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Presentation on our report for Huawei

Environmental impact of additional mid-band spectrum attribution

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Contents

Introduction [1/2]

- This study estimates the impact of spectrum availability on the carbon emissions of a 5G mobile network addressing connectivity targets for 2030

- The study focuses on **mid-band spectrum**, which is widely used for 5G today due to its ability to deliver both capacity and coverage
  - this builds on other published studies, particularly a previous study conducted on behalf of the GSMA, entitled "Estimating the mid-band spectrum needs in the 2025–2030 timeframe"[1]
  - while the conclusions have relevance for mid-bands in general, some of the analysis and assumptions (i.e. spectral efficiencies and coverage) focus on the upper 6GHz band (6425–7125MHz)

- The model forecasts the hypothetical deployments required to provide:
  - MBB services in **dense urban areas**
  - MBB and FWA services in **rural towns or villages**

- According to the following connectivity targets:
  - MBB services delivering **100Mbit/s downlink and 50Mbit/s uplink** to users in the busy hour
    - *ITU-R defines minimum performance requirements for IMT-2020 including 100Mbit/s downlink and 50Mbit/s uplink speeds*
  - FWA delivering **1Gbit/s downlink and 200Mbit/s uplink** to users in the busy hour
    - *the European Commission's Digital Decade policy programme lays out a vision to be achieved by 2030; of most relevance to this study are targets for all end users at fixed locations to have gigabit connectivity at least equivalent in speed to that of 5G*

[1] https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Estimating-Mid-Band-Spectrum-Needs.pdf

Introduction [2/2]

- We assume that the existing network grid will be densified to some extent (over time in terms of the numbers of macro sites and/or outdoor small cells), but in the absence of additional spectrum, the required densification would be significantly greater
  - in dense urban areas we compare densification primarily via macro sites with densification primarily via additional outdoor small cells

- Estimated network carbon emissions over the 2022–32 time period are based on the output of network modeling (sites/km^2)
  - **embodied costs**: carbon emissions due to the raw material acquisition, manufacturing, distribution and installation of passive and active equipment at a 5G site, as well as construction of the required site infrastructure
  - **recurring costs**: carbon emissions due to providing energy to operate and maintain the sites

- The study does not consider the enablement impact of mobile networks on other sectors (e.g. by enabling other sectors to improve the efficiency of their real-time or remote operations)

- This study also considers the impact of additional spectrum availability on the carbon emissions of Wi-Fi indoor access points

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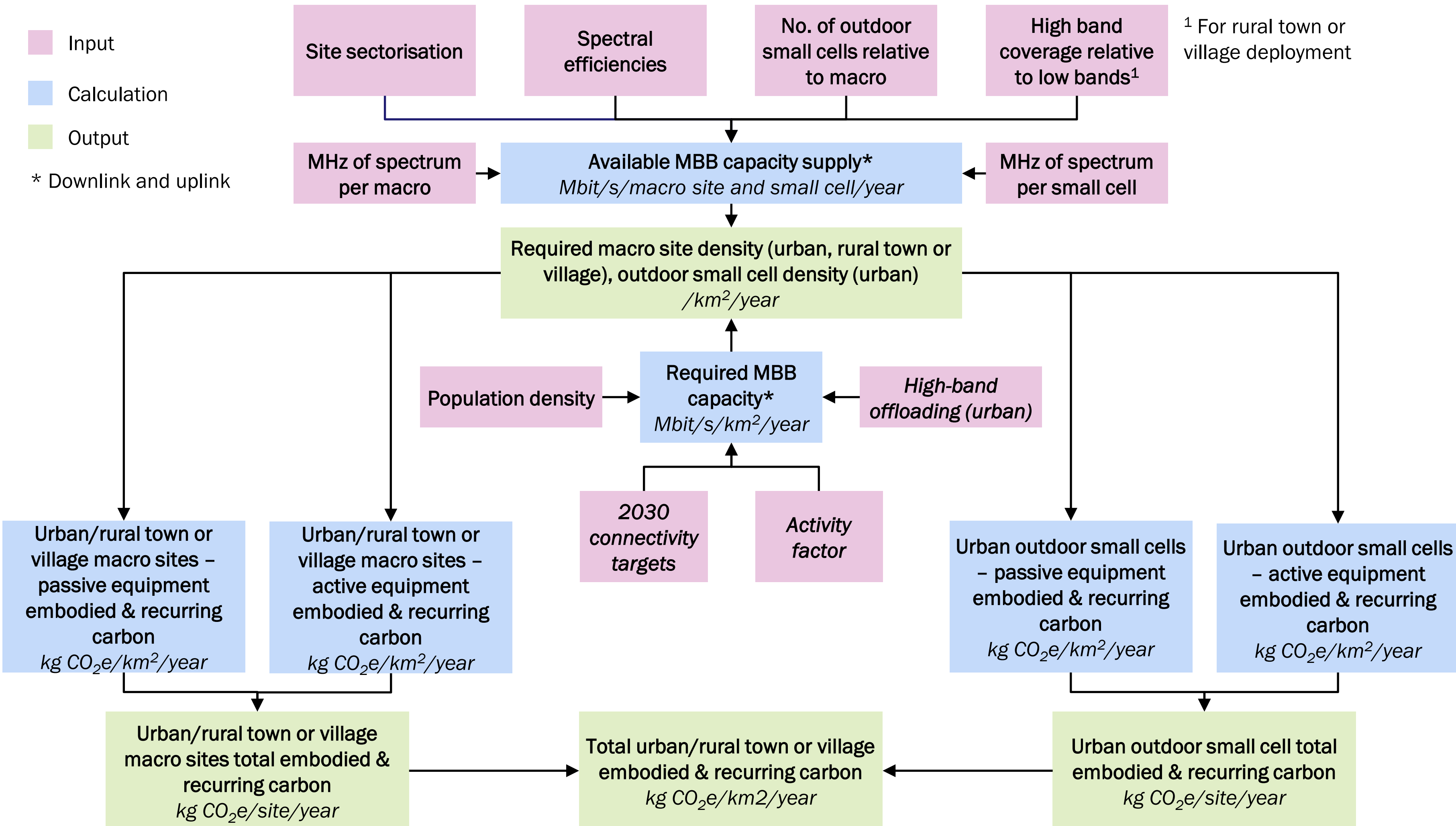
Modelling overview



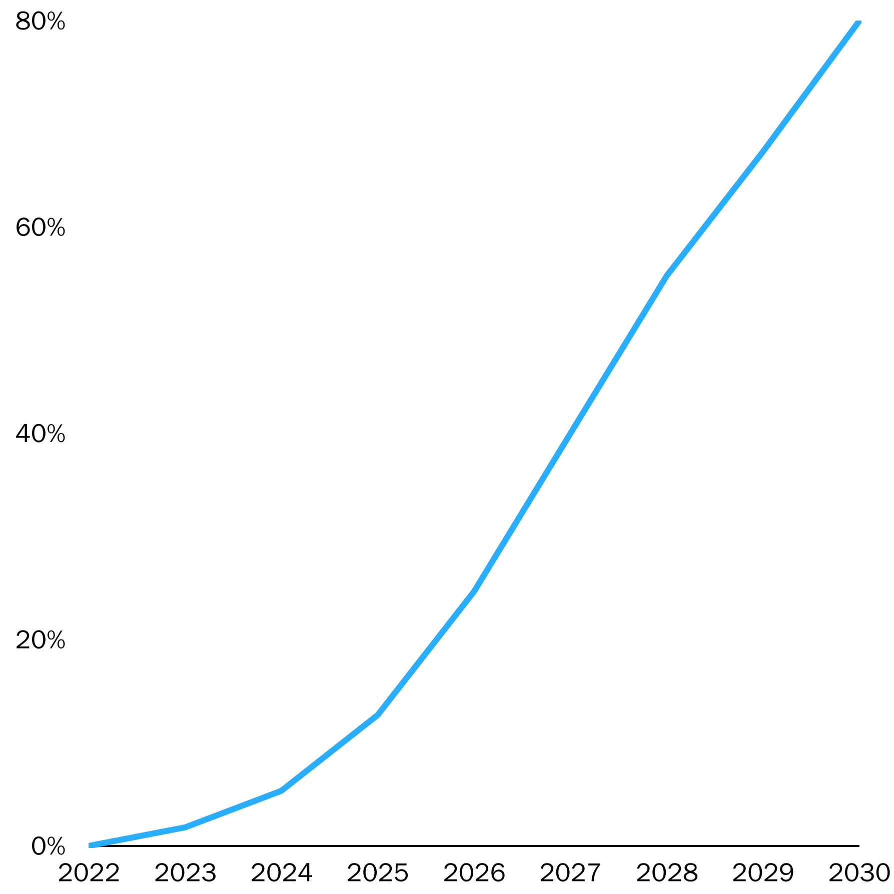
Source: Analysys Mason

Inputs for modelling MBB and FWA required capacity

Inputs for modelling MBB and FWA required capacity

Input	Dense urban areas	Rural towns and village
Future connectivity targets	MBB services delivering 100Mbit/s downlink and 50Mbit/s uplink to users in the busy hour	MBB services delivering 100Mbit/s downlink and 50Mbit/s uplink to users in the busy hour, and FWA delivering 1Gbit/s downlink and 200Mbit/s uplink to users in the busy hour
Population density	15 000/km^2	▪ 300/km^2 ▪ Average of 2.8 people per household
Activity factor (busy hour)	▪ 5% ▪ Sensitivity analysis up to 25%	▪ 10%
Outside-in coverage	10% devices within premises use MBB connectivity	N/A
High band offloading	Linear increase from 0% in 2022 to 10% in 2027	Explicitly modelled within the capacity supply (not modelled through offloading of demand)

