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Spectrum: the Climate Connection

Spectrum policy and carbon emissions

GSMA

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Executive summary

Spectrum management is linked to carbon emissions

The potential for spectrum policy to help tackle climate change has recently garnered increased interest and focus among regulators. Some, such as the European Commission, have even set specific objectives to use spectrum policy to contribute to their climate action goals.

This research examines how spectrum policy can affect carbon emissions. First, it considers the impact on the mobile sector's emissions through mobile network energy consumption, emissions embodied in manufacturing and the construction of base stations, device energy consumption, and other operator activities (such as the running of offices and data centres).

Second, this research considers the impact that the mobile sector has as an enabler of emission-saving use cases for other sectors of the economy and households. Examples include video calling (reduced emissions from physical travel) and connected electrical grids (improved efficiency).

Inefficient spectrum policy can raise the cost of building and operating mobile networks and lower the adoption of emission-saving technologies. This could result in a missed opportunity to reduce emissions from households and other sectors that rely on mobile connectivity.

Sub-optimal spectrum policy can lead to tens of millions of tonnes of additional CO2 emissions

This analysis evaluates the impact of four spectrum policy aspects that can vary between countries: the timeliness of spectrum assignments, amount of spectrum assigned, level of fragmentation, and flexibility to use spectrum for different technologies.

We estimate the impact during the main period of 5G rollout (2022–2031) for two representative, medium-sized countries, both with a population of 80 million. One is a low-income country; the other is a high-income country.

Key findings

— A two-year delay to 5G spectrum assignment can increase emissions by 40 million tonnes of CO2 equivalent (MtCO2e) in the high-income country, and 10 MtCO2e in the low-income country. Late 5G assignments can slow the adoption of technologies that improve energy efficiency. They can also increase costs, lowering the adoption of emission-saving use cases elsewhere.

— Assigning 100 MHz less to 5G is associated with a 15 MtCO2e increase in emissions in the high-income country and 2 MtCO2e in the low-income country. With less spectrum, more base stations are needed to meet demand for mobile data, increasing the sector's impact through the supply chain.

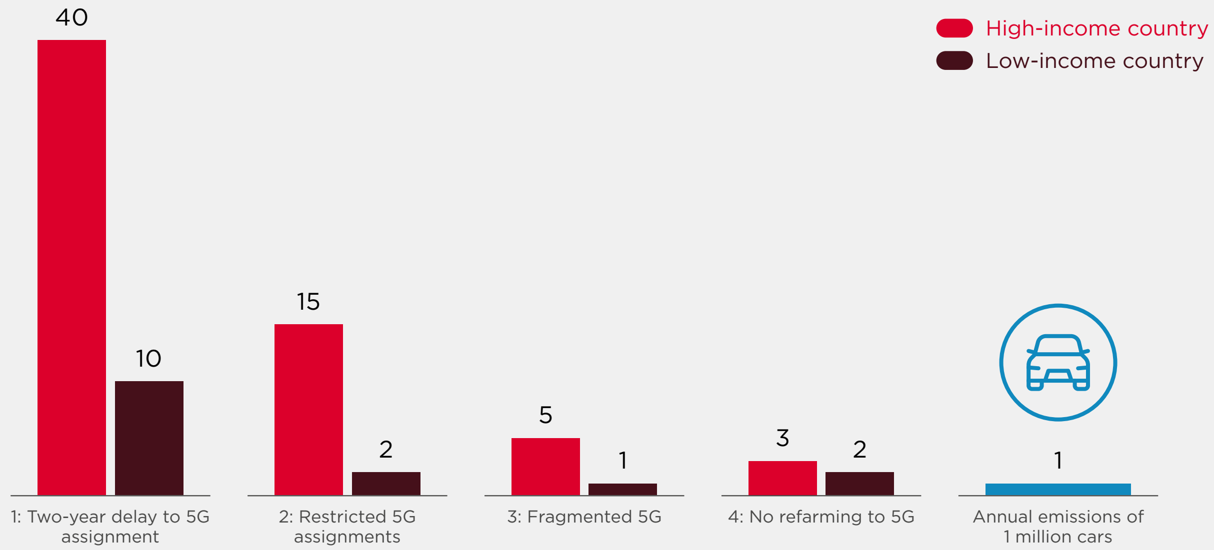
— Fragmented spectrum can result in additional emissions of 5 MtCO2e in the high-income country and 1 MtCO2e in the low-income country. Fragmented spectrum reduces spectrum usage due to the need for guard bands. Fragmented spectrum also forces operators to rely on carrier aggregation technology to deliver fast connectivity. These two consequences reduce network energy efficiency and increase emissions in the mobile sector and beyond.

— Non-neutral assignments that prevent spectrum refarming can result in additional emissions of 3 MtCO2e in the high-income country and 2 MtCO2e in the low-income country. Spectrum assignments that are not technology-neutral can tie operators to older, less efficient technologies. This increases emissions from networks and their operating costs.

Figure 1

Cumulative emissions impact, 2022–2031

MtCO2e



Source: GSMA Intelligence

Efficient use of spectrum can lead to a reduction in carbon emissions and generate other economic benefits

The main challenge regulators face when assigning spectrum is to deliver the greatest socioeconomic benefit. Regulators should therefore incorporate the assessment of climate change into their spectrum roadmaps and assignment considerations.

Non-monetary impacts, such as carbon emissions, should not be overlooked: they determine quality of life and productivity globally. More directly, effective spectrum policy contributes to the achievement of climate action goals set nationally and internationally.

In the case of a two-year delay to 5G assignments, the additional emissions are comparable to the annual emissions of nearly 40 million cars (for the high-income country) or 10 million cars (for the low-income country). We also estimate a substantial emissions impact if the assigned spectrum is limited or fragmented, or where old assignments prevent reconfiguration to 5G.

Spectrum policy that leads to efficient radio networks will help realise the economic benefits of mobile connectivity and reduce carbon emissions. This is a win–win situation for regulators as effective spectrum policy principles also ensure long-term affordability of communications services, maximising their economic benefit.

01

Climate action and mobile spectrum policy

How spectrum policy can affect carbon emissions

This study examines the impact of spectrum policy on carbon emissions. Radio frequencies are a limited natural resource. How this resource is managed impacts the mobile sector by changing the ways networks can be deployed and operated. Relevant policies include the timely assignment of spectrum, the amount and type of spectrum assigned, whether the assignments are fragmented into smaller channels, and whether there are any additional restrictions placed on its use that could prevent refarming (see Figure 2).

