Received: 17 December 2023 | Revised: 16 March 2024 | Accepted: 23 March 2024

DOI: 10.1002/sd.2995

RESEARCH ARTICLE

Sustainable Development WILEY

Sustainable use of a smartphone and regulatory needs

Martin Kögler[1] | Katharina Paulick[2] | Jürgen Scheffran[3] | Mario Birkholz[4,5]

[1]VTT Technical Research Centre of Finland, Oulu, Finland

[2]MINAUTICS GmbH, Berlin, Germany

[3]Institute of Geography, Universität Hamburg, CLISEC, CEN, Hamburg, Germany

[4]IHP–Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder), Germany

[5]Technische Universität Berlin, Berlin, Germany

Correspondence

Martin Kögler, VTT Technical Research Centre of Finland, Kaitoväylä 1, Oulu 90590, Finland.
Email: martin.kogler@vtt.fi

Mario Birkholz, IHP–Leibniz-Institut für innovative Mikroelektronik, Im Technologiepark 25, Frankfurt (Oder) 15236, Germany.
Email: birkholz@ihp-microelectronics.com

Abstract

The significance of information and communication technologies (ICT) for the Paris Climate Agreement is continuously increasing because of its growing energy consumption. Here we examine the question for the smartphone and extend the investigation to more aspects of sustainability. Critical issues are identified for ten UN Sustainable Development Goals. Measurements of smartphone energy consumption show that a significant savings potential can be unlocked by reducing the data outflow and the large amount of personal data stored in data centers. Main discrepancies are also traced to the oligopolistic market structure of operating systems (OSs), messenger services, and social media apps. Technical means for a sustainable smartphone use are suggested as alternative OSs, social media channels of the Fediverse, as well as free and open-source software. Finally, societal conditions are emphasized to make the market for OSs and apps more diverse so that a sustainable smartphone use can generally prevail.

KEYWORDS

alternative mobile operating system, custom ROM, Fediverse, FOSS, information and communication technologies (ICT), smartphone

1 | INTRODUCTION

There is overwhelming consensus in the scientific community that the human use of natural resources on planet Earth is threatening the foundations of life and urgently needs to be directed onto sustainable paths (Ripple et al., 2017). A crucial aspect of the threat concerns the greenhouse gas (GHG) emissions of CO_2 and CH_4 caused by energy production, compared with the Sixth Assessment Report of (IPPC, 2021, 2022). To comply with an average temperature increase of the Earth's atmosphere of maximally 1.5°C, a critical examination of all energy consumption is required as well as major investments and legal regulations to improve energy efficiency and CO_2 reduction (Aslan et al., 2018; Pihkola et al., 2018; Scheffran et al., 2020).

A large growth in the last decades has been associated with the development and expansion of the internet (Andrae & Edler, 2015; Bieser et al., 2023; Freitag et al., 2021; Lange et al., 2023; Shift Project, 2019), that is, component manufacturing, commissioning and maintenance of data centers (EC CGCNCT, Environment Agency Austria, Borderstep Institute, & Umweltbundesamt, 2020), network infrastructure, and end devices (Pihkola et al., 2018). For example, the electricity demand of EU member states' data centers alone increased from 53.9 terawatt-hour per year (TWh/a) in 2010 to 76.8 TWh/a in 2018, representing nearly 3% of the EU28's electricity demand (EC CGCNCT et al., 2020). Overall, the internet now claims 10% of global electricity production and is projected to increase to 20% in 2030 (Andrae & Edler, 2015). Among internet-using devices, the importance of mobile devices has steadily increased. Thus, the number of smartphone subscriptions worldwide amounted to 6.6 billion by the end of 2022 and is projected to more than double from 3.6 billion in 2016 to 7.5 billion in 2026 (Ericsson, 2022) (a smartphone here is understood to be an electronic device that operates as a mobile phone with internet functionality).

The challenges can be classified within the framework of UN Sustainable Development Goals (SDGs), with the aforementioned aspects of the energy supply being judged primarily against SDG#7 "Affordable and clean energy" and SDG#13 "Climate Action." In the following, we will focus on the use of smartphones—and not on their production. The latter is responsible for much of the energy consumption over the lifetime of a smartphone (Jattke et al., 2020), and in other respects the manufacturing process collides with various SDGs, such as #8, which demands decent work (Lüthje & Hürtgen, 2013). Notably, methods for improving the sustainability of the manufacturing process were already developed by the pioneering activities of the Fairphone company (Haucke, 2018; Jindra et al., 2019).

However, there is a severe need to innovate the daily use of smartphones. It is the main component of a personal information and communication technology (ICT) sphere, which is likely to become increasingly resource-demanding due to the expansion of the internet-of-things (IoT), including medical systems, wearables (Birkholz, 2023; Birkholz et al., 2016; Green, 2021; Nguyen et al., 2022; TaheriNejad et al., 2022), connected cars, (Marosi et al., 2018) and other digitization trends (El-Mougy et al., 2019; Paulick et al., 2022). It thus seems reasonable to develop techniques and methods today that will allow users to manage their ICT devices in a sustainable way in the future. Therefore, our study focuses on this question.

In order to examine the extent to which the SDGs are met or violated by smartphone use, we consider the associated effects at the three affected tiers: the end devices, data centers, and network infrastructure (Bieser et al., 2023; Shift Project, 2019). To this end, we first present the data on power consumption of centralized and decentralized internet components as known from the literature and obtained by own measurements. For this purpose, various smartphone programs (apps) and measurements of battery levels were applied. We then estimate the share of energy consumption used for technical and behavioral monitoring of users by data-collecting internet companies.

We discuss this data, as well as operating systems (OSs) and commonly used apps in the context of the UN Sustainable Development Goals, compared with Figure 1. The paper concludes with suggestions on how smartphone users can configure their system to become "more sustainable." This includes the use of selected apps and alternative OSs, as well as the configuration of system settings. Setting the course also in the political sphere, as outlined in the last section, appears to be urgently necessary to curb the global energy demand of a rapidly growing ICT sector in accordance with UN SDGs.

2 | ENERGY CONSUMPTION AND GHG EMISSIONS

The ICT sector contributed an estimated 1.5%–4% (Bieser et al., 2023; Freitag et al., 2021) to global GHG emissions of 41 GtCO_2-eq in 2021 (Ritchie et al., 2020), for which 3% would correspond to an absolute amount of 1.2 GtCO_2-eq (equivalent gigatons of CO_2 emissions from fossil fuels and land use change). In total globally generated electric power, the share was 5%–9% in 2018, corresponding to an absolute amount of 1300–2340 TWh/a (100% = 26,000 TWh [Ritchie et al., 2022]). All studies dealing with the energy consumption of the ICT sector assume a growing energy demand until 2030, with estimated increases ranging from 50% to 100% (Belkhir & Elmeligi, 2018; Freitag et al., 2021).

FIGURE 1 Logos of the UN Sustainable Development Goals and highlighting the ones where smartphones have a critical impact.

Such an increase would be incompatible with the requirements of the Paris Climate Agreement of 2015, in which a reduction in GHG emissions to 3.78 $GtCO_2$-eq in 2050 and 23.6 $GtCO_2$-eq in 2030 is envisaged to limit global warming to 1.5°C (Freitag et al., 2021). In the studies mentioned, there is a consensus that "drastic measures are required to significantly reduce the energy demand of ICT" (Freitag et al., 2021) causing a lower carbon footprint (Malmodin & Lunden, 2018).

Smartphones now have a very high global penetration rate, and current estimates suggest that of the 8 billion people living on Earth, around 7 billion are in possession of a smartphone. In 2021, around 1.4 billion new systems were sold. Based on our own measurements (see Supporting information Data S1 and S2), we estimate the average energy consumption of a smartphone to lie between 1 and 5 kWh/a, with large variations depending on model, mobile OS, and user habits. This results in a total energy demand for the level of local smartphone operation on the order of about 7 TWh/a. If a global CO_2 emission factor of 0.63 kg CO_2-eq/kWh is assumed (Freitag et al., 2021), this results in total emissions on the order of 4.4 $MtCO_2$-eq/a. Other sources assume an emission of 47 kg CO_2 during the entire service life of a single smartphone, with the main share being attributable to production (Bieser et al., 2022).

Measured against the corresponding levels for data centers and network operation, these figures appear comparatively low. For example, the worldwide energy consumption of data centers in 2018 was estimated to 205 TWh (Dienste, 2021), which would correspond to a GHG emission of 129 $MtCO_2$-eq. Nevertheless, it has been shown that consumption at both tiers of data centers and network traffic is largely determined by user behavior and settings of the smartphone OS, that is, on tier three of end user devices (Papadopoulos et al., 2019; Uijttewaal et al., 2021).

In connection with the energy requirements of the ICT sector, it has frequently been argued that the dissemination of corresponding systems will pave the way to significant saving potentials that will more than offset the emerging demand. However, the increasing electricity consumption over the last three decades suggests that the Jevons paradox (Polimeni, 2008) is particularly effective for the ICT sector. Today, the paradox is generally captured under the term of rebound effects (Ruzzenenti et al., 2019). In addition, we seem to observe the Jevons effect to act in the ICT sector in an exemplary way, since all the gains in effectiveness in computing power have never led to a decline in power consumption in the recent years (Mills, 2019).

Summarizing, the power consumption of global smartphone use shows a conflicting trend to the required reduction of GHG emissions. There is a clear contradiction with SDG#7, which calls for "ensuring access to affordable, reliable, sustainable, and timely energy for all", since the increasing allocation of resources to this sector will limit its availability to others. The efficiency gains repeatedly predicted with the dissemination of ICT in recent decades have not materialized, neither in the global energy balance nor in that of the ICT sector itself. There is thus a pressing need to understand the causes of rising energy consumption and to develop measures that will stop it from escalating further and even reduce it.

3 | State-of-the-Art HARDWARE AND OS

The mobile OS of a smartphone and how it supports the hardware have a significant effect on energy consumption. For instance, almost all mobile OSs currently allow for smart battery charging that is, aging protections and warnings when a threshold of low and high charge is reached, see Supporting Information Figure S1. In the following, we will therefore take a closer look at the hardware and OSs of smartphones and their interaction.

3.1 | Hardware sustainability factors

Figure 2 displays the interior view of a typical current smartphone device. It shows that the battery, currently lithium-ion or lithium polymer types, represents a major component of the overall system, taking up most of the hardware space. Its capacity, usage, and charging characteristics play a big role on the power consumption (Takeno et al., 2005). Charging from near zero up to 100% is not always the best option in terms of sustainability due to the wearing out of the equilibrium between the lithium cobalt oxide and the graphite layer (Kim et al., 2019; Palacin, 2018). Elevated and low temperatures during charge and discharge, as well as the charging current affects the battery's lifetime and pose a safety risk (Bandhauer et al., 2011; Rauhala, 2020; Vetter et al., 2005).

Other hardware properties and settings which affect the power consumption are the screen type for example, liquid-crystal displays or organic light-emitting diodes, its dimension, pixel resolution, and density as well as the back illumination brightness (Carroll & Heiser, 2010).

It is typically the task of each vendor to optimize the relation between form factor and hardware components. In recent years, smartphones became increasingly similar, whereas just marginally increasing the size of the screen. Furthermore, sensors embedded into the smartphone that report periodically status information to the system-on-chip (SoC) also affect battery lifetime. Therefore, a software-controlled battery management system is crucial (Pasricha et al., 2020). For example, the light sensor when hovering over the phone would be responsible for adjusting the back-illumination brightness. Enhancing the battery lifetime can be performed by tailoring power management algorithms of the SoC. In addition, user interactions require a large amount of power like connecting the phone to wireless networks (mobile networks, Wi-Fi, and Bluetooth), turning the screen on or off, as well as notifications that unlock the screen, touches, and swipes.