Assumed FWA penetration in a rural town or village receiving high-speed broadband connectivity via a 5G-based FWA network



Source: Various – see the report

Inputs for modelling MBB and FWA capacity supply [1/4]

Spectrum bands deployed by site type

Spectrum	Deployed for MBB on dense urban macro site?	Deployed for MBB on dense urban outdoor small cell?	Deployed for MBB on rural town or village macro site?	Deployed for FWA on rural town or village macro site?
Low-band (700–900MHz)	✓	✗	✓	1/3 [1]
Lower mid-band (1.5–2.6GHz)	✓	✗	✓	✗
Upper mid-band (3.4–3.8GHz)	✓	✓	✓	✓
Additional upper mid-band (6.425–7.125GHz)	✓	✓	✓	✓
High band (25.1–27.5GHz)	✗ [2]	✗	✓	✓

Bandwidth availability for each band over time

Spectrum	Bandwidth available (MHz)								
	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low bands – FDD[3]	190	190	190	190	190	190	190	190	190
Lower mid-bands – FDD	410	410	410	410	410	410	410	410	410
Lower mid-bands – SDL[3]	40	40	40	40	40	85	85	85	85
Lower mid-bands – TDD[3]	40	40	40	40	40	40	40	40	40
Upper mid-bands – TDD	400	400	400	400	400	400	400	400	400
Additional upper mid-bands – TDD	–	–	–	–	–	700	700	700	700
High band[4] – TDD	–	2400	2400	2400	2400	2400	2400	2400	2400

[1] Only one low band is assumed to be used for FWA;

[2] The high band is not explicitly modelled in dense urban areas, but rather a high band offloading factor is used;

[3] FDD spectrum: 50% downlink and 50% uplink, SDL spectrum: 100% downlink; TDD spectrum: 75% downlink and 25% uplink;

[4] This report assumes that the lower part of the 24.25–27.5GHz band is assigned for lower-power, local area assignments

Source: Various – see the report

Inputs for modelling MBB and FWA capacity supply [2/4]

Spectral efficiencies

Spectral efficiencies		Downlink spectral efficiency (bit/s/Hz)		Uplink spectral efficiency (bit/s/Hz)	
		2022	2030	2022	2030
MBB macro sites	Low bands (700–900MHz) (*)	1.87	1.87	1.03	1.23
MBB macro sites	Lower mid-bands (1.5–2.6GHz) – FDD (*)	1.87	3.50	1.03	1.68
MBB macro sites	Lower mid-bands (1.5–2.6GHz) – SDL (*)	1.87	3.50	N/A	N/A
MBB macro sites	Lower mid-bands (1.5–2.6GHz) – TDD (*)	2.34	3.28	1.05	1.05
MBB macro sites	Upper mid-bands (3.4–3.8GHz)	5.01	7.15	3.31	4.73
MBB macro sites	Additional upper mid-bands (6.425–7.125GHz)	5.51	7.87	3.64	5.20
MBB macro sites	High bands (25.1–27.5GHz) (**)	3.10	4.65	1.50	2.25
Urban small-cell	Upper mid-bands (3.4–3.8GHz)	1.67	2.38	1.10	1.58
Urban small-cell	Additional upper mid-bands (6.425–7.125GHz)	1.84	2.62	1.21	1.73
FWA macro site	Low band (e.g. 900MHz)	2.06	2.20	1.13	1.45
FWA macro site	Upper mid-bands (3.4–3.8GHz)	5.51	8.40	3.64	5.56
FWA macro site	Additional upper mid-bands (6.425–7.125GHz)	6.06	9.24	4.01	6.11
FWA macro site	High bands (25.1–27.5GHz)	4.65	6.98	2.25	3.38

We also include a radio access network design margin of 15%

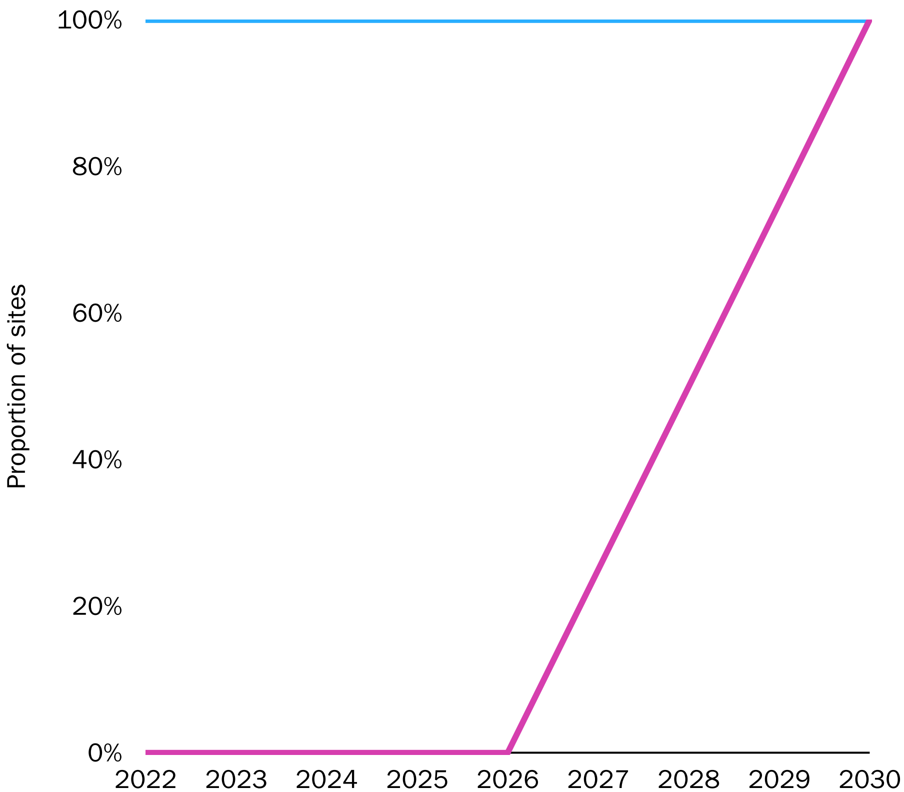
(*) Non-active antenna system (AAS) base stations are assumed for frequencies below 3.4GHz.

(**) Only applicable to rural macro site modelling.

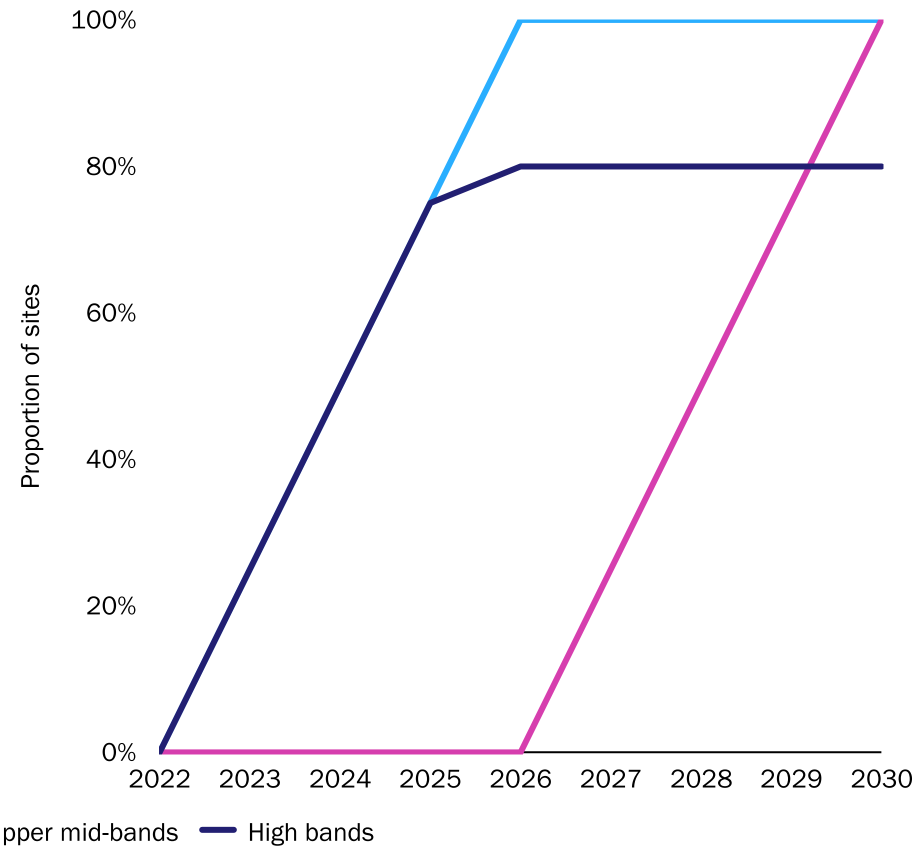
Source: Various – see the report

Inputs for modelling MBB and FWA capacity supply [3/4]

New mid-band spectrum roll-out on dense urban macro sites and small cells



New mid-band and high-band spectrum roll-out on rural town or village macro sites

