

Energy Footprint of Mobile communications in the 21st century

Andreas Nicklaus

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Zusammenfassung

deutsche Version

Abstract

englische Version

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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 influential 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 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, 2024a] 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 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 efficiency“ are applicable to the build site and lifecycle of BS and UE and are applicable to mobile communications.

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

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

The indicators „Carbon dioxide emissions“, „Air quality“ and „Noise pollution“ all boil down the source of electrical power of the base station and UE. [Huawei Technologies, 2019] implicates that near all BS use whatever electrical 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 Influence of mobile communication on 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 similar 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 green feed-in were imported [DESTATIS Statistisches Bundesamt, 2024b]. 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, 2023d].

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

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 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.

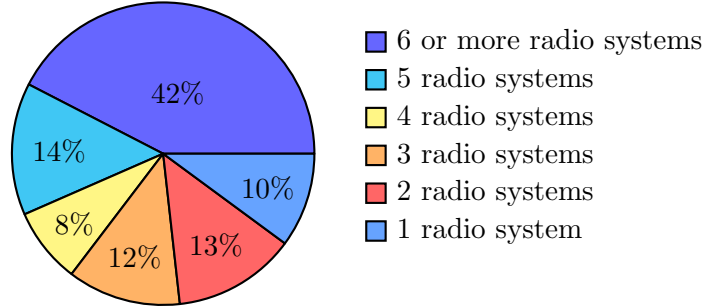


Figure 1: Distribution of radio systems within all Radio Base Station sites in Germany [Bundesnetzagentur, 2024] (missing one percent due to rounding errors)

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).

4.3 User Equipment

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.

UE User Equipment.

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