devices as used in the TEM1.0. It sums the individual energy use by condition for connected devices, and allocates the upstream energy use of the network (DC and WAN) to each device type by region. In TEM2.0 the network-connected regional Annual Energy Consumption

(AEC_{Region_id}) for each type of device is the sum of the network-connected energy consumption of all operating devices installed. The regional upstream energy use is estimated for the DC/WAN component by using the energy consumed per byte of data, the energy intensity, transferred in the DC and WAN, and the data transfer rate. Using the streaming media and non-streaming data transmission rate, the upstream energy use is attributed to the network connected devices, according to each device type as a portion of the DC/WAN energy consumption.

The TEM2.0 utilises a number of new data sources, including forecasts of device shipments by region. In addition, research was also conducted to obtain estimates of streaming media power use for Casting Sticks, as well as the estimated time of media streaming operation by device.

This report includes a selection of key outputs from the expanded TEM2.0 model including energy consumption of edge devices by condition, and the upstream energy attributed these network connected devices when streaming media or not steaming. Energy consumption of categories of devices and upstream is also shown by region. An example is the total network connected energy consumption comprising upstream IP traffic, including streaming and non-streaming, and connected devices in all conditions is shown below.



With global electricity demand rising from 23,000 TWh in 2018 to 29,900 TWh in 2030 (IEA, 2019), the share of total network-connected energy consumption of total electricity demand is 3.9% in 2018 and projected to be 4.1% in 2030.

Total energy consumption for streaming media (both edge device and upstream energy use of connected devices) is projected to grow from 210 TWh in 2018 (0.9% share of electricity demand) to 350 TWh in 2030 (1.2% of total electricity demand).

1 Introduction

1.1 Background

In June 2019 IEA 4E Electronic Device and Network Annex (EDNA) published the original Total Energy Model, referred to herein as TEM1.0, and associated report (EnergyConsult, 2019). The purpose in developing TEM1.0 was to provide "*a quantitative model of the "total energy use" of connected devices, globally*." TEM1.0 was developed as a flexible tool which could be updated as additional data became available, and expanded to encompass new network technologies and devices associated with the rapidly evolving range of services over the Internet. The overall purpose of the model was to provide a reputable source of energy use information on connected devices, for use by energy efficiency policy makers in all jurisdictions.

Broadly, TEM1.0 modelled energy use:

- By the network connection component of devices connected to an edge network.
- By network equipment made up of wired and wireless Local Area Networks and mobile networks.
- By Data Centres and WAN

Across these categories, the energy use was segmented into residential, business and public sector use, edge device type, network equipment etc. Further, for appropriate device categories (ICT, entertainment, automation and security) energy use was separated into network standby and network active. It was intended that TEM1.0 would model energy use of network connected devices by region however, because of sufficient data being unavailable, TEM1.0 was a global model. A further limitation of TEM1.0 was that it did not categorise the type of data being transmitted and received over the network, so data related to general web use and media streaming was not separately identified.

To overcome these limitations, 4E EDNA has commissioned an expanded version of TEM1.0, the TEM2.0.

1.2 Objective

The objective of this study is to develop an expanded TEM to include streaming media energy use and regionalize the TEM. Estimating the energy use of streaming media services, requires separating the total transmitted data into streaming data and non-streaming traffic in the downstream (connected device and edge network), and upstream (data centres, wide area and core networks) categories. The downstream category includes the streamed media receiving edge device which may include a display or require a separate display (a TV). Unlike TEM1.0, the energy use associated with streaming media will be the total energy used by the decoding and display devices, not just the network interface energy consumption. Similarly, the upstream portion of the streaming media needs to be separated from the total transmitted data.

In addition, the TEM2.0 study includes provision of a web interface for displaying the results of the model, publicly accessed via the EDNA website.

2 Scope of Study

2.1 TEM2.0 Expansions

An aim of TEM2.0 is to regionalize the model and to start identifying the total additional energy use of network-connected devices, including the upstream component of individual categories of individual edge connected devices not just categories. The new devices included in the TEM2.0 entertainment and automation categories are:

- Casting Sticks or Digital Media Adapter video streaming devices, and
- Digital Voice Assistants, DVA-Video Display and DVA-Speaker, collectively referred to as "smart speakers" or "smart displays".

In TEM1.0 connected edge devices had two conditions: network active and network standby. In both conditions, only the power consumed by the network interface was included in the model. For TEM2.0 a third condition is introduced, streaming media. For this condition, the energy use is modelled as the total of the edge device including that used by any associated display device, e.g. a TV, to which the receiving edge device, e.g. a Casting Stick, is connected, not just the network interface energy use, see

Figure 1. Scope of network connected energy consumption

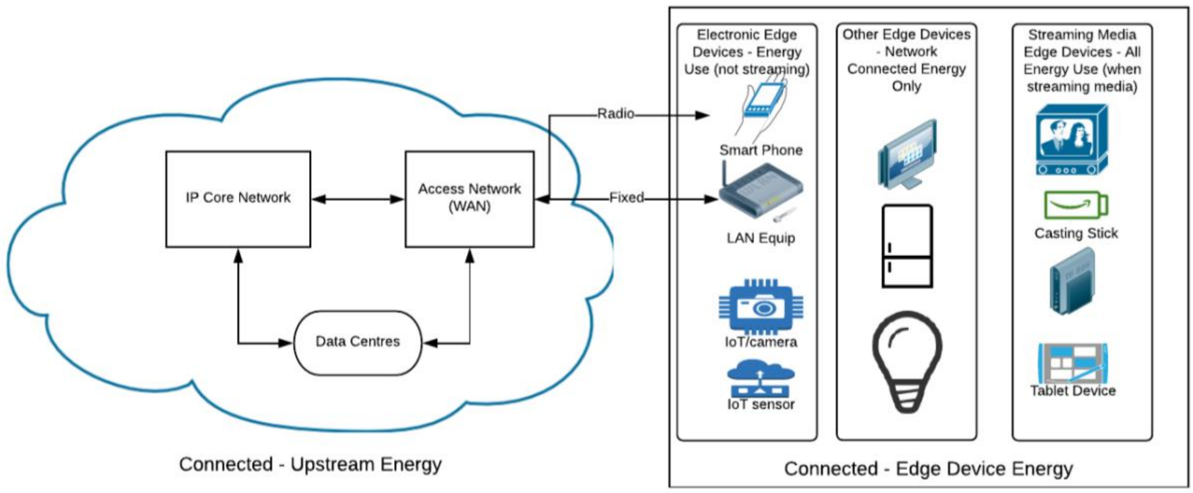


Figure 1.

The TEM2.0 also includes a functionality to create energy use scenarios which enable assumptions regarding future developments to be tested or determine steps that need to be taken to reach some desired outcome. The TEM2.0 model provides the ability to test scenarios related to policy making.

2.2 TEM2.0 Additional Devices

2.2.1 Casting Sticks

Casting Sticks or, as Cisco refers to them, Digital Media Adapters, are streaming media receiving devices. Casting Sticks, e.g. Google's Chromecast and Amazon's Fire TV, started appearing on the market in 2013, and were designed to provide a ready means of connecting services such as YouTube, Netflix and Amazon Prime, to any TV. By 2019, 232 million casting sticks were in use globally, and received around 17 exabytes of media traffic (CISCO, 2019). Typically, Casting Sticks consume about 2 to 3 watts in when active, and around 2 watts in standby (Wimmer and Dangl, 2017).