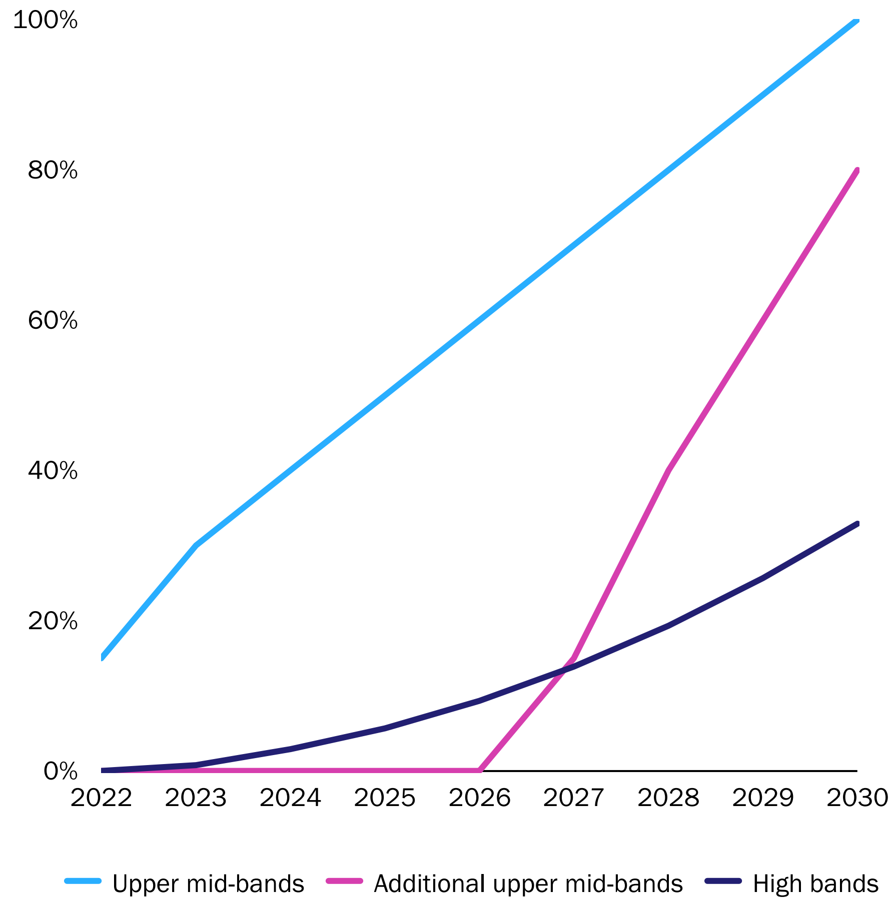


- The spectrum roll-out in our model is completed by 2030, and the final roll-out then applies thereafter, until 2032

Source: Analysys Mason

Inputs for modelling MBB and FWA capacity supply [4/4]

Penetration of MBB devices compatible with upper mid-band, additional upper mid-band and high band



Inputs for modelling site density

Input	Dense urban areas	Rural towns and villages
Number of operators in the market	3 operators	3 operators
Macro site inter-site distance (ISD) in 2022	400m (i.e. site density of 7.2km^2 and a radius of 267m)	3750m (i.e. site density of 0.08km^2 and a radius of 2500m)
Small-cell radius	65m, remaining constant	N/A
High-band rural cell radius	N/A	1000m in 2022, reducing linearly to 500m by 2030 as demand grows and radios prioritise throughput over coverage

Note: assumptions on spectral efficiencies and coverage were verified as reasonable by Huawei as far as possible. In some cases estimations have been made (e.g. for future upper 6 GHz band commercial equipment)

Source: Various – see the report

Inputs for modelling environmental impact

Environmental impact inputs

Category			Urban macro site[1]	Urban small cell[1]	Rural macro site[1]
Embodied carbon cost (kg CO_2e)	Low bands, lower mid-bands	Passive equipment	150 000	6000	190 000
		Active equipment	12 000	N/A	12 000
	Upper mid-band	Passive & active equipment	9000	900	9000
	Additional upper mid-band	Passive & active equipment	9000	900	9000
	High band	Passive & active equipment	N/A	N/A	4500
Lifetime of passive equipment			20 years	20 years	20 years
Lifetime of active equipment			8 years	8 years	8 years
Recurring carbon cost (kg CO_2e/year)	Low bands, lower mid-bands		12 000	150	12 000
	Upper mid-band	Fixed component [2]	4000	250	4000
		Variable component [3]	2000	150	2000
	Additional upper mid-band	Fixed component	4000	250	4000
		Variable component	2000	150	2000
	High band	Fixed component	N/A	N/A	2000
		Variable component	N/A	N/A	1000
Carbon intensity for electricity used by the telecoms sector (gCO_2e/kWh)					100[4]

[1] Each calculated macro site would comprise three macro sites – one per operator – sharing all the available spectrum. As such, the environmental inputs are the sum for three operators each using a third of the total spectrum.

[2] Irrespective of loading

[3] Loading dependent – based on an average over the day

[4] Assuming MNOs' use a greener energy mix than typical grids in Europe (currently ~250gCO_2e/kWh), improvements in emissions anticipated by 2030

Source: Carbon costs have been derived from public sources, as far as possible verified as reasonable by Huawei. In some cases estimations have been made (e.g. for future additional upper mid-band equipment)

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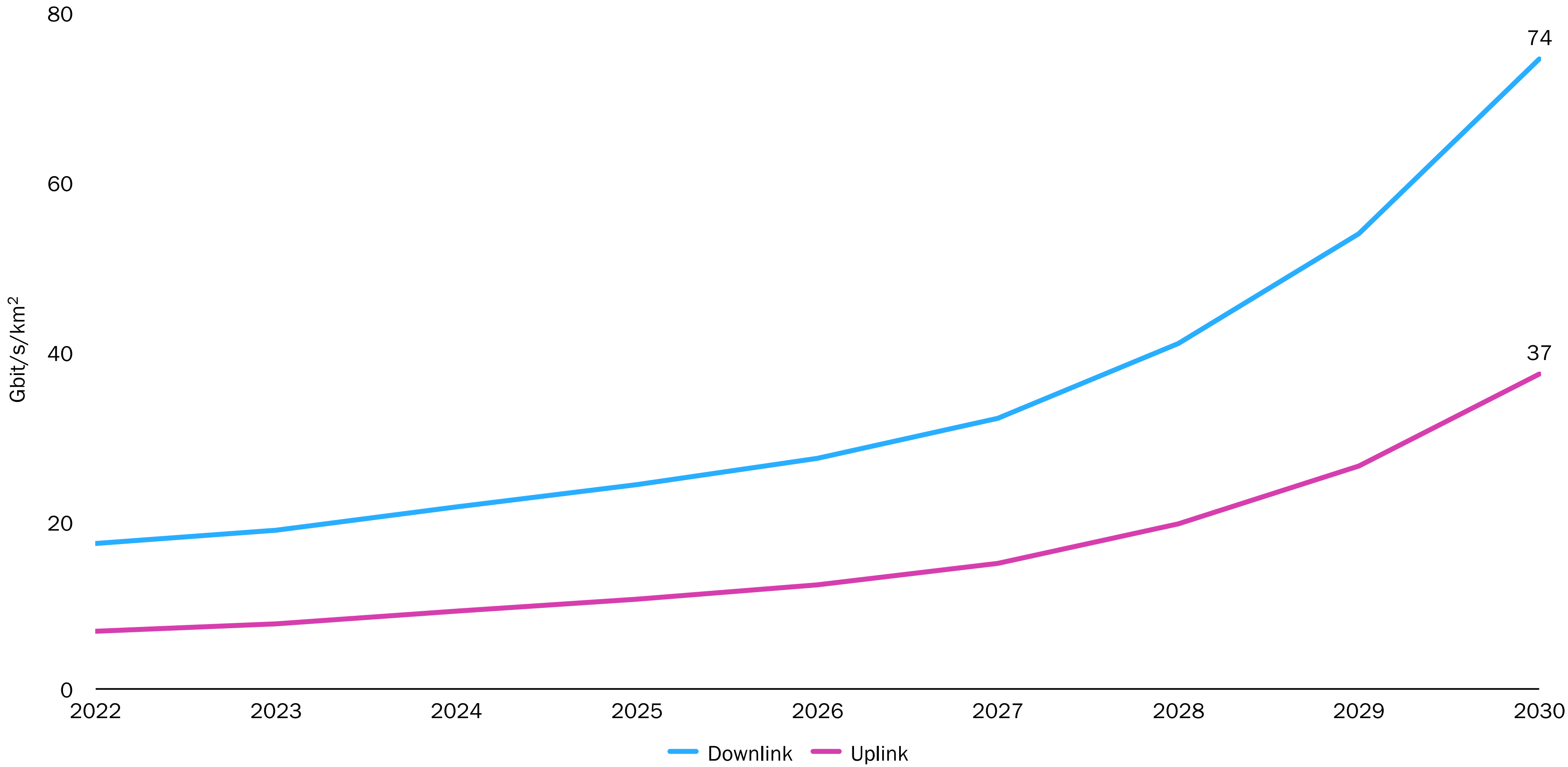
Dense urban area – required capacity