3.2 | The unsustainable landscape of mobile operating systems

Today there are two dominating OS platforms for smart-phones, Android, and iOS. Both are effectively closed source, both are owned by large companies, namely Alphabet/Google and Apple and both collect enormous amounts of personal data about their users

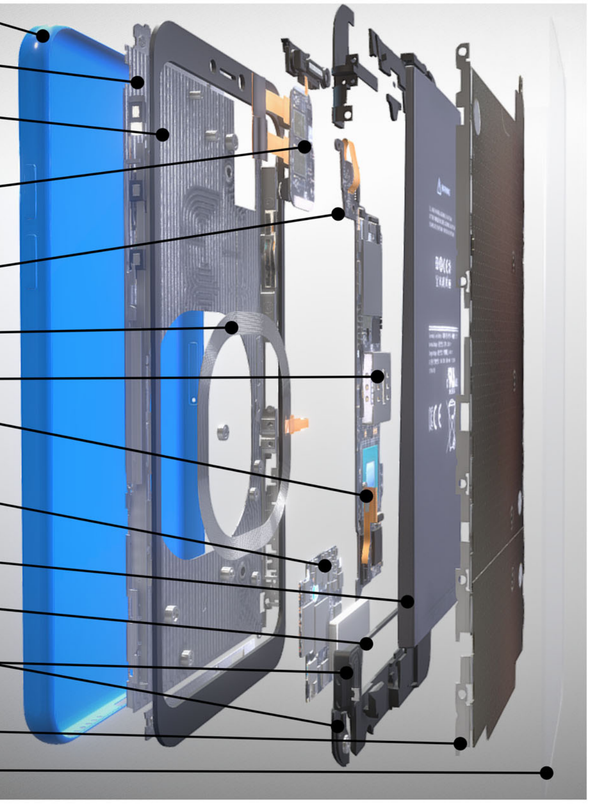

FIGURE 2 Schematic interior of a recent smartphone and the ones where smartphones have a critical impact in bold letters (reproduced with permission from Martin Hajek, artstation.com).

(Cooke, 2020; Kollnig et al., 2022; Leith, 2021, 2023). Implemented into Google's Android and Apple's iOS are system trackers, which the user has to accept in order to use the phone via agreeing to the End User License Agreement at the first booting up (Agrawal et al., 2022). In 2020, the global market share of mobile platforms was about 73% Google's Android and 26% iOS, which leaves only a small share to alternative OSs (Garg & Baliyan, 2021). Both major platforms thus constitute an oligopoly in the global market.

In particular, in the case of Google's Android, there exists a confusing mix of open-source and proprietary software shares, which is not transparent to the majority of users. This is because, as a pure Linux OS, Android is based on the Android Open Source Project (ASOP), developed as free and open-source software (FOSS) by a worldwide community of volunteer and dedicated programmers. Google's Android™, which dominates the global market, on the other hand, includes as an essential component a group of proprietary software modules collectively known as Google Mobile Services (GMS). They encompass application programmable interfaces (API) and key programs such as PlayStore to gain access to more GMS apps, Google Maps, and YouTube, among many others. By integrating more programs into GMS, Alphabet/Google has transformed Android into an increasingly closed OS in recent years, originally designed according to FOSS principles (Amadeo, 2018).

Alternatively, there are Android OSs available that can run without GMS. An important prerequisite for this was created by the microG project, which replaced the programs and APIs integrated in GMS by FOSS modules (Laksono, 2020). OSes based on this are, for example, /e/OS and LineageOS-microG (Ponakala, 2017). Also in China, most smartphones are running on AOSP-based OS versions. For instance, Huawei as the second largest handset maker after Samsung needed to develop its own system after the Trump administration ban. Huawai's OS is called HarmonyOS and has gained about 4% global market share by the end of 2023.

Other non-AOSP and pure mobile Linux OSs are Ubuntu-Touch (continued by UBport) and since 2012, SailfishOS, which continues Maemo and MeeGo, originally implemented by Nokia and Intel back in 2010 (Tzvetanov & Karabiyik, 2020). Those alternatives are mature and stable and thus can fully replace Google's Android, especially since they allow to run Android apps in a subsystem (Grolleau, 2021). Figure 3 shows the family of mobile OSs for smart-phones in the global market.

In summary, the structure of the mobile OS market is in conflict with SDG#10, which defines the goal of "reducing inequality within and between countries." The two dominating companies, Alphabet/Google and Apple, shield key areas of their services in order to monopolize markets and to generate huge profits. The latter amounted to about 60 and 100 billion US $ in 2022 (Lohmeier, 2023; Statista Research Department, 2023) and exceeded the state revenues of various countries (Wikipedia, 2023), where finances are urgently needed to meet other SDGs, such as organizing education for all, fighting hunger or improving health care. The pronounced concentration of economic power in private hands must also be seen as a threat to SDG#16 (Moscariello et al., 2024), which aims to "Promote peaceful and inclusive societies for sustainable

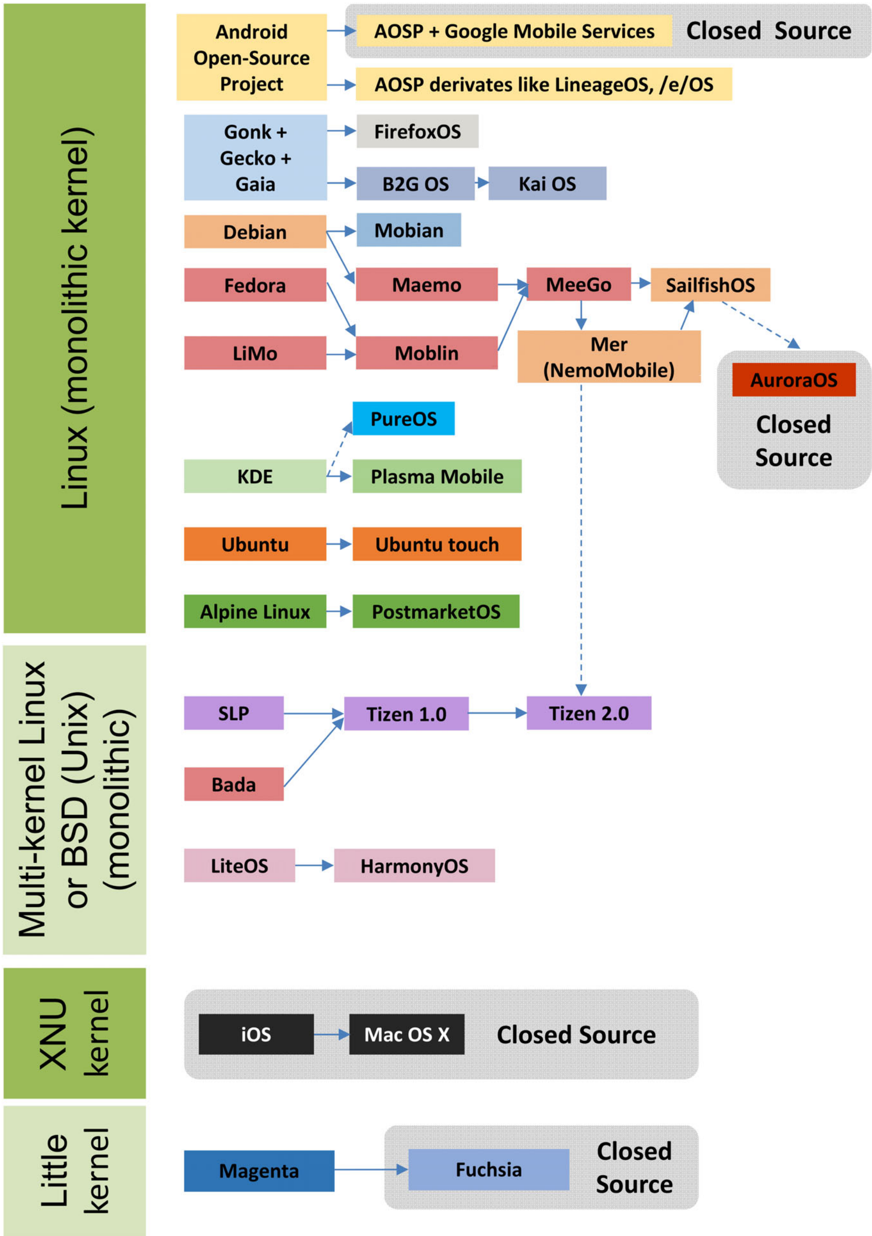

FIGURE 3 Evolution of smartphone operation systems; based on and further developed from Grolleau, (2021).

development, … and build effective, accountable, and inclusive institutions at all levels."

4 | USER SURVEILLANCE

Internet users are systematically monitored when they call up numerous pages on the web. The techniques required for this were developed in the early 2000s as so-called cookies, when internet use was still tied to personal computers (Binns, 2022). With the advent of cell phones, these techniques also diffused into mobile internet use and became continuously more advanced and highly sophisticated. The main purpose of tapping user data is to enable the advertising industry to precisely identify potential customers and target them (Zuboff, 2019). The focus is on virtually all personal data like age, gender, education (SDG#4), occupation, income, credit card sales, assets or debt level, living situation, daily routine, hobbies, leisure activities, sexual orientation, preferences, circle of friends and relatives, sporting activities, fitness, diet, health status, illnesses, medication or drug consumption, and so on, which allow an estimate of success when advertising a particular product. In a recent study, the cookie load of the top one million websites was determined to encompass >22 million cookies per single visit to all these sites, belonging to more than 1200 different companies (Cucchietti et al., 2022).

In addition to cookies, various other techniques have been developed that allow comprehensive tracking of users for virtually all online and many offline activities (Urban et al., 2020). Whereas cookies primarily make use of the IP address of the device calling up a website to identify the user, current methods use additional identifiers. Cross-site tracking like cookie-synchronization is made possible simply by stringing together several identifiers (Karaj et al., 2018; Libert, 2018; Papadopoulos et al., 2019). Moreover, new tracking methods are constantly being developed (Meineck, 2023), with one well-established example is being browser fingerprinting, which enables user identification based on technical parameters, such as screen size, browser type, version number, and so on. (may be checked on www.amiunique.org). Another approach relies on Facebook's engagement buttons allowing the company to monitor about 52% of all websites visited (Aguiar et al., 2022).

The main application of personality profiles is currently in the auctioning of advertising space on websites. The user's data were transmitted to an auction platform when a web page is called up. The latter triggers an automatic auction of the advertising spaces available on the page among a group of ad providers. Each bid is based on the appropriateness of the advertised product to the user's presumed interest, which is calculated from his personality profile. The auctions happen in the first few 100 ms in which the page is built up on the user's screen.

However, personality profiles determined were not only used to advertise commercial products, but also to influence political elections, such as the UK's vote to leave the European Union in 2016 or the election of the US president in the same year. In both cases, the personality classes of the OCEAN model (McCrae & John, 1992) derived from Facebook data were used to target millions of users (Bachrach et al., 2012; Kosinski et al., 2013; Wylie, 2019). In G7 countries, organizational measures have meanwhile been introduced to counteract undemocratic election interferences. In other countries, however, such techniques are sometimes used excessively, as in the 2018 and 2022 Brazilian presidential elections, where slanderous disinformation campaigns against the political opponent were conducted by the previous incumbent via the social media platform WhatsApp (Boadle, 2018; Evangelista & Bruno, 2019). These campaigns did even not stop at death threats against female journalists (Amnesty International, 2018; Di Meco, 2023).

Only little information is available on the amount of personal user data stored in data centers, and we have to rely on individual samples. We are assisted by the European General Data Protection Regulation (GDPR), according to which companies are obliged to provide information to users about whom they store personal data (Art. 15 GDPR). Some data-storing companies, for instance Google/Alphabet, have created access for users to automatically retrieve some of the data stored about them, but in most cases, the assistance of non-governmental organizations (NGOs) and initiatives is required to enforce regulations (Datarequests, 2023; Noyb, 2023).