2.2.2 Digital Voice Assistants

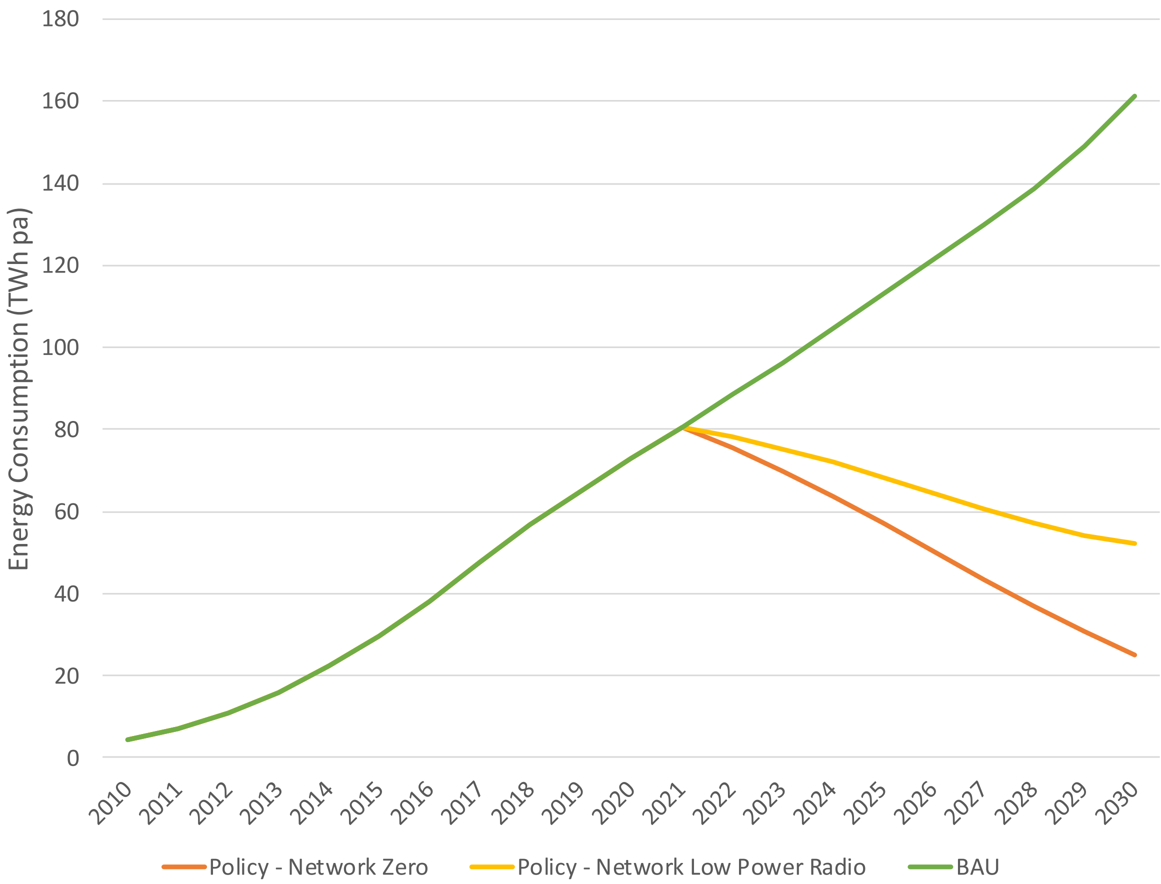
Digital Voice Assistants (DVAs) are multi-functional devices which cross the category boundaries, they can be regarded equally as entertainment or automation devices, both to control other entertainment equipment and a range of appliances, as well as acting as AV devices. DVAs may include a display, identified in TEM2.0 as “DVA-Video Display”, or not. DVAs without a display, identified in TEM2.0 as “DVA-Speaker”, are commonly referred to as a “smart speakers”. In TEM2.0, DVA-Speakers have been included in the automation category, while DVA-Video Display are included in the entertainment category. Typically, DVA-Video Display consume around 10 Watts when active and around 3 Watts in standby.

2.3 Energy Use Scenarios

The TEM2.0 model includes the additional functionality of using scenarios which permit model data to be analysed and results to be presented. Scenarios to be included in TEM2.0 relate to examining how changes in policy, technology, device sales over time and daily time of use by condition impacts energy use. The available scenarios include a BAU case. For example, the model could be used to estimate the impact of introducing limits on the power consumption of specific devices within a category, by comparing an estimated BAU energy use against the revised energy use with the proposed power limits. The scenario modelling in this version is simple in implementation, and constrained in complexity, by applying percentage changes to the power consumption of products by condition from specific years. However, it does provide a credible and transparent tool to policy makers with which the impact of potential voluntary and regulatory measures could be assessed.

Figure 2 shows an example of how the scenario function may be used for comparing policy cases for improving energy efficiency . In this case, it provides a comparison between two technology options, identified as Network “Zero” and Low Power Radio, with a (hypothetically) starting in 2021 and a BAU case out to 2030, applied to the automation category of devices (Siderius, Beletich and Ryan, 2020) The scenario shows a rapid decrease in energy consumtpion from 2021, as the implementaion is assumed to apply to all products sold from that year onwards, where in practice a transition period woud be utilised. In addition, the scenario assumes a significant reduction in power use, with Network “Zero” a 100%, and Low Power Radio an 80%, reduction in network standby power consumption for all devices installed from 2021.

Figure 2. A TEM2.0 technology-enhancing policy scenario which compares the energy consumption up to 2030 for Network "Zero", Low Power Radio and BAU



2.4 Model Web Access

The TEM2.0 study includes provision of a web interface for the model to be accessed on the EDNA website. The website will provide access to the outputs of the TEM2.0 model, to display scenarios and view selected model results. Please refer to https://www.iea-4e.org/edna/charts/

3 Methodology

The expanded TEM2.0 employs the same method of calculating the network-connected energy use of devices as in TEM1.0. It sums the individual energy use by condition for all globally connected devices, and allocates the upstream energy use of the network (DC/WAN) to each device type. The approach taken in building the model varies with the model's component parts and the modifications from the TEM1.0 are described below.

3.1 TEM energy use calculations

3.1.1 Edge device and LAN equipment calculations

In TEM2.0 the network-connected regional Annual Energy Consumption (AEC_{Region_id}) for each type of device is the sum of the network-connected energy consumption of all devices installed and operating. The model uses a methodology similar to the residential sector activity equations of the Lawrence Berkeley National Laboratory, Bottom-Up Energy Analysis System or BUENAS model (McNeil *et al.*, 2012).

Network-connected energy use is calculated for each of the conditions: network active, network standby, and, for appropriate devices, streaming media.

The Annual Energy Consumption equation is as follows:

$$AEC_{Region\_id}(y,c) = \sum_{age=0}^{30} Sales\ (y - age)\ \times UEC_c(\ y - age) \times Surv(age)$$

Where

AEC_{Region_id} *(y,c)* = the Annual Energy Consumption according to region (see Table 1) in year *y* for mode *c.*

Sales (y) = unit sales (shipments) in year *y.*

UEC (y) = unit energy consumption (UEC) of units sold in year *y.*

Surv (age) = probability of the device surviving to *age* years.

Age = a period of up to 30 years.

Table 1. Region ID for TEM2.0 regions

Region ID	Region	Region Name
1	NA	North America
2	WE	West Europe
3	CE	Central & East Europe
4	FE	Far East and China
5	IN	Indian subcontinent
6	AP	Asia Pacific
7	LA	Latin America
8	AF	Africa and Middle East
9	GL	Global

The UEC for each device and condition is calculated as follows:

$$UEC_c = Power_{\ c} \times Time_{\ c}$$

Where

Power = watts of network-connected load for condition *c*

Time = hours of time in condition *c*

Including regionalised energy use in the TEM2.0 model was a prime aspect of the model's expansion. The population, household numbers, and the fixed broadband numbers data in the model is based on United Nations (United Nations, 2017, 2019) and ITU-D statistics (ITU-D, 2020).

3.1.2 DC and WAN energy use calculations

The regional upstream energy use is estimated for the DC/WAN component by using the energy intensity (EI) of the data traffic from the DC and over the WAN, and the data rate. As described in the EDNA report (EnergyConsult, 2019), the traffic EI is separately determined for DC and WAN system architectures and equipment generations. In TEM2.0 the DC and WAN traffic components are further split into the streaming media and non-streaming EI, and allocated so that the average EI is unchanged. The DC EI is further disaggregated by ICT equipment and infrastructure equipment, and by utilization rate, to ensure that underlying changes in efficiency and use are included in the model outputs.

Video streaming requires the DC perform two functions:

- video streaming itself, and
- management and video transcoding[1].

The EI for video streaming is based on the calculations used in (Fulton, 2020). This gives the optimal EI but is not fully representative of typical use. To create a more realistic estimate, the EI is calculated for different types of servers, and two different levels of utilization.

High utilization is defined when many people are streaming a large amount of data simultaneously, and occurs for a relatively short period during the evening, while during low utilization there are fewer

[1] Transcoding video content can involve a number of processes including but not limited to: changing the codec standard, e.g. MPEG-4 to HEVC; re-scaling the video resolution and/or frame rate, e.g. high to standard definition; file packet format for the specific decoding device, e.g. Apple TV or Windows Media Video.

streams occurring over a long period of time. Based on various studies (Morley, Widdicks and Hazas, 2018; Widdicks *et al.*, 2019), the amount of data streamed during high and low utilization levels was estimated to be approximately equal. However, this segmentation is still necessary since the EI of the server's traffic changes with utilization level.

Servers using solid state disk (SSD) storage are fast and efficient but more limited in storage capacity. These storage drives are used for the most popular videos and represent the majority of the Streaming Media related data. Servers using hard disk drive (HDD) storage have a higher capacity and are used to store less popular videos. The management and transcoding assumed to take place on a 'standard' server with non-video traffic EI. It is important to note that the EI calculated for traffic from both types of server and at high and low utilization levels is still approximately 100 times lower than a 'standard' server i.e. 100 times less energy is needed per byte of video data streamed. The average EI is weighted proportionally to the server utilization for each type in Table 2.

Table 2. Proportion of video data processed by server type.

Server types	High utilization	Low utilization
SSD storage server	23-32%	23-32%
HDD storage server	13-22%	13-22%
'Standard' server	10%	

The average EI for server traffic was calculated for 2018 using the equation shown below. For all other years, it is assumed that, the relative efficiency improves at the same rate as standard servers.

$$average\ DC\ EI_{video} = \sum EI_{servertype} * \%data_{servertype}$$

The WAN's Core network traffic EI is determined mainly by the distance travelled and specifically the number of routers it passes through (Vereecken *et al.*, 2011). This is represented by the number of 'hops' the data makes, for which some research is available. The majority of data, including video, is now carried over Content Delivery Networks (CDNs) to servers located geographically and logically close to the client. Typically in a CDN, data makes 1-4 hops, depending on the CDN type[2], compared to ~15 hops (Fei *et al.*, 1998; Chen, Xing and Ma, 2011) over non-CDN networks. A simple CDN traffic EI calculation, based on the proportion of traffic travelling over different distances, was created. The calculation is made for each year in the period 2010 to 2030, it is also assumed that the number of hops between the CDN server and client reduces over the same period.

$$relative\ core\ EI_{video} = \frac{\sum \%video\_data_{CDNtype} * EI_{CDNtype}}{\sum \%all\_data_{CDNtype} * EI_{CDNtype}}$$

Where $EI_{CDNtype} = \sum Quantity_{hop} * EI_{hop}$

[2] CDNs can be split into backbone, IXP and ISP. Backbone is the oldest CDN where there are fewer nodes located further from the user, approximately 4 hops. IXP are placed at the interconnections between regional networks and are typically 2-3 hops from multiple ISPs. The ISP CDNs lie within the ISP and are only 1 hop away. This data is not considered to travel through the core network. One of the largest CDNs, Akamai, estimate they are within 1 hop of 90% of their users (Akamai, 2020).

