Energy assessment of 4G vs. 5G deployment

Mobile Network Technical Experts committee

Executive summary

1 Report objectives and scoping

The introduction of 5G technology, to keep pace with increasing traffic and many uses made of mobile networks, gives rise to questions over this technology's capacity to reconcile target performance objectives on the one hand and, on the other, the need to limit energy consumption and the carbon footprint – compared to a counterfactual, business-as-usual scenario based on 4G and its evolution, i.e. without deploying 5G.

The first major prerequisite when comparing the two situations (4G vs. 5G), is to have a concrete definition of what is being compared and to consider the types of deployment that have been realised thus far and likely to be in future in France, for these two technologies:

- For 4G, the exercise considers the frequency bands that have been deployed in France and their future technological development;
- For 5G, the 3.5 GHz band or the reuse of frequencies previously used by 4G are considered.

Another key prerequisite is to factor in the implementation method used (activated features such as beamforming, type of antennae, equipment capacity, etc.), the deployment environment, the level of technological maturity, as well as the strategy for renovating sites using existing bands as traffic is switched over to 5G over the course of several years. The exercise incorporates a number of assumptions of this kind, as detailed below.

The Mobile Technical Experts Committee, which Arcep created in 2018, has undertaken the technical work of assessing the impact that 5G technology will have on energy consumption and the carbon footprint. Committee members include experts representing mobile network operators, equipment suppliers, academics, and participants from French frequency management authority, ANFR. It is chaired by Catherine Mancini, and Arcep departments handle its secretarial duties. The Committee's composition is detailed in Annex F of the complete report.

This study constitutes the initial contribution to emerge from the Committee's work. It delivers a comparison of energy consumption (in kWh) and corresponding GHG[1] emissions over the same geographic area from 4G vs. 4G+5G base stations where 5G is planned to be deployed in the 3.5 GHz band for enhanced mobile broadband (eMBB) services, in the form of projections up to 2028. In this report, 5G in the 3.5 GHz band is therefore evaluated when deployed for essentially capacity-related reasons, to cover pockets of traffic and, in particular, to comply with regulatory requirements. In future, it should be noted that operators will also be able to deploy 5G for other purposes, such as

[1] The study only factors in the GHG emissions generated during utilisation of the deployed equipment.

providing new services to verticals, but such new services are not evaluated as part of this study which compares 4G and 4G+5G on an equal service footing.

This comparison of the different types of network deployment area can in no way be directly extrapolated to the entire network. An analysis on that scale would require an analysis of a greater number of different site typologies, incorporating the sites' meshing dynamics and considering the increased density and additional coverage that is inherent in a mobile network's ongoing development.

This Executive Summary synthesises this comparative study's methodology and assumptions, and lays out its main conclusions. The modelling exercise's technical developments are detailed in the full report, along with an FAQ that shares the most frequently asked questions about this topic.

All feedback is welcome and can be sent to the following e-mail address ComiteExpertsMobile@arcep.fr before 31/03/2022.

The aim in sharing this study is to contribute to a better understanding of the impact that the introduction of 5G will have on energy consumption, in a timely fashion and based on well-defined assumptions.

2 Methodology and analytical assumptions

2.1 Methodological approach

There are three main strands to the methodological approach taken in this report:

- The first strand consists of **modelling a macro base station's energy consumption according to the** upstream and downstream **speeds generated,** and the technological developments in terms of hardware generations and the standard used: 4G vs. 5G, TDD (Time Division Duplexing) vs. FDD (Frequency Division Duplexing). The development of this strand is detailed in Annex A of the complete report.
- A second strand consists of **calculating the content in carbon equivalent (CO2 eq.) emitted by a piece of equipment during its utilisation phase,** according to energy consumed (i.e. by kWh consumed). The development of this strand is detailed in Annex B of the complete report.
- A third strand is based on the first two strands, and consists of adding supplementary assumptions on how traffic will develop between 2020 and 2028, and a profile of a cell site's daily load to be able to **model the progression of energy consumption (in kWh) and GHG emissions up to 2028** within a same geographic area for 4G vs. 4G+5G base stations where 5G in the 3.5 GHz band is currently planned to be deployed for eMBB services. The development of this strand is detailed in Annex C of the complete report.

