The Total Energy Model for Connected Devices.

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ABSTRACT: The rising number of devices connected to networks has implications on energy demand and use. Although network connected devices can reduce energy wastage of appliances and equipment by controlling and optimizing the operation of systems that deliver energy services, there is often additional energy used to create, maintain and transmit data over the network. Network connected devices include a large diversity of products in the residential, business and public sectors, such as smart TVs, mobile phones, sensors, lighting, thermostats, voice assistants, speakers, video cameras, etc.
The Electronic Devices and Networks Annex - EDNA of the International Energy Agency´s Energy Efficient End-Use Equipment collaboration provides analysis and policy guidance for promoting and improving the energy efficiency of connected devices and systems. This paper discussed EDNA´s Total Energy Model (TEM). TEM is a quantitative model of the "total energy use" of connected devices, which was developed to better understand the *additional* energy needed for devices when connected to a communications network (EDNA, 2019). TEM results, in particular those for network standby and streaming energy use, provide a reputable source of information to assess possible energy efficiency measures. Selected results are discussed as well.

1. INTRODUCTION

The global stock of network connected devices is estimated to increase from around 15 billion in 2018 to 46 billion in 2030, as shown in Figure 1, for the product categories security, information and communication technologies (ICT), entertainment, automation, and local area networks. This represents a 300% increase from 2018 to 2030, or an average compound annual growth rate of 9.8%. The majority of this growth of stock corresponds to automation network connected devices, which includes sensors, controls and connected appliances. The estimated energy consumption of network connected devices in all categories is estimated to reach 1200 TWh/year in 2030, and from 2018 until 2030 the *standby* energy consumption of all devices is projected to double (Ryan et al., 2019; Ryan et al., 2020). One major driver for this rising energy consumption is the increasing installation of entertainment and automation devices which require a permanent network connection to enable their func-

tions on demand (Ryan et al., 2019). Results from the TEM model show that, despite the large stock of automation devices, their energy consumption is relatively low, compared to a lower stock for the ICT and entertainment categories, with higher energy consumption, largely due to the streaming functionality.

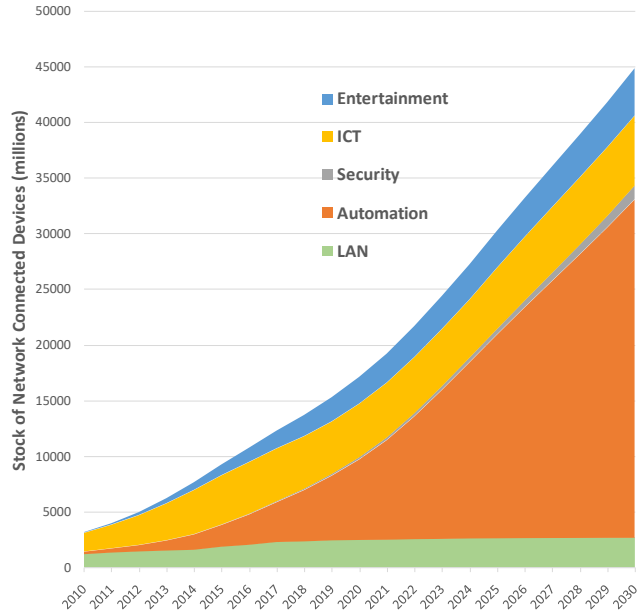

Figure 1: Estimated global stock of network connected devices by category (Ryan et al., 2020).

2. SCOPE OF THE TOTAL ENERGY MODEL

TEM quantifies the total *additional* energy that results from devices becoming network connected. The key definitions that guide the scope of the TEM are the definition of network-connected devices, the definition of what is *"additional"* energy use, identifying the conditions of energy use, and defining what energy use is related to being *"network connected"*. The scope of network connected devices includes three sectors: residential, business, and public; and the product categories of security, ICT, entertainment, and automation. The devices are identified as:

- **Electronic edge devices**: devices that store and use data (e.g., laptops and smart phones), and *Other* edge devices with no data-related functions (e.g., networked kitchen and household appliances).