Figure 2

Key pillars of mobile sector climate action and spectrum policy aspects

Mobile sector's climate action pillars:

- Energy efficiency
- Renewables
- Supply chain

Spectrum policy aspects:

- Timely assignment
- Amount of spectrum
- Spectrum fragmentation
- Spectrum refarming
- Availability of different bands

Source: GSMA Intelligence

The United Nations' Agenda for Sustainable Development declared 17 overarching Sustainable Development Goals (SDGs) for humanity and set the pathway to achieving them by 2030. Among these, SDG 13 urges action to combat climate change and its impact, while SDG 9 calls for increased resource-use efficiency and the adoption of clean technologies.[1]

With mobile data traffic projected to increase five-fold by 2028, mobile operators need to achieve substantial carbon savings to meet their own environmental impact targets and contribute to global and national commitments.[2]

Mobile industry commitments (end-2022):[3]

63%

Mobile operators accounting for 63% of global mobile revenues have committed to **rapidly cut their emissions by 2030** in line with science-based targets.

38%

of mobile operators by global revenue have **committed to net-zero targets by 2050**.

1 United Nations (n.d.) "Transforming our world: the 2030 Agenda for Sustainable Development". https://sdgs.un.org/2030agenda
2 Ericsson (2022) "Mobile data traffic outlook". https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast
3 GSMA (2022) "Mobile Net Zero: State of the Industry on Climate Action 2022". https://www.gsma.com/betterfuture/wp-content/uploads/2022/05/Moble-Net-Zero-State-of-the-Industry-on-Climate-Action-2022.pdf

Operator strategies to minimise climate impact

Improving energy efficiency

Increasing the share of renewables to minimise carbon impact of consumed energy

Collaborating with suppliers to reduce emissions related to purchased equipment and services

Spectrum policy regulates how, when and where efficiency-improving mobile network technologies can be deployed.

Currently, the emissions of the mobile sector are estimated at about 220 million tonnes of CO_2 per year, including the direct and indirect emissions of mobile network operators and emissions associated with handsets.[4] Together, these represent 0.4% of total global emissions.

Some regulators have recently started to examine whether spectrum policy could be an effective tool to tackle climate change, and have adopted specific objectives:[5] [6]

- Ofcom has stated its intention to 'help reduce the UK's overall carbon emissions, in line with the Government's Net Zero Strategy'.[7]
- In Europe, the Radio Spectrum Policy Group (RSPG) 'established a work item to focus on spectrum policy aspects which are closely related to the efforts of ensuring climate-neutrality'.[8]

While the mobile sector has its own footprint, it plays a key role as an enabler of emission-saving use cases for households and other sectors. Examples include video calling (lowering emissions from physical travel) and connected smart grid systems (enabling efficiencies in the energy sector). These use cases are made possible by mobile devices such as smartphones, fixed wireless access terminals, and IoT devices.

The mobile sector therefore has a bidirectional impact on emissions: it is a net carbon emitter itself, but it also enables the reduction of emissions in other sectors. To fully account for the impact of spectrum policy, this research investigates not only the impact on the sector's own emissions (Chapter 2), but also how spectrum policy interacts with the mobile enablement effect (Chapter 3). Finally, it is also important to consider the carbon impact from other radio spectrum uses and how comparable efficiency is across technologies (Chapter 4).

4 GSMA (2019) "The Enablement Effect". https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf

5 The European Commission: DG Connect (2021) "RSPG Opinion on the role of radio spectrum policy to help combat climate change". https://radio-spectrum-policy-group.ec.europa.eu/system/files/2023-01/RSPG21-027final-Draft_RSPG_Opinion_on_Climate_Change.pdf

6 Plum Consulting (2022) "The role of spectrum policy in tackling the climate change issue". https://www.techuk.org/resource/report-how-spectrum-policy-can-help-to-tackle-climate-change.html

7 Ofcom (n.d.), "Environmental sustainability" https://www.ofcom.org.uk/about-ofcom/policies-and-guidelines/environmental-policy

8 European Commission: DG Connect (2021) "RSPG Report on the role of radio spectrum policy to help combat climate change". https://rspg-spectrum.eu/wp-content/uploads/2021/06/RSPG21-026final_RSPG_Report_on_Climate_Change.pdf

02
Impact on emissions of the mobile sector

Modelling the impact of spectrum policy aspects

Building on previous analysis of the carbon impact of the mobile sector, consultations with the mobile sector, and other sources,[9] [10] GSMA Intelligence modelled the emissions impact of the spectrum policy aspects shown in Figure 3.

Figure 3

Spectrum policy aspects affecting the emissions of the mobile sector

Delay to 5G assignments

IMPACT

Delay in the adoption of more efficient network technologies, increasing emissions

Restricted 5G assignments

IMPACT

More base stations and higher emissions in their manufacture

Fragmented 5G

IMPACT

Reduced spectrum usage, resulting in network inefficiencies and higher emissions

No refarming to 5G

IMPACT

Prevention of refarming to more efficient technologies

Source: GSMA Intelligence

9 European Commission: DG Connect (2021) "RSPG Report on the role of radio spectrum policy to help combat climate change". https://rspg-spectrum.eu/wp-content/uploads/2021/06/RSPG21-026final_RSPG_Report_on_Climate_Change.pdf

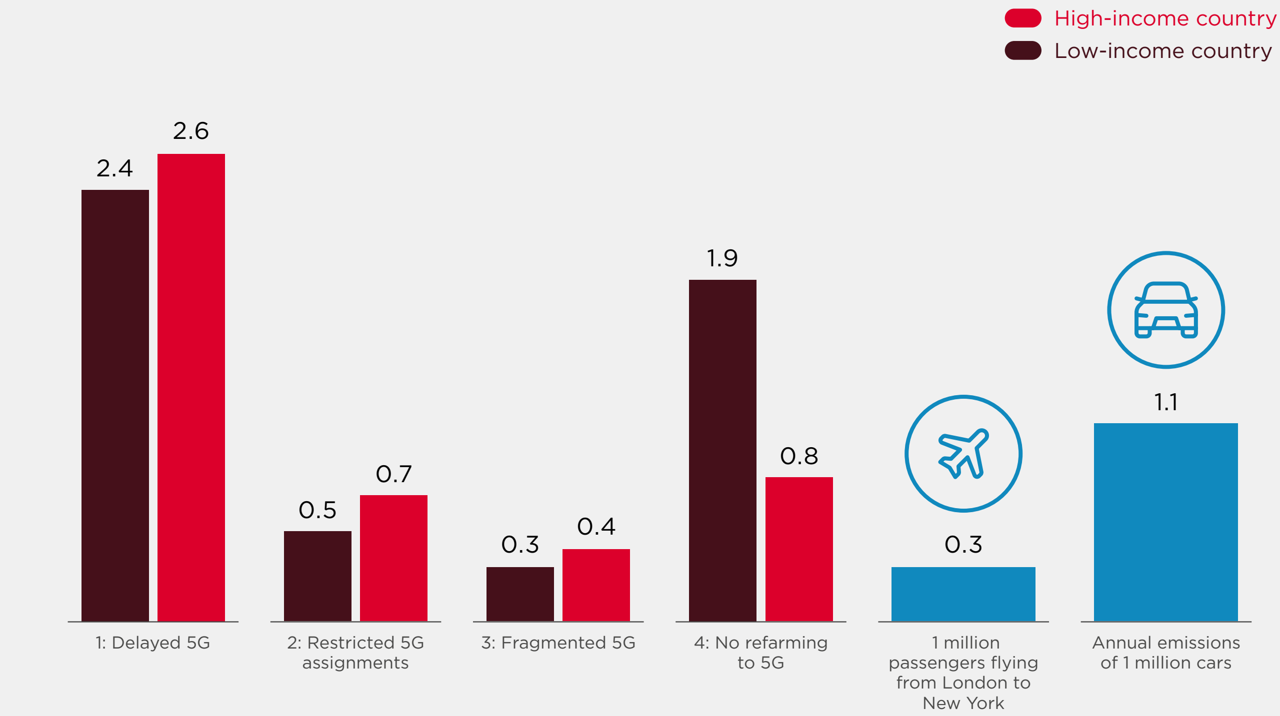
10 Plum Consulting (2022) "The role of spectrum policy in tackling the climate change issue". https://www.techuk.org/resource/report-how-spectrum-policy-can-help-to-tackle-climate-change.html

