# Energy Footprint of Mobile communications in the 21st century

Andreas Nicklaus

16. Februar 2024, Hochschule der Medien, Stuttgart

**Zusammenfassung**

deutsche Version

**Abstract**

englische Version

## Contents

# 1 Introduction

Since around 2010, mobile communication has been a vital part of everyday-life for most of the western world. In 2007, we saw the launch of the iPhone, arguably one of the most influencial inventions in the mobile market ever. With the introduction of 4G in late 2009 came a massive increase in mobile communication over the internet. For almost one and a half decades, more and more technology has been invented for the mobile phone market.

In addition, the Oculus Rift has ushered in the reincarnation of the idea of Virtual Reality and spacial computing, plainly meaning the usage of 3D-space as a way to distribute user interfaces. More and more, we rely on small, wireless devices with a sleek, modern and fashionable design and people seem to keep buying in. With that in mind, most mobile User Equipment (UE) has had one spatial constraint that has so far never been overcome: Battery life and usage breaks to recharge at a wall socket. This paper focuses on the effectiveness of energy consumption in respect to the overall environmental impact of modern mobile communications. To this end, the following chapter 2 summarizes other work done in the field and its topics. Chapter 3 introduces a definition of environmental footprint and its relevance to this topic. The chapters 4 and 5 go into detail about the energy production and consumption in Germany both in general and related to mobile communications. Chapter 6 then names a few opportunities for saving energy.

# 2 Related Work

When inspecting the relevance of mobile communications within the global energy market, one can only rely on data given out by nations or leagues of nations. [Umwelt Bundesamt, 2024] gives a summary of the electricity consumption in Germany by year and [DESTATIS Statistisches Bundesamt, 2023a] shows the production of electrical power between 2019 and 2022 by energy source.

[Bayerisches Landesamt für Umwelt, 2024] lists generalized indicators for environmental impact. These indicators are meant to help analyze the effect of any product or project on the environment.

The whitepaper [Huawei Technologies, 2019] is a technical report on the state of Radio Base Station (BS) and gives insight into the power consumption of BS as a whole and parts. The paper also outlines challenges for the construction of site power supply and gives pointers to what efficient power saving strategies could do.

[Shurdi et al., 2021] describe the energy consumption and efficiency of BS in detail and examines the power consumption of switching between a sleep state and an active state.

[Shen et al., 2022] outline the technical changes going from 4G to 5G infrastructure. Based on those findings, they propose multiple sleep mode switching policies and gives a comparison between them.

# 3 Environmental footprint

This chapter gives an outline of the meaning of environmental impact and the metrics for it. First, the section 3.1 summarizes the indicators factoring into the effect on the environment. Second, the section 3.2 gives first answers to the relevancy of those indicators and interprets why some indicators are more relevant to this topic than others.

## 3.1 Indicators for environmental footprint

When we want to analyze the impact something has on the environment, we need to have consistent metrics to give values to and compare. [Bayerisches Landesamt für Umwelt, 2024] gives 27 general indicators as to what those metrics have to reflect on and are grouped into four categories. Table 1 show all indicators within its category.

For this paper, these indicators will be used to narrow down the topic down to the most relevant factors.

## 3.2 Relevancy of indicators

On the topic of mobile communications in general, all indicators of the category „Nature and landscape“ can be ignore due to the fact that they are not applicable to either BS, cable laying to and from those BS or the UE.

From the category „Climate and Energy“, the indicator Climate change and vegetation development will be ignored due to the BS' signal outputs' unproven significance on the vegetation. The effect of BS on the climate change is only noticable through the usage of electicity which is inspected under the other indicators of the category.

The category „Environment and health“ only yields the relevant indicators air quality and noise pullution, both mainly dependent on the energy source of BS and UE. The other indicators of the category will be ignore because they are not applicable to mobile communications. The positive effect that mobile communications might have towards the management of traffic and both freight and public transport are not inspected in this paper.