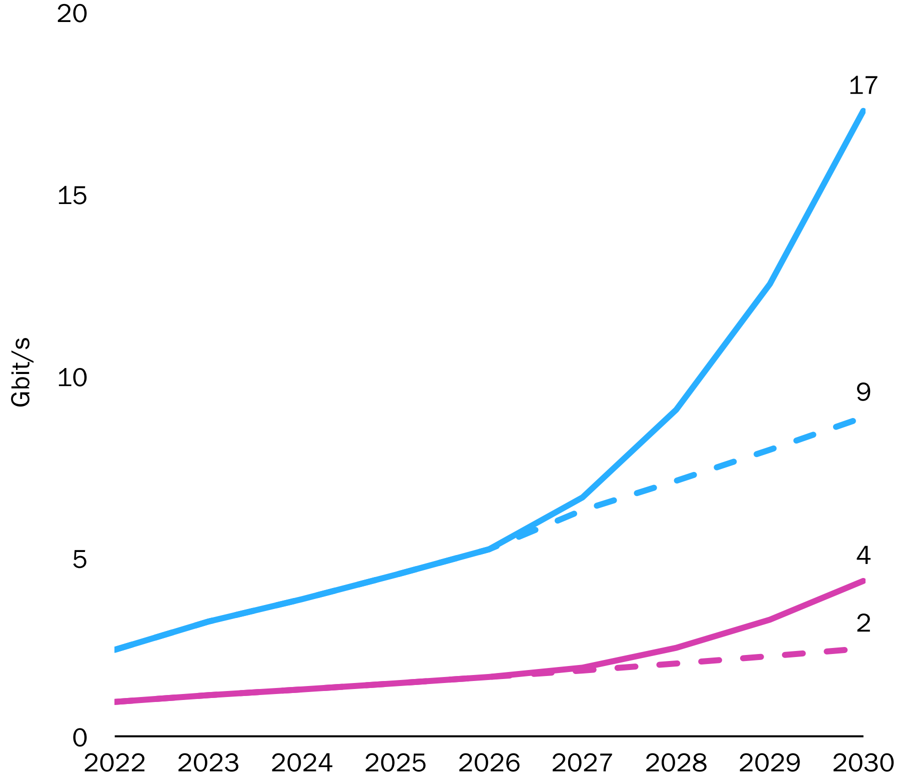
Dense urban MBB required capacity



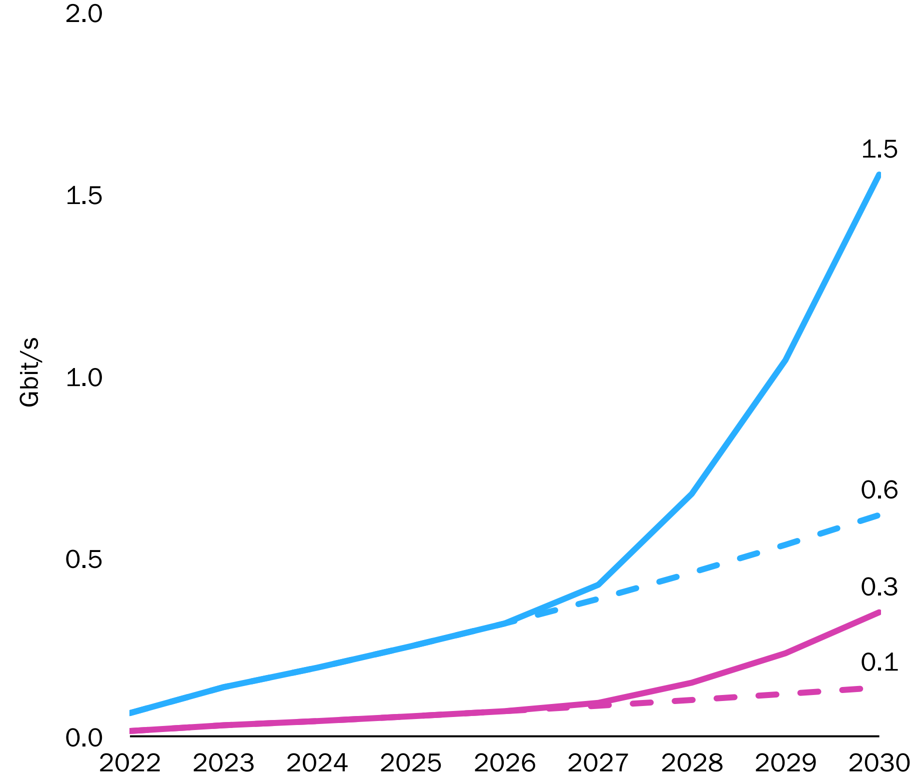
Source: Analysys Mason

Dense urban area – capacity supply

Dense urban MBB capacity supply per average macro site



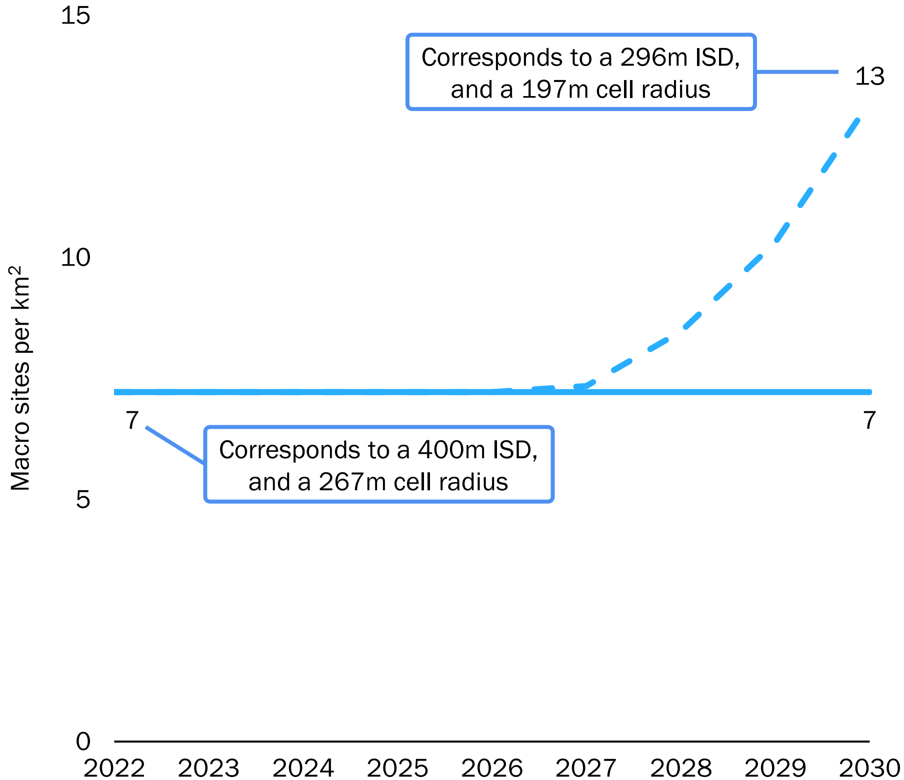
Dense urban MBB capacity supply per average small cell



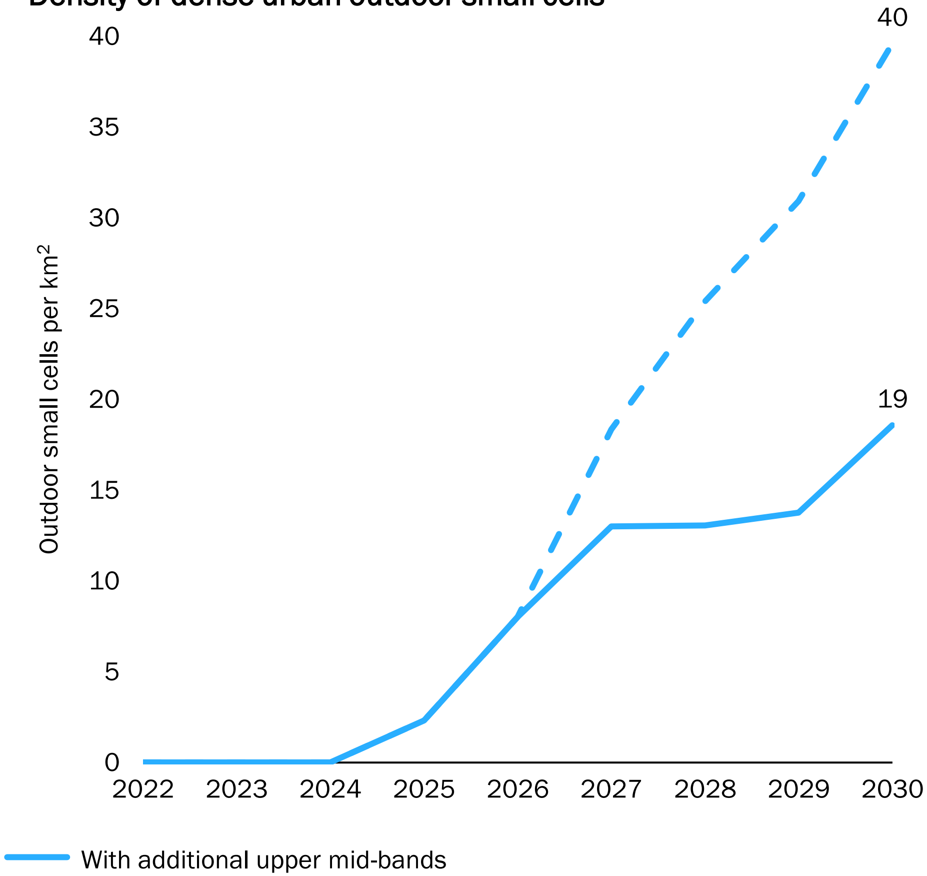
Source: Analysys Mason

Dense urban area results – densification primarily via macro cells [1/4]

