



SMALL NETWORK EQUIPMENT: CONSIDERATIONS FOR ENERGY EFFICIENCY POLICY

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1 EXECUTIVE SUMMARY

The energy use of small network equipment (SNE) – network equipment typically used in the residential and small commercial sectors – will continue to grow as consumers connect more products to the Internet and demand more data and information from them. Energy efficiency in SNE, however, remains a secondary factor in manufacturer design and consumer purchasing decisions, which tend to focus primarily on performance. Energy efficiency policy may provide the necessary incentive for the development of more efficient SNE products.

This project lays a foundation for future policy making to improve SNE energy efficiency. We develop a product categorization system for SNE based on product functions, analyze available data to estimate relationships between product functions or component characteristics and power draw, review energy savings strategies and the barriers that may be preventing their implementation, and discuss policy considerations and approaches.

We find that groups of SNE products that perform similar functions can draw a wide range of power. This indicates that some products may be performing more efficiently than others, and that energy efficiency policies may encourage the market to shift to more efficient designs. We estimate that SNE currently consume 120 TWh per year globally. Through power scaling and efficiency improvements, SNE energy use may be decreased by 20 to 50%.

Current voluntary measures to improve energy efficiency are likely too complex to be used in crafting and enforcing policy. We review the elements necessary for SNE efficiency policy, including metrics and policy structure, and approaches that could lead to successful policy implementation. Policy approaches such as minimum energy performance standards (MEPS) and energy labeling can be implemented with varying degrees of complexity and stringency, and therefore varying degrees of development effort for policy makers. Creative approaches, such as a combination of MEPS and labeling, may yield better results than MEPS alone.

2 INTRODUCTION AND MOTIVATION

In the landscape of consumer electronics, network equipment has a unique role of facilitating data transfer between products and services. As the adoption of network connected end user products continues to grow, and as those products consume and produce more data, the demands on network equipment will increase. Consumers demand ever faster data rates and improved wireless range lead to more functionality in network equipment, which in turn leads to increased energy use. This increased functionality and energy use warrants an examination of the energy savings potential of network equipment, and the potential role for energy efficiency policy to realize energy savings.

This project examines small network equipment (SNE), which is network equipment used in residential and small commercial applications, and how energy efficiency policy can be structured to encourage energy savings. SNE is not currently covered by government efficiency policies, with the exception of the EU Ecodesign regulation. Industry-led voluntary measures to improve energy efficiency are in place in two major economies. In the EU, the Code of Conduct for Broadband Equipment (CoC) covers SNE as well as upstream network equipment (Bertoldi and Lejeune 2020). In the U.S. and Canada, the Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of SNE (VA) has been in place since 2015 and 2020, respectively (SNE VA Signatories 2020). These voluntary measures establish SNE product categories based on functions of and components within a SNE product. They establish maximum idle power targets based on product type, network functions and components (such as network interfaces), as well as non-network functions. The VA requires annual data reporting and is one data source examined in this project.

In this report, we investigate key elements of potential policy, including SNE product categorization and policy approaches. We analyze available data to characterize power draw of SNE products currently on the market, and identify data gaps that may need to be filled as policy is developed. In the sections below, we first review and categorize SNE products based on functions and the components that provide the functions. Next, we analyze the available data to identify relationships between product categories and power draw. We discuss energy savings strategies and estimate the energy savings potential of SNE in major economies. We end with a discussion of data gaps and policy approaches.

3 OVERVIEW AND CATEGORIZATION OF SNE DEVICES

Network equipment is a broad range of products whose main purpose is to pass data traffic within a network and, in some cases, provide that network (Harrington and Nordman 2014, Lanzisera et al. 2010). SNE is the specific group of network equipment used in homes and small businesses, on what is often called the “edge” of the network.¹ The reader may be familiar with common SNE products such as modems, firewalls, routers, and access points.

An SNE product offers one or more *functions* – actions or services – to the user. These functions are provided by *components*, which are discrete hardware within the product (e.g., Harrington and Nordman 2014), and the related software that controls and orchestrates component operation. The components and software impact product power draw (e.g., EDNA 2018). Given that power is impacted by components and software, which are used to deliver the function of a product, we develop a tiered categorization for SNE: a primary categorization based on functions, and a secondary one based on characteristics of the components and software used to provide the given functions.

In this section, we review the main functions of SNE products and outline a primary categorization based on those functions. We next discuss the components that provide the SNE functions, and the characteristics of the components and software that impact power draw. Lastly, we outline component characteristics that can be identified from product specifications, such as network protocols and the number of ports or radios, that are a useful basis for secondary classification.

3.1 Product overview and main functions

An SNE product provides one or both of two main functions on the edge of the network: (1) receiving and sending data from or to an external wide area network (WAN, e.g., the Internet or the cloud) and (2) moving data within a local area network (LAN) to end user products such as computers, appliances, or mobile devices (Figure 1).²

Broadband access equipment provides the first function listed above; it allows consumers to access high-speed data services to a service provider’s wired, wireless or optical network. The defining function of broadband access equipment is that of a modem: receiving and demodulating analog signals from, and modulating and sending signals to the broadband service provider network. SNE that performs only this function are **modems**. We refer to SNE that provide additional functions, such as telephone interfaces or LAN-related functions (discussed in the next paragraph) as **integrated access devices (IADs)**, following the

¹ More specific definitions of SNE include that of the U.S. ENERGY STAR program, which defines SNE as network equipment that operates on “small networks or a subset of a large network,” including any with “integral wireless capability” or stationary equipment with 11 wired network ports or less for use outside of data center equipment racks (U.S. EPA 2014).

² For a more detailed illustration, see Harrington and Nordman (2014).

terminology of ENERGY STAR (U.S. EPA 2013). A number of other names are used for IADs or a subset of them, including home gateway, broadband gateway, or modem-router. Market research suggests that sales of broadband access equipment is flat or growing slowly in North America (CA IOUs 2020) and we expect that these trends apply to other economies in which a large fraction of the residential sector has broadband access.

LAN equipment includes SNE devices that do not have a direct interface to a service provider. Rather, the defining function of these products is to move traffic between products within a LAN (Figure 1). Common LAN equipment includes routers, access points, and switches, and newer-to-market equipment such as Wi-Fi mesh systems (multi-component products that improve Wi-Fi coverage by establishing and maintaining a mesh network), and smart home or IoT gateways (a type of proprietary LAN equipment that connects consumer end products like light bulbs or home security systems to the LAN). Market research estimates growth in LAN equipment, particularly in Wi-Fi mesh systems, as consumers seek to improve access throughout their homes (CA IOUs 2020).

The term “gateway” can cause confusion in SNE product terminology. Generically, a gateway is any type of SNE product that links two networks. A “home gateway” is a broadband access product that links a WAN and a LAN. The terms “IoT gateway” or “smart home gateway” are used to describe a LAN device that links two LANs. A home security system, for example, may include an IoT gateway that connects a LAN of the security system to the broader LAN within the home.

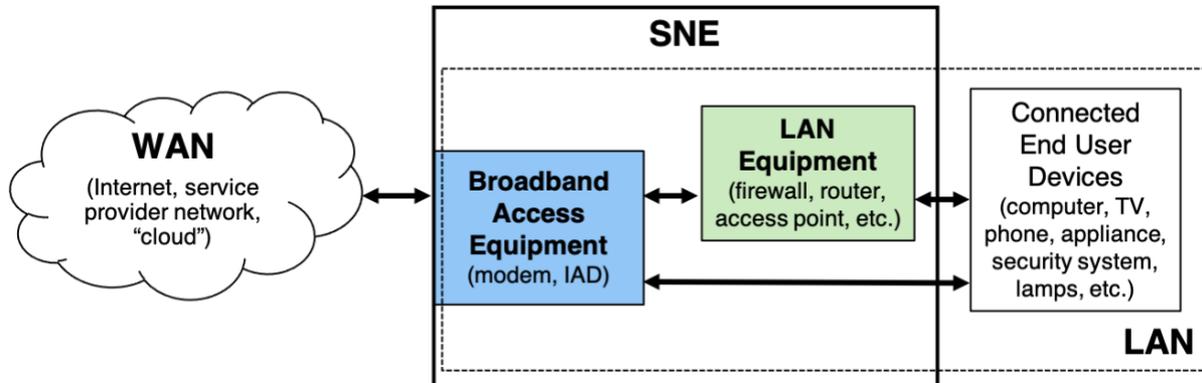


Figure 1: Project scope (within solid black box) in relation to broader networks (WANs) and local networks (LAN).