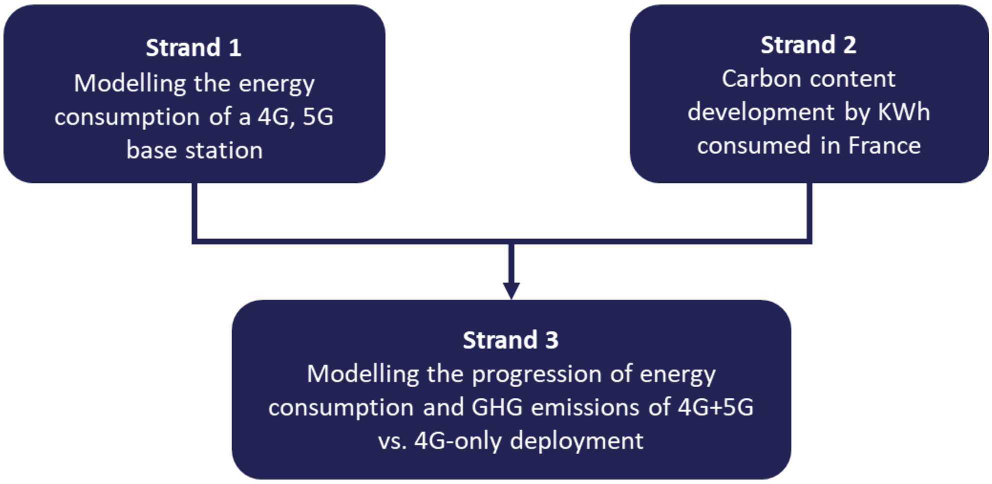

Figure 1 - Illustration of the interplay between the different strands of the methodological approach

The methodology is based on assessing the incremental differences between the two scenarios:

- **"4G-only" Scenario**: all of the extensions and new base stations needed to keep pace with increased traffic are realised in 4G. This scenario serves as the baseline for each of deployment described hereafter.
- **"4G+5G" Scenario**: 5G in the 3.5GHz band is added to handle the increase in traffic. Depending on the types of deployment, hardware used previously for 4G can be refurbished.

The two scenarios are compared over the same geographic area represented by the coverage of a macro site in 2020, over the course of eight years (from 2021 to 2028). The comparison is made for the same level of eMBB services, aimed chiefly at consumers.

Different types of macro site rollout where the 3.5 GHz band will be deployed are examined for the area in question, creating the ability to pinpoint trends and draw conclusions from the comparison of the two scenarios. These different types of deployment were selected, from the densest to the least dense areas where there are plans to deploy 5G in the 3.5 GHz band for enhanced Mobile Broadband (eMBB) services. For each scenario and each type of deployment, the choice of equipment (notably between 64T64R, 32T32R 5G equipment) corresponds to a trade-off between energy performance, coverage performance, capacity performance and the operator's operational choices.

The progression of base stations' energy consumption, greenhouse gas emissions and energy efficiency[2] in each scenario is indexed to 100, respectively, to the energy consumption, greenhouse gas emissions and energy efficiency of a 4G base station in 2020.

2.2 Deployment types

The two scenarios have been explored for the different types of deployment chosen (see the Annex of the complete report for more details on the technical considerations applied).

[2] A base station's energy efficiency is defined as the ratio between the volume of data delivered by the base station (in bits) during a given period of time, and the energy the base station consumes during that period (source: ETSI TS 203 228 (2020)

- **Type of deployment A** (which we will call “high capacity”): Where the point of departure is a 4G base station that has been upgraded to its maximum configuration of 2x65 MHz[3] in FDD. Under this scenario, 5G is introduced starting in 2021 using 64T64R AAS (Active Antenna System) equipment.
- **Type of deployment B** (which we will call “medium capacity”): Where the point of departure is a 4G triple-band base station with an initial medium capacity (2x45MHz in FDD) then upgraded with extensions (addition of a low-end band, upgraded with 4T4R MIMO antennae in the upper bands) before adding new sites under the “4G-only” situation, while in the “4G+5G” situation 5G is introduced starting in 2023 using 32T32R AAS equipment.