Density of dense urban macro sites



Density of dense urban outdoor small cells

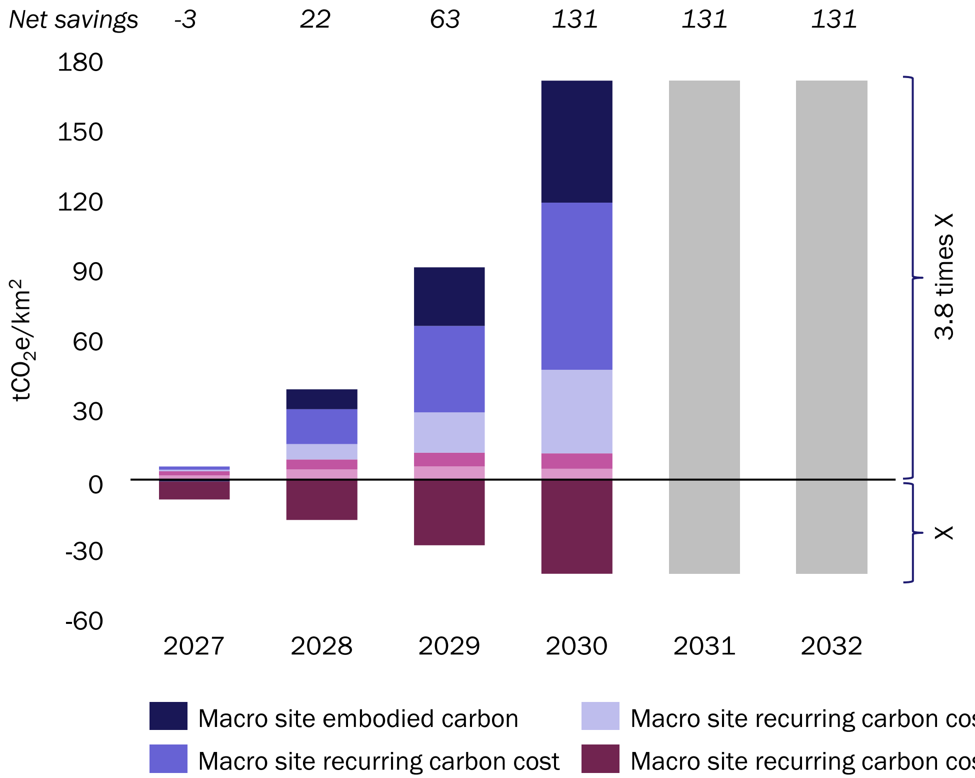


- The outdoor small cells density is capped at 3 small cells for each macro site (deployment variant focused on macro site densification)
  - with additional upper mid-bands, there is only gradual small cell densification, whereas without additional upper mid-bands significant macro and small cell densification is required

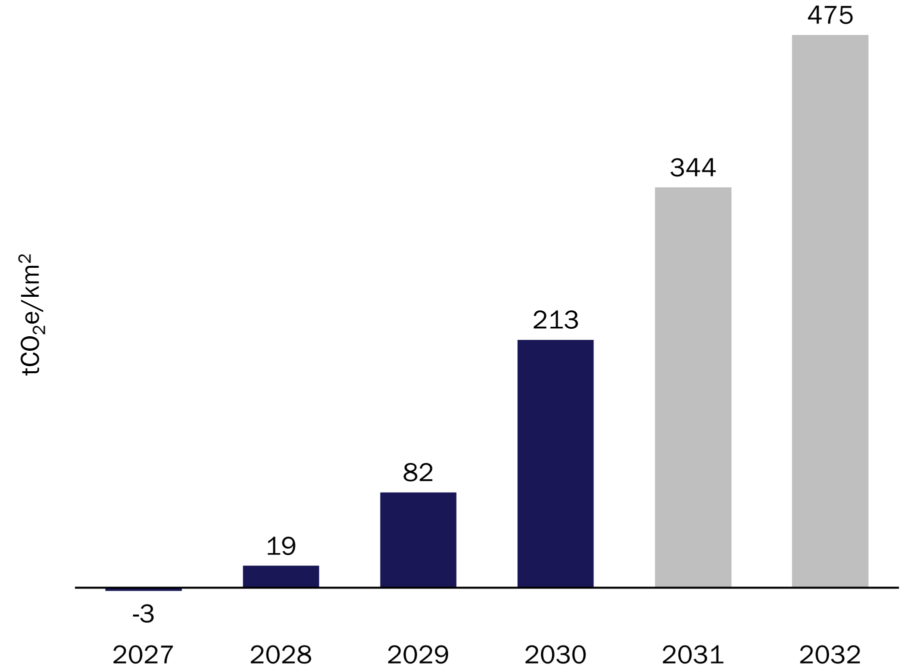
Source: Analysys Mason

Dense urban area results – densification primarily via macro cells [2/4]

Annual carbon savings per dense urban km²



Cumulative carbon savings per dense urban km²



For a 100km² city 47 500tCO_2e would be saved by 2032 if the upper 6GHz band was available to mobile networks, this corresponds to:
800 million km of car travel[1] 26 383 round-trip London-New York flights[2] Annual energy for 11 872 Cambridge homes[3]

[1] Based on the EU target of 59.4gCO_2e/km by 2030 (https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics), [2] https://co2.myclimate.org/en/flight_calculators/new, [3] https://impact-tool.org.uk/footprint/footprint

Source: Analysys Mason

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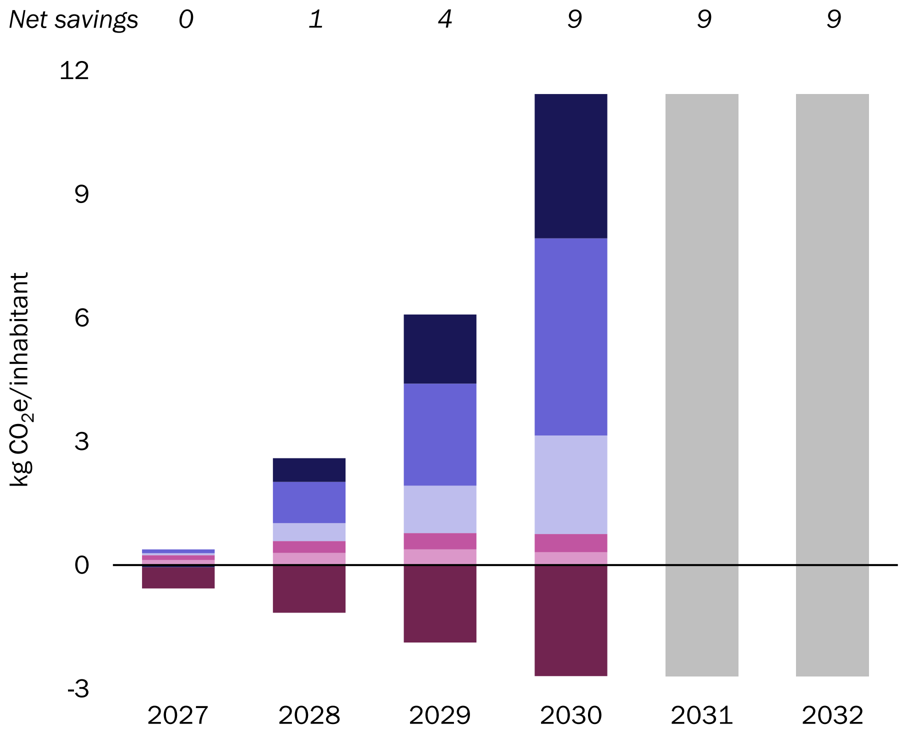
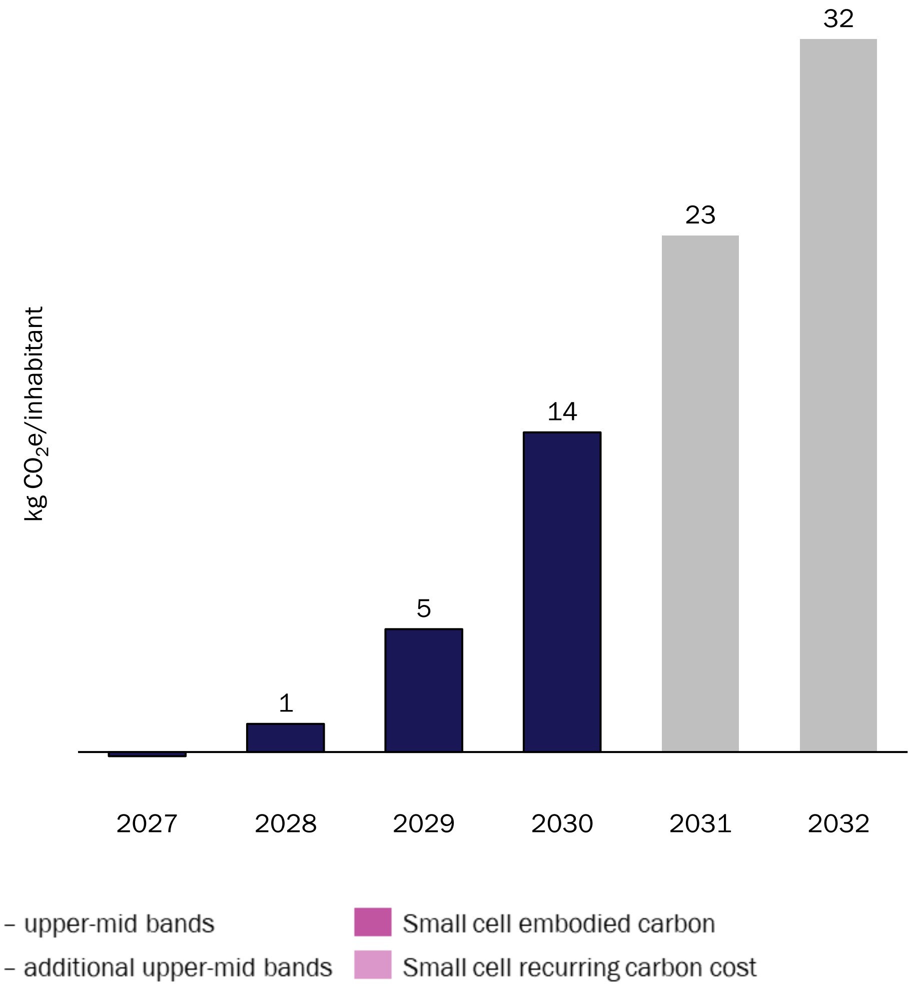
Dense urban area results – densification primarily via macro cells [3/4]