In a recently published request for disclosure, the volume of data that were accumulated for a single user on his Google account became known (Schallenberger, 2022). Over the course of 9 years, the company had collected and stored 10 gigabytes (GB) of data, with geolocation alone comprising a good 535 thousand data points, corresponding to one location information every 10 min. However, this is not all the data stored by Google, but only an excerpt that the company was willing to transmit due to an algorithm it has set up itself.

Spying on virtually all smartphone users and broad-based user profiling is not in line with SDG#12 to ensure sustainable consumption and production patterns. Indeed, SDG#12 aims to reduce resource consumption, whereas ever more technically optimized advertising causes overconsumption of natural resources. Moreover, the progressing accumulation of sensitive personal data at private companies does not comply with SDG#16 to "build accountable and inclusive institutions at all levels." Rather, the large tracking companies generally evade their duty of disclosure and accountability to users.

5 | ENERGY CONSUMPTION

In order to analyze the energy consumption of smartphone use, we have to consider its effect on three different tiers (Bieser et al., 2023). Due to strong variations in user behavior and the lack of transparency in the internet industry, energy consumption can in part only be estimated. The analysis of existing data in combination with our own measurements, nevertheless leads to valuable conclusions for a sustainable smartphone use.

5.1 | Energy consumption of smartphones

The main energy consumers on a smartphone can be determined straightforward from the battery function. As an illustration, we show screenshots of three devices in Figure 4, running with both dominant OSs (Android with GMS and Apples' iOS, Figure 4a,b) and exemplarily SailfishOS as FOSS alternative (Figure 4c). As can be seen from the figure, the consumption is generally given in percentage, related to the discharge of the battery. Figure 4a,b demonstrate the oligopolistic utilization of modern smartphones with a selection of the few billion-user apps (Facebook, GoogleLocations, Instagram, LinkedIn, TikTok, Twitter, WhatsApp, and YouTube) within the top five of the list (Rosen et al., 2015). It has to be stated that percentage values are rather unspecific indicators, but apps that provide a precise power consumption in energy units are hard to find.

Because of the wide variation in circulating devices and in user behavior, there are only a few studies on the breakdown of energy consumption of individual smartphone processes like (Gupta, 2016; Pasricha et al., 2020; Perrucci et al., 2011) and some of their results have been collected in Table 1. In addition, we performed further measurements on a Sony Xperia 10 III with a 4500 mAh battery, on which the Stock-Android (GMS) was replaced with the current version of SailfishOS, including an activated android (AOSP) subsystem (additional Sailfish X license). This device can be considered as a typical, but tracker-free smartphone due to its state-of-the-art performance. The open-source app SystemDataScope (rinigus, 2022) was applied for the measurements and the data obtained have also been included in Table 1. It is evident from the table that not only screen usage, especially with white background, but also communication in mobile and WLAN networks consumes significant portions of energy. In

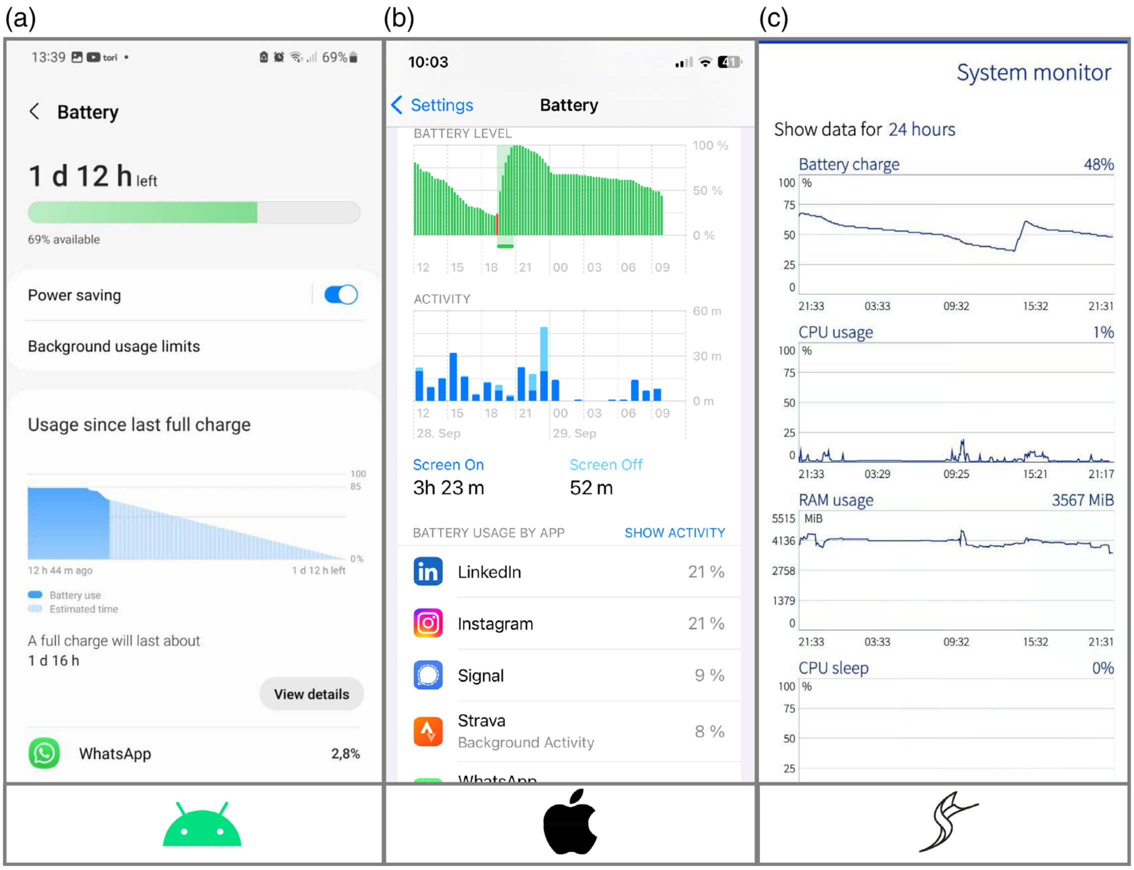

FIGURE 4 Screenshots of Android (a) and Apple's iOS (b) displays showing battery usage in system settings—typical consumers are system apps (Google Play services, geolocation, etc.) and third-party apps such as (WhatsApp, Instagram, Facebook, and TikTok); (c) SailfishOS System Monitor app as comparison of the dominating OS to a FOSS example with very detailed information.

addition, video calling severely contributes to a rapid temperature increase and discharge of the battery.

We also measured the total energy consumption of individual smartphones, which are presented in detail in the Supporting information Data S1 and S2. However, a precise determination of the energy required globally for smartphones use is difficult to derive, because of the wide dispersion of user interests and individual energy consumption. From various measurements and literature sources we estimate, however, that a single smartphone requires between 1 and 5 kWh of electrical energy per year. With a total number of 6.6 billion subscriptions active, this results in an amount of about 7–33 GWh/a of electrical energy that was consumed by smartphones in 2022.

5.2 | Energy consumption of data centers and mobile data transfers

The carbon footprint and energy consumption of data centers and mobile networks associated with smartphone usage in Europe has recently been estimated by CE Delft (Uijttewaal et al., 2021). The main focus of the study was on advertising and tracking services (ATS), to which the 546 million European cellular subscriptions in 2020 were subjected (World Bank, 2023).

Starting point for the calculations was the work of Vallina-Rodriguez et al., (2016), who examined third-party tracking and advertising in 1732 mobile apps. In the 200 apps with the highest data turnover, an average share of 17% was determined for AT activities; but even for 70% of all apps, this share still exceeded 10%. In addition, mobile data transfer volumes were included in the calculation, which amounted to 11.3 GB/month for Western Europe in 2020 (135.6 GB/a). Based on previous studies by CE Delft to determine energy efficiencies for the different *n*G networks, $n = 2.5$ (Scholten et al., 2020), the specific total energy of smartphone data transfer could be determined. This resulted in a value of 1.49 ± 0.44 kWh/GB, giving a total amount of 189 TWh for the transferred data volume.

This results in an energy consumption of 19 and 32 TWh/a for advertising and tracking activities on smartphones in Europe, if ATS shares of 10% and 17% are assumed, as determined before (Vallina-Rodriguez et al., 2016). These values are on the order of 10%–20% of the energy generated in 2020 by photovoltaics in Europe, amounting to 170 TWh (Hanna Ritchie et al., 2022), and appears an enormous waste of energy, since about 60% of users reject the playout of ATS on their smartphones (Uijttewaal et al., 2021).

On a global scale, mobile network data transfer have been increased from about 120 exabyte annually (EB/a) in 2017 to 1680 EB/a in 2023, according to Ericsson, and will still increase to

TABLE 1 Energy profile and average power consumption of various hardware components during operation in a smartphone from own measurements (exemplarily a Sony Xperia 10 III with a 4500 mAh battery was used) and from literature sources.

Hardware power consumption category	Modes of the hardware modules at specific settings	Settings and test description	Average power consumption (mW)	Power budget in (%) of a 4500 mAh battery	References
Display	Backlight intensity and a dark or black background setting	Black background 20% intensity	63	1.4	(Perrucci et al., 2011)
		Black background 60% intensity	97	2.2	
		Black background 100% intensity	260	5.7	
	White background setting	White background 20%	197	4.4	
		White background 60%	254	5.6	
		White background100%	527	11.7	
	screensaver mode	Low power screen (that is, showing time, date and weather info)	14	0.3	
	Touch screen (OLED/LCD) interaction by user at a 50% black ground illumination	Using the touch screen for extended time (measurement of continuous finger movements, multi-touch for 10 min.)	585	13	This work, (Pasricha et al., 2020)
CPU	Clock frequency optimization	CPU usage at 2%	55	1.2	(Perrucci et al., 2011)
		CPU usage at 25%	310	6.9	
		CPU usage at 50%	462	10.3	
		CPU usage at 75%	561	12.5	
		CPU usage at 100%	612	13.6	
Memory	File saving operation	Saving a 1 Mb file to internal storage	588	13	
		Saving a 1 Mb file to external (micro-SD card) storage	613	14	
Signaling modules	Bluetooth (BT)	BT off	12	0.2	
		BT on	15	0.3	
	Bluetooth low energy (BLE)	BLE scanning mode	5	0.1	(Gupta, 2016)
		BLE connect (average Tx/Rx)	7	0.2	
	WiFi (IEEE802.11 infrastructure ure mode)	Connected	868	19.3	(Perrucci et al., 2011)
		Disconnected	135	3	
		Idle	58	1.3	
		Idle but in power save mode	26	0.58	
		Downloading at 4.5Mbps	1450	32.2	
	WiFi (IEEE802.11 ad hoc)	Sending @ 700 kB/s	1629	36.2	
		Receiving (Rx)	1375	30.5	
		Transmitting (Tx)	979	21.7	

(Continues)

TABLE 1 (Continued)

Hardware power consumption category	Modes of the hardware modules at specific settings	Settings and test description	Average power consumption (mW)	Power budget in (%) of a 4500 mAh battery	References
Video	Front facing camera	Video call on WiFi (Telegram, Signal, WhatsApp…) dark background picture	780	17.3	This work
		Video call on WiFi (Telegram, Signal, WhatsApp…) white background picture	1130	25.1	
		Video call on 3G	2200	48.9	(Perrucci et al., 2011)
		Video call on 4G	1850	41.1	This work
	Main camera	Opened non-recording	605	13.4	
		Opened recording (autofocus)	1210	26.9	
Audio	Audio subsystem (microphone, speakers) while streaming	Voice call on WiFi (Telegram, Signal, WhatsApp…) with screen on	420	9.3	This work
		Voice call on WiFi (Telegram, Signal, WhatsApp…) screen off	235	5.2	
	Audio subsystem without streaming	Microphone and speakers (depending on speaker volume)	33	7.3	
		Voice call on 4G cellular network	680	15.1	This work
		Voice call on 3G cellular network	1250	27.7	(Perrucci et al., 2011)
		Voice call on 2G cellular network	665	14.7	
Mobile network	Use and switching between networks (exemplarily between 2G and 3G)	Idle state of 3G cellular network	25	0.5	
		Idle state of 2G cellular network	15	0.3	
		Handover from 3G to 2G	591	13.1	
		Handover from 2G to 3G	1389	30.9	