The impact on the emissions of the mobile sector could reach millions of tonnes of CO2

Figure 4

Cumulative mobile sector emissions impact for the modelled scenarios over a 10-year period

Cumulative emissions impact 2022–2031 (MtCO2e)



Source: GSMA Intelligence

Figure 4 presents the cumulative emissions impact for the representative low- and high-income countries over the 10 years between 2022 and 2031, which corresponds to the main period of 5G rollout. Unlike Figure 1, Figure 4 estimates concern only the impact on the emissions of the mobile sector, including the emissions of mobile network operators and those linked to user devices (smartphones and IoT devices).

The representative countries used for modelling are similar in size (with initial populations of 80 million) but differ in their level of economic development and adoption of mobile connectivity. See the Appendix for a detailed description of the model and the assumptions.

Scenario 1:
Delay to 5G assignments

A two-year delay to 5G spectrum assignments could result in additional mobile sector emissions of 2.4 MtCO2e in the low-income country and 2.6 MtCO2e in the high-income country. To put these figures into perspective, the impact is higher than the current annual emissions of the network operators in the studied representative countries, at 1.8 MtCO2e for the low-income country and 2.3 MtCO2e for the high-income country. The impact on emissions is a result of several overlapping effects: slower adoption of more efficient 5G, higher energy consumption and the need for more base stations.

Scenario 2:
Restricted 5G assignments

The restricted 5G assignment scenario shows the impact of reducing frequencies for 5G by 100 MHz. Insufficient spectrum leads to an additional 0.5 MtCO2e emitted by the mobile sector in the low-income country and 0.7 MtCO2e in the high-income country over the 10-year period. In this scenario, 5G adoption can be up to 5 percentage points lower than in the baseline scenario. In both countries, the impact of restricted 5G assignments is higher than the emissions that would arise from 1 million passengers flying from London to New York (0.3 MtCO2e).

Scenario 3:
Fragmented 5G

This scenario assumes that 5G spectrum is divided into 40 MHz instead of 100 MHz channels. The cumulative impact of this is 0.3 MtCO2e in the low-income country and 0.4 MtCO2e in the high-income country. Fragmented spectrum decreases its use and requires carrier aggregation to deliver the same speeds. More base stations and energy are therefore required to meet demand for mobile data.

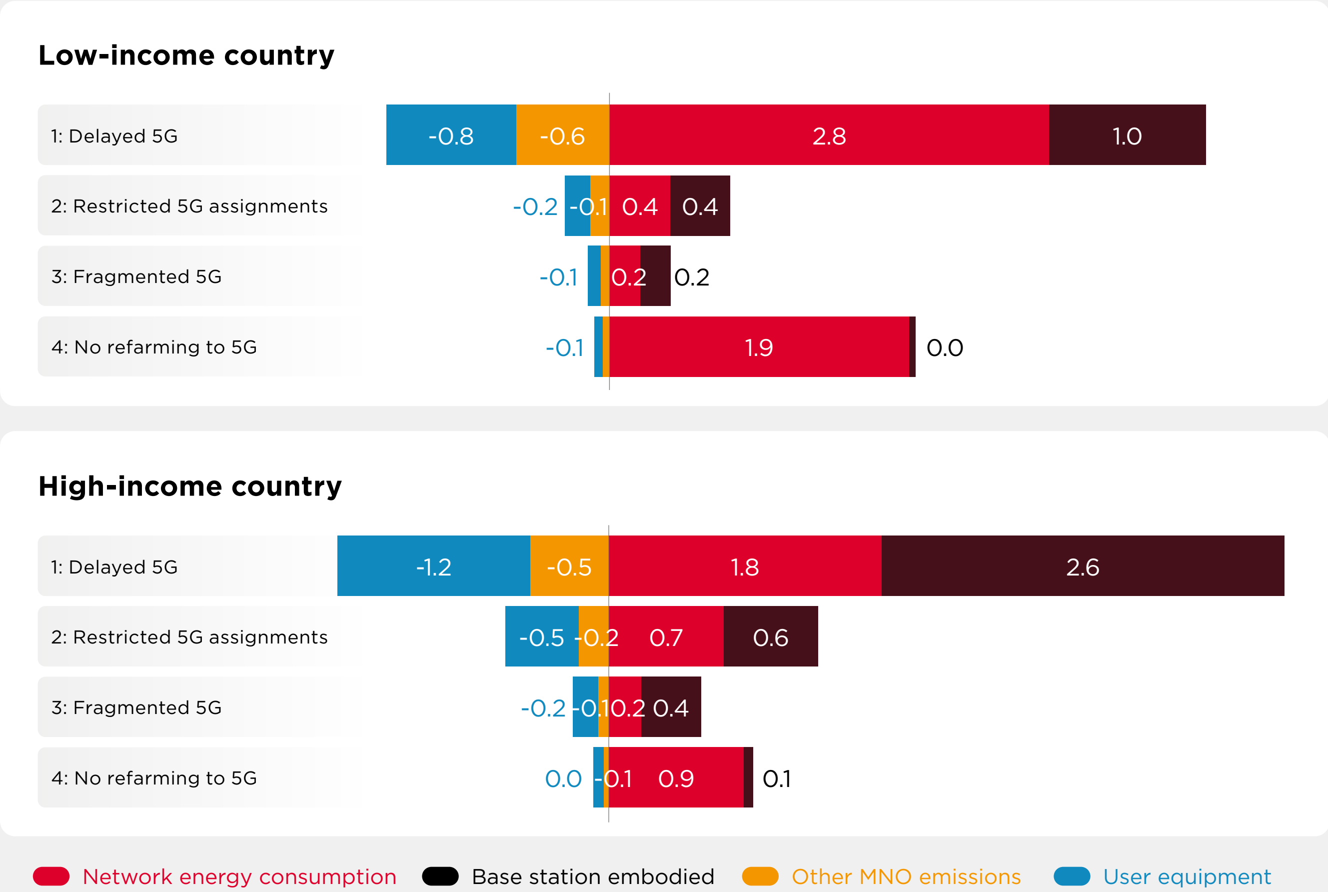
Scenario 4:
No refarming to 5G

Spectrum assignments that are not technology-neutral and prevent spectrum refarming could lead to additional emissions from the sector of 1.9 MtCO2e in the low-income country and 0.8 MtCO2e in the high-income country. Spectrum assignments that are not technology-neutral would force operators to rely on less energy-efficient 3G and 4G networks, while also slowing adoption of 5G. This results in increased emissions, primarily due to higher network energy consumption.