3.2 Primary categorization by function

At the highest level of the categorization, we segment SNE products into the two functional categories introduced above: broadband access equipment and LAN equipment. Broadband access equipment is further segmented into modems and IADs based on the absence or presence of LAN-related functions (Table 1). LAN equipment is segmented by how it moves

data on the LAN and the associated sophistication of the device. These categories are related to the functional layers on which products operate within OSI model network topology. Processing requirements (and therefore, in theory, power requirements) increase with layer (Fraunhofer IZM 2019).

Layer 1 LAN equipment includes simple products that provide functions associated with OSI layer 1, using the physical layer to transmit data traffic as simple bits. These devices do not perform any data processing and therefore should require the least amount of power of the LAN equipment products (Pearson 2002). Examples of layer 1 LAN products include hubs and range extenders.

Layer 2 LAN equipment includes products that provide functions that reside on layer 1 and 2 of the OSI model. They operate on the data link layer to transmit frames of data to MAC address, and may multiplex data streams, detect data frames, and allow medium access and error control (Garg 2007). Prevalent examples include access points and switches.

Layer 3 LAN equipment can provide functions associated with OSI layer 3 and below. These products operate on the network layer to move data packets across the network using the most appropriate paths. They also address messages and translate logical addresses into physical addresses. A router is a common type of layer 3 device.

Layer 4+ LAN equipment utilizes higher OSI model layers and levels of processing to provide more security or additional intelligence to the act of passing network traffic. This category includes firewalls, which scan for and eliminate unauthorized or malignant data (Lanzisera et al. 2010).

Table 1: Function-based SNE categorization

Type	Category	Function	Product Examples
Broadband Access Equipment	Modem	Receiving/sending and demodulating/modulating analog signals from/to the broadband service provider network	Modem
	IAD	Modem plus additional function(s)	Home gateway Modem-router
LAN Equipment	Layer 1	Transmit bits	Hub Range extender
	Layer 2	Transport frames containing physical addressing	Some switches Access point Bridge
	Layer 3	Transport packets containing IP addresses	Router

Type	Category	Function	Product Examples
			Some switches
	Layer 4+	Security or other advanced functions	Firewall

This approach is similar to other classification schemes for SNE. The VA, for example, splits LAN equipment into two categories based on a similar criteria; “basic” products with low data processing needs that operate on OSI model layer 1, and “advanced” products that include routers, access points, and VoIP-capable devices associated with OSI model layers 2 and up (SNE VA Signatories 2020).

3.3 Components that provide SNE functions

As the data will show in Section 4, the function-based categories segment SNE products into groups that show wide ranges of power draw. To develop a meaningful categorization, characteristics that impact SNE power draw must be included. These characteristics are related to the components and software that SNE products use to implement network-related and other functions. For the purposes of this discussion, we group the common components of SNE products into the three types below.

All broadband access equipment (modems and IADs) contain at least one **WAN interface**, which is a physical connection point that provides access to the Internet service provider’s wired, wireless, or optical broadband network using an appropriate communication protocol. The type of WAN interface used in a product depends on the data transmission medium. DSL and DOCSIS interfaces transmit data over phone lines and coaxial cables respectively; optical network interfaces transmit data over fiber optic cables; cellular interfaces enable wireless broadband access.

All LAN and broadband access equipment contain one or more **LAN interfaces**, which are physical connection points that allow end user devices such as computers, printers or TVs within a building to connect to one another and share data. LAN equipment and IADs may have multiple wired (e.g. Ethernet or USB) and wireless LAN interfaces (e.g. Wi-Fi, Bluetooth, Zigbee) (Fraunhofer IZM 2019). Modems contain only wired LAN interfaces.

WAN and LAN interfaces – collectively referred to as network interfaces – are designed to transmit data using a network protocol: a set of rules that determines the format, speed, and other properties of the data transferred. These factors can impact SNE power requirements; faster data transfer rates may require more power. Wireless data transfer generally requires more power than wired transfer. New versions of a network protocol are progressively added to enable improvements such as faster data rates or improved security. Common protocols and current versions are listed in Table 2.

SNE products also require **central components** such as processors, network controllers, memory, and power supplies, to provide supporting functions (Fraunhofer IZM 2019). The capability or capacity of the central components is determined in part by the network functionality. A more function-rich product will include more processing and memory capacity than a simple product, for example.

Table 2: Common protocols utilized by SNE interfaces

Component type		Common or current versions & protocols
WAN interface	DSL	ADSL VDSL VDSL2 Collectively, xDSL
	Cable	DOCSIS 3.0 DOCSIS 3.1
	Fiber optic	GPON EPON
	Cellular	LTE 4G LTE 5G
LAN interface	Ethernet	IEEE 802.3bx (10/100/1000 Mbps) IEEE 802.3bz (2.5 & 5 Gbps) IEEE 802.3ae (10 Gbps)
	Wi-Fi	IEEE 802.11n IEEE 802.11ac IEEE 802.11ax
	Low speed wireless*	IEEE 802.15.4 (Zigbee) Bluetooth Bluetooth Low Energy (LE)
	USB	2.0 3.0 3.1
	MoCA	2.0 2.5
	Powerline	G.hn HPNA
* Maximum bandwidth of current low speed wireless protocols is 2 Mbps (Bluetooth).		

A given SNE product possesses central components and any variety of network interfaces. The number and types of components and their characteristics depend on the network functions of a given device. Figure 2 illustrates common components within SNE products. All SNE products include the central components shown in the center of the figure. Broadband access equipment include at least one WAN interface such as those listed on the left side of the figure. LAN equipment and IADs contain at least one LAN interface (right), but

can include several types and/or several interfaces of a certain type depending on the functionality of a given device. An access point, for example, which connects end-user devices on a wireless LAN to a wired network, contains a number of wireless LAN interfaces (e.g., Wi-Fi), a wired interface (e.g., Ethernet), and central components; it does not contain any WAN interfaces. A modem, on the other hand, contains a WAN interface and central components.

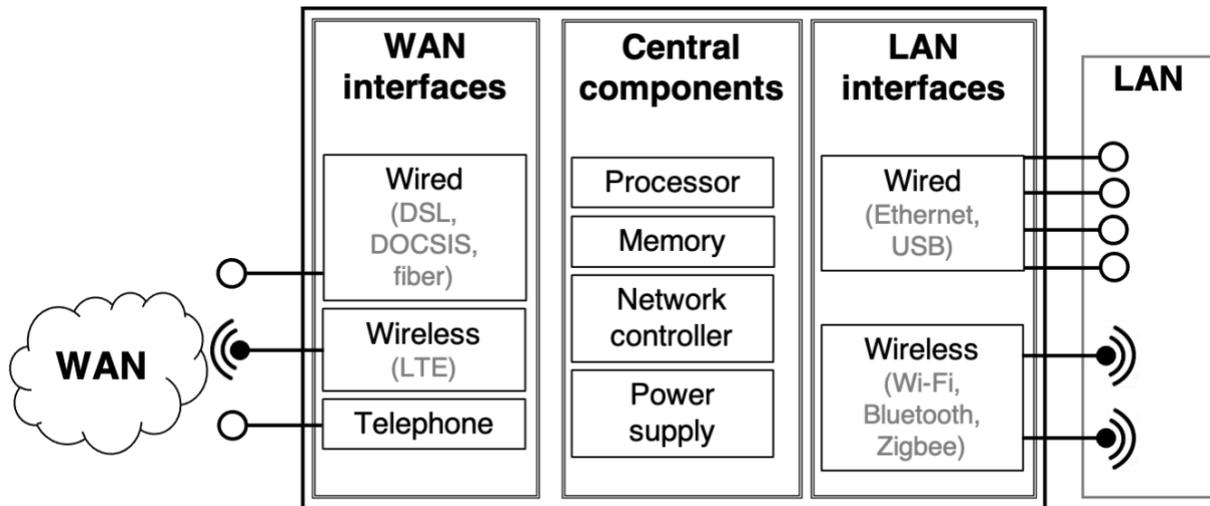


Figure 2: Main components in SNE products. All SNE contain central components. Broadband access equipment contains WAN, and in some cases LAN, interfaces. LAN equipment contain LAN interfaces. Adapted from Fraunhofer IZM (2019).