It is assumed that there is no difference in the efficiency for streaming video over the Fixed Area Network (FAN) and Radio Area Network (RAN) compared to the non-video data.

The critical part of the WAN's Core network and DC video EI calculations is estimating the amount of data that must be processed by and transmitted from the DC. This includes data related to the service management and user interface for video selection, but most critically, the amount of video transcoding, and the access demand on cached data within the CDN. While video streaming is often characterized solely as streaming video services such as Netflix, uploaded user created content such as YouTube; livestreaming applications such as Twitch and TikTok/Douyin, are a significant proportion of streaming media traffic. Surveillance cameras and video-based IoT streamed to the cloud, are also included as video streaming.

No conclusive information to help determine the proportion of centrally processed data has been found, and it is therefore assumed that it comprises 10% of the video data. This is considered to be relatively high and hence a conservative assumption, as YouTube, for example, streams approximately 1000 hours of video for every hour uploaded (and transcoded) (Andrew Keen, 2018; James Hale, 2019). For Netflix and similar services, this is likely to be even lower.

3.1.3 Attribution of upstream energy to devices.

To attribute the upstream energy use to the networked connected devices, the TEM2.0 uses the amount of streaming media and non-streaming data traffic, by each device type to proportion the DC/WAN energy consumption. This requires estimating by device type the amount of streaming media and non-streaming data traffic in the DC/WAN. The upstream energy use is allocated to devices by the following calculation:

$$Upstream\ Energy_{device}(y,c) = Data_{device}\ (y,c) \times Stock_{device}\ (y)\ \times EI(y,c)$$

Where,

$Data_{device}$ = average annual data traffic for each device in year y and condition 'c' (streaming and non-streaming).

$Stock_{device}$ = total stock for the device type in year 'y'.

EI = Energy intensity (kWh/GB) of the DC/WAN in year y and condition 'c'.

The proportion of network data traffic generated/consumed by device type is calculated as follows:

$$Data_{device}\,(y) = IP\ Data_{category}\ (y)\ \times IP\ Share_{device}\,(y)$$

Where,

$IP\ Data_{category}$ (y) = the projected data consumption for the IP data category in year 'y'.

$IP\ Share_{device}$ (y) = the share of IP category data for each device type of the category in year 'y'. This is calculated from the estimated monthly data consumption per device type and the share of stock of the devices in the IP data category for year 'y'

These estimates allocate the upstream energy use for the DC/WAN energy consumption to the device type, and account for the network, FAN or RAN, that is being used to communicate, and the type of data, streaming media and non-streaming.

3.2 Regional classifications

The original TEM1.0 was structured in a manner that would allow a regional analysis of global energy use, but unfortunately it was not possible to do so in the completed model, primarily because of limitations on regionalized data availability. The TEM2.0 model builds on the original model's structure enabling regional estimates to be developed.

The regional classifications are largely based on regional differences in appliance and equipment installed. There are eight regions plus Global defined in the model, see Table 3.

Table 3. TEM2.0 Regions.

TEM2.0 Region	Region Abbreviation
North America	NA
West Europe	WE
Central & East Europe	CE
Far East & China	FE
India Subcontinent	IN
Rest of Asia Pacific	AP
Latin America	LA
Africa and Middle East	AF
Global	GL

The regions shown in the table match those used by Juniper Research (Juniper Research, 2020) in its product sales/stock forecast to 2030 by region (see regions description in Appendix A).

The associated population, household numbers and fixed broadband data for each region is based on United Nations (United Nations, 2017, 2019), and ITU-D statistics (ITU-D, 2020). The population data for each of the Juniper Research regions was calculated using the UN's population data for individual economies comprising the regions.

A preliminary analysis of the regionalised data clearly shows, see section 4.3, that the development of connected networks, including the expansion of available web services, is not uniform across the eight regions. The inclusion of regionalization in TEM2.0 enables policy makers to develop approaches to improving energy efficiency in their respective jurisdictions.

3.3 New and updated data sources, assumptions and limitations

To expand the TEM1.0, a number of new data sources were sourced, including the product shipments forecasts by region. In addition, research was also conducted to obtain estimates of streaming media power use for a number of devices, as well as estimates of time of media streaming operation by device.

3.3.1 Sales of devices by year and region to 2030

The source for the key updated data in TEM2.0 was Juniper Research. This data was procured specifically for this project, and included shipments of selected devices by region to 2030 (see Appendix A for the segmentation). The data was provided confidentially to EnergyConsult under agreement that these specific shipment forecasts are not published. The shipments by region are used in the model to provide sales inputs by region. The products included are those shown in Table 4.

Table 4. Selected devices updated with regional shipment data in the TEM2.0

Category	Group	Device
Automation	– Appliances	• Fridges • Freezers • Washing Machines • Tumble Dryers
	– Space Conditioning	• Air Conditioners • Smart thermostats
	– Lighting	• Home lighting
	– Street lights	• Street lights
	– IoT	• Sensor/SIM (LTE-M, NB-IoT & LPWA)
	– Audio	• Digital Voice Assistants
ICT	– Mobile	• Smart Phones
	– Tablet	• Tablet
	– PC	• Desktop • Laptop
Entertainment	– Display	• Smart TV • Digital Signage
	– Media Device	• Casting Sticks • Games Consoles
Security	– Control	• Smart locks
	– Video	• IP cameras

3.3.2 Media streaming power consumption by device and time of use estimates

The streaming media condition power consumption is a key input to the calculations of energy consumption by device in the TEM2.0. The sources for this estimated value by device are:

- Smart TV – model weighted average power input for HD (n=304) and UHD (n=207) TVs in the EU market in 2017 (used for the updated EU Ecodesign directive).
- Displays connected to OTT media players, STBs, Casting sticks, etc, - same value as for smart TVs.
- OTT Media players and STBs, Game consoles – estimated from (Fraunhofer, 2017)
- Casting sticks – EDNA measurements
- DVA speakers – EDNA measurements
- DVA -Video – selected website reports (individual user measurements)
- AV Receiver and AV Speakers – US EPA reported power consumption, increased by 50% to account for the small number of higher efficiency Energy Star products.
- Mobile devices (smart phones, tablets) – assumed to be same as in-use power consumption when operating in all conditions, which is very low in comparison to mains powered stationary devices.

The average time of use of devices when streaming media was derived by device from multiple sources, including (Nielsen, 2018; GlobalWebIndex, 2019; CONVIVA, 2020; Hootsuite, 2020). These sources were assessed and normalised on a per device basis (as connected TVs were often recorded on a per user basis, with multiple users per TV). The average media streaming usage per day was estimated from these multiple sources as follows:

- Smart TVs, AV receivers, AV Speakers – 2 hours per day
- OTT media players, STBs, Casting sticks – 3 hours per day
- Games consoles, DVA-Video Display – 1 hour per day
- Smart phone, Tablet, laptop PC – 1 hour per day
- Desktop PC – 0.5 hours per day.

3.3.3 Limitations of the TEM2.0

The limitations of the TEM2.0 include:

- Although there is an increasing trend over the last 5 years in the average time devices are used for media streaming, the model uses a constant value for the modelling period in order to simplify model calculations.
- The average time and power consumption by device media streaming is estimated as the global average. Later enhancements can be made to the TEM2.0 to regionalise these values, provided valid estimates would be found for each region.
- One of the extensions to TEM1.0 incorporated in TEM2.0 is the regionalization of the upstream and downstream energy consumption of devices and the separation of the data traffic into that related to streaming media and non-streaming data. However, it was not possible to incorporate a regionalization of the upstream data traffic. Consequently, TEM2.0 assumes that in all regions there is the same mix and proportion of network technologies, i.e. the mix of FAN and RAN and variety of each, carrying the data traffic. This report reveals that from around 2021, despite there being an overall flat character, there is an upward trend in upstream data traffic energy use. This is primarily due to the global movement of traffic, particularly streaming media traffic, to mobile broadband networks, and mobile broadband networks being more energy intensive. The progression from 2G to 5G mobile technologies has been driven by the demand for higher mobile broadband data rates, 2G was capable of up to 348 kbps and 5G is anticipated to provide >1 Gbps. Therefore, care must be taken with interpreting regionalised upstream data traffic, as the energy intensity of the upstream WAN/DC is based on global assumptions.