Annual carbon savings per dense urban inhabitant



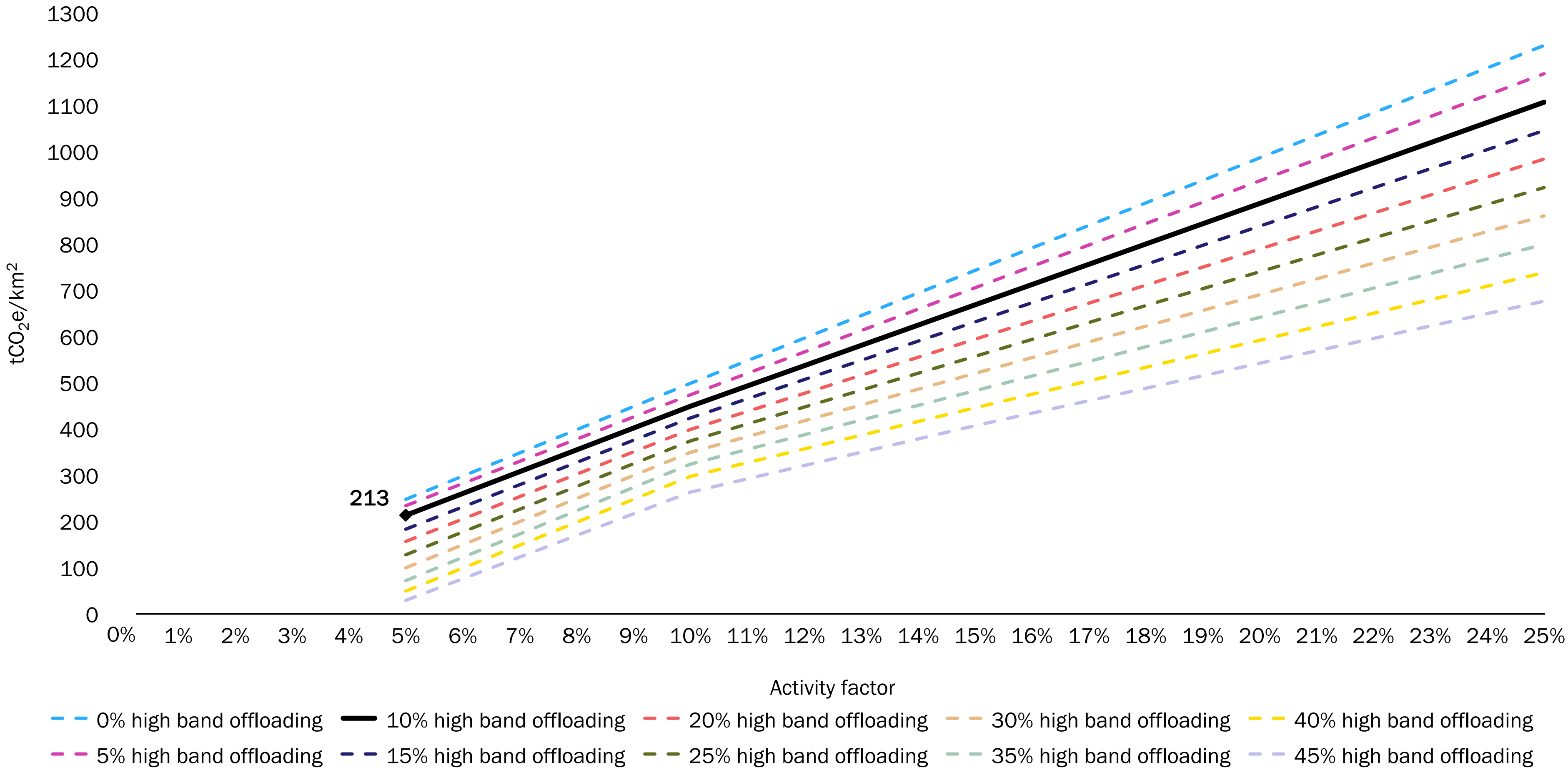
Cumulative carbon savings per dense urban inhabitant



Source: Analysys Mason

Dense urban area results – densification primarily via macro cells [4/4]

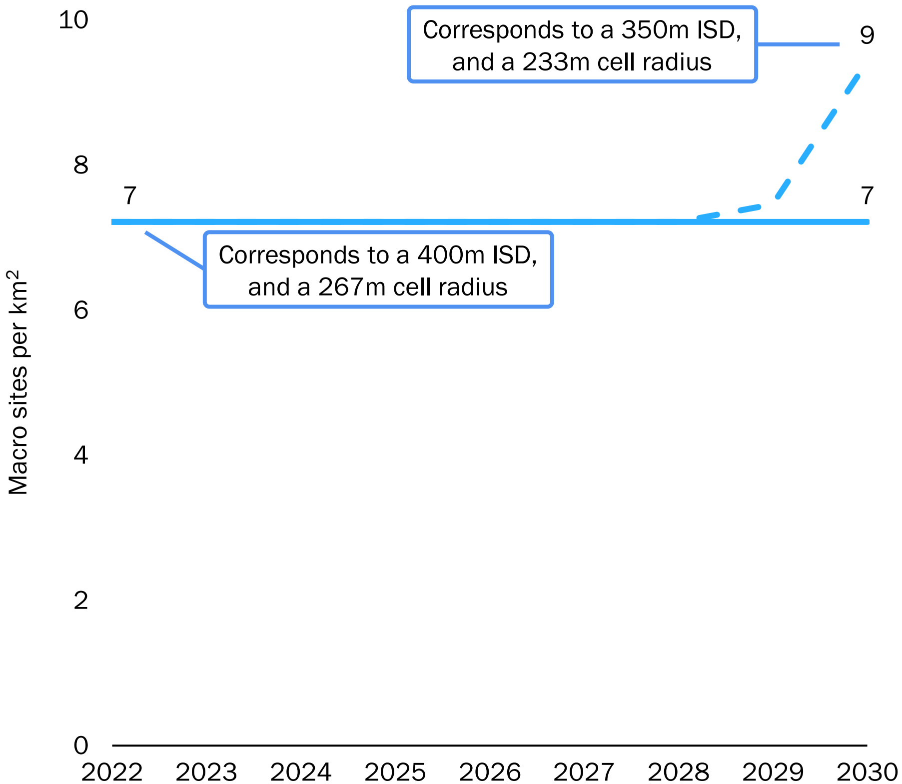
Cumulative carbon savings to 2030 – activity factor and high band offload sensitivity



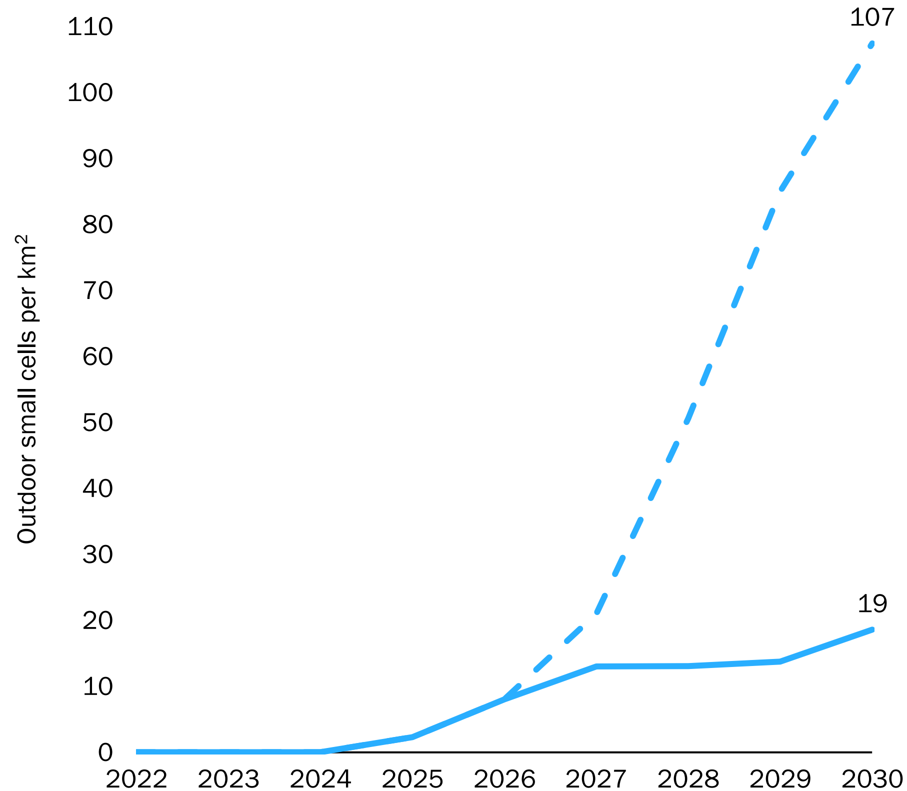
Source: Analysys Mason

Dense urban area results – densification primarily via outdoor small cells [1/4]