SNE products can provide additional functions that are not directly related to moving data on a WAN or LAN. For example, a recent addition to the market are products that incorporate SNE functionality into other product form factors, such as an LED bulb with an integrated access point.³ These products possess components that provide network functions, as well as additional components to provide the non-network functions. The LED bulb with access point example would contain a wireless network interface to provide its network functions and an LED and LED driver to provide the lighting function. In these types of products, central components may be dedicated to a certain function, such as a dedicated network processor, or shared by functions, such as power supply. The principles described in this report apply to the network-related functions and components of such products, however the non-network components and increased capacity of shared components are beyond the scope of this discussion.

³ See, for example: <http://xy-connect.com/en/>

3.4 Secondary categorization by component characteristics

Because the functions delivered by a SNE product determines component and software choices, and those in turn impact product power, the SNE categorization developed here includes a secondary layer based on component characteristics.⁴ Based on previous EDNA research (EDNA 2018), we outline three such characteristics that likely influence the power draw of SNE devices (Figure 3).

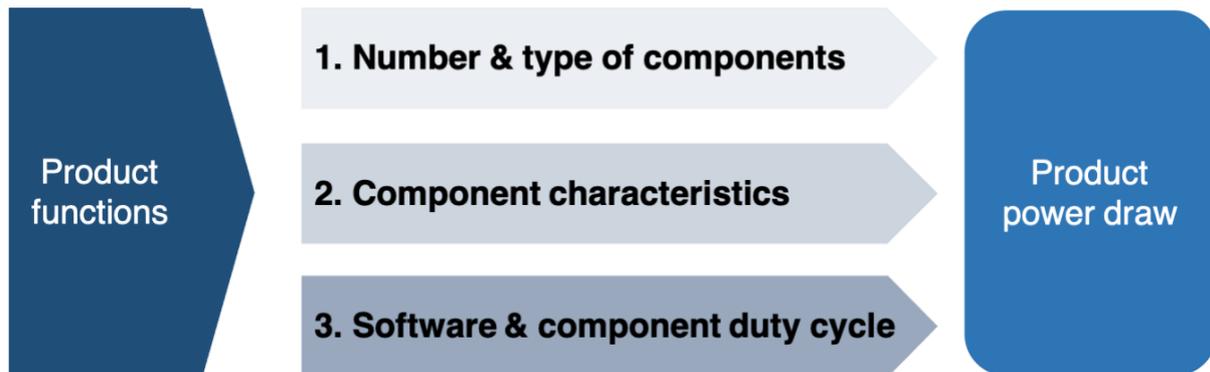


Figure 3: Component characteristics that impact SNE product power draw. A given product's functions drive design choices that includes the selection and implementation of components and software, which impact whole-product power draw.

Number and type of components. A product's functions determine the number and type of components needed. Of particular importance are the network interfaces; as shown in Section 4, network interface type impacts product power draw. The more interfaces a product contains, the more power it is expected to draw.

Component characteristics. Key characteristics of components influence functionality and likely the power draw of products. Focusing on network interfaces, such characteristics include bandwidth (the maximum data transfer rate of an interface) and network protocol. For wireless interfaces, transmit power and the number of antennas are also important characteristics (Ayre et al. 2021, Gray 2021). Products with higher bandwidth, greater transmit power, and more antennas will, in theory, draw more power. Wired types of interfaces, which move data along a cable, should draw less power than most wireless interfaces, which require power to broadcast signals over an acceptable distance like a house.⁵ Other characteristics are inherent to the component itself, such as its efficiency in delivering its function. Product power draw can be reduced by using efficient components.

⁴ In the remainder of this discussion, we use the term component characteristics to include both the hardware and software.

⁵ Low speed, low power wireless technologies like Zigbee, Z-wave, and Bluetooth Low Energy may draw lower power than high speed wired interfaces like Ethernet, but are designed for use for much lower data traffic applications.

Software and component duty cycle. The power of a component with any given set of characteristics depends on its duty cycle – the time spent in its various operating states – which is controlled by software. A component that only utilizes its higher power states will draw more power than a comparable component that utilizes lower power states when its function is not needed. Software can enable such power scaling, which is an important energy savings strategy that scales power to the work being done and powers down unused components (Section 5.1).

Of the many factors potentially impact power of SNE products, which should be used in a categorization scheme? In reality, software and component duty cycles are difficult if not impossible to discern from product inspection or specifications, and therefore are not useful for categorization. Factors that are easily identified and therefore useful for categorizing SNE include the types of components, particularly network interfaces, the number of components of a particular type, and bandwidth (EDNA 2018). Network protocols apply to a specific type of network interface and determines bandwidth. Therefore, network protocol can be used in the categorization as a proxy for interface type and bandwidth. For products with wireless network interfaces, the transmit power is a significant power impact (Ayre et al. 2021, Gray 2021).

In summary, the SNE classification described here based on first functions, then component characteristics. The function segmentation in Table 1 forms the primary level of categorization. Secondary categorization is based on network protocol (Table 2) and, for products with wireless network connectivity, potentially radio transmit power.

A categorization scheme based on network protocol faces one complication: many SNE products utilize more than one network protocol. Although most broadband access equipment contains only one WAN interface type, IADs and LAN equipment can contain many types of LAN interfaces. The categorization may therefore group products based on the combination of protocols used. The VA addresses this issue differently; broadband access equipment categories are based on WAN protocol, whereas LAN equipment categories are based on function, and LAN interfaces are addressed with adders rather than specific categories. The granularity of the categorization, particularly related to LAN protocols, is thus an important policy decision, discussed in Section 6.

4 ANALYSIS OF SNE POWER DRAW

In this section, we analyze existing SNE power data to better understand relationships between power draw and functions or component characteristics.

4.1 Dataset background and methodology

We leverage four datasets in this analysis, each which contains idle power measurements⁶ for a range of SNE products. Due to the rapid pace of change in SNE products, we focus on test data from the past five years to include the most up-to-date information possible. The datasets include:

- **C't:** c't Magazin is a German magazine and website geared towards tech-savvy consumers. It offers a range of content on electronic products, including reviews and tests, some of which contain idle power measurements. We collected about 120 reviews that included idle power measurements from 2016 to 2020 and recorded product characteristics such as WAN interface type and number, and LAN interface bandwidth.
- **Dangl:** This dataset was collected by Georg Dangl with support from EDNA (Dangl 2019). It includes idle power measurements of three IADs and six IoT gateways. The year of first release of the products ranges from 2013 to 2018. Each product was tested up to five times, each test with a different combination of connected network interfaces.
- **NRCan:** Similar to the Dangl dataset, this data collected by Natural Resources Canada (NRCan) includes multiple tests per product, with different network interface connections. It contains test results for six modems, four IADs, ten routers, and four smart home gateways.
- **U.S. VA:** Internet service providers and manufacturers that participate in the VA are required to report idle power and the characteristics of the product that determine its power allowance, including product category, WAN interface number and type, and LAN interface number and type. We gathered the data reported in the U.S. for 2016 through 2019.⁷ After duplicate data points were removed the dataset contained about 400 data points. U.S. VA participant shipments are estimated to represent about 80% of broadband access equipment and no more than 50% of LAN equipment in the U.S. (CA IOUs 2020).

In the discussion below, the datasets are referred to by their names in bold above. Note that all power measurements available are idle power measurements in which little or no data traffic is moved during the test. We did not have access to any data of SNE products tested under non-idle conditions.⁸

Based on the information available in the data sets, we examine the following questions:

1. For each function-based primary category, what range of power do products draw?
2. How do network components (WAN and LAN interfaces) impact power draw?
3. How do certain characteristics of WAN and LAN interfaces, such as number of interfaces, maximum data transfer rate, or number of Wi-Fi radios impact power draw?
4. Do SNE products employ power scaling to power down components when they are not needed?

⁶ SNE is most commonly tested in a low-traffic “idle” state, in which no user-generated traffic exists on the network.

⁷ U.S. data for 2020 was not available at the time of our analysis. Note that the Canadian VA was established in 2020 and reporting data is not yet available.

⁸ One of the tests required by the CoC is a fully-loaded condition, where all interfaces are tested at maximum data rates. The CoC data, however, is not publicly available and we were unable to obtain it.