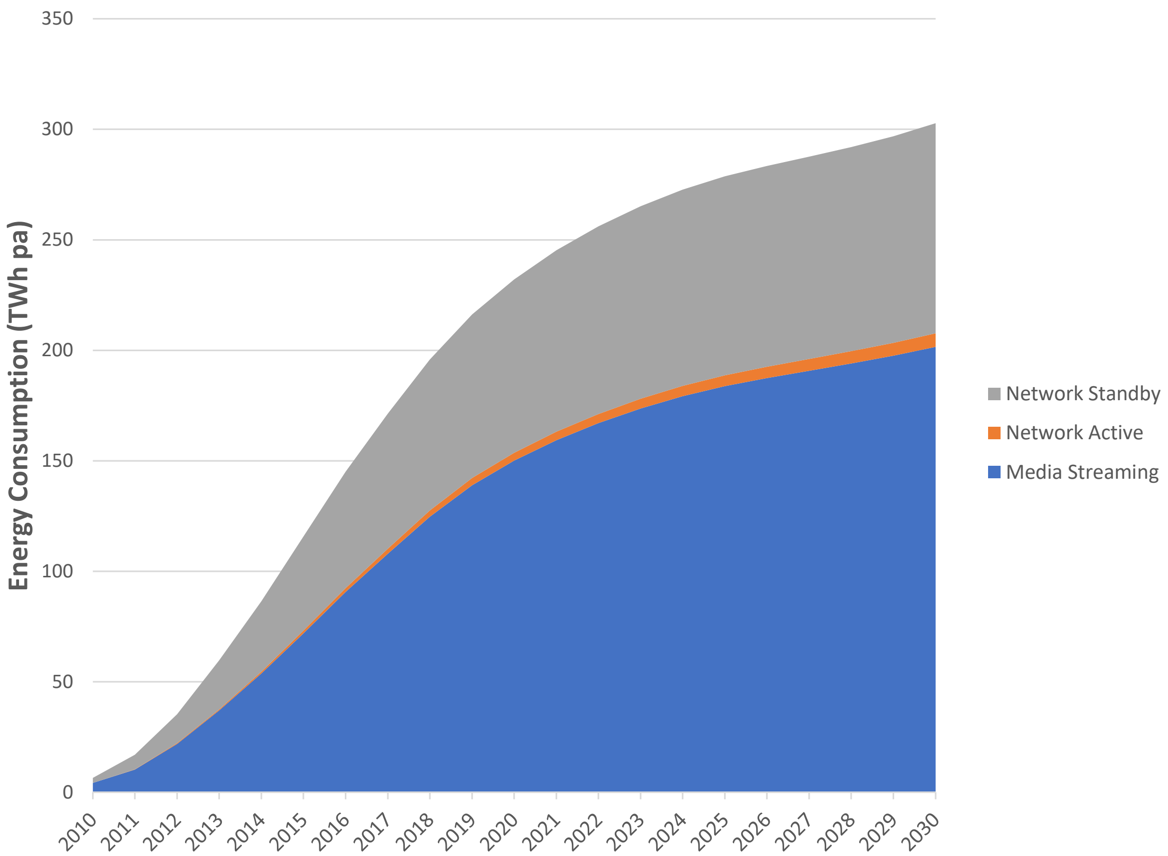
4 Key outputs of TEM2.0

This section provides a selection of the key outputs from the TEM2.0. Further result outputs can be accessed at https://www.iea-4e.org/edna/charts/.

4.1 Streaming and non-streaming network connected energy use

The energy consumption of devices in the entertainment category by condition is shown in Figure 3. It reveals that by 2030 devices in streaming media condition will be consuming around twice as much energy as other devices in that category in network standby condition. Changes to energy consumption due to increased streaming media associated with the recent Coronavirus lockdowns have not been included in the modelling due to insufficient data and time to model these impacts.

Figure 3. The entertainment category device energy consumption globally by condition; network standby, network active and Media Streaming; from 2010 to 2030.



The global energy consumption of entertainment category devices in Steaming Media condition is shown in Figure 4. The combination of TV and STB & OTT Media Player (e.g. Apple TV) or Casting Stick (e.g. Roku) are the dominant energy consumers.

Figure 4. The energy consumption of entertainment category devices in Media Streaming condition, globally.

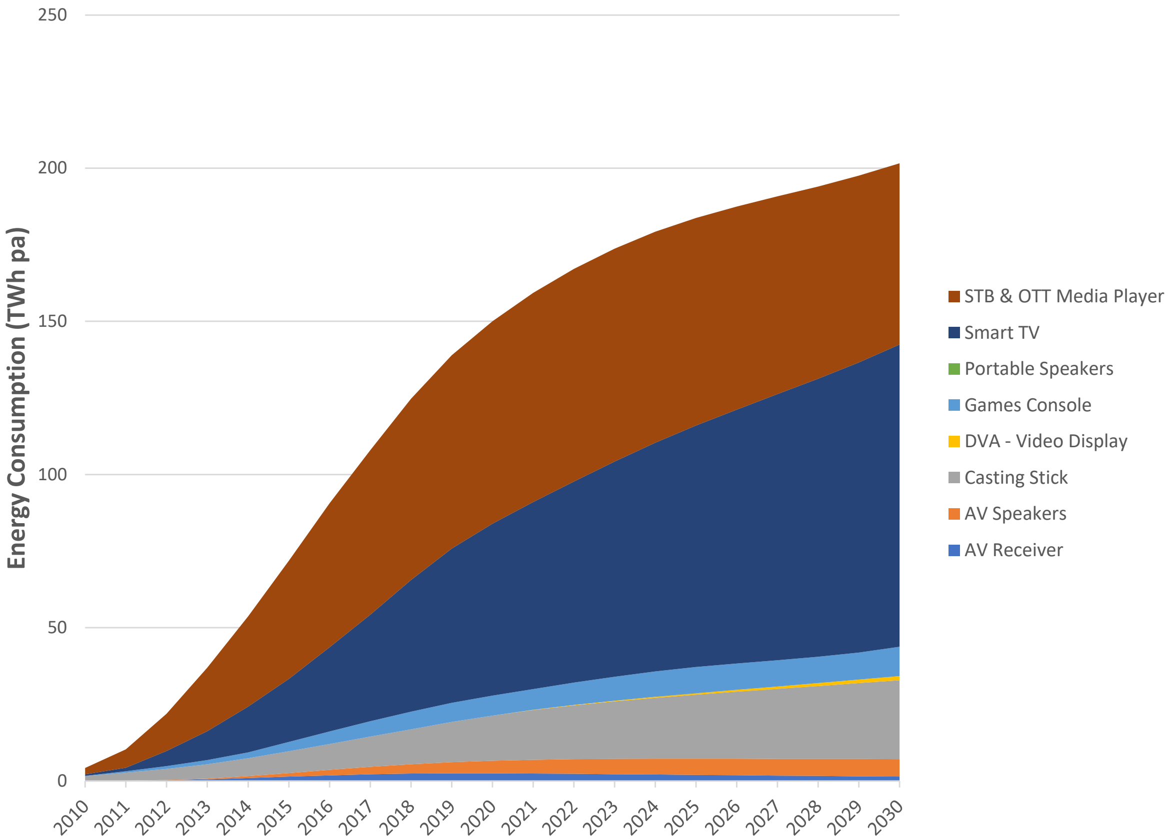


Figure 5 shows the upstream portion of the total global energy consumption along with the connected device portion. It estimates that, by 2030, the device consumption will be around 225 TWh, while the upstream portion will be around a tenth of the device consumption, 25TWh. However, it also reveals that streaming over a mobile network reverses that balance, not unexpectedly as Smart Phones are low energy consuming devices. The energy associated with the service delivery to the device is considerably higher. More importantly, it forecasts that by 2030 the mobile network energy use could be around four times that of the fixed network energy consumption.

Figure 5. The total energy consumption (device and upstream portions) globally for streaming devices.