Density of dense urban macro sites



Density of dense urban outdoor small cells



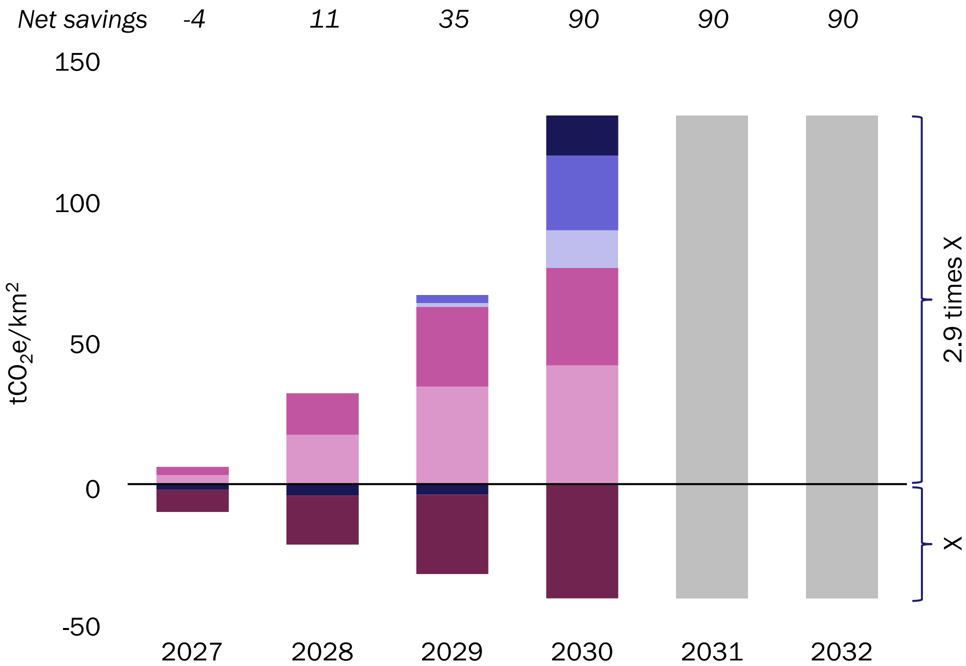
Without additional upper mid-bands — With additional upper mid-bands

- Macro site density is capped at 9.4/km² (350 ISD), representing 31% increase relative to current macro site density
  - with additional upper mid-bands, there is only gradual small cell densification, whereas without additional upper mid-bands significant small cell densification is required

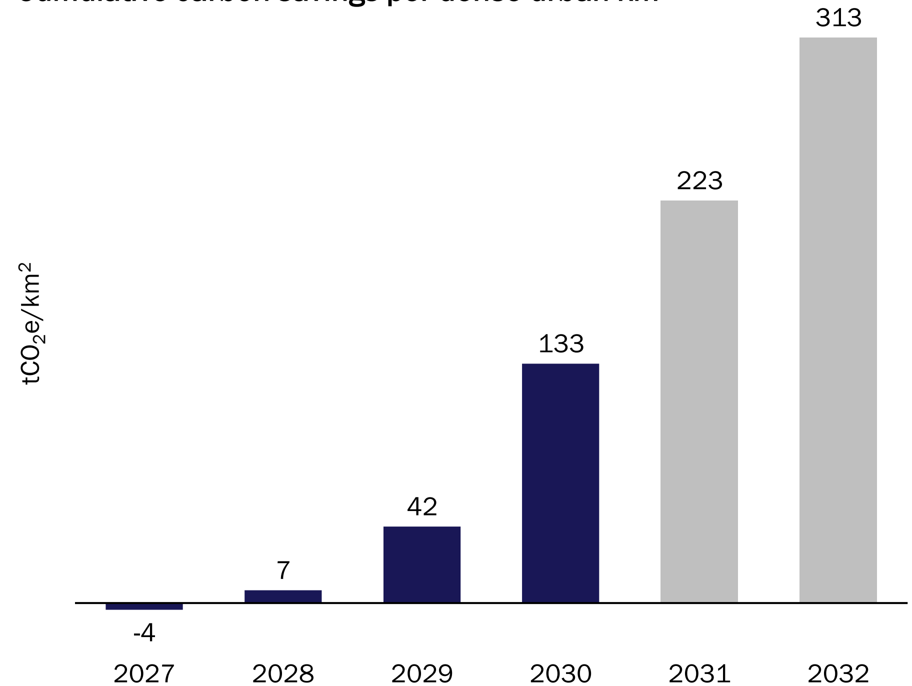
Source: Analysys Mason

Dense urban area results – densification primarily via outdoor small cells [2/4]

Annual carbon savings per dense urban km²



Cumulative carbon savings per dense urban km²



Macro site embodied carbon | Macro site recurring carbon cost – upper-mid bands | Small cell embodied carbon
Macro site recurring carbon cost | Macro site recurring carbon cost – additional upper-mid bands | Small cell recurring carbon cost

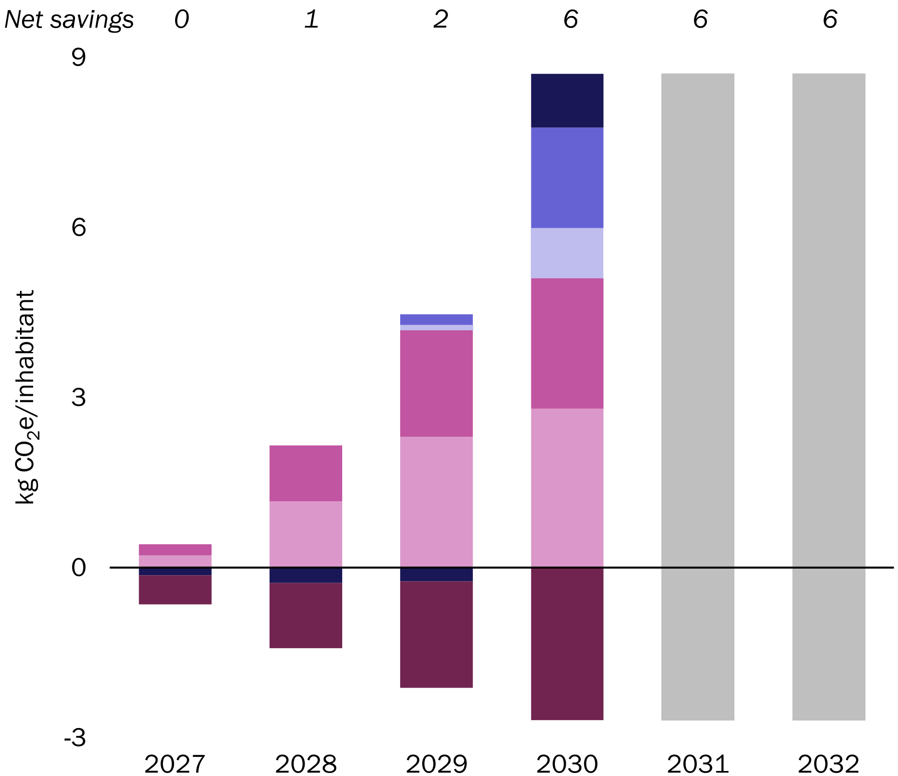
For a 100km² city 31 300tCO_2e would be saved by 2032 if the upper 6GHz band was available to mobile networks, this corresponds to:
527 million km of car travel[1] 17 393 round-trip London - New York flights[2] Annual energy for 7827 Cambridge homes[3]

[1] Based on the EU target of 59.4gCO_2e/km by 2030 (https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics), [2] https://co2.myclimate.org/en/flight_calculators/new, [3] https://impact-tool.org.uk/footprint/footprint