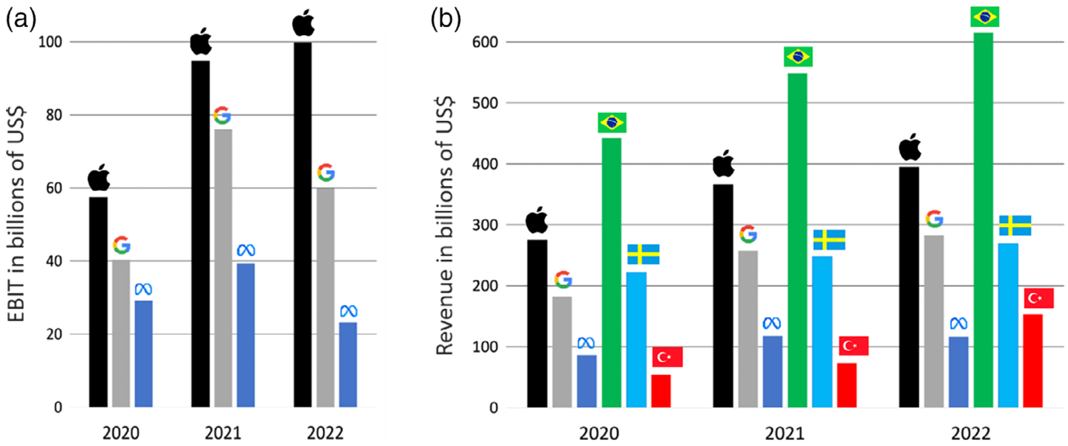

FIGURE 5 (a) Earning before interests and taxes and (b) revenues in billions US $ of the three major internet companies in the smartphone sector, Alphabet/Google, Apple, Meta/Facebook, and exemplarily a comparison of revenues to countries like Brazil, Sweden, and Turkey.

5,400 EB/a by 2028 (Ericsson, 2022). This represents an increase of one and a half orders of magnitude in 10 years, or an average compound annual growth rate (CAGR) of 46%. The increase in the coming years is accompanied by a rollout of 5G networks.

In connection with the introduction of 5G technology, reference is frequently made to the supposedly lower energy consumption compared to 3G or 4G networks, and a good overview of such studies can be found in Williams et al., (2022). For example, one study suggests that data transfer can be quadrupled by the upgrade while energy consumption remains the same (Ericsson, 2022). Other authors doubt that the energy saving effect can actually compensate for the annual growth rate of mobile data transfer (Morley et al., 2018; Pihkola et al., 2018).

As Williams et al., (2022) point out, studies on mobile data traffic usually fail to consider aspects such as overall operational energy, the impact of embodied energy and changes in user behavior. For embodied energy in particular (Humar et al., 2011), they note that the new installation of network infrastructure with energy costs for the manufacture of devices and the disposal of old devices is hardly considered and systematically underestimated.

We may conclude that the overall smartphone multitude is responsible for only a small share of the ICT sector's energy consumption. The significantly higher share is attributable to mobile data transmission and storage in data centers. The question of sustainability of smartphone use thus cannot be limited to the device level, but has to integrate the other tiers. A significant amount of renewable energy is directed to advertising and tracking application that would have been more wisely used to strive for climate action in terms of SDG#13.

6 | USER BEHAVIOR AND MONOPOLISTIC MARKET STRUCTURE

The design of apps triggers large energy consumption, which is accompanied by the acquisition and storage of personality profiles and ATS activities. In the end, the users pay the energy bill through the products for which the ads were played on their smartphones. This is a rather unsustainable business model, as it has led to increased energy consumption in smartphone use over the last two decades and has seduced users to unsustainable consumption.

The changes in user behavior due to technological advances also appear interesting from a technical point of view. For example, in total data transfer, the volume of transmitted videos has increased steadily and is now responsible for the largest share. This is mainly due to video streaming from stationary TV devices, but the share of mobile devices is steadily increasing and is also estimated to account for 80% of the total transfer volume in 2028 (Ericsson, 2022). In general, it can be seen that with the availability of bandwidth, applications have been rolled out that were hardly thought of when the more energy-efficient technology was introduced, but which have come to dominate usage over time. The situation is not coincidentally reminiscent of the Jevons paradox, but confirms to analyze and understand the developments in the ICT sector in a comparable theoretical framework.

For smartphone usage, it is evident that the high proportion of video applications is attributable to the dominant apps YouTube and TikTok. Both act as exchange platforms and social media, but economically, their operation is based on the advertising revenues generated. The methods of video platforms do not live up to SDG #12, which calls for "sustainable consumption and production." In particular, for TikTok analysts note that the endless looping of videos implements an algorithm that tries to get people addicted rather than giving them what they really want (Bain, 2023). As of March 2023, it is reported that the hashtag #TikTokmademebuyit has been accessed more than 40 billion times, in many cases by disappointed users who did not need the purchased product at all.

The question to which extent the use of smartphones promotes or obstructs the implementation of sustainability goals cannot bypass a consideration of the market structure. As outlined above, the market for mobile OSs breaks down into an oligopoly of two providers. Both providers, Google and Apple, keep masses of users in their OS ecosystems on a scale that far exceeds the number of inhabitants of individual states. A similar monopole structure exists for the most frequently used messenger systems and social media platforms with WhatsApp, Instagram, and Facebook, and which are supplied by Meta as a single company.

The profits and revenues generated by these companies as published for 2020–2022 are shown in Figure 5. The national budgets of three politically important countries are also displayed for comparison and can be seen to be on the same order of magnitude as the revenues of Apple, Google, and Meta. The data suggest that the activity of internet companies are diverting societal wealth increasingly unjust—away from societies and toward a few billionaires and monopoly companies. It should be borne in mind that the tax rates effective for Apple, Google, and Meta in Europe are generally well below those for domestic companies (De Mooij et al., 2021).

In withdrawing financial resources from billions of smartphone users to a few companies, there is a clear discrepancy with SDG #10, which calls for less inequality within and between countries. As a consequence, there results another incompatibility with the UN SDGs, namely SDG #1, which addresses the fight against poverty. In fact, the profits accumulated by a few companies are no longer available to the great mass of users and are lacking in the fight against poverty and homelessness or for financing school buildings and qualified teachers in many countries, to mention only a few pressing issues.

7 | MEASURES TO IMPLEMENT A SUSTAINABLE SMARTPHONE USE

Smartphones may be considered as a major component of the rapidly growing IoT, and as such, they can serve as example for the methods to be developed for shaping the future IoT more energy-efficient and less data-transmitting. This transformation will have to be enforced by users, researchers and policymakers alike, and we list in the following some consequences that can be derived from the above analysis.

7.1 | Continued use

A crucial step toward improving the sustainability balance is to use the smartphone for as long as possible. Consumers should try to keep their system continuously updated to prolong its lifespan in order to contribute to activities in reducing electronic waste (Borland et al., 2019; Testa et al., 2024). In a more general sense, this point stands for not looking for visionary increases in efficiency from ICT developments, but instead focusing more on sufficiency to implement the SDGs (EEB, 2022).

A new acquisition is often motivated by the damage or technical failure of components like the display or battery. From a technical perspective, they would be easy to repair, but most manufacturers have built high barriers for self-repair into their devices, so consumers are tempted to purchase a new smartphone (Jattke et al., 2020). In turn, a political movement has formed demanding the right for repairable hardware, so that politicians have taken up these demands, and, for instance, a proposal on "rules promoting the repair of goods" has been drafted in the EU (European Commission, 2023). In fact, in the sense of SDGs #12 ("Responsible consumption and production") and #13 ("Climate action") it appears urgently necessary that the right to repair be made binding.

If a new purchase is unavoidable, a repairable smartphone should be chosen, where at least the battery and the display can be easily replaced by the user. Ideally, a new system should also be equipped with an alternative OS (see Section 7.4).

7.2 | Smart app settings

To protect the longevity of the battery and to reduce energy consumption for data processing, energy-saving measures can be taken via app settings, which may also secure the privacy of users and their contacts. In the settings menu of a device, users can monitor the battery status and which applications use energy most, see Figure 4. From the view of ecological sustainability, it is less important how much energy is used locally on the phone, instead applications regularly updating in the background or tracking locations are transferring data, compare Section 5.2. Using the phone sustainable means to improve the phone's longevity and reduce data transfer to a minimum.

7.2.1 | Battery longevity

Users can restrict battery charging from 20%–80% to promote battery health, see Figure S1. Depending on the percentage of battery usage per app, one may also adapt the corresponding app settings, see Table 1. Measuring the battery capacity in percentage is not an accurate metric; the unit watt hour is the more consistent to compare the total amount a battery can store and a precise way to reveal the energy consumption by apps. In addition, battery capacities and other specifications can be examined on various web pages. At certain circumstances the phone's battery dynamics could lead to unexpected shutdowns under high load, especially with worn batteries due to internal resistance and discharge current, which could happen also without prior information of the user, see the detailed analyzes in Lee et al., (2020); Takara, (2023).

7.2.2 | Updates and synchronization

Background updates can be turned off in most applications. In addition, tracking services and mobile data can be disabled in all applications not used on the road.

7.2.3 | Data privacy

In location and system services, location tracking should be turned off. In addition, sharing the contact list is optional for most applications but activated by default. Privacy-aware users should deactivate digital voice assistants like Siri, Amazon Alexa or Google Assistant, given reports about leaked speech recordings (Su, 2019). Users can

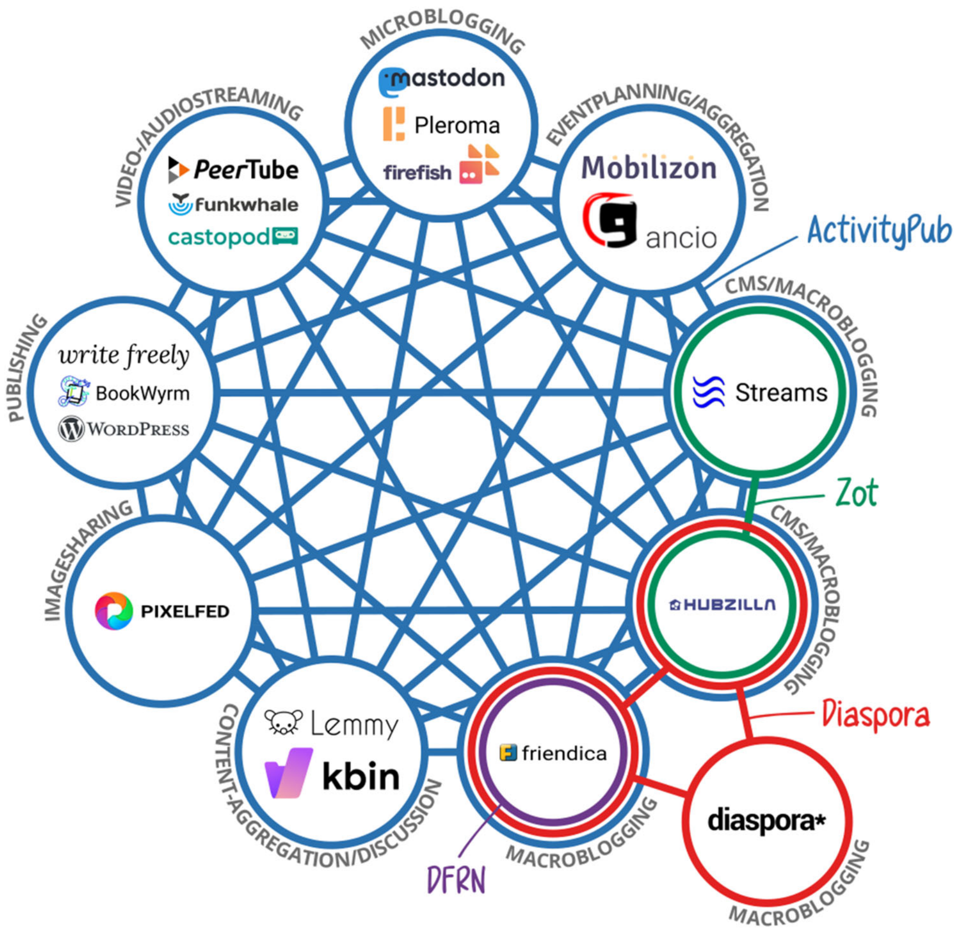

FIGURE 6 Platforms of the Fediverse, which refers to a network of federated, mutually independent social networks, microblogging services, and websites for online publication or data hosting. One may create a user account on any platform and use it to exchange with users on all the others without creating an account there (from Imke Senst & Mike Kuketz, CCBY-4.0).

turn off tracking important places in system services to prevent apps from requesting tracking or tracking usage behavior, see Figures S2 and S3. One should also be aware of the device's advertising identifier, which can be used for offline data sharing and tracking user behavior across different applications (Altpeter, 2022).