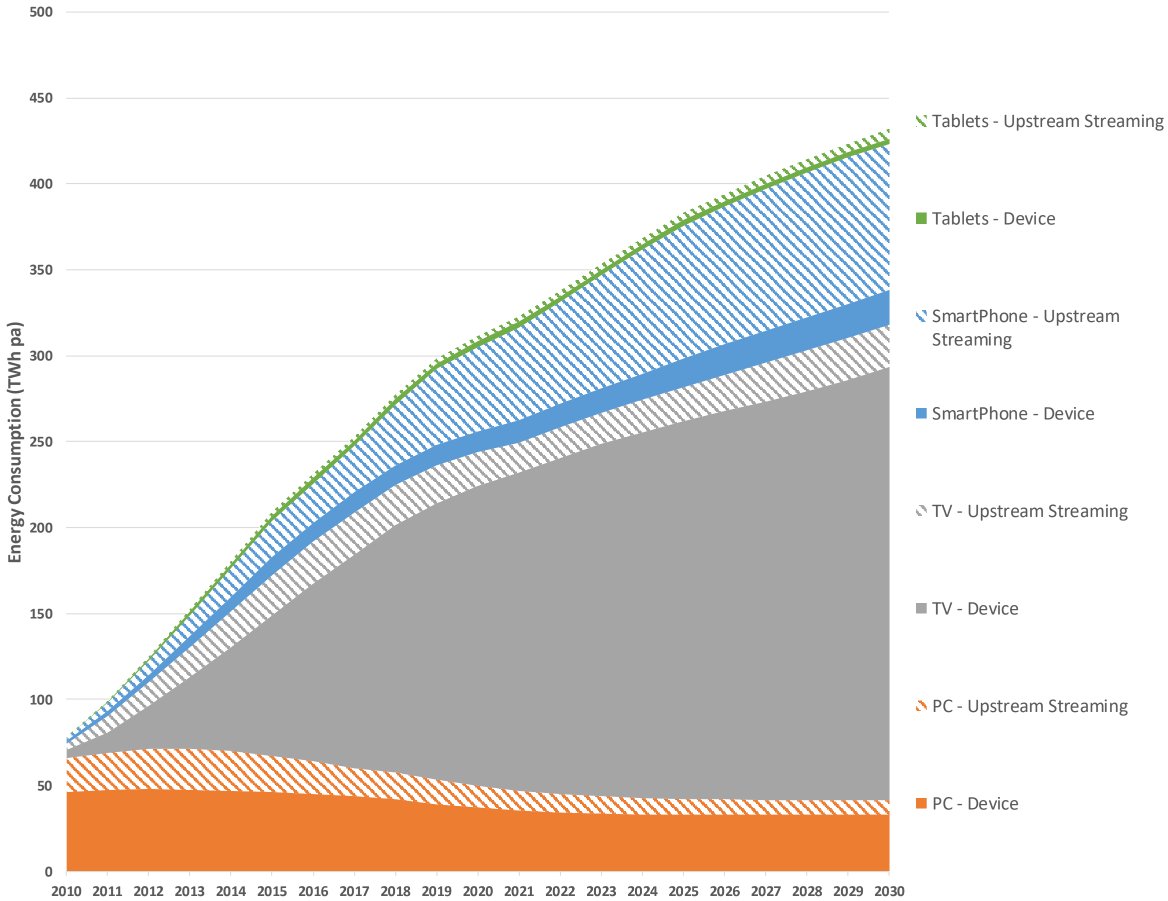


Figure 6 highlights the relative portions of the streaming media traffic and non-streaming upstream traffic energy use. The downward trend, starting in 2014, in streaming media and non-streaming traffic energy use reflects the improvement in the efficiency of DC and WAN equipment (i.e., servers, routers, switches, etc.).

Streaming media traffic is impacted in a number of ways, including the improvement in transcoding and transmission efficiency, which will tend to continue out to 2030 and beyond. The growing demand for higher quality video in the form of high definition, 4K and future 8K resolutions; and the techniques used to adaptively transmit the streams over the network. However, the improvements in transcoding and transmission efficiency will not overcome the loss in efficiency of the mobile broadband networks which will tend to be the primary carriers of streaming media post 2021.

The upward trend expected from 2021 is the result of the very rapid increase in mobile data use, generally and for streaming media particularly, compounded by a slower rate of energy efficiency improvements in mobile broadband networks, *viz*. 4G and 5G. The initial fall in energy from 2014 is primarily due to the replacement of inefficient 2G equipment, and transition to 3G and even newer 4G, resulting in a rapid reduction in energy intensity. At this time mobile data consumption was increasing at a slower rate than now, and coverage in regional areas was limited. Further, the energy efficiency of optical fibre based fixed networks (including FANs), which were still carrying the bulk of the streaming media and non-streaming traffic, continued to improve. From 2021, however, mature

4G and the early 5G, in particular, with their provision of high data rates especially for streaming media, are expected to result in very high data consumption, particularly in regions without high speed FANs to the premises Improving energy efficiency in mature 4G networks will be limited, while energy efficiency improvements in the nascent 5G networks might not be achieved until the equipment and technology matures.

Figure 6. The upstream energy consumption for streaming and non-streaming traffic.

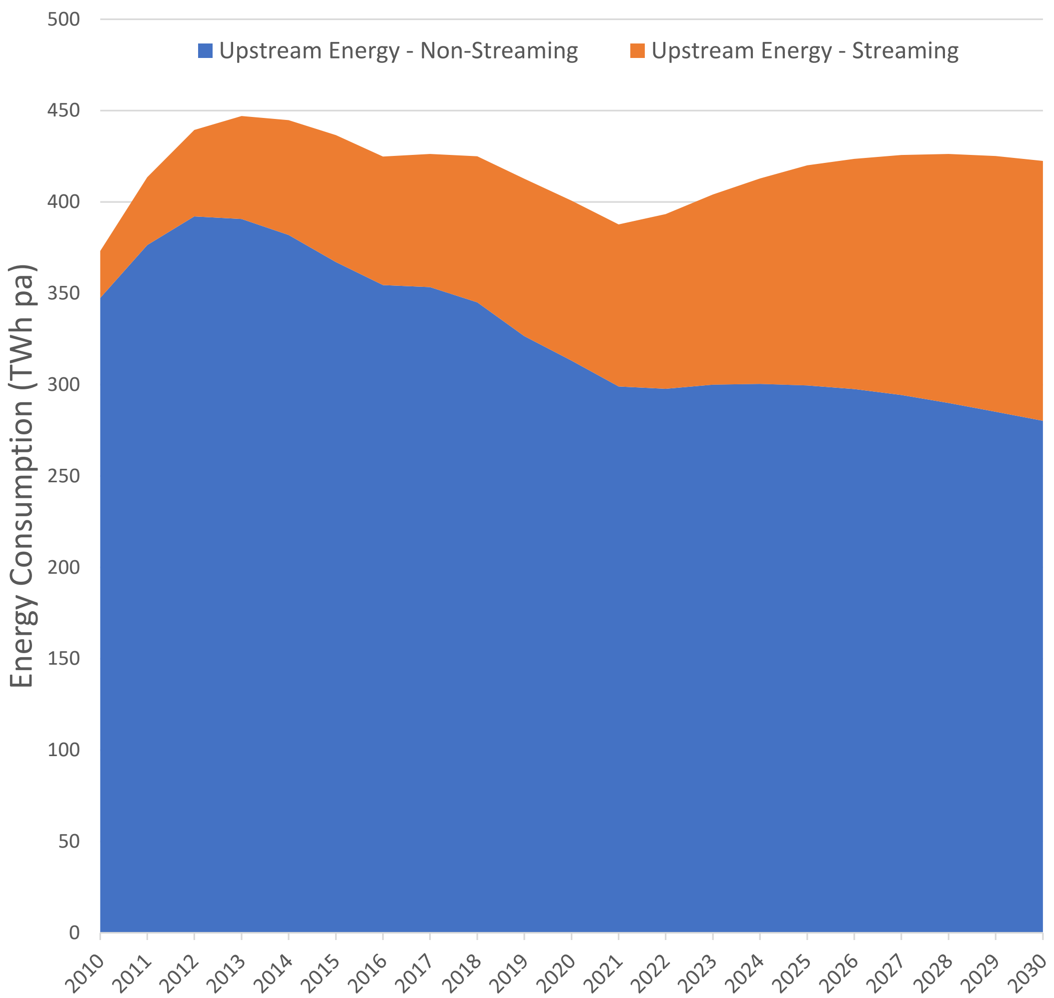
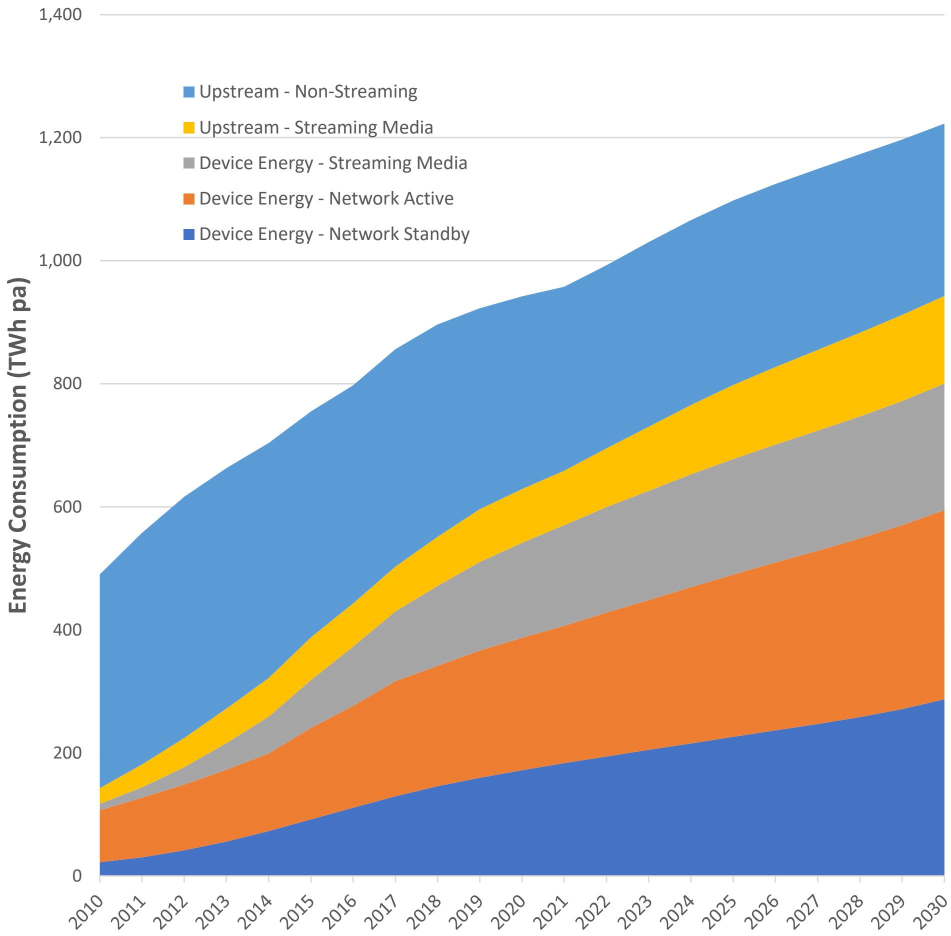


Figure 7 shows the energy consumption of the principal components associated with streaming media traffic and non-streaming traffic and connected devices. It reveals that the upstream streaming traffic component is the smallest.