Figure 5

Cumulative impact on mobile sector emissions by source (2022–2031)

MtCO2e



Source: GSMA Intelligence

Figure 5 shows the breakdown of impacts on the mobile sector's emissions. Sources include the energy consumption of operator networks (RAN and core components of the network), the emissions embodied in manufacturing and construction of base stations, other operator emissions (the running of offices and data centres) and user equipment (emissions related to the manufacture of smartphones and IoT devices, and the energy consumption of smartphones).

— For the low-income country, in all scenarios, the emissions increase primarily due to higher consumption of electricity by the network, followed by an increase in emissions embodied in base stations.

— In the high-income country, emissions as a result of increased network energy consumption account for a relatively smaller contribution. This is because operators purchase more than 70% of energy powering the network from renewable sources, which mitigates some of the emissions impact.[11]

— In scenario 4 (no refarming to 5G), the distribution of impacts differs from other scenarios as emissions embodied in base stations increase only negligibly. We estimate a slight increase in base stations needed to serve mobile traffic due to the lower spectral efficiency of 3G and 4G. However, extended reliance on 3G and 4G increases network energy consumption, which is the main source of the estimated emissions impact.

11 Based on Europe estimates from GSMA (2022) "Mobile Industry position paper Access to renewable electricity" https://www.gsma.com/betterfuture/wp-content/uploads/2022/11/Mobile_Industry_Position_Paper_Access_to_Renewable_Electricity_Nov22.pdf

— For all scenarios, we estimate smaller, emission-reducing impacts from other functions of mobile operators (the running of data centres and offices) and user equipment (emissions related to devices and the energy consumption of smartphones). These impacts are negative because restrictive spectrum policy reduces demand for mobile communications, which causes a fall in the need for mobile devices and scaled down operator activities. Nevertheless, the reductions are much smaller than the increases in emissions linked to network energy consumption and embodied in base stations. Hence, the net impact for all considered scenarios is greater overall emissions. Moreover, lower adoption of mobile connectivity can have further effects on emissions outside the mobile sector, as examined in Chapter 3.

Delay to 5G assignments slows the adoption of more energy-efficient technologies

- Each successive mobile technology generation (2G, 3G, 4G, 5G) has been more efficient in terms of energy use per unit of data. Estimates show 3G networks brought a 10-fold improvement in network energy efficiency over 2G, while 4G networks improved the efficiency nearly 30 times over 3G.[12] A similar improvement is expected for 5G.[13]
- Energy efficiency of the RAN is paramount as it represents the largest component of energy consumption by operators. Estimates show emissions linked to the RAN account for between 57% and 73% of the total operator footprint.[14] [15]
- Delays to 5G spectrum assignment will slow its adoption, and a larger share of data will continue to be transmitted over less efficient, older mobile generations, meaning higher emissions.[16]

Restricted 5G spectrum assignment means more base stations requiring energy and higher emissions in their manufacture

- Only a certain amount of data can be transmitted per unit of radio frequency over a given time. The maximum data throughput per base station therefore increases with the availability of more radio frequencies.
- With limited spectrum, operators require more base stations to serve the same amount of traffic. This means increased footprint in terms of equipment, construction and transport.
- The amount of emissions embodied in base station equipment is a significant part of the overall footprint. For example, countries such as the UK and Germany have more than 50,000 mobile base stations. Each base station can have up to 128 tonnes of CO2 linked to it, depending on the type.[17]

12 Comparisons based on: Pihkola et al. (2018) "Evaluating the Energy Consumption of Mobile Data Transfer—From Technology Development to Consumer Behaviour and Life Cycle Thinking". https://www.mdpi.com/2071-1050/10/7/2494; Malmodin et al (2018), "Life Cycle Assessment of ICT". https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12145; Orange (2020), "5G: energy efficiency "by design"" https://hellofuture.orange.com/en/5g-energy-efficiency-by-design/

13 Orange (2020) "5G : energy efficiency "by design"". https://hellofuture.orange.com/en/5g-energy-efficiency-by-design/

14 Elisa (2014) "Elisa 2014 Annual Report". https://corporate.elisa.com/attachment/content/Elisa_Annual_Report_2014.pdf

15 GSMA Intelligence (2021) "Going green: benchmarking the energy efficiency of mobile". https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=60621137&file=300621-Going-Green-efficiency-mobile.pdf

16 GSMA Intelligence (2019) "The impact of spectrum prices on consumers". https://www.gsma.com/spectrum/wp-content/uploads/2019/09/Impact-of-spectrum-prices-on-consumers.pdf

17 GSMA calculations based on Ding et al. (2022) "Carbon emissions and mitigation potentials of 5G base station in China". https://www.sciencedirect.com/science/article/abs/pii/S092134492200177X?via%3Dihub

Fragmented 5G spectrum reduces its usage, resulting in network inefficiencies and higher emissions

- Spectrum fragmentation refers to assignment of spectrum bands that are narrow and scattered. For example, a single mobile operator may have two 50 MHz channels, with each channel separated by assignments to other operators, instead of a single, contiguous 100 MHz band.
- Such fragmentation can reduce network performance as more frequencies need to be used as guard bands to prevent interference. Fragmentation into non-contiguous 50 MHz channels can reduce spectrum usage by 2.5% compared to a contiguous 100 MHz channel.[18]
- Network operators are forced to rely on carrier aggregation when using fragmented spectrum. Carrier aggregation uses up some of the bandwidth to transmit the data necessary to coordinate network activity (signalling overhead). This reduces the bandwidth that can be used for user data, as the overhead can double from 6% for a single 100 MHz channel to 12% when two separate 50 MHz channels are used.[19]
- Combined, these two effects reduce network throughput, increase the number of base stations required for the same level of service, and therefore increase the associated emissions.
- Separately, the use of carrier aggregation can also impact power consumption of user equipment.[20] Increased power consumption of smartphones generates additional emissions in the energy sector as the demand for grid electricity increases.

No refarming to 5G means spectrum assignments cannot be used with more efficient technologies

- Spectrum assignments that are not technology-neutral restrict spectrum use to a specific technology.
- Such restrictions slow spectrum refarming and migration to the latest technologies, preventing gains in energy efficiency and increasing emissions.