This paper assumes that only a insignificant number of BS are built on agricultural land and that once built these BS produce next to no waste at all. Therefore the indicators waste generation and organic farming can be left out of this paper. All other indicators from the category „Resources and

| **Climate and Energy** | **Nature and landscape** | **Environment and health** | **Resources and efficiency** |
|---|---|---|---|
| Climate change and vegetation development | Landscape fragmentation | *Air quality* | Waste generation |
| *Carbon dioxide emissions* | Species diversity and landscape quality | *Noise pollution* | *Recycling rate* |
| *Energy consumption* | Red List species | Road traffic noise | *Resource productivity* |
| *Renewable energies* | Area for nature conservation objectives | Freight transport performance | Organic farming |
| | Agricultural land with high nature value | Local public transport | *Settlement and traffic area* |
| | Forest condition | Nitrate in groundwater | *Land use* |
| | Acidity and nitrogen input | Heavy metal input | *Contaminated sites* |
| | Nitrogen surplus | | |
| | Ecological status of surface waters | | |

Table 1: 27 Environmental Indicators [Bayerisches Landesamt für Umwelt, 2024], italics are relevant to mobile communications

efficiency“ are applicable to the build site and lifecycle of BS and UE and are applicable to mobile communications.

The indicators „Carbon dioxide emissions“, „Air quality“ and „Noise pollution“ all boil down the source of electical power of the base station and UE. [Huawei Technologies, 2019] implicates that near all BS use whatever electical power they can get on-site and have lithium-ion batteries for emergency-power. With that electrical equipment the effect of those three indicators are dependent on the source on the power grid and therefore dependent on the indicators „Energy consumption“ of the equipment and the „Renewable energies“ produces for the power grid of the region.

„Settlement and traffic area“, „Land use“ and „Contaminated sites“ come down the the area that build site of BS. [Deutsche Funkturm, 2024] states in its advertisement for new build site of BS „Around ten square meters of technical space is required to operate a radio station on the roof, and around 150 square meters of floor space or technical space is required for a mast". Because it is possible to use already developed areas and effect on the above mentioned indicators is not caused by the building of new BS, the effect of BS can be considered nonexistent.

This means that only four of the 27 indicators are relevant to mobile communications:

1. **Energy consumption**: Energy, electrical and other, consumed per consumer unit and consumption time. Usually measured in kWh per person and year.
2. **Renewable energies**: Share of renewable energy in energy consumption and production (assumed to be equal here).
3. **Recycling rate**: Share of recycled materials in total waste generation.
4. **Resource productivity**: Ratio of gross domestic product to primary energy consumption or raw material consumption in relation to a base year.

The upcoming chapters will only cover those four topics.

# 4 Numbers: mobile communication and national power consumption

Having narrowed down the topic of environmental impact of mobile communications down to the power consumed by the equipment and the resources used in production and after usage, this chapter aims to give comparison and numbers filling in the indicators of chapter 3. For the comparison, the assumption is made that the usage and production of base stations is similiar around the world although for the energy consumption and production, the mobile communications and energy markets of only Germany will be inspected.

## 4.1 National energy data of Germany

In the year 2022, 573.1 TWh of electricity were produced gross, close to 2% less than the three-year average of ca. 584.06 TWh in 2019-2022. Of that, 254 TWh (44%) were produced using renewable energy sources, mainly wind power and photovoltaics [DESTATIS Statistisches Bundesamt, 2023a]. Over the whole year 2022, 11,01% (63,1 TWh) of the greed feed-in were imported [DESTATIS Statistisches Bundesamt, 2024]. In the third quartal of 2022, 10.99% (13 of 118.2 TWh) have been imported and 16 TWh have been exported. The third quartal of 2023 showed an increase of imported feed-in to 23.1 TWh and 9.9 TWh exported power [DESTATIS Statistisches Bundesamt, 2023b].

In 2022, 552 TWh have been consumed gross [Umwelt Bundesamt, 2024] and 490.6 TWh net [Statista, 2024]. Of the gross consumption, 46% have been from renewable energy sources [Umwelt Bundesamt, 2024].

## 4.2 Base Stations

According to Deutsche Funkturm [2024], a build-site for single BS needs a power supply that can deal with a constant load of 3kW. In Buchheister [2023], Vodafone states to have have built 14200 sites with at least some 5G capabilities and there are 41945 5G Radio Base Stations in Germany [Statista, 2024]. The exact number of BS is probably difficult to determine because there are only very few public technical reports on the expansion to 5G and most of the marketing publications online have no technical information as to which „5G Radio Base Stations" include sites with LTE functionality used for NSA mode 5G New Radio.