  Two Type B variants are considered to factor in the timing of the hardware replacement: a variable that considers an early replacement of the 4G base stations (type B1: medium capacity/refurbished hardware[4]); and a variant where 4G base station replacement is postponed until 2023 onwards (type B2: medium capacity/hardware to be refurbished).

  To be able to factor in the diversity of urban deployments in France, and particularly the inter-site distance (ISD) that can influence the adoption of MIMO, and therefore the 5G TDD[5] system’s capacity, two B1 variant cases are considered:

  - the case that creates the ability to take full advantage of Multi-User MIMO (Case a);
  - the case of longer inter-site distances which does not make it possible to take full advantage of Multi-User MIMO and where 5G TDD base station capacity is lower (Case b: higher ISD).
- **Type of deployment C:** This type of deployment represents the least densely populated areas where operators are currently planning 5G deployments in the 3.5 GHz band for eMBB services to cover traffic spots, and especially to comply with regulatory imperatives (e.g. in municipalities that must represent 25% of total 5G deployments in the 3.5 GHz band by 2025).

  The following assumptions are made for this type of deployment C:
  - The point of departure is a low-capacity, two band (800 and 1800 MHz) 4G site with a total 30 MHz of spectrum in 2020.
  - The 4G hardware is considered already refurbished and does therefore not require further upgrades before the end of the study’s period of observation.
  - The volume of traffic increases by 30% a year, as with other types of deployment.
  - If there is no need for additional capacity, 5G in the 3.5 GHz band will be introduced in 2025 at the latest, notably in keeping with the licences’ obligations.
  - 5G in the 3.5 GHz band will be introduced with 32T32R AAS with a reduced capacity due to higher inter-site distances (capacity equal to type B1b).
  - For both the 4G-only and the 4G+5G scenario, use of the 700 MHz band will be added as a compulsory measure by 2027 at the latest to comply with regulatory rollout obligations for this band.

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[3] Average value by aggregating the amount of spectrum available in 2020 for mobile operators in France in the following FDD frequency bands: 700/800/1800/2100/2600 MHz.

[4] A base station is typically refurbished periodically by upgrading some of its hardware which has reached the end of its life and/or to introduce new features, notably the addition of capacity.

[5] For instance, in very high-density areas (where there are therefore more opportunities for simultaneous transmission between users) and with a denser cellular grid (shorter inter-site distance), the MU-MIMO gain is brought to bear thanks to a good multi-path propagation environment, a better quality of radio link and pairing opportunities with the device.

Two variants of this type of deployment will be explored to take more sparsely populated areas into account:

- C1 with a load point in peak hours in 2020 of 50%, a 3.5 GHz band absorption rate of 80%[6] and the possibility of deploying 2600 MHz for capacity reasons.
- C2 with a load point in peak hours in 2020 of 30%, a 5G absorption rate of 60%. For the 4G-only scenario, the conclusion is that 2600 MHz does not bring sufficient coverage to the area, and its deployment will thus be excluded for capacity reasons.

These types of deployment and their chronology are summarised in Figure 2.

[6] The absorption rate refers to the 3.5 GHz band's capacity to absorb traffic, in other words the percentage of traffic on this band if device penetration stood at 100%, the remaining complement being on FDD bands. This capacity is below 100% for various reasons (site engineering, type of environment, etc.). see Annex C of the complete report for more details.

Figure 2 - Illustration of the different types of deployment and their chronology

2.3 Study assumptions

To model the progression of a 4G/5G base station's energy consumption up to 2028, several core assumptions were made, and are summarised in Table 1.