A system-wide solution to prevent unwanted tracking is to use the internet's domain name system (DNS). The process of translating a URL into an IP address can be exploited by using dedicated DNS servers that maintain lists of compromising sites. For each request of a web page, the DNS server may block a translation for undesired pages and thus tracking cannot be played out. Although this method is subject to permanent contest, it has proven to be comparatively effective (Kuketz, 2021).

7.3 | Smart app selection

Apps like Blockada for iOS or TrackerControl for android are available in app stores. These apps allow users to monitor and significantly restrict unwanted data transfers.

As exemplified in Figure 4, a large part of the data traffic is attributable to the use of the so-called social media of the major providers Meta/Facebook, Google/YouTube, TikTok, or Twitter/X. These media have been widely criticized for their barely moderated dissemination of hate speech (Hickey et al., 2023; Pluta et al., 2023), cyberbullying (Kansok-Dusche et al., 2022), especially against women and women's rights activists (Amnesty International, 2018; Di Meco, 2023), manipulative influence on democratic elections (Wylie, 2019), and endangering the healthy psychological development of children and young people (Twenge et al., 2018; Twenge et al., 2022). This wide range of misconduct stands in stark contrast to SDGs#3 ("Good Health and Well Being"), #5 ("Gender Equality"), #16 ("Peace, Justice and Strong Institutions"), and #17 ("Partnership for the Goals").

Fortunately, the FOSS community has also developed alternatives for social media apps, most of which belong to the so-called Fediverse, which stands for "federated universe" (La Cava et al., 2021). They are based on the ActivityPub protocol, a standard formulated by the World Wide Web Consortium (W3C) for decentralized sharing of content on the internet (Word Wide Web Consortium, 2018). Figure 6 shows the Fediverse platforms with the largest user numbers and their interconnects. Their usage provides the opportunity to pursue a whole set of SDGs simultaneously.

7.4 | Alternative operating systems and custom ROMs

Sustainable operation can be improved by installing an alternative OS like a mobile Linux OS or a custom ROM for an android derivate, see Figure 3 (Maksutov et al., 2018). They are free of system trackers,

TABLE 2 Selection of downloadable alternative mobile OS.

OS name, type and link to installation instruction	Properties	AOSP-based or android-compatibility, microG	Latest version (March, 2023)	Supported devices
/e/OS AOSP-derivate https://e.foundation/e-os/	Fork of LineageOS since 2017, but with microG included	AOSP-based with microG	v 1.9	227+ officially supported
GraphenOS (AOSP-der.) AOSP-derivate https://grapheneos.org/	FOSS mobile OS since 2014 with focus on privacy, security and complete protection from Google tracking	AOSP-based w/o Google apps or services	2023032600	Mainly Google Pixel devices
HarmonyOS pure Linux kernel https://www.harmonyos.com/en/	Semi-FOSS but only for Huawei phones	Unix multi-kernel based, but with AOSP compatibility; libraries to support legacy Android apps (APK)	v. 3.0.0.76	n/a
LineageOS AOSP-derivate https://lineageos.org and unofficial https://forum.xda-developers.com/	AOSP system for smartphones, tablets, and set-top boxes. It is successor to CyanogenMod since 2016. AS the source available at GitLab/Github it's pure FOSS, but it does not contain microG	AOSP-based w/o microG, proprietary Google apps or services (gapps) may additionally be flashed (zip file)	v 20 (Tiramisu)	175+ officially supported and many more unofficially
Plasma Mobile pure Linux kernel https://plasma-mobile.org/	FOSS, based on KDE Linux desktop, privacy respecting. Running on top of a Linux distribution based on Qt framework.	Android app (APK) support via Waydroid (https://waydro.id/)	Factory Image 202212201610 Latest	n/a
postmarketOS pure Linux kernel https://postmarketos.org/download/	postmarketOS is an extension of Alpine Linux to run on smartphones and other mobile devices, it's installed by default e.g. on the PinePhone (https://www.pine64.org/pinephone/)	Android app (APK) support via Waydroid (https://waydro.id/)	v. 22.12	n/a
SailfishOS (short SFOS) pure Linux kernel https://sailfishos.org/	Sailfish Alliance by Jolla Oy since 2013 based on Nokia's MeeGo/Maemo (Mer Linux Kernel), focusses on privacy with a unique UX SailfishOS (SFOS), has a large developer community. Semi-FOSS, since parts based on Qt framework are closed source; supports signature spoofing and deactivation of checking of Android-App support.	Android app (APK) support (compatibility) via license in supported Xperia and Gemini PDA devices, optional microG and Waydroid (for some ports of SFOS) installation.	v 4.5.x.x (Struven ketju)	100+ ports and selected Sony Xperia's, Planet Computers Gemini PDA, Jolla 1, C and Tablet
Ubuntu-touch pure Linux kernel https://ubuntu-touch.io https://ubports.com	Mobile version of Ubuntu desktop OS developed by UBports for smartphones and tablets also incorporating Qt (as originally developed for MeeGo/Maemo). FOSS with source code on GitHub.	Android app (APK) support via Waydroid (https://waydro.id/)	20.04 (focal fossa)	56+ devices, supports Android 9 + -based devices

Abbreviations: AOSP, android open-source project; APK, file extension for android apps; FOSS, free-and-open-source software; microG, open-source version of proprietary Google libraries; OS, operation systems.

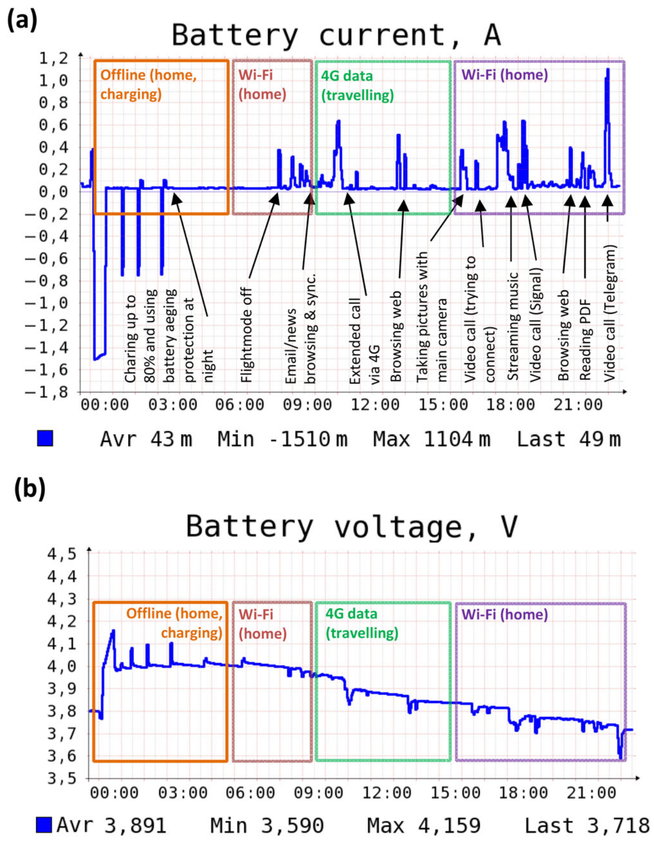

FIGURE 7 Battery charge and discharge logging 24 h (a) current and (b) voltage profile using SystemDataScope FOSS app (data extraction via RRDtool) using a SailfishOS (v.4.5.0.21) Sony Xperia 10 III device, containing a 4500 mAh battery with Android subsystem (v.11, API level 30) activated. Labels and arrows were added to the measurement curves for explanation.

fully functional and stable, as well as mature for daily customer and corporate use, compared with the case study of the European-developed SailfishOS as example (Grolleau, 2021). A selection with further information of "unGoogled" and tracking-free OS is shown in Table 2. Other alternatives, which are based on the AOSP are LineageOS and the fork/e/OS. Non-AOSP mobile OSs purely based on Linux are for example Ubuntu-Touch (continued by UBport) and SailfishOS.

A convincing example of the extended performance of the purely Linux-based SailfishOS is shown in Figure 7, which displays the course of battery voltage and (dis)charge currents over the period of 1 day (for additional transients see ESM). All processes on the system triggered by the user can be assigned to individual spikes in the transient. Thus, the user can to optimize his behavior with respect to energy consumption and to make it as sustainable as possible. Such a feature is not included in the OS of market-dominating suppliers, which would make transparent the numerous data outflows and could not remain hidden. Further power savings are possible in SailfishOS by simply turning off the android sub-system and the use of native apps instead.

An OS change is de facto feasible for android-based smartphones only, but no established custom ROM is available for iPhones (Cooke, 2020). In case of android systems, however, even trustworthy app stores are at disposal like F-Droid (Grano et al., 2017). It has to be noted, however, that the user needs to unlock the phone's bootloader, which requires dedicated knowledge of the boot process (Maksutov et al., 2018) and may cause the warranty to expire (Wieser & Tröger, 2018). Only in case of /e/OS official installations are available that do not affect the system's warranty. In any case, a change to an alternative OS makes sense in order to retain a good user experience, data security, privacy and thus having the full device control and—most importantly—to operate more sustainable (Berker, 2023).

7.5 | Research tasks

Research can make important contributions to the development of open-source software, which includes the creation and optimization of source code as well as the continuous verification of the security of custom ROMs/mobile Linux-OSs and apps against cyber-attacks (Raut et al., 2021). In the future, it will also be necessary to examine not only the software but also the hardware to determine the extent to which it is used to systematically tap user data. Here, research may contribute to the development of open-source hardware with which illegal data leaks can be systematically avoided (Heikkinen et al., 2020).

Edge technologies, that is software running on the end user's peripheral devices, should also be developed to implement functions locally that previously used data exchange with data centers. This reduces energy consumption at the level of data exchange and ensures that personal data remains with the user (Garcia Lopez et al., 2015). A good example was the shrinking of speech recognition in Android OS from Google's servers to the user, which became possible after AI techniques with large computing technology were developed centrally and then transferred in condensed form to smartphone systems (Cormie, 2019).

We also see an important task in making user tracking more transparent so that internet users get a clear picture which of their personal data are being tapped, stored elsewhere and used for what purposes (Altpeter, 2022).

In addition, more attention must be paid to the health consequences of excessive smartphone use and corrective measures must be developed. This concerns psychological aspects such as the increase in depression among young girls (Twenge et al., 2022) or physical aspects such as the increase in eye diseases and overweight among adolescents (Chen et al., 2021; Tayhan Kartal & Yabancı Ayhan, 2021). Such symptoms were first observed in Korean studies (Moon et al., 2016) but appear relevant for various other countries with high levels of smartphone use among children, adolescents, and students (Lema & Anbesu, 2022; Wróbel-Dudzińska et al., 2023).