To examine question 1, we segment the c't and U.S. VA datasets into function-based product categories and plot the range of power draw for each category. To examine question 2, we further segment broadband access equipment by WAN interface type, and LAN equipment by LAN interface type. We perform simple and multiple linear regression analyses to address question 3, which estimate the predictive value of SNE characteristics (e.g., primary category, network interface type, number of interfaces, maximum data transfer rate, number of Wi-Fi radios) on power draw. To answer the final question, we analyze the incremental power of network interfaces using the Dangl and NRCan datasets.

We find that large spread in power draw of SNE products exists, even when comparing products within a function-based category with similar component-level factors. This finding suggests that some products are more efficient than others of comparable functionality, indicating that energy efficiency policy can play a role in reducing energy use of less efficient products.

4.2 Power draw of function-based categories

We first examine idle power for the function-based product categories outlined in Table 1. Broadband access equipment shows a wide range in idle power, from 3 to 28 W (Figure 4). The small number of modems in the datasets (n=32) draw 4 to 12 W. Many IADs, which have modem and any number of additional functions (mainly LAN interfaces and phone functions) draw power that is comparable to modems, but some IADs draw significantly more.

LAN equipment similarly shows a wide spread in idle power (Figure 4). We segment Wi-Fi mesh systems, which consist of a base unit with router (level 3) functions and one or two satellite units with access point (level 2 or 3) functions, into additional categories depending on the number of units in the mesh system.⁹ Although the data shows a general trend of higher functioning products drawing more power, broad spread within product categories exist. As previously noted, the VA segments LAN equipment into two categories, equivalent to level 1 and level 2 and above. The U.S. VA data shows similarly broad spread in power for level 1 products: 0.4 to 8 W for level 1 LAN products, and 0.7 to 18 W for level 2 and level 3 equipment. It does not include any mesh systems.

⁹ Mesh system power is the sum of the power of each unit.

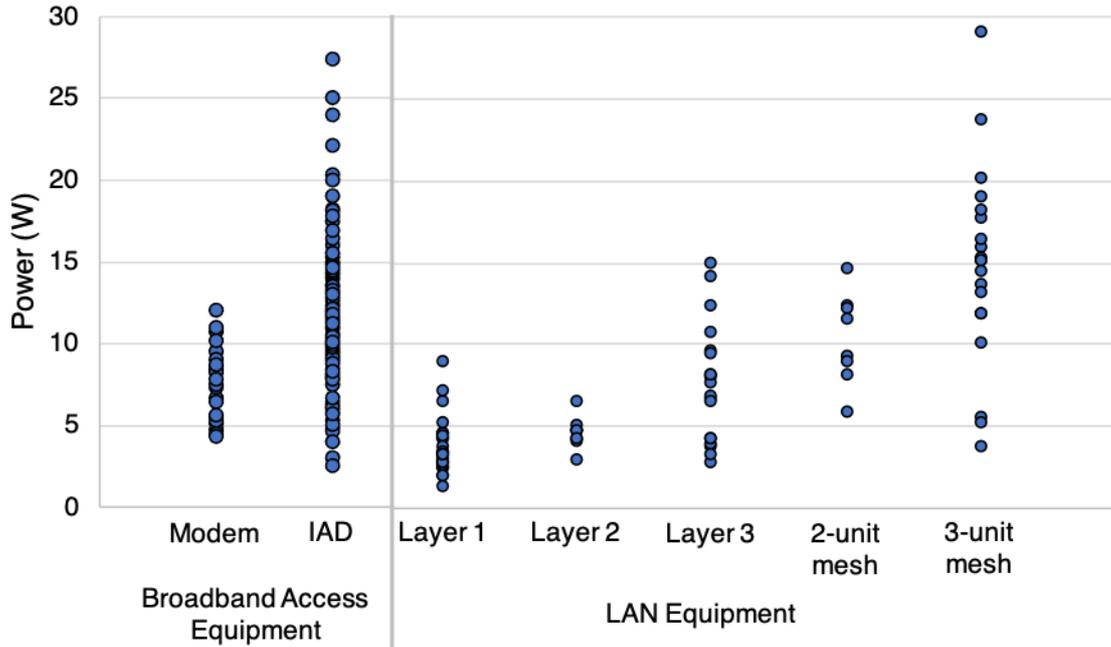


Figure 4: SNE idle power for function-based product categories. Broadband access equipment categories include data from c’t and U.S. VA datasets. LAN equipment categories include data from c’t dataset.

4.3 Impact of network-related components

We expect that some WAN interfaces require more power than others; power depends on the medium (e.g., copper, fiber, air) over which data is transmitted. Segmenting by WAN interface type, however, still shows a wide spread in idle power, particularly for xDSL and DOCSIS equipment (Figure 5). WAN interface categories show at least a 2x and at most a 5x spread in power between the lowest and highest power products in the group. For IADs, additional LAN functions can explain some of the spread, which may also be a result of some products containing more efficient components than others or utilizing power scaling strategies.

Most of the LAN equipment in the datasets contain both wired Ethernet and wireless Wi-Fi interfaces, and show wide spread in power draw within function-based product categories (Figure 6). The data hints that increasing product functionality increases power draw, however some level 3 products use less power than some level 1 products.

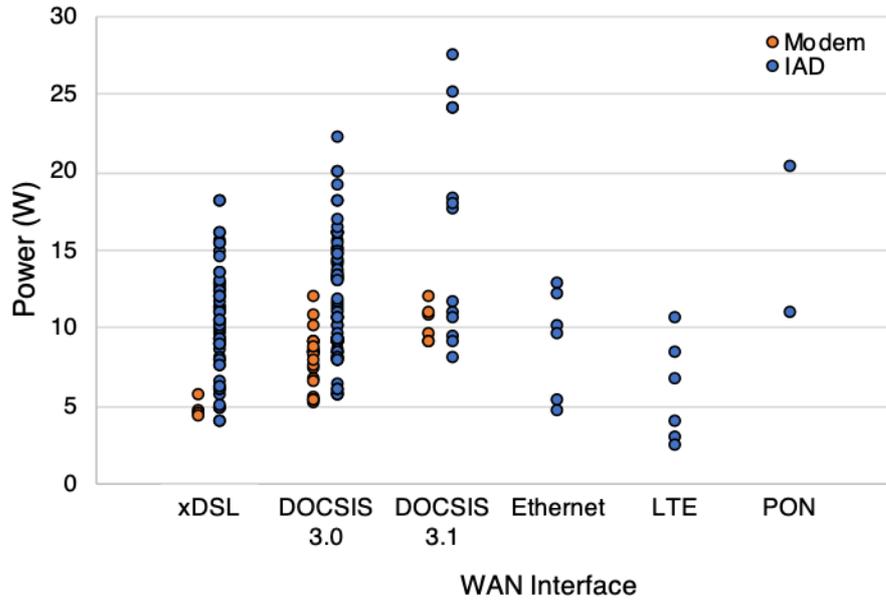


Figure 5: Idle power for broadband access equipment by WAN interface type. Data is from c’t and VA datasets.

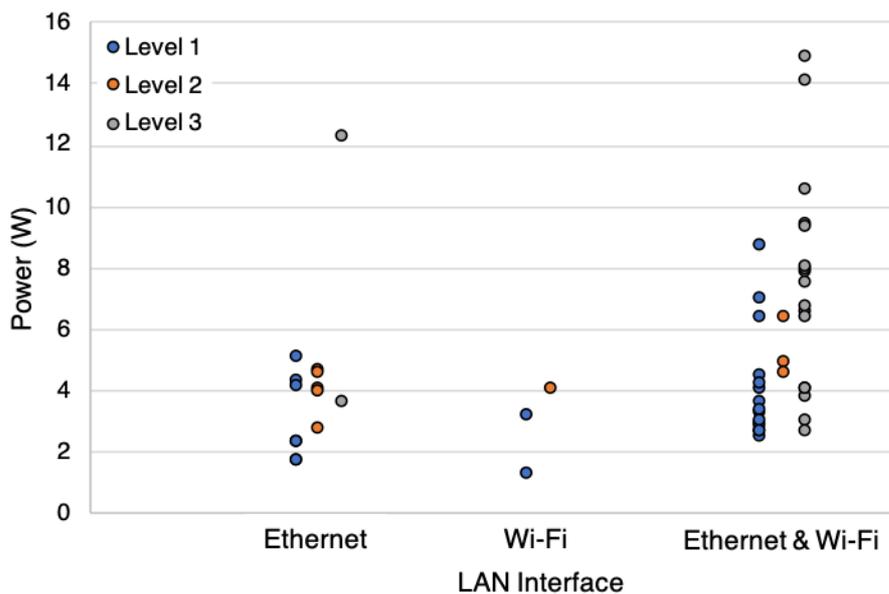


Figure 6: LAN equipment idle power by LAN interface type and subcategory. Data from c’t dataset.