These assumptions are detailed in the complete report:

Table 1 – Summary of the study's main assumptions

Spectrum holdings considered in the study	• Low (700/800) and medium (1800/2100/2600) bands in FDD for 4G and the 3.5 GHz band in TDD for 5G • The study does not take into consideration the reuse for 5G of both 4G frequencies and 2G/3G (900 MHz) frequencies • Only the bands authorised to date: exclusion of the 1.4 GHz and the 26 GHz bands • Spectrum holdings of a representative operator with the average holdings of the four operators in France, i.e. 2x65 MHz in 4G and 80MHz in the 3.5 GHz band
Energy consumption parameters	• The modelled energy consumption parameters for base stations deployed in France and supplied by an equipment manufacturer who is a Committee member, to ensure consistent comparisons • The Committee's other two equipment supplier members confirm that the trends are representative and that analogous conclusions of the different scenarios studied would be reached using their own equipment, which is also deployed in France
Speed performance	• Assumptions on base stations' speeds depending on the technology (4G vs. 5G), bandwidths, types of bands and the antenna's MIMO configurations (cf. details in Annex of the complete report)
Standards framework	• Existing standardisation framework (ETSI standards and ITU-T L.1410 recommendation) pertaining, notably, to the energy consumption model for a base station (use of an affine function-based model according to the base station load, in the form of $\boldsymbol{a}.x+\boldsymbol{b}$), to the energy efficiency design and to the environmental impact assessment of the digital products, networks and services. Any discrepancies or exclusions are noted and justified.
Services/uses and traffic demand	• Comparison between the two scenarios for the same level of eMBB services, aimed chiefly at consumers. New uses and services for businesses/verticals enabled by 5G's features in future (low latency, IoT) are not evaluated. The secondary environmental effects (the GHG emissions avoided by these services) and other effects (societal, economic, rebound effects) are not studied. • eMBB services generating a volume of traffic that increases by an average 30% a year per site up to 2028. In accordance with the standardisation framework (ITU-T), that same rate of traffic growth is applied to the two scenarios to make them comparable.
5G in the 3.5 GHz band	• Factoring in the rise in 5G penetration (at an average annual rate of 14%) and its resulting traffic, considering the traffic absorption capacity of the 3.5 GHz band under the "4G+5G" scenario

Exclusions	• Only the equipment's utilisation phase is considered in the comparison of the two scenarios. The equipment's production, transport and installation phases are not considered. • The different sleep modes have not yet been modelled in any recommendation or standard, although well-defined at the operational level (3GPP), and have varying characteristics and performance levels depending on the equipment. They are not considered in this study. • Software and hardware developments and innovations that emerge in the coming years that could help increase 4G and 5G's energy efficiency are not incorporated prospectively in this study.

Because traffic growth is considered to be among the most influential factors in the scenarios' dynamics, a sensitivity analysis was performed on this parameter to assess the validity of the study's conclusions by testing a low traffic growth scenario (25% growth per annum) and a high traffic growth scenario (35% growth per annum) around a baseline value of 30% – see Annex D of the complete report for details. To test the model's sensitivity with respect to the energy performance of the 5G equipment considered for the study, a sensitivity analysis was performed by varying (+/- 10%) the energy consumption affine function-based model's parameters for 5G base stations – see Annex D of the complete report.

It should also be noted that the study of the different types of deployment from the densest to the least dense areas where there are currently plans to deploy 5G in the 3.5 GHz band for eMBB services also constitutes a sensitivity analysis for comparing the two scenarios.

3 Study results and conclusions

The calculations and detailed findings of the different types of deployment of macro sites where the 3.5 GHz band will be deployed are set out in Annex C of the complete report.

The choice of the different types of deployment selected from the densest to the least dense areas where there are currently plans to deploy 5G in the 3.5 GHz band for eMBB services made it possible to pinpoint trends and conclusions from the comparison of the two scenarios. The energy gains from the 4G+5G scenario compared to the 4G-only scenario are greater for deployments involving a high density of traffic (A, B1 and B2 type deployments), but weaker if not nil for deployments involving low traffic density (C1 and C2 type deployments). This conclusion can be visualised in the two figures below.

To assess the impact of introducing 5G in terms of energy efficiency for each type of deployment, the energy efficiency ratio of the 4G+5G scenario compared to the 4G-only scenario was calculated per year and by type of deployment, and its progressions is illustrated in Figure 4. This shows that after a momentary decrease in energy efficiency following the introduction of 5G, the energy efficiency ratio regains its equilibrium and the 4G+5G scenario gradually overtakes the 4G-only scenario in efficiency as traffic increases. The regained equilibrium of the energy efficiency ratio between the two occurs faster with high-density type deployments (A and B) than low-density ones (type C). In addition, Figure 4 also illustrates the progression in 5G technology's energy efficiency per annum and by type of deployment only for the 4G+5G scenario compared to the total energy efficiency of the 4G-only scenario, and demonstrates by its magnitude the 3.5 GHz band's potential to improve energy efficiency.