- **Wireless and fixed network equipment**: made up of wired and wireless Local Area Networks (LAN) and mobile networks; as well as Data Centers (DC) and Wide Area Networks (WAN).

The energy uses for each device category are considered as follows:

- **Electronic edge device**: all modes/conditions of energy use of *connected* edge devices.
- ***Other* edge devices**: all modes/conditions of energy use of connected devices that exists to service the device functions while connected to the network, where this is *additional* to the normal functioning of the device or service that is being performed.
- **LAN equipment**: all modes/conditions of energy use of LAN equipment is due attributable to data services for connected edge devices.
- **Data centers (DC)/WAN**: energy use by the DC/WANs that is attributable to the data services for connected edge devices.

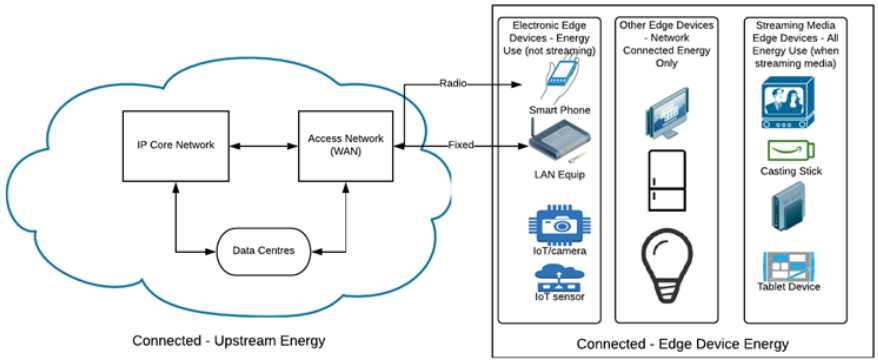

Figure 2: Scope of network connected energy consumption (Ryan et al., 2020).

The total *additional* energy use of network-connected devices focuses on *three main conditions* (For a constant network connection the **off-mode** of devices is not relevant, and thus it is not included in the TEM):

- **Network active:** the condition in which a device is communicating actively with another device on a network.
- **Network standby:** the condition which allows a device to resume its main function upon a receiving a remotely initiated trigger via a network connection.
- **Media streaming:** the condition in which audio-visual content data is transmitted over a network to a smart TV, casting stick or similar enter-

tainment device, and includes the energy that the device uses to fulfill its primary function. 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 centers, wide area and core networks) categories. The downstream category includes the streamed media receiving edge device, e.g., a display or a TV (Ryan et al., 2019; Ryan et al., 2020).

Tab. 1 shows the example of energy uses for smart TVs and connected lights.

Tab. 1: Energy uses for Smart TV and connected lights (Ryan et al., 2019).

Device	Condition	Functions	Included in TEM	Explanation
Smart TV	On mode	Streaming video	No	*On mode* is not additional energy use to the normal use
	Network standby	To enable on demand streaming	Yes	Is required to be connected to stream video
	Network active	Provide data control and transfer while streaming or main functions	Yes	Is required for data functions (assumed to be the same power demand as network standby condition)
Connected light	On mode	Providing light	No	Not additional to normal use of light.

3. ENERGY USE DATA AND SCENARIO MODELLING

The TEM includes different energy use scenarios to examine, for example, how changes in technology, device sales over time, and daily time of use by condition impacts energy use of network connected devices. The TEM sums the individual energy use by condition (network active/network standby/streaming) for connected devices, and allocates the upstream energy use of the network (DC and WAN) to each device type. For the edge device and edge network equipment, a bottom-up product stock model of energy is used, meaning that energy use is estimated at the device level, and summed to provide global/regional energy consumption. For each product included, relevant data to model the network connected energy consumption was acquired, including e.g., (regional) sales and shipment data, and streaming media power consumption. The data relating to the sales, the service life, stock of equipment, and the energy use characteristics all vary over time. For the DC/WAN