From a legal and sociopolitical perspective, we consider it necessary to clarify the concept of property in connection with the internet economy. The constitutions of most countries recognize the right of ownership in principle, but formulate the reservation that it should be in balance or in equilibrium with the common good (Graziadei &

Smith, 2017). In our view, the concentration of previously unimaginable large financial resources in private hands as described above and illustrated by Figure 5 lies beyond a just societal balance.

Last but not least, science and research should lead the way in the use of FOSS apps, custom ROMs, and Fediverse platforms (Brembs et al., 2023), and try to decarbonize research institutes, universities and scientific societies by setting examples in the implementation of measures (Kuppel et al., 2023).

7.6 | Political measures

On the part of policymakers, measures must be taken to extend the service life of smartphones. These can be achieved, for example, through standardization as has already been demonstrated in the case of charging connectors in the EU. For the standardization based on the USB-C plug, which will become mandatory from 2024 on, a reduction in electronic waste of nearly 1000 t can be expected (EC, 2022), whereas environmental groups see much larger potentials (ECOS, 2020). Similar specifications should be made for smartphone batteries to enable easier replacement and self-repair by the user. In addition, specifications should be made for the long-term stability of electrical parameters, which would reduce the volume of battery waste in accordance with SDG#12.

Research funding programs for the advancement of FOSS, custom ROMs, and the Fediverse should be set up and developed. In part, such funding programs are already available, but the funding volumes should be adapted to the budgets available to proprietary software. This would be inline with FOSS intention to promote social cohesion in agreement with SDG#16 and #17.

Of central importance for a more sustainable use of smartphones will be the replacement of OSs and apps from oligopoly offers. To this end, the following specific measures appear suitable.

1. Introduction of open app stores.
2. Promotion of edge computing to enable data processing and storage on users' local devices.
3. Enforcing alternative social media based on the Fediverse.

In implementing these measures, political institutions can act in their role as consumers and support the use of FOSS, custom ROMs, and the Fediverse themselves.

In the context of SDG #10, we also consider it appropriate to expropriate the socially unacceptably high profits of large internet companies and return them to society. These resources should be used to solve important tasks in the areas of education and combating hunger and poverty. Such redistribution schemes have already been proposed to compensate for the damage caused by climate change (Dehm, 2023; Neckel, 2023) and would also relax geopolitical conflict potentials in the North–South context (Grasso & Heede, 2023; Scheffran, 2023). As outlined above, the concept of private property seems no longer applicable to the enormous profits of large internet companies. This is because the high value creation on the order of hundreds of billions of euros is based on the preliminary work of tens of thousands of scientists and engineers, all of whom have contributed to this economic success. The wealth they have generated therefore belongs to society as a whole. In the European Union, for example, such a repatriation of profits can be derived from Article 17 of the Charta of Fundamental Rights, which provides for expropriation "in the public interest and in the cases and under the conditions provided for by law" (European Union, 2009). The task of politicians and lawyers will be the formulation of corresponding laws and regulations, even expropriations, that have to be drafted for the implementation of such measures. In addition to expropriation, there is also the possibility of splitting up dominant enterprises under antitrust laws. The division of the US telephone company AT&T, from which a group of seven successor companies in 1982 was spun off in order to reduce the negative effects on consumer protection associated with the company's market power, can serve as a historical model case (Usman, 2021).

8 | CONCLUSIONS

The smartphone was originally introduced as a mobile telephone. The latter in fact represents an outstanding innovation of the 20th century, allowing almost the entire world population to communicate with other people quickly and reliably as never before in history. This represents a real progress in the sense of SDG #9 "industry, innovation and infrastructure."

However, in an interplay between technology development, service providers, and consumers, the smartphone has been equipped with more and more functionalities, mainly related to the spread of the internet, which have marginalized its mobile phone function. Overall, the introduction of new technologies has reduced the energy consumption of mobile data transmission per bit, but at the same time has fueled new user behaviors. Smartphone usage may be regarded as a prototypical example of the Jevons effect, showing how efficiency gains have not only saved resources like energy, but also introduced new technologies (3G, SMS, BT, GPS, WiFi, 4G, MMS, NFC, BLE, 5G, AR, AI, VR, …) that created new demands.

Meanwhile, the energy consumption of smartphones and the network infrastructure pose a severe threat to SDG#7. This energy consumption, and especially its ongoing increase, is counterproductive to SDG#13, and "… the international community is falling far short of the Paris goals, with no credible pathway to 1.5°C in place" (UNEP, 2022).

Although an almost infinite variety of apps is offered in app stores, core areas of the smartphone market are highly monopolized, as in the sectors of OSs and social media. The market power of large internet corporations often exceeds the ability of governments to protect their consumers, who are misled into unsustainable behavior, so that mass smartphone use has come into conflict with UN SDGs #7, #10, #12, and #13. We propose to consider the expropriation of large internet companies before their financial and political power surmounts those of national states, which—as democratic representations of their people—should be responsible for their regulation.

Since the introduction of Internet2.0 technologies, the smartphone has been used by the dominant companies to grab as much information about users as possible and sell it for advertising, which violate the GDPR and the ePrivacy Directive (Paci et al., 2023). These intercepts are systematically hidden from users and represent a large part of the data transfer of today's smartphones. Moreover, scandals like Cambridge Analytica or the failure to obtain cookie consent by Meta/Facebook and fines through authorities like the Federal Trade Commission or the European Commission set against the practices of the Big Tech had little consequences and even no effect to their stock prices (Ibrahim et al., 2024; Pybus & Coté, 2024). Another possible measure is the breakup of dominant companies under the antitrust law, as practiced in 1982 in the case of the telecommunications company AT&T in the USA.

Fortunately, alternative OSs, social media and apps are available to allow for a sustainable consumer behavior.

In the coming years, science will have to investigate the sustainability and unsustainability of smartphone use beyond the question of climate change mitigation (SDG#13)—as we have attempted to begin with in this work. Because of the high interdisciplinarity of the task, different disciplines such as computer and energy science, economics, law, ethics, health psychology, social sciences, and others will have to be involved (Armand, 2012). In addition, science can also support climate protection and the achievement of UN SDGs, by disengaging from oligopolistic market structures of smartphone use and the internet in general through the application of sustainable ICT systems.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ORCID

Martin Kögler https://orcid.org/0000-0003-2154-8879
Katharina Paulick https://orcid.org/0000-0002-8079-5944
Jürgen Scheffran https://orcid.org/0000-0002-7171-3062
Mario Birkholz https://orcid.org/0000-0002-5818-7379

REFERENCES

Agrawal, D., Zhang, C., Kettinger, W. J., & Adeli, A. M. (2022). Spy it before you try it: Intrinsic cues and open data app adoption. *Communications of the Association for Information Systems*, *50*, 554–575.

Aguiar, L., Peukert, C., Schaefer, M., & Ullrich, H. (2022). Facebook Shadow Profiles (February 2022). DIW Berlin Discussion Paper No. 1998. https://doi.org/10.2139/ssrn.4032514

Altpeter, B. (2022). *Informed consent? A study of "consent dialogs" on android and iOS*. TU Braunschweig.

Amadeo, R. (2018). Google's iron grip on android: Controlling open source by any means necessary [Arstechnica technical review]. Access from Google's Iron Grip on Android: Controlling Open Source by any Means Necessary from the Archives: Android Is Open—Except for all the Good Parts. Website https://arstechnica.com/gadgets/2018/07/googles-iron-grip-on-android-controlling-open-source-by-any-means-necessary/

Amnesty International. (2018). Toxic twitter – A toxic place for women [research report]. https://www.amnesty.org/en/latest/research/2018/03/online-violence-against-women-chapter-1-1/

Andrae, A., & Edler, T. (2015). On global electricity usage of communication technology: Trends to 2030. *Challenges*, *6*, 117–157.

Armand, J.-L. (2012). The bringing together of technology, sustainability and ethics. *Sustainability Science*, *7*, 113–116.

Aslan, J., Mayers, K., Koomey, J. G., & France, C. (2018). Electricity intensity of internet data transmission: Untangling the estimates: Electricity intensity of data transmission. *Journal of Industrial Ecology*, *22*, 785–798.

Bachrach, Y., Kosinski, M., Graepel, T., Kohli, P., & Stillwell, D. (2012). *Personality and patterns of Facebook usage. Proceedings of the 4th annual ACM web science conference* (pp. 24–32). ACM.

Bain, I. (2023). Is TikTok's 'shoppertainment' sales model pushing Gen Z into debt? Just look at the numbers. *The Guardian*. https://www.theguardian.com/commentisfree/2023/mar/16/tiktoks-shoppertainment-model-gen-z-debt

Bandhauer, T. M., Garimella, S., & Fuller, T. F. (2011). A critical review of thermal issues in lithium-ion batteries. *Journal of the Electrochemical Society*, *158*, R1.

Belkhir, L., & Elmeligi, A. (2018). Assessing ICT global emissions footprint: Trends to 2040 & recommendations. *Journal of Cleaner Production*, *177*, 448–463.

Berker, T. (2023). Infrastructures by the users for users: Motivations, constraints, and consequences of user-driven infrastructuring of mobile phones. *New Media & Society*, https://doi.org/10.1177/14614448231166896

Bieser, J. C. T., Blumer, Y., Burkhalter, L., Itten, R., Jobin, M., & Hilty, L. M. (2022). Consumer-oriented interventions to extend smartphones' service lifetime. *Cleaner and Responsible Consumption*, *7*, 100074.

Bieser, J. C. T., Hintemann, R., Hilty, L. M., & Beucker, S. (2023). A review of assessments of the greenhouse gas footprint and abatement potential of information and communication technology. *Environmental Impact Assessment Review*, *99*, 107033.

Binns, R. (2022). Tracking on the web, Mobile and the internet of things. *Foundations and Trends® in Web Science*, *8*, 1–113.

Birkholz, M. (2023). Microelectronic implants. In A. Kumar & R. K. Gupta (Eds.), chapter 21, *Bioelectronics—Materials, technologies, and emerging applications* (1st ed.) (pp. 341–355). CRC Press.

Birkholz, M., Mai, A., Wenger, C., Meliani, C., & Scholz, R. (2016). Technology modules from micro- and nanoelectronics for the life sciences. *WIRE Nanomedicine and Nanobiotechnology*, *8*, 355–377.

Boadle, A. (2018). Facebook's WhatsApp flooded with fake news in Brazil election. *Reuters*. https://www.reuters.com/article/us-brazil-election-whatsapp-explainer-idUSKCN1MU0UP

Borland, H., Bhatti, Y., & Lindgreen, A. (2019). Sustainability and sustainable development strategies in the UK plastic electronics industry. *Corporate Social Responsibility and Environmental Management*, *26*(4), 805–818.

Brembs, B., Lenardic, A., Murray-Rust, P., Chan, L., & Irawan, D. E. (2023). Mastodon over Mammon: towards publicly owned scholarly knowledge. *Royal Society Open Science*, *10*(7), 23020710. https://doi.org/10.5281/ZENODO.7974099

Carroll, A., & Heiser, G. (2010). *An Analysis of Power Consumption in a Smartphone.*, USENIXATC'10: Proceedings of the 2010 USENIX conference on USENIX annual technical conference, 14. https://dl.acm.org/doi/10.5555/1855840.1855861

Chen, C.-Y., Chen, I.-H., O'Brien, K. S., Latner, J. D., & Lin, C.-Y. (2021). Psychological distress and internet-related behaviors between schoolchildren with and without overweight during the COVID-19 outbreak. *International Journal of Obesity*, *45*, 677–686.

Cooke, T. N. (2020). Metadata, jailbreaking, and the cybernetic governmentality of iOS: Or, the need to distinguish digital privacy from digital privacy. *Surveillance & Society*, *18*, 90–103.