Based on the findings for the different types of deployment, the energy consumption avoided and the GHG emissions avoided thanks to a 4G+5G scenario rather than a 4G-only scenario were deducted for each year in Figure 5. Savings in terms of energy consumption (GHG emissions respectively) between the two scenarios are expressed in multiples of the energy consumption (GHG emissions respectively) calculated in 2020.

$$Consumption\ avoided\ by\ 4G + 5G\ vs.4G\ = [Q(yearX) - C(yearX)]/Q(2020)$$
$$with\ Q\ consumption\ by\ 4G\ in\ kWh\ and\ C\ consommation\ by\ 4G + 5G\ in\ kWh$$

This study suggests the value-added of 5G, and that its introduction – under the study's simulated conditions – is necessary to limit energy consumption and the resulting GHG emissions. According to the different scenarios for its introduction, although it generates a short-term rise in energy consumption (during the first years of its deployment[7]), network densification via 5G enables cumulated[8] savings of between three and more than 10 times the energy consumption in 2020 for all types of deployment except C2 by 2028, compared to a densification via 4G-only. Similarly, in terms of carbon footprint, densification via 5G makes it possible to avoid a total of between two and eight times the volume of GHG emissions in 2020 for all types of deployment except C2, compared to a densification via 4G-only.

For C2 type deployments, however, the outcome in terms of energy consumption will not return to a state of equilibrium until 2028 at the earliest, but remains slightly negative in terms of corresponding GHG emissions up to then.

Different additional levers that are not factored into this study should help limit energy consumption even further under a 5G deployment scenario compared to a 4G-only deployment. These levers include activating networks' advanced sleep modes and improving energy efficiency by increasing throughput performance (bandwidth, AAS systems with higher order MIMO). Moreover, although this study can provide qualified knowledge on the value-added of 5G in terms of energy efficiency for the different types of deployment, its findings are confined to the technology's utilisation phase, and are not intended to provide an exhaustive assessment of its impact, which should be addressed through a complete lifecycle assessment.

A sensitivity analysis was also performed of traffic growth and the energy consumption affine function-based model's parameters for 5G base stations, for the compared energy consumption and GHG emissions of the "4G-only" and "4G + 5G" scenarios up to 2028 (see Annex D of the complete report).

The main findings are as follows:

- The results of the simulations reveal a sensitivity to the rate of traffic increase, and confirms this is an influential parameter for the introduction of 5G under the assumptions of this study, especially in more sparsely populated areas (type C deployment).
- A +5% variation in traffic growth compared to the baseline case (i.e. 35% growth instead of 30%) generates increased gains (avoided consumption) of around 23% to 54% for deployment types A and B; the outcome for C2 type deployments even goes back to being positive, whereas it remained relatively unchanged in the baseline case. We also identify the

[7] The point of equilibrium reached in 2022-2023 for type A deployment and in 2024-2026 for the other types (except type C2).

[8] The aggregate energy and GHG emissions savings are calculated by combining the savings determined each year from 2020 to 2028 without discounting.

same variation when it comes to gains in terms of GHG emissions during the utilisation phase.

- A -5% variation in traffic growth compared to the baseline case (i.e. 25% growth instead of 30%) generates decreased gains (avoided consumption) of around 38% and 48% for deployment types A, B. The outcome for C1 type deployments, however, becomes slightly negative (the introduction of 5G results in an increase in consumption of 0.25 times a 4G site (in 2020) compared to a scenario without 5G) and for C2 type deployments, the introduction of 5G induces a consumption increment of around 1.7 times a 4G site's consumption (2020).
- The low sensitivity of the study's results (as much in terms of avoided emissions/energy consumption as energy efficiency ratio) to the energy consumption model's parameters for 5G base stations demonstrates that the rate of traffic growth, as well as the different types of deployment are the factors that most heavily influence the study's results and conclusions.