Other mechanisms that were not modelled could include use of different spectrum bands and spectrum pricing

- The energy efficiency of a network can also be affected by the band in which it operates. Empirical data on the performance of network equipment shows that the energy efficiency of power amplifiers boosting the mobile signal can decrease when amplifying higher band signals.
- However, there are other differences between higher and lower spectrum bands, including the propagation characteristics of the signal and the availability of sufficient spectrum to enable wide channels. Low- and high-band spectrum are therefore not direct substitutes; rather, they are complementary resources that will need to be used to enable fast and reliable mobile connectivity in various conditions.
- Another crucial aspect of spectrum policy is spectrum pricing. High spectrum prices are associated with lower investment in mobile infrastructure.[21] Under-investment in networks can slow the rollout of the fastest, most reliable and most energy-efficient technologies. This could indirectly lead to lower network energy efficiency and higher emissions.

18 ECC (2018) "Guidance on defragmentation of the frequency band 3400- 3800 MHz". https://docdb.cept.org/download/3a143dbe-7cbc/ECCRep287.pdf
19 Idem.
20 Santos et al. (2020) "LTE-A UE Power Consumption for Carrier Aggregation Scenario", https://www.sbrt.org.br/sbrt2020/papers/1570661121.pdf
21 GSMA (2019) "The impact of spectrum prices on consumers". https://www.gsma.com/spectrum/wp-content/uploads/2019/09/Impact-of-spectrum-prices-on-consumers.pdf

03
Spectrum and the mobile enablement effect

How mobile connectivity can enable emission-saving use cases

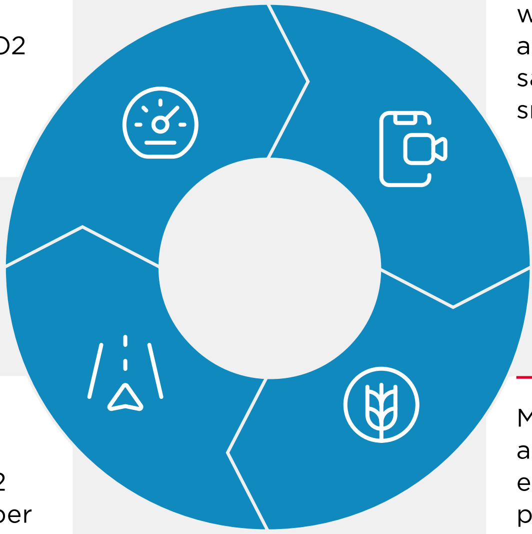
The mobile enablement effect refers to mobile communications increasing connectivity, improving efficiency or helping behavioural change that ultimately results in avoided emissions across households, government and business sectors.[22] Examples of how the mobile enablement effect can reduce emissions are shown in Figure 6.

Figure 6

Examples of emission-saving use cases enabled by mobile connectivity

Thanks to behavioural change, each smart meter in a residential setting can enable 60 kg of CO2 savings annually.

By reducing the need for travel, video calling with friends and family and remote working can save 79 kg of CO2 per smartphone per year.



Use of navigation apps enables emissions savings of 18 kg of CO2 per smartphone user, per year.

Mobile-enabled smart agriculture can improve efficiency and boost productivity, saving 11 tonnes of emissions per farm, per year.

Source: GSMA Intelligence

According to estimates, the mobile sector can enable emission savings 10 times greater than its own footprint.[23][24] The vast potential of mobile-enabled technologies to contribute to carbon abatement is illustrated by example estimates for individual sectors:[25]

Transport: mobile connectivity can enable savings of 2.8 gigatonnes of CO2 emissions by 2030. These can be achieved through fuel savings and efficient routing thanks to IoT connectivity, remote working via fast wireless connections, and other emission-saving use cases.

Buildings: mobile connectivity can enable savings of 2.2 gigatonnes of CO2 emissions by 2030 with the adoption of residential and commercial smart meters, behavioural change and the use of efficient monitoring systems that reduce consumption of energy and fuel.

Manufacturing: smart factories can enable a reduction of 1.6 gigatonnes of CO2 by 2030. This can be achieved thanks to IoT-connected machinery and robots that boost productivity and efficiency, as well as the use of remote diagnostics and augmented/virtual-reality technologies that improve maintenance tasks and reduce halts in production.

22 GSMA (2019) "The Enablement Effect". https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf

23 GSMA (2019) "The Enablement Effect".https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf

24 AT&T (2021) "AT&T Gigaton Goal Overview and Methodology". https://about.att.com/content/dam/csr/2019/environment/Combined_10x_%20ATT%20Gigaton%20Methodology%20FINAL%20August%202021.pdf

25 GSMA (2021) "The Enablement Effect 2021 How can mobile tech help us reach Net Zero faster, easier, and cheaper?" https://www.gsma.com/betterfuture/wp-content/uploads/2022/04/The-Enablement-Effect-2021.pdf

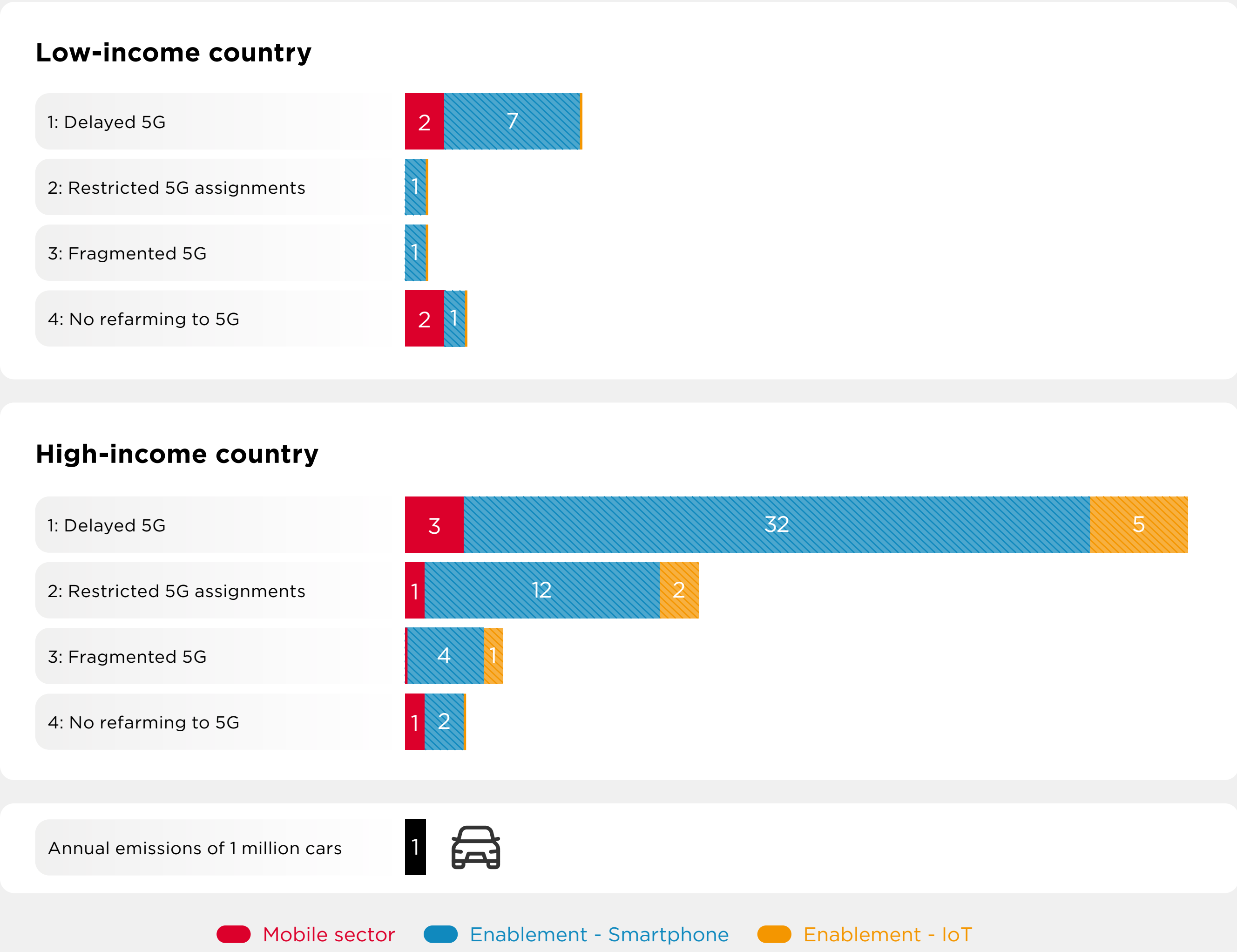
Sub-optimal spectrum policy can lead to tens of millions of tonnes of CO2 emitted throughout the economy