component, including access networks, the specific energy intensity of DC/WAN equipment types per data traffic carried over the WAN was included. The regional upstream energy use is calculated according to the share of data attributed to various DC/WAN technology types of the total projected data traffic. The energy intensity (energy use per data transferred, or EI), the share attributed to each DC/WAN technology types, and the total network traffic also vary over time. To attribute the upstream energy use to the edge devices, the estimated data consumption of network devices is used to proportion the upstream energy use to the connected device Finally, 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. Very specific considerations are included in the TEM for the streaming media, for example the amount of data streamed during high and low utilization levels. This segmentation is necessary since the EI of the server's traffic changes with utilization level. Media streaming power consumption by device and time of use estimates are also key variables included. The type of server (Solid state disk server – SSD, Hard disk drive storage server - HDD and "standard" server with non-video traffic) and the WAN's Core network traffic EI, were considered in the model (as explained in Ryan et al., 2020).

The TEM shall provide a current/historical and projected energy use of the connected devices and their upstream energy impacts, on a global and regional basis. Input data are collected from historical values over the period up to 2016 or 2017, so the year 2017 presents the *current estimated energy use*, and the period 2010 to 2017 is historical energy use. The model uses projections from various sources for the period 2018 to 2030. This is the *projected energy use*. Data sources are not readily available after 2023, so projections until 2030 are highly uncertain, with rapidly changing technologies and services (Ryan et al., 2019). The inclusion of regionalization in the TEM is largely based on regional differences in equipment installed. The model covers eight regions and a Global (GL) category. The regions are 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), and Africa & Middle East (AF) (Ryan et al., 2020).

4. PROJECTIONS OF ENERGY CONSUMPTION UNTIL 2030

The TEM allows modeling global and regional projections of network connected energy consumption. Selected results are discussed in this section. Driven by many more products becoming network connected, device energy is increasing remarkably until 2030, whilst the energy demand of non-streaming

upstream is slightly decreasing, as shown in Figure 3. 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).

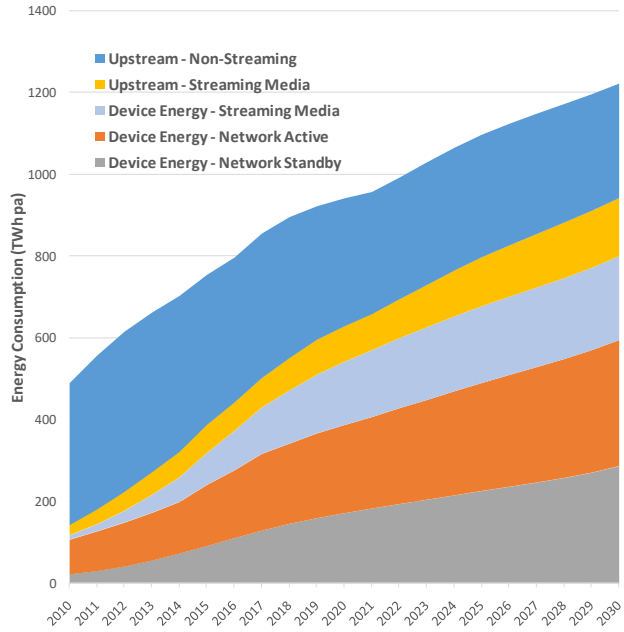

Figure 3**:** Total energy consumption comprising upstream traffic, including streaming and non-streaming, and all connected devices in all conditions (Ryan et al., 2020).