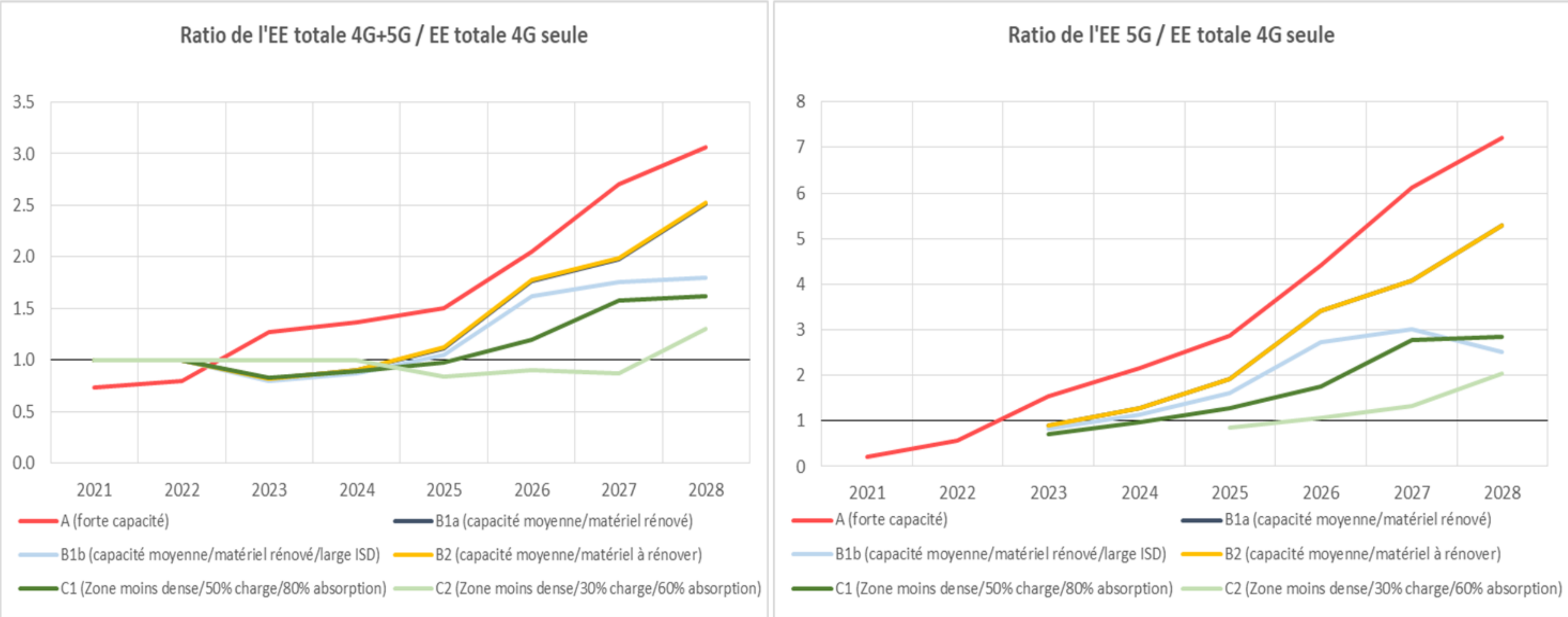
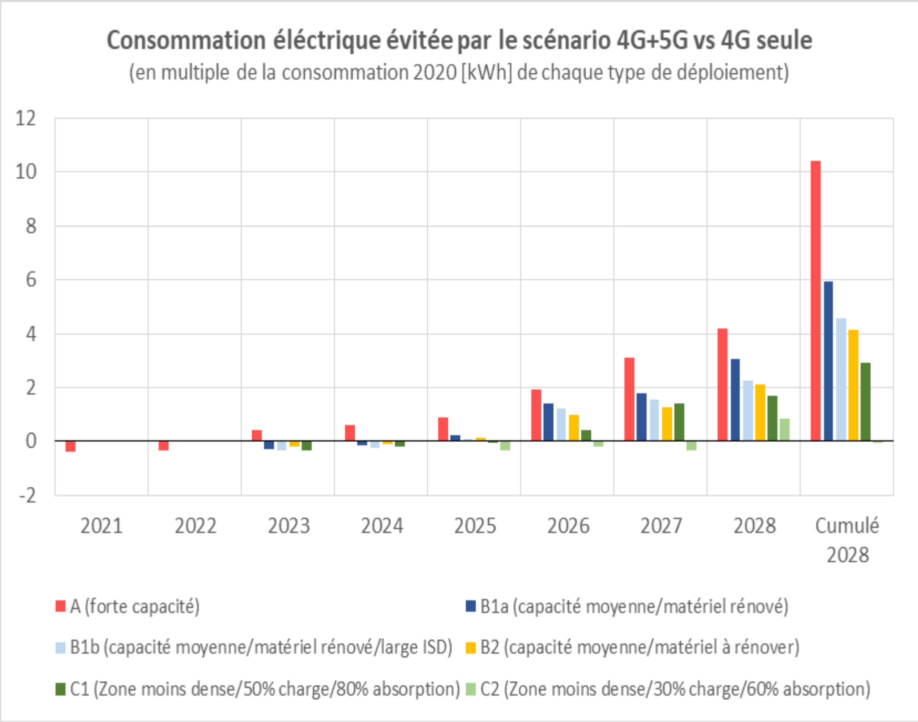