Under the modelled scenarios that illustrate sub-optimal spectrum policy cases, the adoption of carbon-saving use cases will decline and result in a missed opportunity for the mobile enablement effect (Figure 7).

Figure 7

Cumulative emissions impact, 2022–2031: the enablement effect

MtCO2e



Source: GSMA Intelligence

- When 5G is delayed or spectrum assignments are restricted or fragmented, the enablement effect impact is markedly greater than the impact on the mobile sector's own emissions, with up to tens of millions of tonnes of additional CO2 emissions.
- When spectrum refarming to 5G is not permitted, the knock-on impact on the enablement effect is less important. This is because the number of base stations required to serve the traffic is impacted only very mildly, so operators' capital costs are less affected than in other scenarios. This results in a relatively smaller impact on the adoption of emission-saving use cases. However, some enablement effect opportunity is missed because the lower network energy efficiency of 3G and 4G increases network energy costs.
- The impact of the enablement effect is greater in the high-income country because of greater adoption overall of emission-saving smartphone and IoT use cases.
- The impact of the enablement effect is lower for IoT-based use cases than smartphone-based use cases. This is because demand for – and adoption of – IoT use cases is relatively unresponsive to the cost of data. Most IoT devices transmit little data, making cost a less important factor.

We advise caution when interpreting these impacts. This is due to uncertainty about the parameters used in calculations of the enablement effect impact and a possible rebound effect, as explained in detail in the Appendix.

Figure 8 illustrates the causal link between spectrum policy and emissions across households and other sectors as a result of the enablement effect. Initially, inefficient spectrum policy can constrain the maximum throughput per base station or slow the adoption of the latest mobile technologies. This introduces inefficiencies into the network, increasing the costs of construction if more base stations are required and increasing energy costs if the spectrum policy hinders transition to more efficient technologies.

Higher costs can lead to higher prices, reduced data use and lower adoption of mobile-enabled emission-saving use cases. This will increase emissions generated by households and other sectors relying on mobile connectivity.

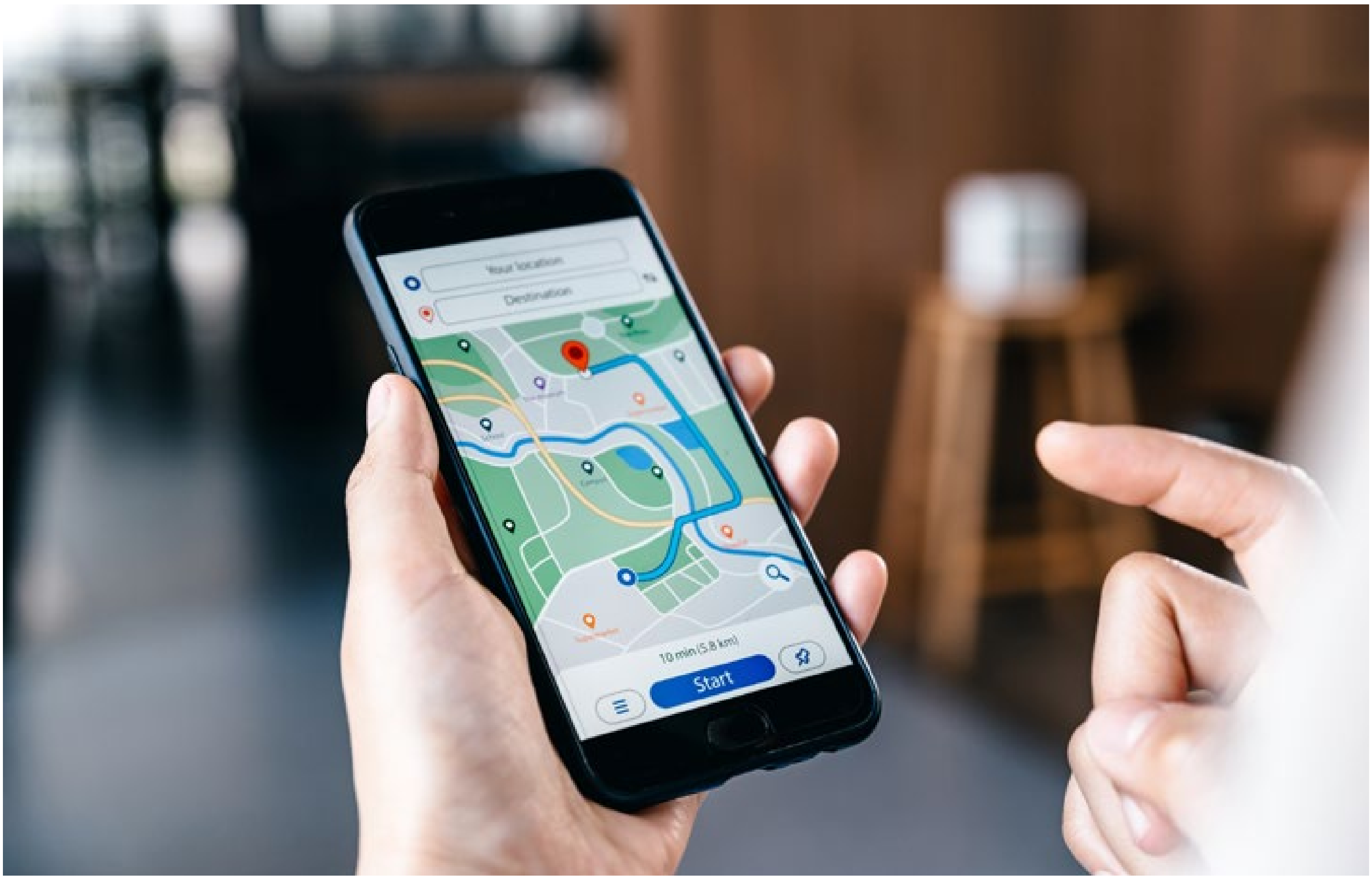
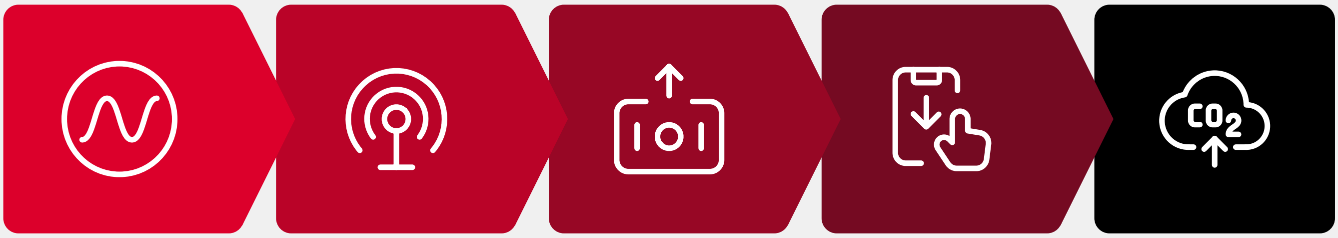