Cormie, A. (2019). Count 'em up: 100 things we announced at I/O' 19. https://blog.google/technology/developers/100-things-we-announced-io-19/

Cucchietti, F., Moll, J., Esteban, M., Reyes, P., & Calatrava, C. G. (2022). *Carbolytics, an analysis of the carbon costs of online tracking*. Barcelona Supercomputing Center. https://carbolytics.org/report.html

Datarequests. (2023). You have a right to privacy! Datarequests.org logo website: https://www.datarequests.org/

De Mooij, R., Klemm, A., & Perry, V. (Eds.). (2021). *Corporate income taxes under pressure*. International Monetary Fund.

Dehm, J. (2023). Beyond climate due diligence: Fossil fuels, 'red lines' and reparations. *Business and Human Rights Journal*, *8*, 151–179.

Di Meco, L. (2023). Monetizing misogyny—Gendered disinformation and the undermining of Women's rights and democracy globally. In *She Persisted*. https://she-persisted.org/wp-content/uploads/2023/02/ShePersisted_MonetizingMisogyny.pdf

Dienste, W. (2021). *Energieverbrauch von Rechenzentren* Sachstand Nr. WD 8-3000-070/21. Wissenschaftliche Dienste.

EC. (2022). *A common charger for electronic devices—Factsheet*. European Commision GROW.01.DIR. https://ec.europa.eu/docsroom/documents/50321

European Commission, Directorate-General for Communications Networks, Content and Technology, Montevecchi, F., Stickler, T., Hintemann, R., Hinterholzer, S. (2020). Energy-efficient cloud computing technologies and policies for an eco-friendly cloud market – Final study report, Publications Office. https://data.europa.eu/doi/10.2759/3320

ECOS. (2020). *One charger to fit them all—Using Ecodesign to deliver an ambitious common charger initiative*. Environmental Coalition on Standards.

EEB. (2022). Locomotion—Energy security, sustainability and sufficiency in Europe and beyond LOW-CARBON SOCIETY: AN ENHANCED MODELLING TOOL FOR THE TRANSITION TO SUSTAINABILITY. Horizon 2020 research and innovation programme under grant agreement No 821105 European Environmental Bureau.

El-Mougy, A., Al-Shiab, I., & Ibnkahla, M. (2019). Scalable personalized IoT networks. *Proceedings of the IEEE*, *107*, 695–710.

Ericsson. (2022). *Ericsson Mobility Report* 2022. https://d110erj175o600.cloudfront.net/wp-content/uploads/2022/11/29180338/Ericsson-Mobility-Report-November-2022.pdf

European Commission. (2023). Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules promoting THE repair of goods. https://commission.europa.eu/document/afb20917-5a6c-4d87-9d89-666b2b775aa1_en

European Union. (2009). Charter of fundamental rights of the European Union. 2012/C 326/02. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:12012P/TXT

Evangelista, R., & Bruno, F. (2019). WhatsApp and political instability in Brazil: Targeted messages and political radicalisation. *Internet Policy Review*, *8*, 1–23. https://doi.org/10.14763/2019.4.1434

Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G. S., & Friday, A. (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. *Patterns*, *2*, 100340.

Garcia Lopez, P., Montresor, A., Epema, D., Datta, A., Higashino, T., Iamnitchi, A., Barcellos, M., Felber, P., & Riviere, E. (2015). Edge-centric computing: vision and challenges. *ACM SIGCOMM Computer Communication Review*, *45*, 37–42.

Garg, S., & Baliyan, N. (2021). Comparative analysis of android and iOS from security viewpoint. *Computer Science Review*, *40*, 100372.

Grano, G., Di Sorbo, A., Mercaldo, F., Visaggio, C. A., Canfora, G., & Panichella, S. (2017). Android apps and user feedback: A dataset for software evolution and quality improvement. *Proceedings of the 2nd ACM SIGSOFT International Workshop on App Market Analytics*, 8–11. Paderborn Germany: ACM.

Grasso, M., & Heede, R. (2023). Time to pay the piper: Fossil fuel companies' reparations for climate damages. *One Earth*, *6*, 459–463.

Graziadei, M., & Smith, L. D. (Eds.). (2017). *Comparative property law: Global perspectives*. Edward Elgar Publishing.

Green, R. A. (2021). Possibilities in bioelectronics: Super humans or science fiction? *APL Bioengineering*, *5*, 040401.

Grolleau, J. (2021). The strategy behind sovereign mobile operating systems adoption. https://manu.hbrt.eu/files/202105rapport.pdf

Gupta, N. (2016). *Inside Bluetooth low energy* (2nd ed.). Artech House.

Haucke, F. V. (2018). Smartphone-enabled social change: Evidence from the Fairphone case? *Journal of Cleaner Production*, *197*, 1719–1730.

Heikkinen, I. T. S., Savin, H., Partanen, J., Seppälä, J., & Pearce, J. M. (2020). Towards national policy for open source hardware research: The case of Finland. *Technological Forecasting and Social Change*, *155*, 119986.

Hickey, D., Schmitz, M., Fessler, D., Smaldino, P., Muric, G., & Burghardt, K. (2023). arXiv, Auditing Elon Musk's Impact on Hate Speech and Bots. Proceedings of the Seventeenth International AAAI Conference on Web and Social Media (ICWSM2023), 1133.

Humar, I., Ge, X., Xiang, L., Jo, M., Chen, M., & Zhang, J. (2011). Rethinking energy efficiency models of cellular networks with embodied energy. *IEEE Network*, *25*, 40–49.

Ibrahim, H., Debicki, M., Rahwan, T., & Zaki, Y. (2024). Big tech dominance despite global mistrust. *IEEE Transactions on Computational Social Systems*, 1–12. https://doi.org/10.1109/TCSS.2023.3339183

IPPC. (2021). *Climate change 2021 – The physical science basis: Working group I contribution to the sixth assessment report of the intergovernmental panel on climate change*.(1st ed) Cambridge University Press.

IPPC. (2022). Climate change 2022: Mitigation of climate change. In *Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge University Press.

Jattke, M., Bieser, J., Blumer, Y., Itten, R., & Stucki, M. (2020). Environmental implications of service life extension of mobile devices. https://doi.org/10.21256/ZHAW-20808

Jindra, B., Hatani, F., Steger, T., & Hiemer, J. (2019). Social upgrading and cooperative corporate social responsibility in global value chains: The case of Fairphone in China. *Global Networks*, *19*, 371–393.

Kansok-Dusche, J., Ballaschk, C., Krause, N., Zeißig, A., Seemann-Herz, L., Wachs, S., & Bilz, L. (2022). A systematic review on hate speech among children and adolescents: Definitions, prevalence, and overlap with related phenomena. *Trauma, Violence, & Abuse*, *24*, 152483802211080.

Karaj, A., Macbeth, S., Berson, R., & Pujol, J. M. (2018). Who tracks me: Shedding light on the opaque world of online tracking. https://doi.org/10.48550/ARXIV.1804.08959

Kim, T., Song, W., Son, D.-Y., Ono, L. K., & Qi, Y. (2019). Lithium-ion batteries: Outlook on present, future, and hybridized technologies. *Journal of Materials Chemistry A*, *7*, 2942–2964.

Kollnig, K., Shuba, A., Binns, R., Van Kleek, M., & Shadbolt, N. (2022). Are iPhones really better for privacy? A comparative study of iOS and android apps. *Proceedings on Privacy Enhancing Technologies*, *2022*, 6–24.

Kosinski, M., Stillwell, D., & Graepel, T. (2013). Private traits and attributes are predictable from digital records of human behavior. *Proceedings of the National Academy of Sciences*, *110*, 5802–5805.

Kuketz, M. (2021). Für Anfänger/Bequeme: Werbung und Tracker unter iOS/Android systemweit verbannen. *Abgerufen von Kuketz—IT-Security* https://www.kuketz-blog.de/fuer-anfaenger-bequeme-werbung-und-tracker-unter-ios-android-systemweit-verbannen/

Kuppel, S., Marc, O., Riva, R., & Wens, M. (2023). Activism as a tool for education and societal outreach: Legitimacy, efficiency and complementarity with classic science communication. Gehalten auf der EGU General Assembly 2023, Vienna https://doi.org/10.5194/egusphere-egu23-8324

La Cava, L., Greco, S., & Tagarelli, A. (2021). Understanding the growth of the Fediverse through the lens of mastodon. *Applied Network Science*, *6*, 64.

Laksono, R. P. B. (2020). The analysis of implementation of custom firmware, microg, and host adblocker on privacy leaking on android operation system. *Jurnal Profita: Kajian Ilmu Akuntansi*, *8*, 1–17 https://journal.student.uny.ac.id/index.php/profita/article/download/16874/16290

Lange, S., Santarius, T., Dencik, L., Diez, T., Ferreboeuf, H., Hankey, S., Hilbeck, A., Hilty, L., Höjer, M., Kleine, D., Pohl, J., Reisch, L., Ryghaug, M., Schwanen, T., & Staab, P. (2023). *Digital reset, redirecting Technologies for the Deep Sustainability Transformation*. oekom Verlag.

Lee, Y., He, L., & Kang, S. G. (2020). Causes and fixes of unexpected phone shutoffs. Proceedings of the 18th international conference on Mobile systems, applications, and services Gehalten auf der Conference on Mobile Systems, Applications, and Services, Toronto, Canada. Toronto, Canada: ACM.

Leith, D. J. (2021). Mobile handset privacy: Measuring the data iOS and android send to apple and Google. In J. Garcia-Alfaro, S. Li, R. Poovendran, H. Debar, & M. Yung (Eds.), *Security and privacy in communication networks* (pp. 231–251). Springer International Publishing.

Leith, D. J. (2023). What data do the Google dialer and messages apps on android send to Google? In F. Li, K. Liang, Z. Lin, & S. K. Katsikas (Eds.), *Security and privacy in communication networks* (pp. 549–568). Springer Nature Switzerland.

Lema, A. K., & Anbesu, E. W. (2022). Computer vision syndrome and its determinants: A systematic review and meta-analysis. *SAGE Open Medicine*, *10*, 205031212211424.

Libert, T. (2018). An automated approach to auditing disclosure of third-party data collection in website privacy policies. In *Proceedings of the 2018 world wide web conference on world wide web-WWW 18, 207–216*. ACM Press.

Lohmeier, L. (2023). Gewinn von Alphabet weltweit bis 2022. Statista GmbH. https://de.statista.com/statistik/daten/studie/155091/umfrage/nettogewinn-von-apple-inc-seit-2005/

Lüthje, B., & Hürtgen, S. (2013). *From Silicon Valley to Shenzhen: Global production and work in the IT industry*. Rowman & Littlefield Publishers, Inc.

Maksutov, A. A., Dmitriev, S. O., Lysenkov, V. I., & Valter, D. A. (2018). Mobile bootloader with security features. In *2018 IEEE conference of Russian young researchers in electrical and electronic engineering (EIConRus)* (pp. 335–338). IEEE.

Malmodin, J., & Lunden, D. (2018). *The electricity consumption and operational carbon emissions of ICT network operators 2010–2015*. Report from the KTH Centre for Sustainable Communications. https://www.diva-portal.org/smash/get/diva2:1177210/FULLTEXT01.pdf

Marosi, A. C., Lovas, R., Kisari, A., & Simonyi, E. (2018). A novel IoT platform for the era of connected cars. In *2018 IEEE International Conference on Future IoT Technologies (Future IoT)* (pp. 1–11). IEEE.

McCrae, R. R., & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of Personality*, *60*, 175–215.

Meineck, S. (2023). Meta legt KI-Systeme offen—Ich fühle mich begafft. Abgerufen 11. Juli 2023, von Netzpolitik.org website: https://netzpolitik.org/2023/meta-legt-ki-systeme-offen-ich-fuehle-mich-begafft/

Mills, M. P. (2019). The "new energy economy": An exercise in magical thinking. The Manhattan Institute: New York, NY, USA.