4.4 Impact of component characteristics

We next analyze the available component characteristics for models in the c’t and U.S. VA datasets to determine which characteristics show a strong relationship to power draw. Figure 7, Figure 8, and Figure 9 show component characteristics that appear to have some

relationship to power: the number of Ethernet ports, maximum Wi-Fi data rate, and the number of Wi-Fi radios, respectively. Although linear regression analysis of the data yield low correlation and therefore low predictive value of a linear relationship between the function capacity and power, visual inspection of the data suggests a trend toward higher power with increased capacity of the component factor in question. For example, products with more Ethernet ports generally to draw more power than products with fewer ports (Figure 7). Similarly, products that have the capacity to transmit more data tend to draw more power than products that have lower data capacity (Figure 8), and products that contain more Wi-Fi radios trend toward higher power than products with fewer radios (Figure 9).

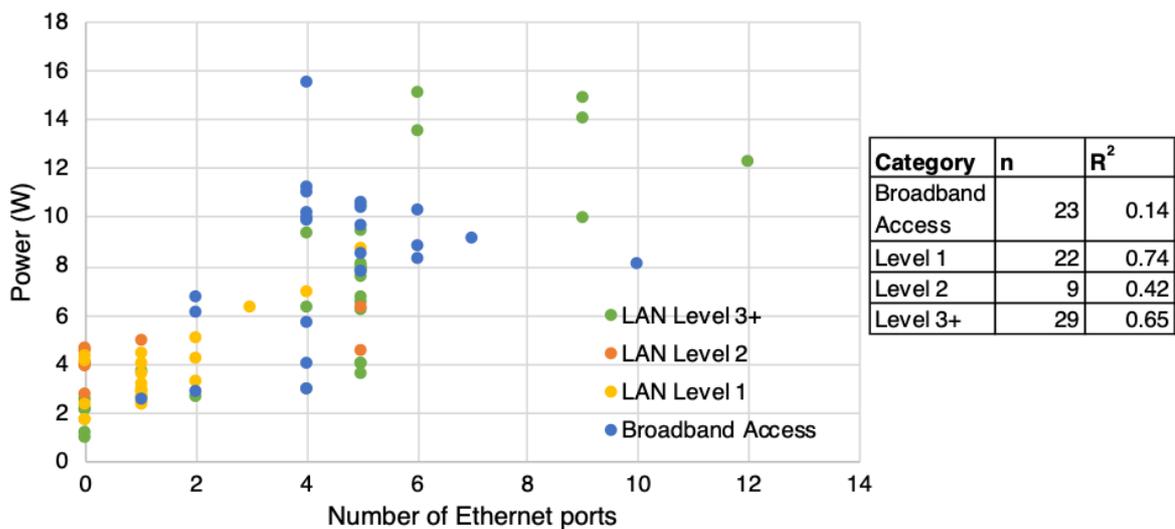


Figure 7: Power versus number of Ethernet ports by product category and simple linear regression results. Data from c't dataset.

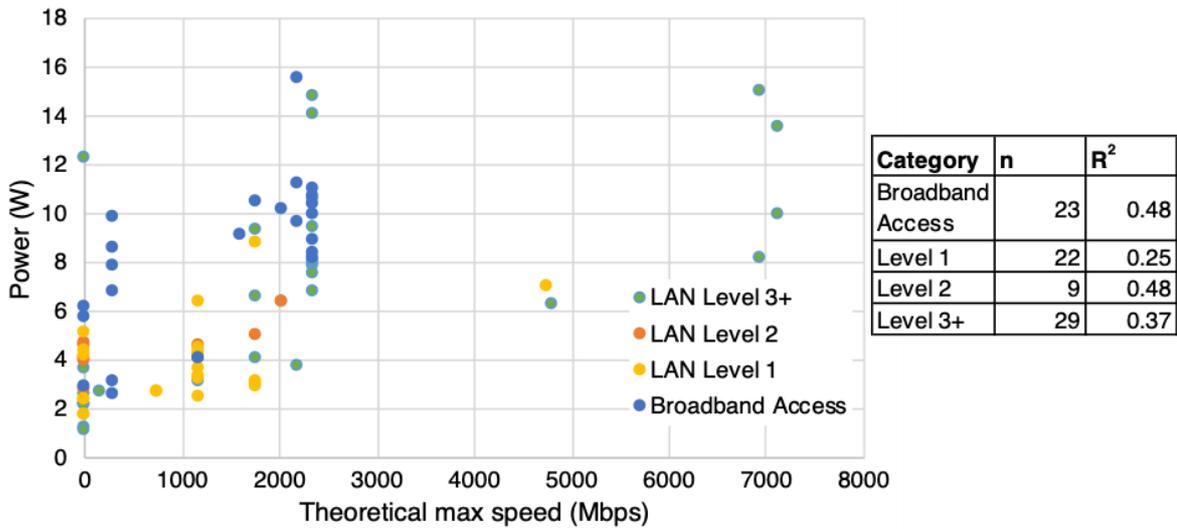


Figure 8: Power versus theoretical maximum Wi-Fi speed by product category and simple linear regression results. Data from c't dataset.

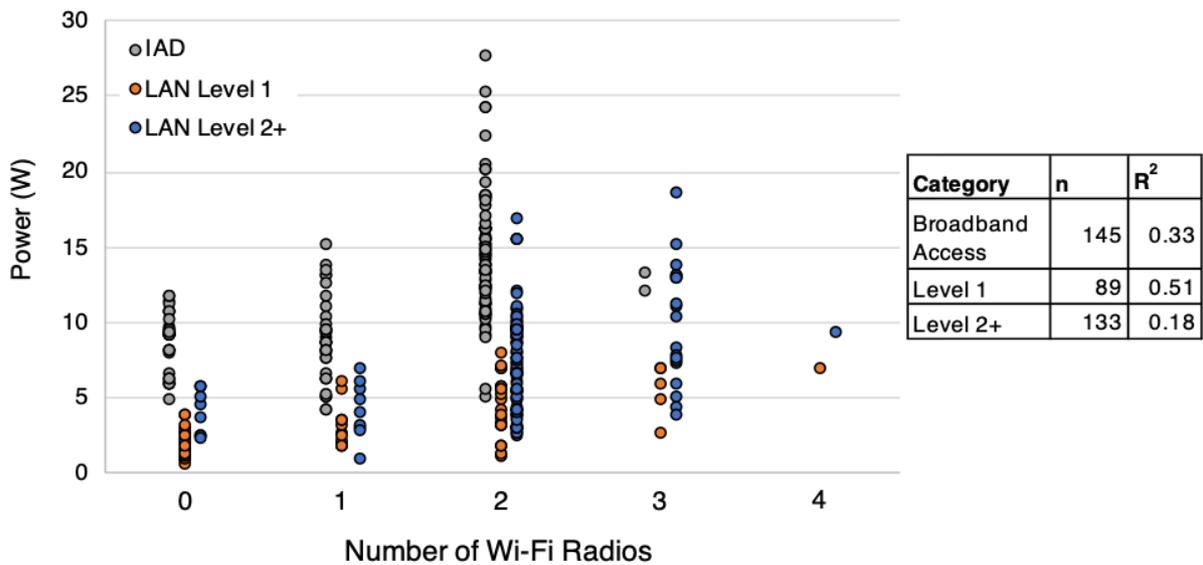


Figure 9: Power versus number of Wi-Fi radios by product category and simple linear regression results. Data from U.S. VA dataset.