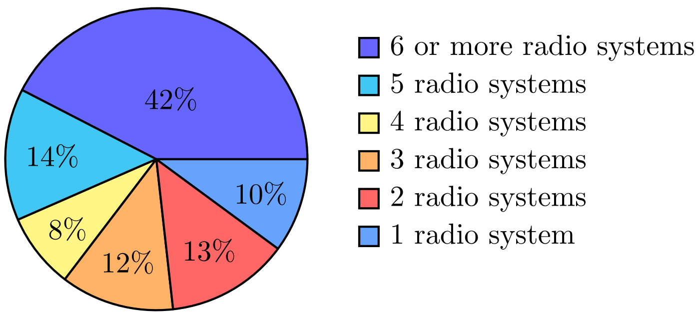


Figure 1: Distribution of radio systems within all Radio Base Station sites in Germany [Bundesnetzagentur, 2024] (missing one percent due to rounding errors)

However, it is known that there are 71510 „mobile phone sites" in Germany. This number includes radio sites with LTE (800 MHz), GSM (900 MHz), GSM/LTE (1800 MHz), UMTS/LTE (2600 MHz) and 5G (3600 MHz) equipment. Figure 1 shows the distribution of number of radio systems on those sites [Bundesnetzagentur, 2024].

Taking 41945 5G Radio Base Stations and 3kW as our reference number of units and power consumption for 5G under full load, it can be estimated that the total grid load is 125.835 GW. Assuming full load all year around the maximum power consumption can be calculated with 1.1023146 TWh per year or 26.28 MWh per site and year. This results in 0.19969% of the gross and 0.224687% of the net national power consumption. 0.19234% of the national electrical power production is used up by the base stations in the Germany.

Note that the number of 5G base stations in 2022 was enough to „only" cover 79% of the nation's area [Bundesnetzagentur, 2022]. To adapt for a complete coverage in the future, the number of the above paragraph will be multiplied by factor of 1.266 (overlap not included). Also, this calculation assumes a full usage of the power supply at all times without idle time or down time.

### 4.3 User Equipment

As for the User Equipment, two categories will be differentiate between in this paper: devices actively used by humans and Machine-to-Machine (M2M) communications. There are 8.59 billion mobile phone subscriptions [Richter, 2023] and 7.41 billion mobile phone users, of which 6.93 billion are smartphone users [Turner, 2024].

In Germany, the number of smartphone users in 2022 was 67.6 million [Statista, 2024c], but there have been 104,904 million mobile phone subscriptions (124 per 100 capita [Statista, 2024a]) for the 84.6 million people living in Germany [DESTATIS Statistisches Bundesamt, 2022]. That only describes the mobile phone subscriptions for human-used devices. The total count of subscriptions including M2M devices is 169 million [Statista, 2024], meaning about 37.93% of mobile communication connections are M2M communication. These number describe the total number of SIM-cards in Germany without specifying wether or not the activity coming from those connections classify as „modern". Only 44.67% of the total number of SIM-Cards in circulation in Germany (77.5 million [Statista, 2024b]) have some form of LTE functionality (see Figure 2).

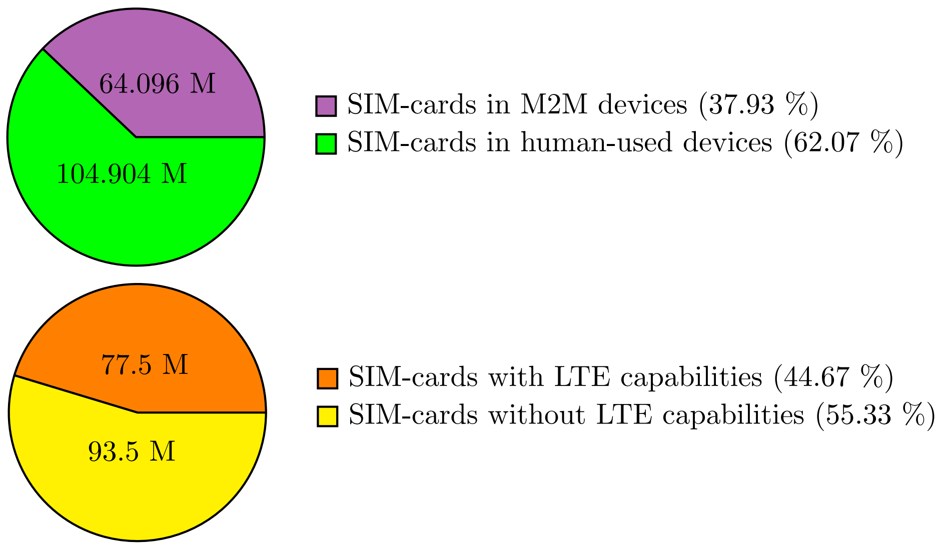


Figure 2: Distribution of SIM-cards in Germany between Machine-to-Machine and human-used devices and between cards with and without LTE capabilities (LTE or more modern), totaling 169 million (M) cards