With global electricity demand rising from 23,000 TWh in 2018 to 29,900 TWh in 2030 (IEA, 2019), the share of total network-connected energy consumption of total electricity demand is 3.9% in 2018 and projected to be 4.1% in 2030.

The total energy consumption, including edge device and upstream, of connected devices for streaming media is projected to grow from 210 TWh in 2018 (0.9% share of electricity demand) to 350 TWh in 2030 or 1.2% of total electricity demand.

Figure 7. The total energy consumption comprising upstream IP traffic, including streaming and non-streaming, and all connected devices in all conditions.



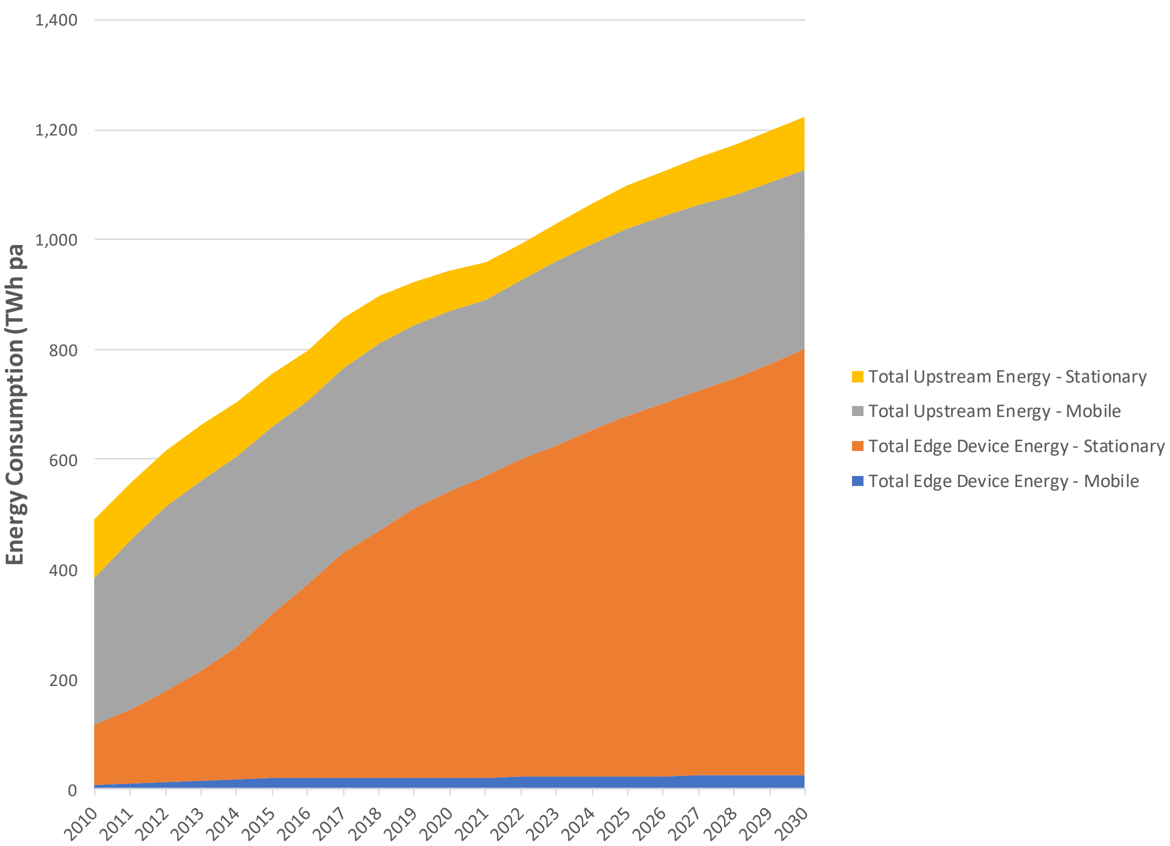
To compare the TEM2.0 upstream energy consumption with other recent analysis, a number of papers have been examined. Analysis by Kamiya (2020) of the upstream energy shows higher energy consumption for data centres. This is expected because the energy intensity is based on the average of all data consumed, and not calculated specifically for video streaming. Another study (Preist, Schien and Shabajee, 2019) uses Netflix reported energy consumption data to estimate the energy intensity which is similarly referenced in Kamiya (2020) but these include all non-streaming business functions, including ownership of a film studio, which cannot be subtracted. However, the energy intensity calculated from the references provided are within the same magnitude and confirm video streaming energy intensity is far lower than average. Comparison of the upstream energy consumption with other reports identified has not been possible due to large differences in methodology, scope of energy use included and data presentation.

4.2 Mobile vs stationary device energy use

In portraying the total energy consumption, Figure 8 compares the energy consumption of mobile and stationary connected devices, and their associated upstream energy consumption. Total energy consumption of edge devices includes streaming media, network active and Network Standby conditions.

Figure 8 reveals the differences in mobile and stationary broadband networks. Stationary networks have low network energy consumption but a relatively high edge device consumption. Whereas mobile networks have higher network energy consumption but a low edge device consumption, primarily because they are battery powered.

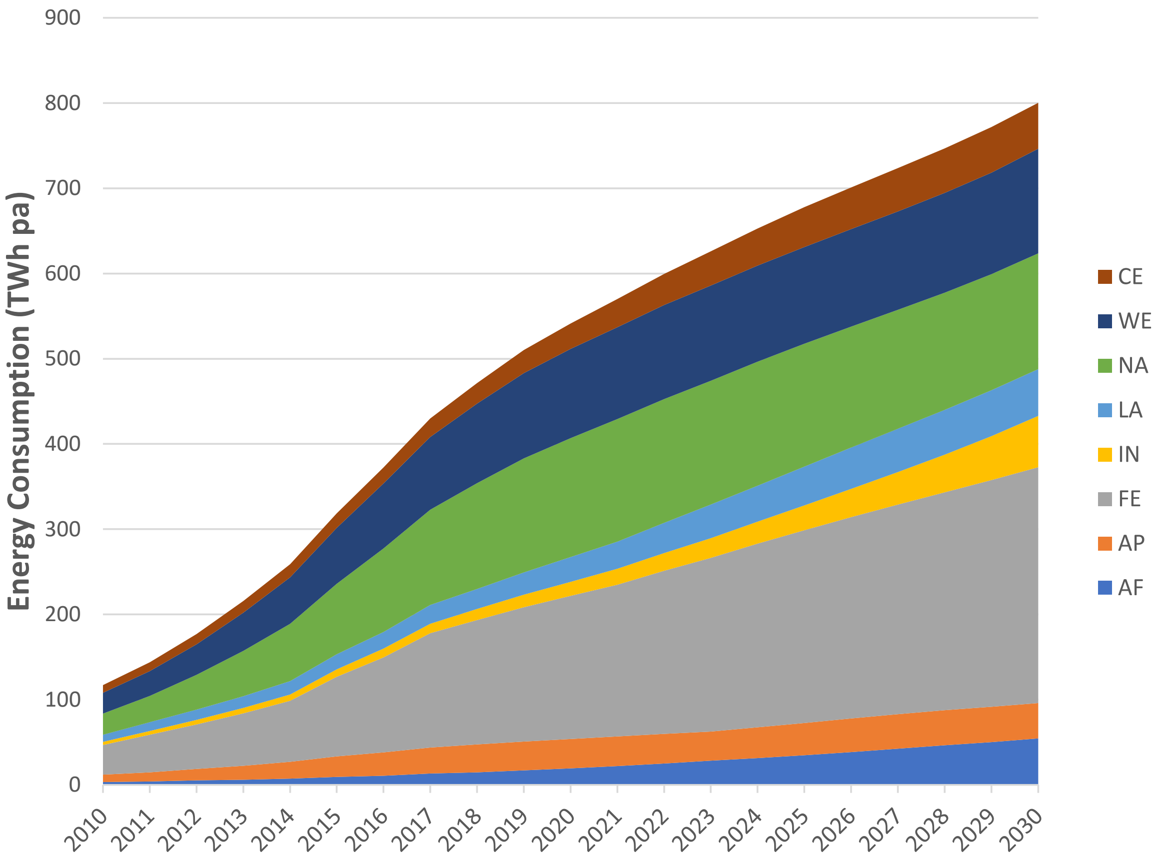
Figure 8. The energy consumption of mobile and stationary edge devices.



4.3 Regional connected energy use

The total energy consumption of connected edge devices by region per year is shown in Figure 9.

Figure 9. Total energy consumption of connected edge device by region, per year.