Given that any SNE product can contain a number of component characteristics that may impact its power draw, perhaps the lack of correlation between one function and power is not surprising. Attempting to better identify power and component characteristics, we perform multiple variable regression analyses on the U.S. VA dataset, segmented by product type, to determine whether multiple characteristics of a product can predict whole product power draw (more details in the Appendix). The analysis shows significant correlation (p-value < 0.01) of some functions, particularly the number and type of Wi-Fi

interfaces, to power. The analysis yields a moderate predictive ability to estimate power from multiple characteristics together, with adjusted R^2 values ranging from 0.63 to 0.81 for our various analyses. In other words, a relationship between some component characteristics and power does exist, and relationship describes some but not all of the variation in the datasets. This finding leads us to conclude that additional factors, which could include power scaling, component choice, and other product characteristics, may have considerable impact on whole-product power. This suggests that policies that encourage efficient components and design strategies in SNE products may have significant energy savings potential.

4.5 Power scaling

To investigate whether SNE products employ power scaling to power down unused components, we examine datasets that include multiple tests on a given product, each with different interfaces connected. Both the NRCan and Dangi studies conducted such tests. As in the c't and U.S. VA datasets, the data show wide spread in power for products of similar functionality. In addition, the data shows little power variation when different interfaces are connected. Figure 10 shows power draw data for 13 modems and IADs under a variety of tests with the following connected interfaces:

- no network interfaces (all products),
- WAN interface (all products),
- WAN and wired LAN interface (all products)
- WAN and wireless LAN interface (IADs)
- WAN, wired LAN, and wireless interfaces (IADs)

One of two potential conclusions may be drawn from this finding: either the interfaces in question draw very little power (on the order of 1 W or less), or power draw of the interface varies little whether it is connected or not – that is, the product does not implement power scaling techniques that power down unused components.¹⁰ Previous research has arrived at the latter conclusion – that network interfaces tend to be in active state all the time, whether or not they are moving traffic or even connected (Ayre et al. 2021, Gray 2021). Reducing power to unused components, therefore, is a potential pathway to saving energy in SNE. This is discussed further in Section 5.1.

¹⁰ We use the term power scaling generically for any strategy that scales whole-product or component power to the work output (e.g., data rate) of the device, following Harrington and Nordman (2014).

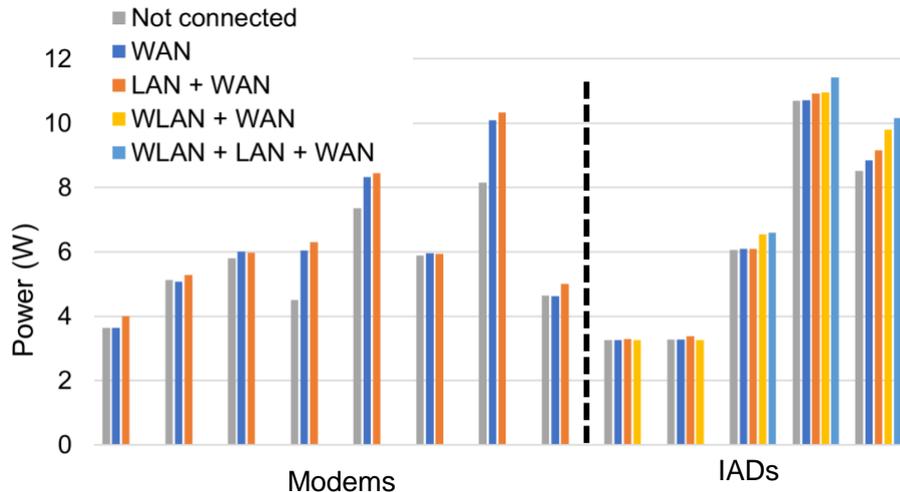


Figure 10: Idle power measurements of modems and IADs tested with various interfaces connected. Data from NRCan and Dangi datasets. Note that LAN indicates wired LAN (Ethernet) and WLAN indicates wireless LAN (Wi-Fi).

5 ENERGY SAVINGS POTENTIAL AND BARRIERS

In this section, we estimate the energy savings potential for SNE in the residential sector and identify the key barriers to achieving that potential. Numerous studies examine strategies to save energy in SNE. The magnitude of the savings and the practical steps needed to achieve the savings are discussed below.

5.1 SNE savings pathways

Pathways to improving the energy efficiency of SNE have been outlined by several researchers (e.g., Baliga et al. 2011, Dangi 2019, Gray 2018, Harrington and Nordman 2014, Hinton 2011, Lanzisera et al. 2010, Van Heddeghem et al. 2012, Vereecken et al. 2011), and include the following three strategies.

Powering down unused components. This includes powering down unconnected network interfaces, especially wired interfaces that can be designed to detect whether or not a cable is attached.

Adjusting processing power to data processing needs. Electronic circuits consume less power when operating at lower speeds; therefore energy consumption can be reduced by adjusting the speed at which the device operates to more closely match the data needs (Harrington and Nordman 2014, Hinton et al. 2011). Connected network interfaces and central components should use strategies to scale their power to the data processing or traffic load, such as Energy Efficient Ethernet (EEE) for Ethernet interfaces. This power scaling strategy is often referred to rate adaptation. Research shows that SNE devices do

not implement aggressive power scaling, and can consume up to 85% of their maximum power draw when in idle state (Fiandrino et al. 2017; Gray 2018, Mahadevan et al. 2009).

Increase efficiency of hardware components: Finally, energy efficiency of SNE can be improved by using more efficient components. This includes using power supplies that are efficient at maximum and, if the product implements power scaling, low load points.

5.2 Savings potential

Previous studies estimate that the energy consumption of SNE devices can be reduced by 20 to 50%. The low end of the range assumes power supply efficiency improvements and implementing EEE (Lanzisera et al. 2010). The high end of the range estimates savings achieved via aggressive power scaling of network interfaces and other component (Lanzisera et al. 2010, Dangl 2019). Near-term savings potential may be estimated by identifying the most efficient products on the market, and assuming that all products adopt those power levels. An analysis of the U.S. VA data from 2018 suggests that SNE energy use could be reduced by approximately 15% if they adopt best-on-market efficiency (CA IOUs 2020). We apply the range of potential energy savings to the total energy use of residential SNE estimated by the EDNA total energy model version 2 (EDNA 2021) in major economies (Table 3). This yields a global estimated savings potential of 18 to 60 TWh per year after stock turnover.

Table 3. Estimated residential SNE energy use and potential savings by region in 2021

Region (defined in EDNA (2021) Appendix A)	Total Energy Use (TWh/yr)	Savings Potential Estimates (TWh/yr)		
		Best-on-market energy efficiency	Power supply efficiency & power scaling	
			Low	High
Far East and China	51	7.7	10	26
West Europe	17	2.6	3.5	8.7
North America	13	1.9	2.5	6.4
Latin America	9.5	1.4	1.9	4.8
Africa and Middle East	8.8	1.3	1.8	4.4
Central and Eastern Europe	8.7	1.3	1.7	4.4
Asia Pacific	6.2	0.9	1.2	3.1
Indian Subcontinent	4.4	0.7	0.9	2.2
Global	120	18	24	60

5.3 Barriers

Although strategies to improve energy efficiency of SNE have been known for more than a decade, it appears that little progress in implementing them has occurred. Studies have shown that SNE products generally not scale power with traffic (Gray 2018; Lanzisera et al. 2010). The data analysis above suggests that SNE products do not power down unused interfaces. One might therefore conclude that significant barriers exist to implementing these savings strategies. To understand these barriers, we reached out to several researchers (Ayre et al. 2021, Gray 2021) who highlighted the following issues:

- 1. Cost considerations.** Manufacturers face pressure to decrease product pricing over time and may be resistant to any design modifications that increase, or prevent them from decreasing, retail prices. If passed on to consumers, incremental cost of energy efficient designs are perceived to be challenging to recoup through energy cost savings because the per-product savings potential is low (on the order of 100s of kWh per year). However, some researchers argue that the assumption that energy efficient products are more expensive is flawed because more efficient products are often ones with higher performance which, rather than efficiency, increases cost (Siderius 2020).
- 2. Little perceived value of energy efficient choices in the market.** Although the U.S. ENERGY STAR specification for SNE has been in place since 2013, only two products are listed on the qualified products list today and the U.S. EPA has proposed to sunset the specification (U.S. EPA 2021). The lack of uptake of the specification suggests that manufacturers do not use energy efficiency in product marketing, and consumers likely consider factors other than efficiency, such as compatibility, speed and range, when purchasing SNE.
- 3. Resistance to change.** Manufacturers may be reluctant to change a product design that works. As noted by one researcher, a culture of “if it works, don’t change it” may characterize the industry (Ayre et al. 2021).
- 4. Product reliability and durability.** To be successful, power scaling strategies must not only power down components appropriately, but also return components to active states reliably and within acceptable latencies. Rather than risk the chance that components will not return to their proper state quickly enough, manufacturers generally choose not to power down components. Durability issues are also a concern. Products are generally designed to operate at constant temperature. Temperature fluctuations resulting from power scaling can result in cracked solder or componentry (Ayre et al. 2021).
- 5. Lack of incentives.** Energy savings must be considered early in the design of any product (EDNA 2019), and can involve significant time and cost that manufacturers have little incentive to invest in today (Ayre et al. 2021). Clear policy that sets

attainable but stringent expectations for energy savings can help provide that incentive.