Figure 8

Mechanisms of impact between spectrum policy and the enablement effect



- Restrictive spectrum policy constrains throughput per base station or slows adoption of 5G
- Network operators need more base stations to meet demand
- Network capital and operating costs increase
- Higher prices lead to lower data use and a decline in adoption of emission-saving use cases
- Emissions increase across households and sectors other than mobile

Source: GSMA Intelligence

Because of their wide area coverage, mobile networks are often the only feasible connectivity option to support a range of mobile telecoms service levels, which in turn are uniquely suited to enable a broad range of emission-saving use cases.[26 27] These have effectively and economically been supported by wide-area mobile connectivity, encouraging their adoption. Examples of specific applications are shown in Figure 9.[28]

Figure 9

Share of total emission savings due to the mobile enablement effect in different sectors

Smart agriculture	Smart energy	Usability of public transport and ride sharing	Smart transport, logistics and fleet behaviour
3%	7%	10%	9%
Monitoring and crop management improving efficiency in use of fertilizer and yields	Machine-to-machine connections improving monitoring, coordination and distribution	Apps detailing routes, or ride-hailing apps	Improved dynamic routing and intelligent traffic systems

Source: GSMA Intelligence

26 Lehr et al. (2021) "5G: A new future for Mobile Network Operators, or not?". https://econpapers.repec.org/article/eeetelpol/v_3a45_3ay_3a2021_3ai_3a3_3as0308596120301762.htm
27 Ericsson (2020) "Benefits of 5G and Wi-Fi: superior indoor connectivity". https://www.ericsson.com/en/reports-and-papers/5g-and-wi-fi-path-toward-superior-indoor-connectivity
28 European Commission (2021) "RSPG Report on the role of radio spectrum policy to help combat climate change".

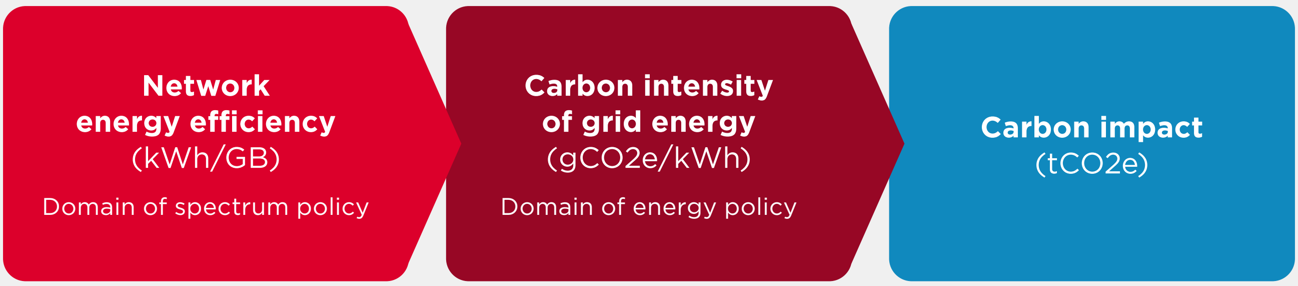
04
Comparing energy efficiency across different network technologies

Making meaningful comparisons of efficiency

Communications technologies vary in their energy efficiency, with comparison between technologies the subject of previous research. This is sometimes initiated by governments and regulators and sometimes by proponents of a particular technology. Comparison of the methodologies used is helpful in understanding this research.

Comparisons between radio networks typically focus on energy efficiency of networks in terms of energy use per unit of data (for example, kWh/GB or bit/Joule). Compared to carbon intensities (such as kgCO2e/GB), these measures can provide a more levelled comparison between networks as they are not influenced by factors such as the emissions intensity of the local electricity grid. While the carbon impact of network depends on the carbon intensity of the electricity powering the networks, electricity generation lies in the realm of energy policy, so typically is considered separately (see Figure 10).

Figure 10
Policy domains mediating the carbon impact of mobile networks



Source: GSMA Intelligence

Comparisons need to recognise differences in scope and assumptions

Figure 11 presents a selection of recent estimates of the energy efficiency of mobile networks. Part of the variation between them can be attributed to different boundaries in the assessments, with some studies focusing only on the network and others considering energy consumption of user devices, servers and data centres. Before making comparisons, the boundaries of the assessment should be checked and adjusted to allow like-for-like comparisons.

An additional difference stems from network utilisation assumptions. Some studies calculate efficiency parameters under the assumption of constant and maximum utilisation of the transmission bandwidth.[29] While these efficiencies can showcase system capabilities, in practice they are not representative of energy consumption under typical operating conditions.

29 Briede, S., Helleberg, S., Schindler, J., & Waßmuth, A. (2021) "Energy consumption of telecommunication access networks". https://europacable.eu/wp-content/uploads/2021/01/Prysmian-study-on-Energy-Consumption.pdf

Figure 11

Selected recent estimates of energy efficiency of networks

Source	Year of estimate	Technology and location	Transmission network (RAN and core network)	Servers and data centres	End-user equipment	Estimated energy efficiency of transmission network only (kWh/GB)
This study	2022	Mobile networks in representative countries	✓			0.55 (low-income) or 0.27 (high-income country)
GSMA[30]	2020	Mobile networks spanning 28 countries	✓	✓*		0.24
Golard, Louveaux & Bol[31]	2020	Mobile networks in Belgium	✓†			0.1
Lundén, Malmodin, Bergmark & Lövehagen[32]	2020	European mobile and fixed network operators	✓	✓*		0.1
Pihkola, Hongisto, Apilo & Lasanen[33]	2017	Mobile networks in Finland	✓	✓*		0.3
Malmodin and Lundén[34]	2015	Mobile and fixed networks combined	✓	✓	✓	0.88

* includes only data centres and servers operated by the network providers.
† includes only the energy use of base stations and excludes data centres and core network.