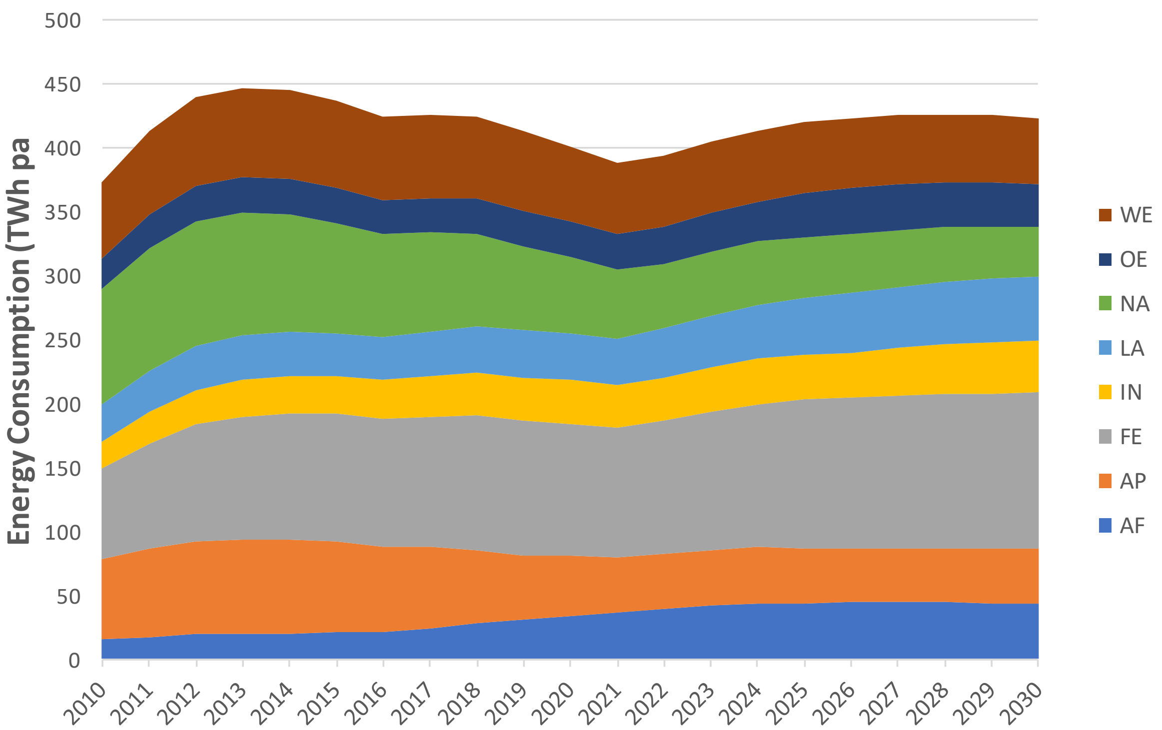


The shift in total edge-device energy consumption out to 2030 appears to reflect the nature of the change in global economic development with the associated change in living standards within the regions, and their higher populations.

Figure 9 indicates that by 2030 the Far East and China (FE) region will be consuming over one third of the world's total edge device energy, and over twice that of North America's consumption. The India Subcontinent (IN), with a marginally larger population than that of the Far East and China region, shows a much lower forecast energy consumption of edge devices, this is primarily due to its lower stock of stationary edge devices. In 2020, the proportion of India Subcontinent stock to total global stock of entertainment category devices is 2.8%, while in the Far East and China it is 18.7%. By 2030, the India Subcontinent proportion increases to 12.1%, while in the Far East and China to 25.4%. This demonstrates that regional differences in the stock of edge devices impacts the relative energy consumption, and that as this difference diminishes so will the comparative edge device energy consumption.

The total upstream energy consumption by region is shown in Figure 10.

Figure 10. The energy consumption of total upstream IP traffic, streaming and non-streaming components, by region.



The total regional upstream energy consumption, Figure 10, displays a relatively invariable relation between time and energy. The upstream energy use is fairly flat over time because while traffic trends upward, so does the efficiency. The inflection in this trend around 2021 is primarily due to the global movement of traffic to mobile broadband networks. And as mobile broadband networks tend to more energy intensive so the energy consumption rises. However, it is difficult to draw precise conclusions from Figure 10 because, while the data traffic is regionalised, the associated EI of the upstream is based on global assumptions. And while the inflection would still appear in many regions, it's form may differ if, the EI better reflected the technology composition of the regional WAN. By technology composition is meant the mix of FAN and mobile RAN, the latter in particular. In many regions, e.g. the Far East and China or Africa, there is likely to be greater proportion of traffic on mobile broadband than fixed networks leading to a higher EI.

Considering the above limitations, it remains likely that upstream energy use will trend higher in the regions: Other Europe (OE), the Far East and China (FE), Africa and the Middle East (AF), the India Subcontinent (IN) and Latin America (LA), where the upstream network is more reliant on mobile than fixed networks. It is similarly noticeable how upstream energy use in North America (NA), Asia Pacific (AP) and Western Europe (WE) displays a falling trend.

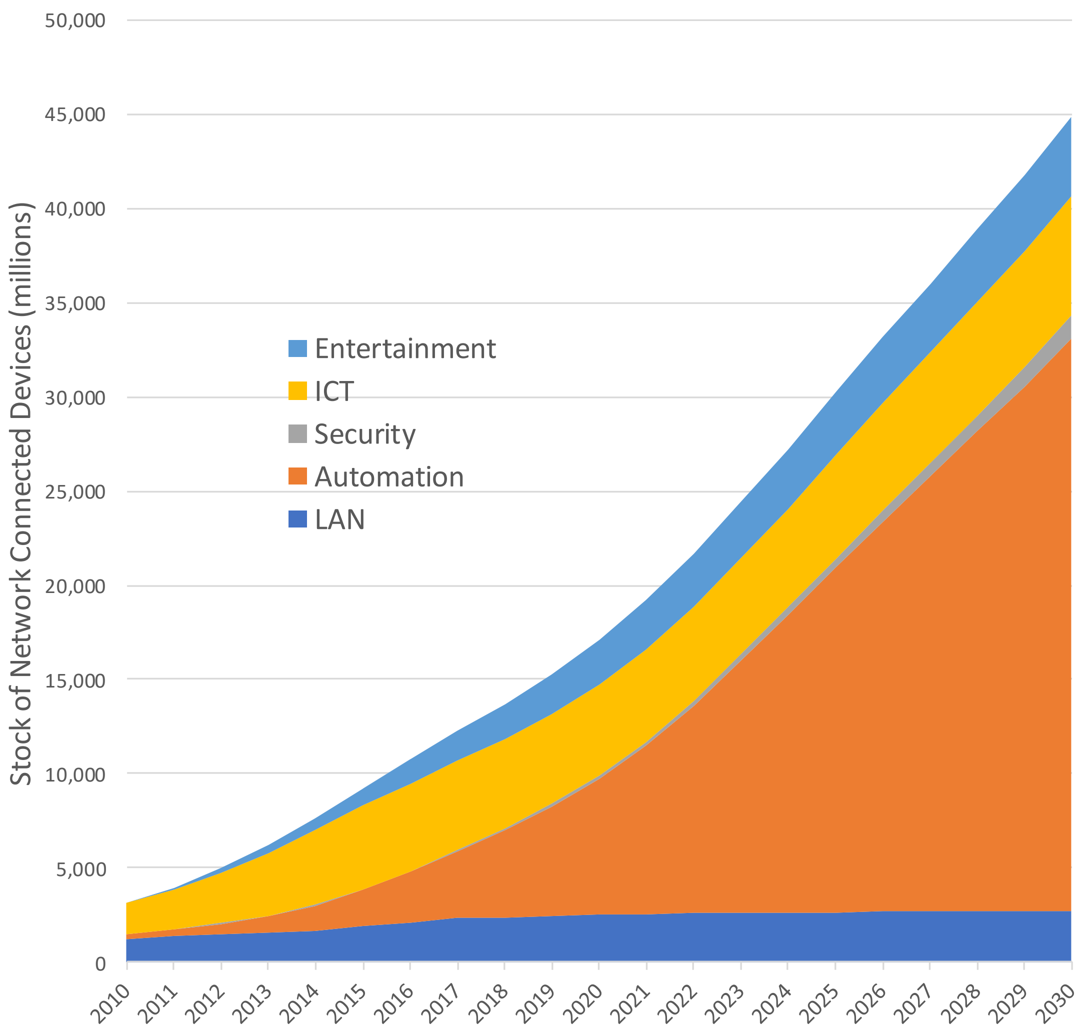
4.4 Updated stock

Figure 11 shows the stock of network connected devices by category. The entertainment category is revised in TEM2.0 to include: Casting Sticks (or Digital Media Adapters), and Digital Voice Assistants (DVAs), with and without a video display. The categories showing the greater growth are: entertainment and automation.

It is because of the growth in Internet video streaming traffic that streaming media energy consumption is a focus for TEM2.0. The growth in video streaming services requires that viewers have devices, such as Casting Stick or Smart TVs, to receive the streamed data.

The growth in automation category devices in part relates to video streaming. DVAs are devices which provide voice control of smart home appliances and other devices, including Casting Sticks and potentially Smart TVs. And DVAs which include a screen can be used to view streaming video services. Similarly, laptop computer and tablets from the ICT category can also be used to view streaming video services, however, from the data it is less clear that there is significant growth in this application.