6 CONSIDERATIONS FOR POLICY

Because SNE presents energy savings opportunities but a lack of incentives exist for manufacturers to adopt savings strategies, policy may play a role in improving energy efficiency. In this section we discuss considerations for crafting efficiency policy, including metrics, data gaps, and policy approaches.

6.1 Energy efficiency metrics

Any energy efficiency policy requires one or more metrics to evaluate whether or not products are meeting policy requirements. To identify possible metrics to evaluate SNE energy use, it is instructive to consider the power draw profile of SNE products and how the efficiency improvement strategies discussed in Section 5.1 modify that profile. In Figure 11, we plot the power draw of a generic SNE device against its traffic load (Gray 2018, Mahadevan et al. 2009). The power draw profile has two elements of interest: the power draw in idle state with no traffic, and a linear slope element that describes power draw as a function of traffic rate, or the degree to which the product uses power scaling (Gray 2018, Hinton and Jalali 2016). Policies should encourage both improved power scaling (a steeper slope in Figure 11) and increased component efficiency (lower power in Figure 11).

Proposed metrics that assess the energy efficiency of SNE products include the Energy Proportionality Index (EPI). EPI determines the difference between a product's measured power and the power it would draw if power was completely proportional to traffic rate (i.e., power is zero when traffic rate is zero) (Fiandrino et al. 2017, Mahadevan et al. 2009). An EPI of 100% represents a perfectly proportional device; an EPI of 0% indicates power draw does not vary with traffic rate. EPI is solely a measure of the degree to which a product scales power to traffic rate. It does not evaluate the efficiency of the product at one or more given traffic rates relative to an efficient product.

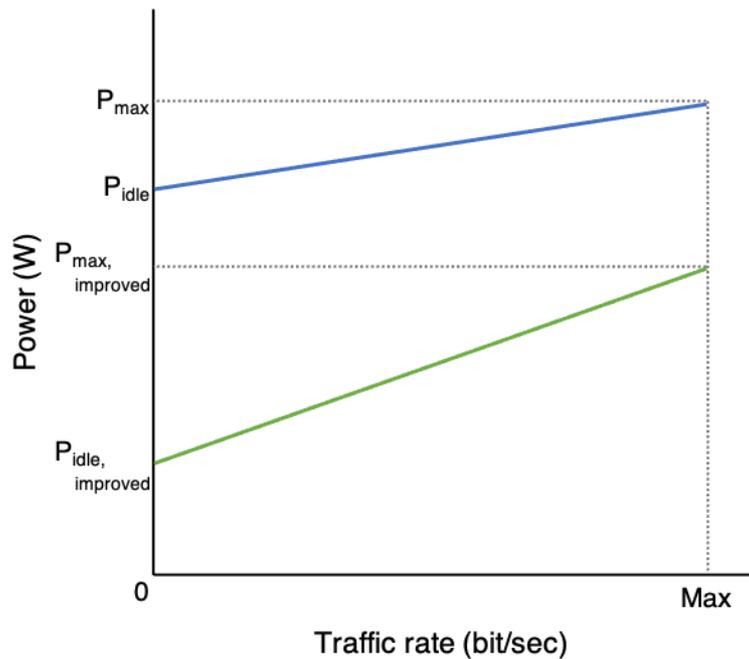


Figure 11: Generic SNE power draw profile (blue line) and improved profile as a result of power scaling and increased component efficiency (green line). Figure modified from Gray (2018).

To evaluate the efficiency of a product at a given traffic rate, policy makers must develop a metric that accounts for product functions and component characteristics. Examples of this type of metric include the power targets set by the CoC and VA. These power targets consist of a base allowance, assigned for function-based product categories, and adders for component characteristics like network interface type. The VA evaluates measured product idle state power relative to the sum of the base allowance and adders applicable to the product. The CoC takes a similar approach, but includes additional targets and measurements at low and maximum traffic rates. As an alternative to multiple targets at various traffic rates, Siderius (2021) proposes a single energy metric that accounts for power draw at various traffic rates with an assumed duty cycle. Policy makers should consider a similar type of approach; the key to using such an approach is developing the targets or reference products via a system of base allowances and adders based on product functions and component characteristics. The CoC and VA are complicated by a large number product categories and functional power adders. For policy making and compliance to be successful, a simpler system of base allowances and adders is desirable.

6.2 Data gaps

To develop a policy based with power or energy metrics described above, policy makers must group products of similar products into categories, and develop metrics to evaluate a product to others in its product category or to a reference or idealized product. In this project we outline a simple, function-based categorization (Section 3), but given our inability to explain the cause(s) of the wide spread of power within product categories, we cannot

conclude at this time whether or not the categorization has an appropriate degree of granularity on which to base policy. Categorization and metric setting will require additional data and research. Whole-product power measurements are useful to understand the power of the product and to estimate total energy use of products in a region or globally, but as we find in the analysis above, do not advance our understanding of how the total power is divided up amongst the components that provide the various functions in the product. Additional efforts to understand component- or function-level power requirements will be necessary to determine appropriate power targets based on the capabilities of any given SNE product.

Previous EDNA research on network standby provides a first estimate of power requirements for functions (EDNA 2018). The project developed power budget ranges for common network interfaces based on datasheet information of network components, plus associated processing and power conversion losses. This approach yields ranges of network function power requirements across several orders of magnitude, making it insufficient for use in predicting power draw based on component characteristics or establishing function-based power targets. Component-level power measurements remain a significant gap in understanding SNE and developing appropriate targets for energy efficiency policies.

Given the complexity of the data needs and the product type, policy makers might benefit by collaborating with manufacturers to obtain data, understand barriers, and determine a path forward on improving SNE efficiency. In our research, we heard that manufacturers may be hesitant to employ power scaling due to durability and reliability concerns. Other electronic products, such as computers and televisions, do employ aggressive power scaling techniques. The fact that SNE do not implement power scaling may point to latency or other operational requirements that manufacturer input could illuminate.

6.3 Policy approaches

Most energy efficiency policies rely on minimum energy performance standards (MEPS) to effectively disallow inefficient products from entering the market. The discussion above illustrates the data gaps and challenges related to setting maximum allowable power targets for SNE. Policy makers may consider other tools, in particular consumer-directed energy labels, that present fewer implementation challenges but present the potential to encourage the market toward more efficient designs.

As shown in Section 4, SNE products can draw a wide range of power for functions (Figure 4). An SNE energy label would indicate a product's power draw or energy use relative to other products with similar functionality. Although energy savings does not appear to be a motivating purchasing factor for most consumers, labeling can be an effective tool to encourage manufacturers to improve efficiency and avoid labeling their products as poor efficiency performers. Labeling can also move the market toward efficient products when large-quantity purchasers like procurement programs use them in their purchasing

decisions. Because labeling does not prevent any product from entering the market, implementing a labeling program presents a lower level of effort for policy makers (Siderius 2020). Compared to MEPS, labeling approaches could use simpler and broader product categories, and reduce the effort and detail needed in addressing the data gaps above.

The degree to which energy labels alone can move the market of a performance-focused product like SNE is untested. Policy makers may therefore consider whether a combined approach of MEPS and labeling can achieve similar or greater energy savings as MEPS alone. Using MEPS and labels together can eliminate the least efficient products from the market (MEPS), while providing a push toward efficient designs to the entire market, especially the least efficient products (labels). Creating market improvement through labels may allow policy makers to set less stringent MEPS, decreasing the level of effort to develop the MEPS (Siderius 2020).