Figure 3 – **Left:** Progression of the total 4G+5G (from the 4G+5G scenario) energy efficiency ratio and that of 4G (4G-only scenario) for the different types of deployment
Right: Progression of the 5G energy efficiency ratio (4G+5G scenario) and that of 4G (4G-only scenario) for the different types of deployment



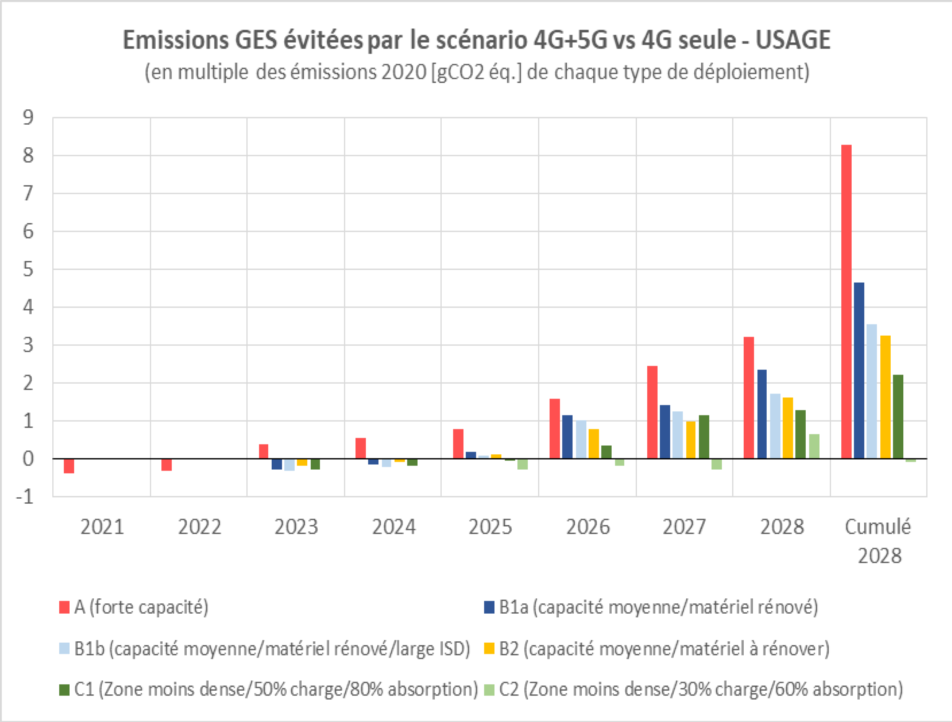


Figure 4 – **Left:** Electricity consumption avoided by the 4G+5G vs. 4G-only scenario (2020 baseline)
Right: GHG emissions avoided (utilisation phase) between the 4G+5G vs. 4G-only scenarios (2020 baseline)