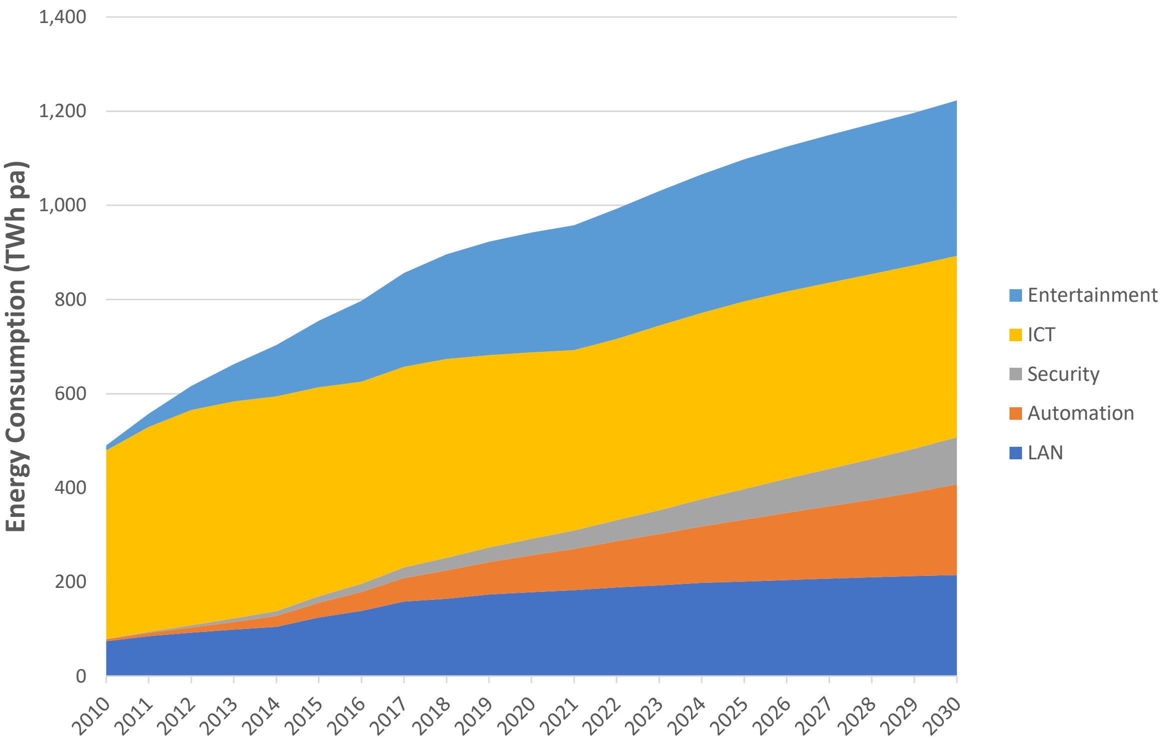
Figure 11. The updated global stock of network connected devices by category in TEM2.0.



4.5 Updated total connected energy by category

Figure 12 shows the updated total energy consumption of connected devices by category globally, which includes the LAN equipment, edge device and upstream energy consumption.

Figure 12. The total updated energy consumption of connected devices by category.



The total energy consumption shown in Figure 12 is higher than in TEM1.0, as it now includes the energy consumption of displays when edge devices receiving video streaming services. This difference can be clearly observed by the increase in energy consumption of the entertainment category of devices compared to the estimates in the TEM1.0 for the same category.

Comparing Figure 12 and Figure 11 it can be seen that, despite the preponderance of automation category devices, their energy consumption is relatively low. And while ICT and entertainment categories dominate the energy consumption, largely due to including streaming media condition[3], their stock numbers are considerably lower than for the automation category.

[3] In making this comparison, it must be remembered that the energy consumption of entertainment category devices used for receiving video streaming services includes the total device consumption not just the network interface energy consumption, as is the case for most automation category devices.

References

Akamai (2020) *The Akamai Intelligent Edge Platform*. Available at: https://www.akamai.com/uk/en/what-we-do/intelligent-platform/ (Accessed: 2 February 2020).

Andrew Keen (2018) *People now watch 1 billion hours of YouTube per day*, *Techcrunch*. Available at: https://techcrunch.com/2018/01/21/2018-might-be-amazons-year-to-end-the-facebook-google-advertising-duopoly/.

Chen, X., Xing, L. and Ma, Q. (2011) 'A distributed measurement method and analysis on Internet hop counts', *Proceedings of 2011 International Conference on Computer Science and Network Technology, ICCSNT 2011*, pp. 1732–1735. doi: 10.1109/ICCSNT.2011.6182303.

CISCO (2019) *Cisco Visual Networking Index: Forecast and Trends, 2017–2022*.

CONVIVA (2020) *CONVIVA'S STATE OF STREAMING Q4 2019*.

EnergyConsult (2019) *Total Energy Model of Connected Devices*. Prepared for the IEA 4E TCP EDNA by EnergyConsult Pty Ltd. IEA, Paris.

Fei, A. *et al.* (1998) 'Measurements on delay and hop-count of the internet', in *IEEE Global Telecommunications Conference*.

Fraunhofer (2017) *Energy Consumption of Consumer Electronics in. U.S. Homes in 2017*.

Fulton, S. (2020) *Data Center Power: Is Netflix Really Contributing to Climate Change?*, *Data Center Knowledge*. Available at: https://www.datacenterknowledge.com/energy/how-much-netflix-really-contributing-climate-change (Accessed: 20 February 2020).

GlobalWebIndex (2019) *Flagship report 2019: Entertainment*.

Hootsuite (2020) *Digital 2020*.

IEA (2019) *World Energy Outlook-2019*. Paris.

ITU-D (2020) *ICT Statistics Home Page*. Available at: https://www.itu.int/en/ITU-D/Statistics/Pages/default.aspx.

James Hale (2019) 'More Than 500 Hours Of Content Are Now Being Uploaded To YouTube Every Minute', *Tubefilter*.

Juniper Research (2020) *IoT Landscape Forecasts to 2030*. Prepared for EnergyConsult Pty Ltd, private data. London, UK.

Kamiya, G. (2020) *The carbon footprint of streaming video: fact-checking the headlines*, *IEA*. Available at: https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines (Accessed: 27 April 2020).

McNeil, M. A. *et al.* (2012) *Bottom-Up Energy Analysis System - Methodology and Results*. Berkeley, CA (United States).

Morley, J., Widdicks, K. and Hazas, M. (2018) 'Digitalisation, energy and data demand: The impact of Internet traffic on overall and peak electricity consumption', *Energy Research & Social Science*. Elsevier, 38, pp. 128–137. doi: 10.1016/J.ERSS.2018.01.018.

Nielsen (2018) *Total Audience Report*.

Preist, C., Schien, D. and Shabajee, P. (2019) 'Evaluating sustainable interaction design of digital services: The case of YouTube', *Conference on Human Factors in Computing Systems - Proceedings*, pp.

1–12. doi: 10.1145/3290605.3300627.

Siderius, H.-P., Beletich, S. and Ryan, P. (2020) ‘IoT: a new Dimension to Network Standby’, in *ACEEE Summer Study on Energy Efficiency in Buildings*.

United Nations (2017) *Household size and composition around the world 2017*.

United Nations (2019) *World Population Prospects 2019 - Population Division*. Available at: https://population.un.org/wpp/Download/Standard/Population/ (Accessed: 6 February 2020).

Vereecken, W. *et al.* (2011) ‘Power consumption in telecommunication networks: Overview and reduction strategies’, *IEEE Communications Magazine*, 49(6), pp. 62–69. doi: 10.1109/MCOM.2011.5783986.

Widdicks, K. *et al.* (2019) ‘Streaming, multi-screens and YouTube: The new (unsustainable) ways of watching in the home’, *Conference on Human Factors in Computing Systems - Proceedings*, pp. 1–13. doi: 10.1145/3290605.3300696.

Wimmer, W. and Dangl, G. (2017) *Projektarbeit: Klassifizierung und Vergleich des Stromverbrauches unterschiedlicher extern ange schlossener Streaming Devices*. Vienna.

Appendix A: TEM2.0 regions and economies

The TEM2.0 uses the same economy groupings as Juniper for the regional segmentation (Juniper Research 2020), as follows:

North America

- Canada, USA

Latin America

- Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Surinam, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela, Virgin Islands.

West Europe

- Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK.

Central & East Europe

- Albania, Belarus, Bosnia Herz, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Turkey, Ukraine.

Far East & China

- China, Hong Kong, Japan, Mongolia, North Korea, Macao, South Korea, Taiwan.

Indian Subcontinent

- Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka.

Rest of Asia Pacific

- Australia, Brunei, Fiji, New Caledonia, New Zealand, Cambodia, Indonesia, Laos, Malaysia, Maldives, Myanmar, Philippines, Singapore, Thailand, Vietnam.

Africa & Middle East

- Afghanistan, Algeria, Angola, Armenia, Azerbaijan, Bahrain, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Democratic Republic of Congo, Djibouti, Egypt, Equatorial Guinea, Ethiopia, Gabon, Gambia, Georgia, Ghana, Guinea, Guinea-Bissau, Iran, Iraq, Israel, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Lebanon, Lesotho, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Oman, Palestine, Qatar, Reunion, Rwanda, Saudi Arabia, Senegal, Seychelles, Sierra Leone, South

Africa, Swaziland, Syria, Tajikistan, Tanzania, Tunisia, Turkmenistan, Uganda, United Arab Emirates, Uzbekistan, Yemen, Zambia, Zimbabwe.