When it comes to the devices used for mobile communication, the situation is opaque. Very little is known about the devices in use and their specifications in M2M communication (47.93%). There only is some information of human-used devices that helps estimate the number of eligable and active devices. The first smartphone with 5G capabilities entered the German market in march of 2019 [yourfone, 2024]. Since the beginning of 2019, 87.9 million smartphones have been sold in Germany until 2022 (22.1 million in 2019, 22 million in 2020, 22.2 in 2021 and 21.6 million in 2022) [Statista, 2024]. The share of smartphones with 5G capabilities is unknown.

The number of other human-used devices is about as opaque as the M2M devices. It is known that there have been only 19 models of 5G-capable tablets in the German market (beginning in November 2021) [Linsner, 2024] and 3 5G-capable laptop models [5G-Anbieter.info, 2024]. The number of other User Equipment, e.g. wearables, remains unclear.

All this makes the calculation of the power demand by User Equipment very difficult. It is not possible to make a reliable and accurate statement about the power consumption for those devices. However, it is possible to make an estimation under some assumptions. Firstly, the assumption will be made that the average power consumption of modern smartphones is a good estimation for the power consumption of any UE. In order to reconsile with this assumption two calculations will be made: One for all devices and one only for human-used devices. Secondly, the share of SIM-cards with/without LTE capability remains a constant throughout the User Equipment space, meaning the share of 44.67% can be used across all devices types. This seems a good assumption because it is unclear with the currently available information to know more about the actual situation and it seems improbable that all 64.096 million M2M devices have SIM-cards with LTE capabilities, leaving only 11.404 million for human-used devices.

With those assumptions established and the information that the charging of a smartphone consumes an average of 3.65 kWh per year (10 Wh per over-night charge for 365 days per year) [GASAG AG, 2024], the estimation of the power consumption of UE is as follows: The 104.904 million human-used devices in Germany consume 382.8996 GWh per year and the total 169 million UE devices in Germany consume 616.85 GWh per year. Of those, we are only concerned with the devices participating in modern mobile communications (44.67%), bringing those numbers down to 171.041 and 275.547 GWh respectively.

# 5 Sources of energy consumption

## 5.1 Base Stations

## 5.2 User Equipment

# 6 Energy saving opportunities

## 6.1 Giga-MIMO

## 6.2 NR-Light

## 6.3 Reduced Capability NR

## 6.4 Sidelink enhancements

## 6.5 Sleep Modes

# 7 Conclusion

# A Acronyms

**BS** Radio Base Station.

**M2M** Machine-to-Machine.

**UE** User Equipment.

# B References


5G-Anbieter.info. Laptops & PC's mit 5G, February 2024. URL `https://www.5g-anbieter.info/hardware/laptops-mit-5g.html`.

Bayerisches Landesamt für Umwelt. Alle Umweltindikatoren auf einen Blick, January 2024. URL `https://www.lfu.bayern.de/umweltdaten/indikatoren/liste_indikatoren/index.htm`.

Helge Buchheister. 5G jetzt für 90 Prozent der Bevölkerung. *Vodafone Newsroom*, August 2023.

Bundesnetzagentur. 5G-Ausbau geht voran, November 2022. URL `https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2022/20221123_5g.html`.

Bundesnetzagentur. EMF - Monitoring, 2024. URL `https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Technik/EMF/start.html/`.

DESTATIS Statistisches Bundesamt. Bevölkerungsstand: Amtliche Einwohnerzahl Deutschlands 2022, 2022. URL `https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Bevoelkerungsstand/_inhalt.html`.

DESTATIS Statistisches Bundesamt. Bruttostromerzeugung in deutschland, April 2023a. URL `https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/Erzeugung/Tabellen/bruttostromerzeugung.html`.