Moon, J. H., Kim, K. W., & Moon, N. J. (2016). Smartphone use is a risk factor for pediatric dry eye disease according to region and age: A case control study. *BMC Ophthalmology*, *16*, 188.

Morley, J., Widdicks, K., & Hazas, M. (2018). Digitalisation, energy and data demand: The impact of internet traffic on overall and peak electricity consumption. *Energy Research & Social Science*, *38*, 128–137.

Moscariello, N., Pizzo, M., Ricciardi, G., Mallardo, G., & Fattorusso, P. (2024). The anti-corruption compliance models in a multinational company: A single case study. *Business Strategy and the Environ-Ment*, *33*(1), 70–80. https://doi.org/10.1002/bse.3331

Neckel, S. (2023). Zerstörerischer Reichtum—Wie eine globale Verschmutzerelite das Klima ruiniert. *Blätter für Deutsche Und Internationale Politik*, *68*(4), 47–56. https://www.blaetter.de/ausgabe/2023/april/zerstoererischer-reichtum

Nguyen, D., Mc Caffrey, C., Silven, O., & Kögler, M. (2022). Physically flexible ultralow-power wireless sensor. *IEEE Transactions on Instrumentation and Measurement*, *71*, 1–7.

Noyb. (2023). NOYB–European center for digital rights. Abgerufen von My Privacy is None of Your Business website: https://noyb.eu/en

Paci, F., Pizzoli, J., & Zannone, N. (2023). A comprehensive study on third-party user tracking in mobile applications. In Proceedings of the 18th International Conference on Availability, Reliability and Security (1–8).

Palacin, R. (2018). Understanding ageing in Li-ion batteries: A chemical issue. *Chemical Society Reviews*, *47*, 4924–4933.

Papadopoulos, P., Kourtellis, N., & Markatos, E. (2019). Cookie synchronization: Everything you always wanted to know but were afraid to ask. The world wide web conference, 1432–1442, San Francisco CA USA: ACM.

Pasricha, S., Ayoub, R., Kishinevsky, M., Mandal, S. K., & Ogras, U. Y. (2020). A survey on energy Management for Mobile and IoT devices. *IEEE Design & Test*, *37*, 7–24.

Paulick, K., Seidel, S., Lange, C., Kemmer, A., Cruz-Bournazou, M. N., Baier, A., & Haehn, D. (2022). Promoting sustainability through next-generation biologics drug development. *Sustainability*, *14*, 4401.

Perrucci, G. P., Fitzek, F. H. P., & Widmer, J. (2011). Survey on energy consumption entities on the smartphone platform. In *2011 IEEE 73rd vehicular technology conference (VTC Spring)* (pp. 1–6). IEEE.

Pihkola, H., Hongisto, M., Apilo, O., & Lasanen, M. (2018). Evaluating the energy consumption of Mobile data transfer—From technology development to consumer behaviour and life cycle thinking. *MDPI Sustainability*, *16*, 1–18.

Pluta, A., Mazurek, J., Wojciechowski, J., Wolak, T., Soral, W., & Bilewicz, M. (2023). Exposure to hate speech deteriorates neurocognitive mechanisms of the ability to understand others' pain. *Scientific Reports*, *13*, 4127.

Polimeni, J. M. (Ed.). (2008). *The Jevons paradox and the myth of resource efficiency improvements*. Earthscan.

Ponakala, R. (2017). A special study report submitted in partial fulfillment of the requirements for the degree of master of engineering in information and communication technology. In *Lineageos Android Open Source Mobile Operating System: Strengths And Challenges*. Asian Institute of Technology School of Engineering and Technology.

Pybus, J., & Coté, M. (2024). Super SDKs: Tracking personal data and platform monopolies in the mobile. *Big Data & Society*, *11*(1), 20539517241231270.

Rauhala, T. (2020). *Electrochemical studies on degradation mechanisms of electrode materials in lithium-ion batteries* (Doctoral thesis, Aalto University). Aalto University.

Raut, S., Prabhu, S. R., & Agrawal, A. K. (2021). Ensuring smartphone security through real-time log analysis. *Proceedings of the International Conference on Smart Data Intelligence (ICSMDI 2021), International Conference on Smart Data Intelligence (ICSMDI 2021) organized by Kongunadu College of Engineering and Technology at Trichy*, 8. http://dx.doi.org/10.2139/ssrn.3852756

rinigus. (2022). SystemDataScope [Depository]. Abgerufen von GitHub website: https://github.com/rinigus/systemdatascope

Ripple, W. J., Wolf, C., Newsome, T. M., Galetti, M., Alamgir, M., & Crist, E. (2017). World Scientists' warning to humanity: A second notice. *Bioscience*, *67*, 1026–1028.15,364 scientist signatories from 184 countries.

Ritchie, H., Roser, M., & Rosado, P. (2022). Electricity production by source, world. Abgerufen von our World in Data—Energy Website: https://ourworldindata.org/energy

Ritchie, H., Roser, M., & Rosado, P. (2020). Global CO2 emissions from fossil fuels and land use change. Abgerufen von Our World in Data—CO_2

and Greenhouse Gas Emissions. https://ourworldindata.org/co2-and-greenhouse-gas-emissions
Rosen, S., Nikravesh, A., Guo, Y., Mao, M., Qian, F., & Sen, S. (2015). Revisiting network energy efficiency of Mobile apps: Performance in the wild. https://doi.org/10.1145/2815675.2815713
Ruzzenenti, F., Font Vivanco, D., Galvin, R., Sorrell, S., Wagner, A., & Walnum, H. J. (2019). Editorial: The rebound effect and the Jevons' paradox: Beyond the conventional wisdom. *Frontiers in Energy Research*, *7*, 90.
Schallenberger, L. (2022). Ich habe mir alle Daten besorgt, die Google über mich hat—Sie sind noch viel intimer als ich befürchtet hatte. *Business Insider* https://www.businessinsider.de/wirtschaft/google-daten-anfrage-das-weiss-google-ueber-mich-meinen-suchverlauf-arztbesuche-und-viele-private-dinge/
Scheffran, J. (2023). Limits to the Anthropocene: Geopolitical conflict or cooperative governance? *Frontiers in Political Science*, *5*, 1190610.
Scheffran, J., Felkers, M., & Froese, R. (2020). Economic growth and the global energy demand. In A. A. Vertès, N. Qureshi, H. P. Blaschek, & H. Yukawa (Eds.), *Green energy to sustainability* (1st ed., pp. 1–44). Wiley.
Scholten, T., van der Niet, S., Nieuwenhuijse, I., & Vendrik, J. (2020). *Energiegebruik 5G-netwerk*. CE Delft.
Shift Project. (2019). Lean ICT: Towards digital sobriety. https://theshiftproject.org/en/article/lean-ict-our-new-report/
Statista Research Department. (2023). Gewinn von Apple bis 2022. Statista GmbH. https://de.statista.com/statistik/daten/studie/155091/umfrage/nettogewinn-von-apple-inc-seit-2005/
Su, J. (2019). Confirmed: Apple caught in Siri privacy scandal, let contractors listen to private voice recordings. Forbes. https://www.forbes.com/sites/jeanbaptiste/2019/07/30/confirmed-apple-caught-in-siri-privacy-scandal-let-contractors-listen-to-private-voice-recordings/
TaheriNejad, N., Perego, P., & Rahmani, A. M. (2022). Mobile health technology: From daily care and pandemics to their energy consumption and environmental impact. *Mobile Networks and Applications*, *27*, 652–656.
Takara, K. (2023). *Batterygate: An ethical analysis of Apple's infamous multimillion Dollar mistake (California State University)*. California State University. https://scholarworks.calstate.edu/concern/projects/3r075211c
Takeno, K., Ichimura, M., Takano, K., & Yamaki, J. (2005). Influence of cycle capacity deterioration and storage capacity deterioration on Li-ion batteries used in mobile phones. *Journal of Power Sources*, *142*, 298–305.
Tayhan Kartal, F., & Yabancı Ayhan, N. (2021). Relationship between eating disorders and internet and smartphone addiction in college students. *Eating and Weight Disorders - Studies on Anorexia, Bulimia and Obesity*, *26*, 1853–1862.
Testa, S., Troise, C., Cincotti, S., & Camilleri, M. A. (2024). The role of electronic waste management solu-tions and message framing in influencing consumer behaviours: Exploring the crowdfunding context. *Business Strategy and the Environment*, *33*(2), 917–929.
Twenge, J. M., Haidt, J., Lozano, J., & Cummins, K. M. (2022). Specification curve analysis shows that social media use is linked to poor mental health, especially among girls. *Acta Psychologica*, *224*, 103512.
Twenge, J. M., Martin, G. N., & Campbell, W. K. (2018). Decreases in psychological well-being among American adolescents after 2012 and links to screen time during the rise of smartphone technology. *Emotion*, *18*, 765–780.
Tzvetanov, K., & Karabiyik, U. (2020). A first look at forensic analysis of sailfish OS. *Computers & Security*, *99*, 102054.
Uijttewaal, M., Bergsma, G., & Scholten, T. (2021). *Carbon footprint of unwanted data-use by smartphones—An analysis for the EU*. CE Delft. https://cedelft.eu/publications/carbon-footprint-of-unwanted-data-use-by-smartphones-an-analysis-for-the-eu/
UNEP. (2022). *Emissions gap report 2022*. UN Environment Programme.
Urban, T., Degeling, M., Holz, T., & Pohlmann, N. (2020). Beyond the front page: Measuring third party dynamics in the field. In *Proceedings of the web conference 2020* (pp. 1275–1286). ACM.
Usman, M. (2021). Breaking up big tech: Lessons from AT&T. *University of Pennsylvania Law Review*, *170*, 523.
Vallina-Rodriguez, N., Sundaresan, S., Razaghpanah, A., Nithyanand, R., Allman, M., Kreibich, C., & Gill, P. (2016). Tracking the trackers: Towards understanding the Mobile advertising and tracking ecosystem. arXiv.
Vetter, V., Novák, P., Wagner, M. R., Veit, C., Möller, K.-C., Besenhard, J. O., & Hammouche, A. (2005). Ageing Mechanisms in Lithium-Ion Batteries. *Journal of Power Sources*, *147*, 269–281.
Wieser, H., & Tröger, N. (2018). Exploring the inner loops of the circular economy: Replacement, repair, and reuse of mobile phones in Austria. *Journal of Cleaner Production*, *172*, 3042–3055.
Wikipedia. (2023). List of countries by government budget. Abgerufen 23 August 2023, von List of countries by government budget website: https://en.wikipedia.org/wiki/List_of_countries_by_government_budget
Williams, L., Sovacool, B. K., & Foxon, T. J. (2022). The energy use implications of 5G: Reviewing whole network operational energy, embodied energy, and indirect effects. *Renewable and Sustainable Energy Reviews*, *157*, 112033. https://doi.org/10.1016/j.rser.2021.112033
Word Wide Web Consortium. (2018). *ActivityPub W3C recommendation 23 January 2018*. https://www.w3.org/TR/activitypub/
World Bank. (2023). Mobile cellular subscriptions (per 100 people)—World. Abgerufen von the World Bank Data Website: https://data.worldbank.org/indicator/IT.CEL.SETS.P2?locations=1W
Wróbel-Dudzińska, D., Osial, N., Stępień, P. W., Gorecka, A., & Żarnowski, T. (2023). Prevalence of dry eye symptoms and associated risk factors among university students in Poland. *International Journal of Environmental Research and Public Health*, *20*, 1313.
Wylie, C. (2019). *MINDF*CK-Inside Cambridge Analytica's Plot to Break the World*. Profile Books Ltd.
Zuboff, S. (2019). *The age of surveillance capitalism: The fight for a human future at the new frontier of power*. Profile books.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Kögler, M., Paulick, K., Scheffran, J., & Birkholz, M. (2024). Sustainable use of a smartphone and regulatory needs. *Sustainable Development*, *32*(6), 6182–6200. https://doi.org/10.1002/sd.2995