7 CONCLUSIONS

Compared to end user products subject to energy efficiency policy, like computers or televisions, SNE has unique functionality that requires it to always be connected to and/or maintain a network in order to pass data traffic whenever necessary. Globally, SNE products consume an estimated 120 TWh annually, which is a figure that will only grow as consumer demand for network services grows. Strategies exist, however, that have the potential to reduce SNE energy use by 20 to 50%. One key barrier to improving SNE efficiency is the lack of incentive for manufacturers to invest time and resources into designing efficient products. Energy efficiency policy can be that incentive. Due to the complexity and unique characteristics of SNE, more data collection and research may be necessary for policy makers to establish power targets or MEPS. However, creative policy approaches, such as using energy labeling or labeling and MEPS in combination, may yield energy savings while reducing the technical burden of developing stringent MEPS.

8 REFERENCES

- Ayre, R, J. Cheong and K. Hinton. 2021. Personal communication, March 11, 2021.
- Baliga, J., R. Ayre, K. Hinton and R. Tucker. 2011. [Energy Consumption in Wired and Wireless Access Networks](#). Communications Magazine, IEEE, vol. 49, p. 70-77.
- Bertoldi, P. and A. Lejeune. 2020. [Code of Conduct on Energy Consumption of Broadband Equipment. Version 7.1](#). European Commission, Ispra.
- CA IOUs (California Investor-Owned Utilities). 2020. [Small Network Equipment: Energy Savings Opportunities and Test Procedure Needs for the LPM Roadmap](#).
- Dangl, G. 2019. [Diplomarbeit Erstellung einer Gestaltungsrichtlinie zur Entwicklung vernetzter Produkte in Haushalten mit reduziertem Stand-by-Energieverbrauch](#). TU Wien, Fakultät für Maschinenwesen und Betriebswissenschaften.
- EDNA. 2018. [Network Standby Power Basics: Factors Impacting Network Standby Power in Edge Devices](#). Prepared by Xergy Consulting for the International Energy Agency 4E Standby Power Annex.
- EDNA. 2019. [Bridging the Network Standby Gap Between Mobile and Mains-Powered Products](#). Prepared by P. May-Ostendorp of Xergy Consulting and Eric Rubin of Energy Solutions for the International Energy Agency Electronic Devices and Networks Annex.
- EDNA. 2021. [Total Energy Model for Connected Devices v. 2](#). Prepared by P. Ryan of EnergyConsult Pty Ltd, T. Smith of Mississippi Consulting Pty Ltd, and A. Wu of Hansheng Ltd for the International Energy Agency Electronic Devices and Networks Annex.
- Fiandrino, C., D. Kliazovixh, P. Bouvry and A. Y. Zomaya. 2017. [Performance Metrics for Data Center Communication Systems](#). IEEE Transactions on Cloud Computing, vol. 5, no. 4, p. 738-750.
- Fraunhofer IZM. 2019. [State of Sustainability Research for Network Equipment: Small Network Equipment](#). Prepared for the Green Electronics Council and TÜV Rheinland in support of criteria development for the EPEAT and Green Product Mark ecolabels.
- Garg, V.K. 2007. Wireless Communications and Networking. Elsevier Morgan Kaufmann.
- Gray, C. 2018. [Energy Consumption of Internet of Things Applications and Services](#). Submitted in partial fulfilment of the requirements of the degree of Doctor of Philosophy Department of Electrical and Electronic Engineering. The University of Melbourne.
- Gray, C. 2021. Personal communication, March 16 2021.
- Harrington, L., B. Nordman. 2014. [Beyond Network Standby: A Policy Framework and Action Plan for Low Energy Networks](#). Prepared for the IEA 4E Standby Annex.

Hinton, K. J. Baliga, M. Feng, R. Ayre and R. Tucker. 2011. [Power Consumption and Energy Efficiency in the Internet](#). IEEE Network, vol. 25, no. 2, p. 6-12.

Hinton, K. and F. Jalali. 2016. [A Survey of internet Energy Efficiency Metrics](#). 2016 5th International conference on Smart Cities and Green ICT Systems (SMARTGREENS), p. 1-9.

Lanzisera, S., B. Nordman and R. Brown. 2010. [Data Network Equipment Energy Use and Savings Potential in Buildings](#). ACEEE Summer Study on Energy Efficiency in Buildings.

Mahadevan, P., P. Sharma, S. Banerjee and P. Ranganathan. 2009. [A Power Benchmarking Framework for Network Devices](#). Networking 2009: International Conference on Research in Networking, p. 795-808. Pearson. 2002. [Pearson IT Certification](#).

SNE VA Signatories (Signatories of the Voluntary Agreement for Small Network Equipment). 2020. [Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Small Network Equipment \(revised\)](#).

Siderius, H-P. 2020. Regulating ICT products through EU ecodesign and energy labelling measures – a new approach. Proceedings of Electronics Goes Green 2020+.

Siderius, H-P. 2021. Personal Communication, May 4 2021.

U.S. EPA (United States Environmental Protection Agency). 2013. [ENERGY STAR Test Method for Small Network Equipment. Final Test Method Rev.](#)

U.S. EPA. 2021. [ENERGY STAR Small Network Equipment – Sunset Proposal Memo](#).

Van Heddeghem, W., F. Idzikowski, W. Vereecken, D. Colle, M. Pickavet and P. Demeester. 2012. [Power consumption modeling in optical multilayer networks](#). Photonic Network Communications, vol. 24, p. 86–102.

Vereecken, W., W. Van Heddeghem, M. Deruyck, B. Puype, B. Lannoo, W. Joseph, D. Colle, L. Martens and P. Demeester. 2011. [Power Consumption in Telecommunication Networks: Overview and Reduction Strategies](#). Communications Magazine, IEEE, vol. 49, p. 62-69.

9 APPENDIX

We perform multiple variable linear regression analysis to determine whether power for various SNE product categories can be predicted with multiple variables. The U.S. VA dataset contains information on several components and characteristics of SNE, on which VA power limits are set. We include characteristics that are applicable to network component characteristics of SNE in the analysis for each product category, and assume that these characteristics are independent variables for the multiple variable analysis.

The p-values yielded by the multiple variable regression analysis are listed in Table 4. P-values less than 0.01 (highlighted in green in the table) indicate a significant relationship between the independent variable and power draw. The analysis shows that the number of Wi-Fi radios has significant relationship with power draw in most cases. Other components, such as phone ports and USB ports, can also show a significant relationship to power. R^2 of the multiple variable regressions range from 0.63 to 0.81 (Table 4).

Table 4: Independent variables included in multiple variable regression analysis, with p-value, coefficient, adjusted R², and intercept outputs for product categories analyzed.

Component	IAD		All LAN Equipment		Level 1		Level 2+	
	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient
Ethernet ports	0.60	-0.157	0.043	0.128	0.21	0.078	0.042	0.232
802.11n radios, low power	0.38	0.653	1.62E-04	0.898	0.006	0.668	0.11	0.601
802.11ac radios, low power	0.28	1.00	2.98E-07	1.50	4.77E-06	1.91	0.003	1.24
Additional chains, low power	3.07E-07	2.00	9.80E-03	0.507	0.067	0.669	0.034	0.532
802.11n radios, high power	2.32E-03	2.89	1.32E-04	1.07	9.21E-06	1.29	0.22	0.555
802.11ac radios, high power	8.05E-04	3.49	9.95E-16	2.56	0.013	0.762	2.71E-11	3.13
Additional chains, high power	0.67	-0.198	9.94E-03	0.385	0.52	0.262	0.45	0.142
HPNA	0.34	0.876	n/a	n/a	n/a	n/a	n/a	n/a
G/hn	n/a	n/a	6.94E-07	2.37	0.019	1.43	7.35E-05	2.45
MoCA	0.092	1.43	1.69E-07	2.56	0.010	1.36	4.02E-06	3.23
Phone ports	2.99E-03	0.850	n/a	n/a	n/a	n/a	n/a	n/a
USB 2 ports	0.16	0.623	1.26E-04	1.12	0.56	0.307	0.028	0.870
USB 3 ports	0.94	-0.056	7.32E-19	2.74	0.67	0.481	4.22E-11	2.59
Bluetooth	n/a	n/a	0.72	0.183	0.27	0.679	0.78	0.191
Additional application processor	0.98	-0.020	0.18	0.685	0.014	1.98	0.54	0.417
Adjusted R ² of multiple variable regression	0.63		0.81		0.73		0.74	
Intercept	6.98		0.907		1.04		1.27	