DESTATIS Statistisches Bundesamt. Stromerzeugung im 3. Quartal 2023: Ein Fünftel weniger Strom als im Vorjahresquartal, December 2023b. URL `https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/12/PD23_462_43312.html`.

DESTATIS Statistisches Bundesamt. Energieerzeugung, January 2024. URL https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/Erzeugung/_inhalt.html.

Deutsche Funkturm. Mobilfunkausbau unterstützen - Antennenstandort anbieten, February 2024. URL https://www.dfmg.de/de/ihr-standortangebot-an-uns/anmietung-von-flaechen.html.

GASAG AG. Stromverbrauch Smartphone, 2024. URL https://www.gasag.de/magazin/energiesparen/stromverbrauch-smartphone.

Huawei Technologies. 5G Power Whitepaper. Technical report, HUAWEI TECHNOLOGIES CO., LTD, February 2019.

Annika Linsner. 5G-Tablets 2024: Die Modelle von Apple, Samsung & Co. im Überblick, February 2024. URL https://www.vodafone.de/featured/smartphones-tablets/5g-tablets-apple-samsung-beste-modelle/#/.

Felix Richter. Charted: There are more mobile phones than people in the world, April 2023. URL https://www.weforum.org/agenda/2023/04/charted-there-are-more-phones-than-people-in-the-world/.

Pengfei Shen, Yulin Shao, Qi Cao, and Lu Lu. Dynamic gNodeB Sleep Control for Energy-Conserving 5G Radio Access Network, 2022.

Olimpjon Shurdi, Luan Ruci, Aleksander Biberaj, and Genci Mesi. 5G Energy Efficiency Overview. *European Scientific Journal, ESJ*, 17(3):315, Jan. 2021. doi: 10.19044/esj.2021.v17n3p315. URL https://eujournal.org/index.php/esj/article/view/13918.

Statista. Anzahl der 5G-Basisstationen in Deutschland in den Jahren 2019 bis 2022, January 2024. URL https://de.statista.com/statistik/daten/studie/1237437/umfrage/anzahl-der-5g-basisstationen-in-deutschland/.

Statista. Nettostromverbrauch in Deutschland in den Jahren 1991 bis 2022, January 2024. URL https://de.statista.com/statistik/daten/studie/164149/umfrage/netto-stromverbrauch-in-deutschland-seit-1999/.

Statista. Anzahl der Mobilfunkanschlüsse pro 100 Einwohner in Deutschland von 1990 bis 2022, 2024a. URL https://de.statista.com/statistik/daten/studie/13264/umfrage/penetrationsrate-der-deutschen-mobilfunknetze-seit-1990/.

Statista. Anzahl der aktiven LTE-fähigen SIM-Karten in DEutschland von 2014 bis 2022, 2024b. URL

%2022:75,5Mio.LTE-fhigeSIM-Karten(44,67%)https://de.statista.com/statistik/daten/studie/974622/umfrage/anzahl-der-aktiven-lte-faehigen-sim-karten-in-deutschland/.

Statista. Anzahl der Smartphone-Nutzer* in Deutschland in den Jahren 2009 bis 2022 und Prognose bis 2027, 2024c. URL https://de.statista.com/statistik/daten/studie/198959/umfrage/anzahl-der-smartphonenutzer-in-deutschland-seit-2010/.

Statista. Smartphone-Nutzung in Deutschland, February 2024. URL https://blogs.fu-berlin.de/hci2023/files/2023/05/study_id71707_smartphone-nutzung-in-deutschland.pdf.

Statista. Anzahl der Mobilfunkanschlüsse in Deutschland von 1992 bis 2022, 2024. URL https://de.statista.com/statistik/daten/studie/3907/umfrage/mobilfunkanschluesse-in-deutschland/.

Ash Turner. February 2024 mobile user statistics: Discover the number of phones in the world & smartphone penetration by country or region., February 2024. URL https://www.bankmycell.com/blog/how-many-phones-are-in-the-world.

Umwelt Bundesamt. Stromverbrauch, January 2024. URL https://www.umweltbundesamt.de/daten/energie/stromverbrauch.

yourfone. 5G Handys: Dies Modelle gibt es, February 2024. URL https://www.yourfone.de/mobilfunk-ratgeber/5g-handys.