Figure 4 shows the energy consumption of entertainment devices. By 2030 devices in streaming media condition will be consuming about twice as much energy as other devices in network standby condition. Changes to energy consumption due to streaming during the recent Corona virus lockdowns were not included in the TEM, due to insufficient data and time to model these impacts. Figure 5 shows that the total energy consumption of edge devices in the Far East and China (FE) region will be over one third of the world's by 2030. The India Subcontinent (IN) shows a much lower forecast of the energy consumption of edge devices, primarily due to its lower stock of stationary edge devices. In 2020, the proportion of the IN 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 IN proportion increases to 12.1%, while in the FE to 25.4%. This demonstrates that regional differences in the stock of edge devices has an impact on the relative energy consumption, and that as this difference diminishes so will the comparative edge device energy consumption (Ryan et al., 2020).

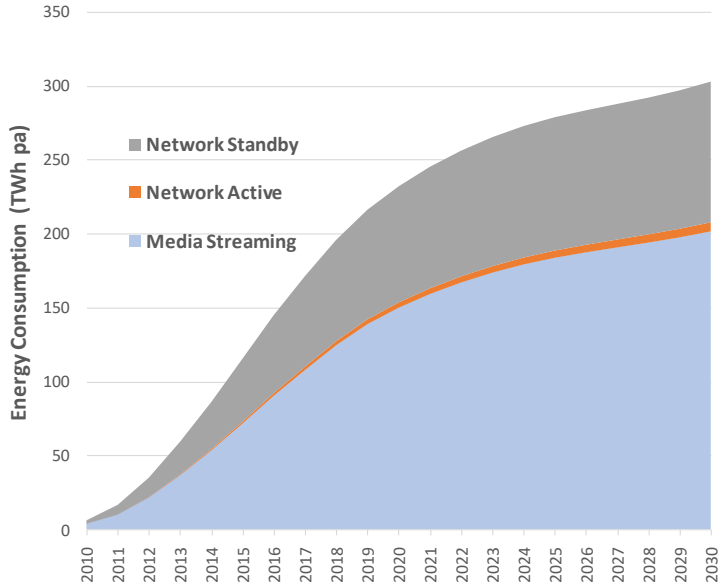

Figure 4: The entertainment category - Device energy consumption globally by condition (Network standby, network active, and media streaming), (Ryan et al., 2020).

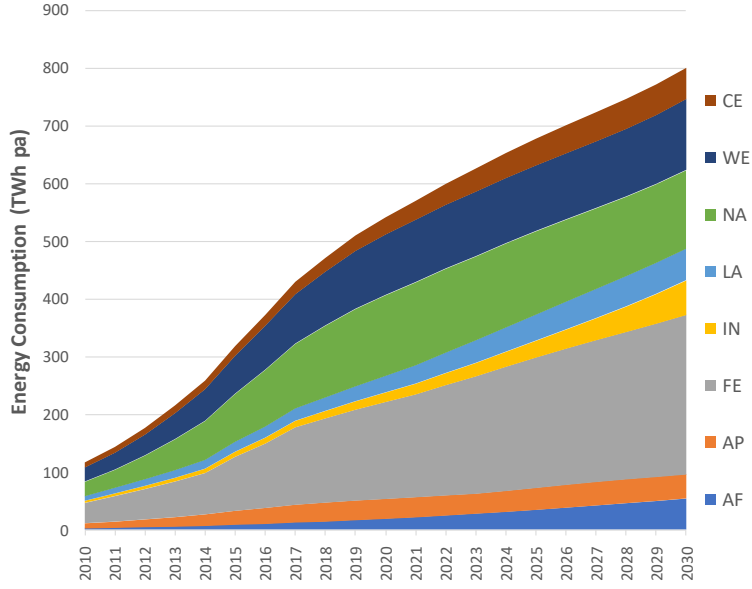

Figure 5: Total energy consumption of connected edge device by region, per year (Ryan et al., 2020).

5. SUMMARY

EDNA´s Total Energy Model (TEM) helps identify emerging issues associated with network connected devices, estimating the additional energy use at device level, but also upstream in the communication network. As the number of network connected devices continues to grow, policy makers need to evaluate and implement effective energy policies. The TEM can guide decision-making towards reducing the energy impacts of connected products, e.g., by evaluating the effects of policy measures on network standby and/or on energy demand from streaming media.

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