30 GSMA (2021) "Going green: benchmarking the energy efficiency of mobile". https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=60621137&file=300621-Going-Green-efficiency-mobile.pdf

31 Golard, L., Louveaux, J., & Bol, D. (2022) "Evaluation and projection of 4G and 5G RAN energy footprints: the case of Belgium for 2020–2025". https://dial.uclouvain.be/pr/boreal/object/boreal:267972

32 Lundén, D., Malmodin, J., Bergmark, P., & Lövehagen, N. (2022) "Electricity Consumption and Operational Carbon Emissions of European Telecom Network Operators". https://www.mdpi.com/2071-1050/14/5/2637

33 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". https://www.mdpi.com/2071-1050/10/7/2494

34 Malmodin, J., & Lundén, D. (2018) "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015". https://www.mdpi.com/2071-1050/10/9/3027

Differences in service characteristics mean like-for-like comparisons require further adjustments

When attempting to compare the energy efficiency of different technologies, it is not sufficient to take into account differences in time, place and scope. Often, different technologies use spectrum to deliver different services (broadcasting versus streaming) and in different conditions (local versus wide area connectivity).

Differences in service characteristics

— Some studies have compared the energy consumption per unit of data of mobile and Wi-Fi networks.[35] These comparisons are largely uninformative because they do not compare the energy efficiency of the same service. Mobile and Wi-Fi networks provide a different service in terms of coverage, mobility and overall user experience. For example, Wi-Fi networks providing wide area coverage would generate massive energy consumption and higher costs for equipment deployment compared to their more common indoor, line-of-sight use. The roles of mobile and local Wi-Fi networks should be understood as complementary, rather than direct substitutes.

— Further examples of uninformative comparisons include studies comparing the energy efficiency of digital terrestrial television (DTT) with other services such as on-demand streaming.[36] DTT network energy consumption is invariant to the number of viewers, meaning that its energy efficiency increases with the number of viewers. However, it typically provides scheduled and inflexible broadcasts. Linear DTT is therefore not a direct substitute for on-demand services delivered over the internet. In high-income countries these already have or are expected to overtake linear TV viewership.[37] This will have a proportional effect, decreasing the energy efficiency of DTT in the future, all else being equal.

Differences in conditions

— Energy efficiency can vary greatly by location. For example, satellite networks usually serve customers where traditional fixed or mobile broadband technologies are less suitable because of remoteness. Taking into account all potential subscribers, some estimates show that network emissions per subscriber for satellite can be four to 10 times higher than emissions per mobile subscriber, and similar multiples for the user equipment energy consumption.[38] [39]

— Satellite network infrastructure does not typically need to be expanded to serve remote areas, so efficiency is almost invariant to remoteness. However, the carbon footprint of terrestrial radio networks is affected by factors such as topography and the existence of infrastructure such as roads. Serving subscribers in these areas with mobile networks could be associated with much higher emissions compared to the average. In the same way, due to low viewership, niche linear television channels occupying radio spectrum can have much higher emissions per viewer than the average.

35 Wi-Fi Alliance (2022) “6 GHz Wi-Fi®: Connecting to the future”. https://www.wi-fi.org/file/6-ghz-wi-fi-connecting-to-the-future-2022

36 Carnstone (2022) “Carbon emissions of streaming and digital terrestrial television”. https://www.ofcom.org.uk/__data/assets/pdf_file/0024/246165/Carbon-emissions-of-streaming-and-digital-terrestrial-television-3.pdf

37 Ofcom (2022) “Media nations: UK 2022”. https://www.ofcom.org.uk/__data/assets/pdf_file/0016/242701/media-nations-report-2022.pdf

38 These comparisons exclude emissions linked to operation of user devices. Osoro, B., & Oughton, E. (2022) “Universal Broadband Assessment of Low Earth Orbit Satellite Constellations: Evaluating Capacity, Coverage, Cost, and Environmental Emissions”. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4178732

39 ISP News (2021) “Electricity Costs of Starlink’s UK LEO Broadband Satellite Service”. https://www.ispreview.co.uk/index.php/2021/03/electricity-costs-of-starlinks-uk-leo-broadband-satellite-service.html

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Conclusions

In recent years, regulators have started to explore the potential role of spectrum policy in tackling climate change.[40] As this area expands, regulators may consider incorporating assessments of climate change into existing spectrum policy frameworks and roadmaps, on top of economic impact assessments.

Non-monetary impacts, such as carbon emissions impacts, should not be overlooked as they have a real effect on quality of life and productivity globally, and will continue to have an impact for future generations. Estimates show that the social cost of carbon, though uncertain, could be between $50 and $100 per tonne of CO2 and will likely increase in the future.[41] More directly, effective spectrum policy will contribute to the achievement of climate action goals set nationally and internationally.

The illustrative scenarios for the two medium-sized countries show that spectrum policy can have a substantial impact on carbon emissions. The impacts of sub-optimal spectrum policies could reach tens of millions of tonnes in the representative countries, which is comparable to the annual emissions of millions of cars. These additional emissions arise as a result of increased emissions from the mobile sector itself, and increased emissions across other sectors and households as a result of lower adoption of emission-saving use cases.

Spectrum policy leading to efficient radio networks can maximise the economic benefits of mobile connectivity and reduce carbon impacts

Policy recommendations that minimise climate impact are closely aligned with the realisation of the economic benefits of mobile connectivity.[42] Sufficient spectrum should therefore be assigned in a timely manner to promote adoption of the newest and most efficient mobile technologies. This can be further supported by assigning contiguous blocks of frequencies and removing any restrictions requiring use of particular technologies in a given band, which will enable optimal transition to the latest technologies.

These spectrum policy principles will lead to mobile networks that are not only more energy efficient but also more cost-effective to build and operate. This ensures the long-term affordability of communications services, maximising their potential to deliver economic benefit while facilitating the adoption of emission-saving use cases and helping to support sustainable development.

40 Ofcom (n.d.) “Environmental sustainability” https://www.ofcom.org.uk/about-ofcom/policies-and-guidelines/environmental-policy

41 OECD (2015) “Monetary carbon values in policy appraisal: An overview of current practice and key issues”. https://www.oecd-ilibrary.org/environment/monetary-carbon-values-in-policy-appraisal_5jrs8st3ngvh-en;jsessionid=JrsmhnJuDY1K8HNBUnHJeTh460Gz_DnkSu0x5qSi.ip-10-240-5-37

42 GSMA (2022) “The Socio-Economic Benefits of Mid-Band 5G Services”. https://www.gsma.com/spectrum/resources/mid-band-5g-spectrum-benefits/

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