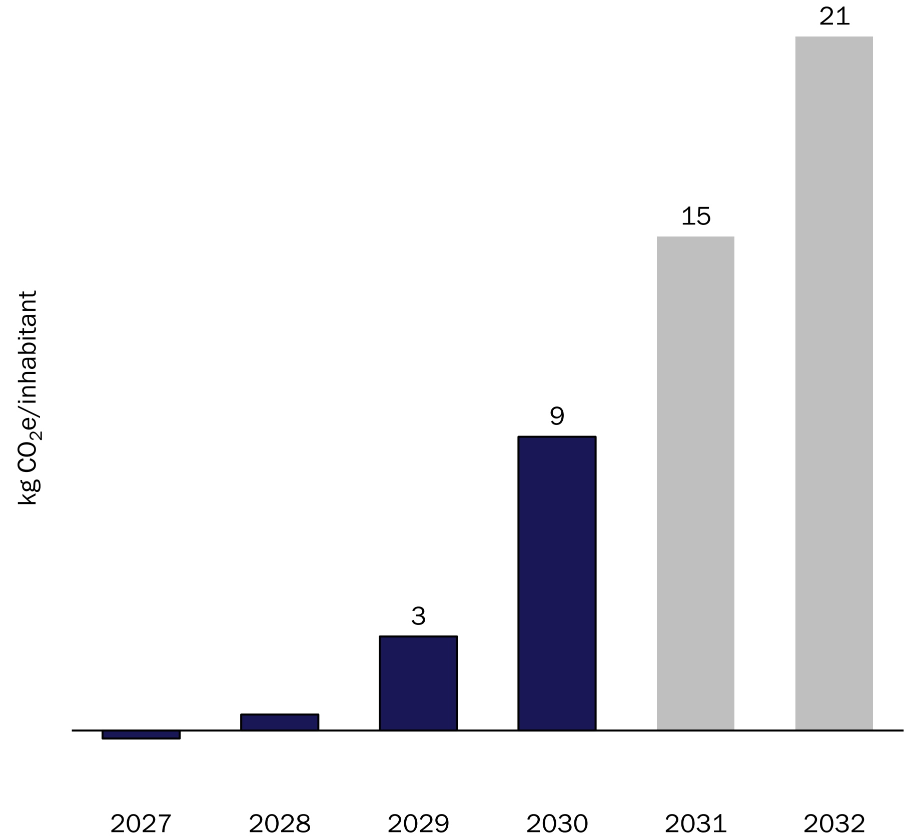
Source: Analysys Mason

Dense urban area results – densification primarily via outdoor small cells [3/4]

Annual carbon savings per dense urban inhabitant



Cumulative carbon savings per dense urban inhabitant

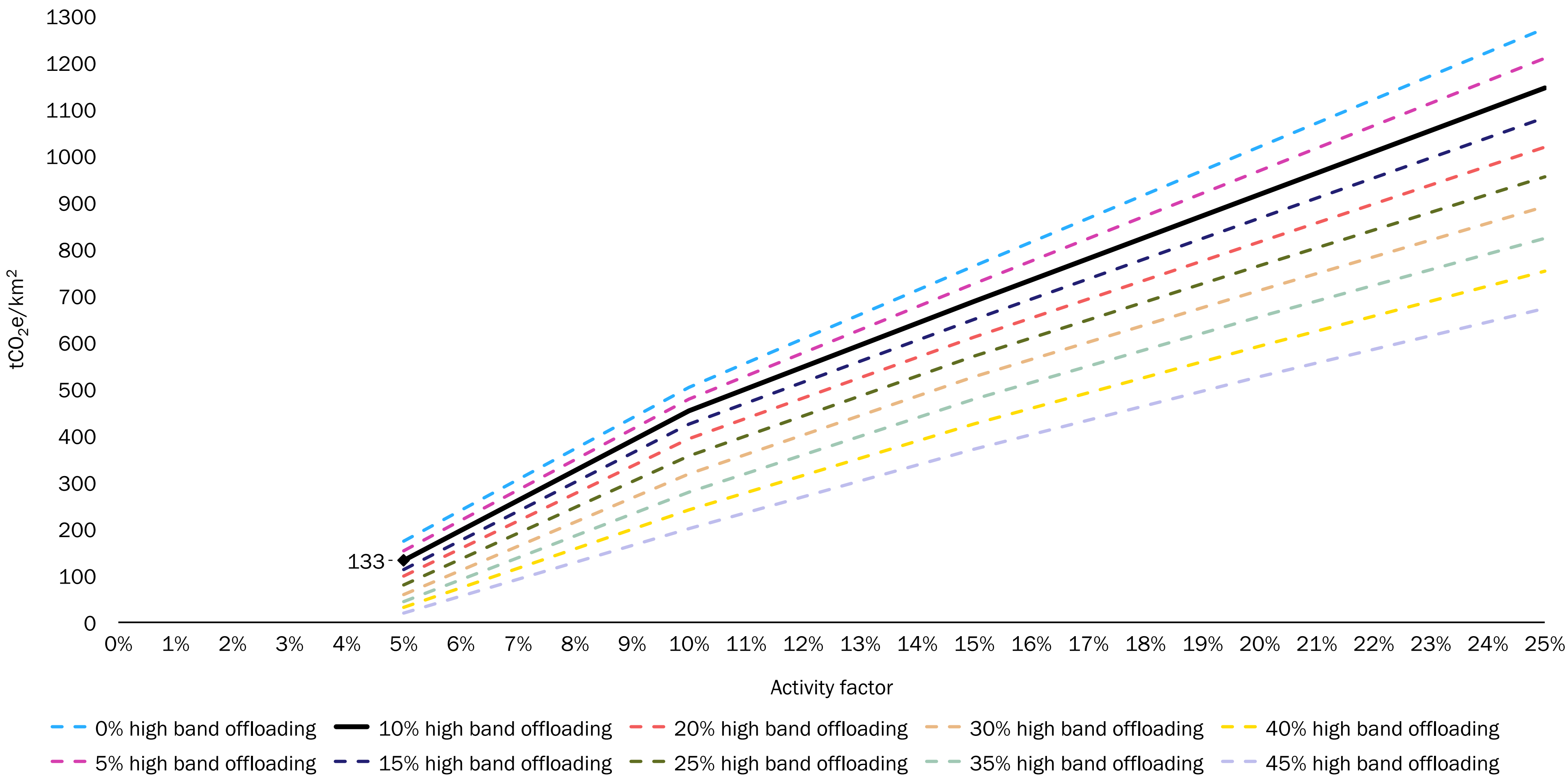


Macro site embodied carbon
Macro site recurring carbon cost
Macro site recurring carbon cost – upper-mid bands
Macro site recurring carbon cost – additional upper-mid bands
Small cell embodied carbon
Small cell recurring carbon cost

Source: Analysys Mason

Dense urban area results – densification primarily via outdoor small cells [4/4]

Cumulative carbon savings to 2030 – activity factor and high band offload sensitivity



Source: Analysys Mason

Practical issues in building additional macro and small cells

- Densifying macro sites or small cells enables operators to meet increased demand, but both options present practical issues in their design, implementation and cost
- **Practical issues with macro site densification**
  - suitable macro site locations in urban areas are increasingly hard to find
  - few locations that would be suitable for improving existing coverage have sufficient physical space
  - planning issues can delay site acquisition
  - densification may be considered ‘unsightly’ or the cause of additional electromagnetic radiation, leading to public resistance
  - as macro site density increases, so too does inter-site interference, which reduces the effective site capacity.
- **Practical issues with outdoor small cell**
  - small cells provide lower coverage compared to macro sites, and so many more small cells would be needed to meet future traffic demand, but there may be public resistance to such proliferation
  - identifying enough suitable locations for small cells (which are typically installed on urban furniture or building facades, rather than rooftops) may be difficult
  - local authority co-ordination/planning issues might affect deployment timescales, or even influence whether sites are viable or not, due to the time taken for planning issues associated new sites and/or modifications to existing sites to be authorised
  - small-cell costs can be high relative to the capacity provided, leading to a potentially unsustainable network deployment model as the number of small cells increases.

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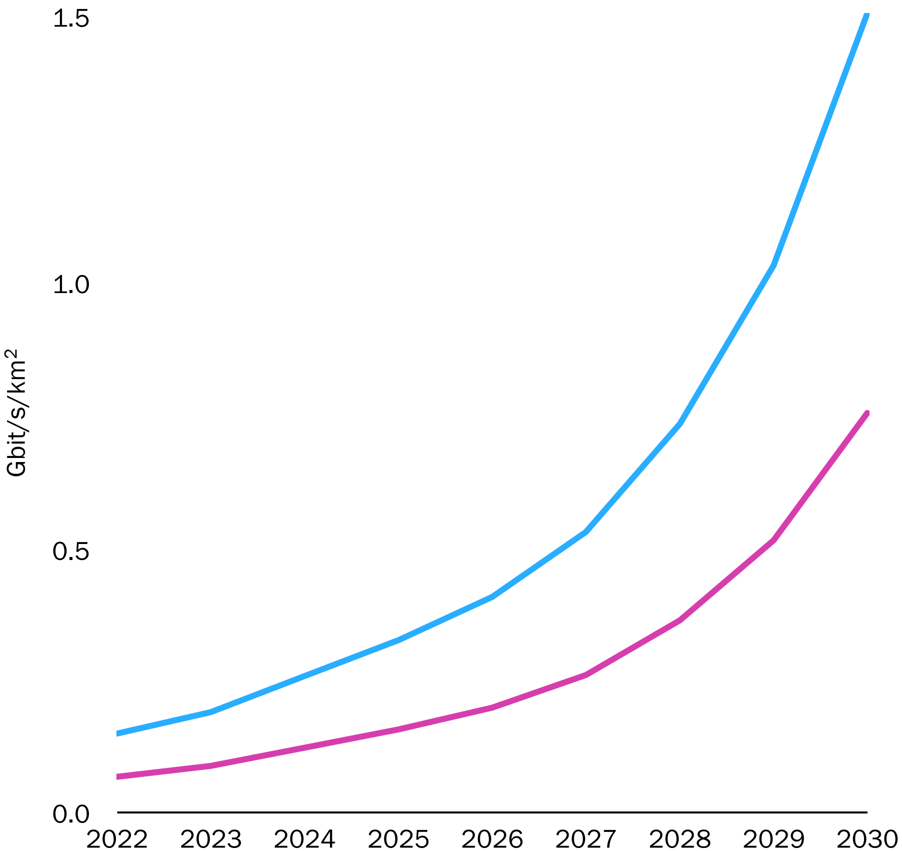
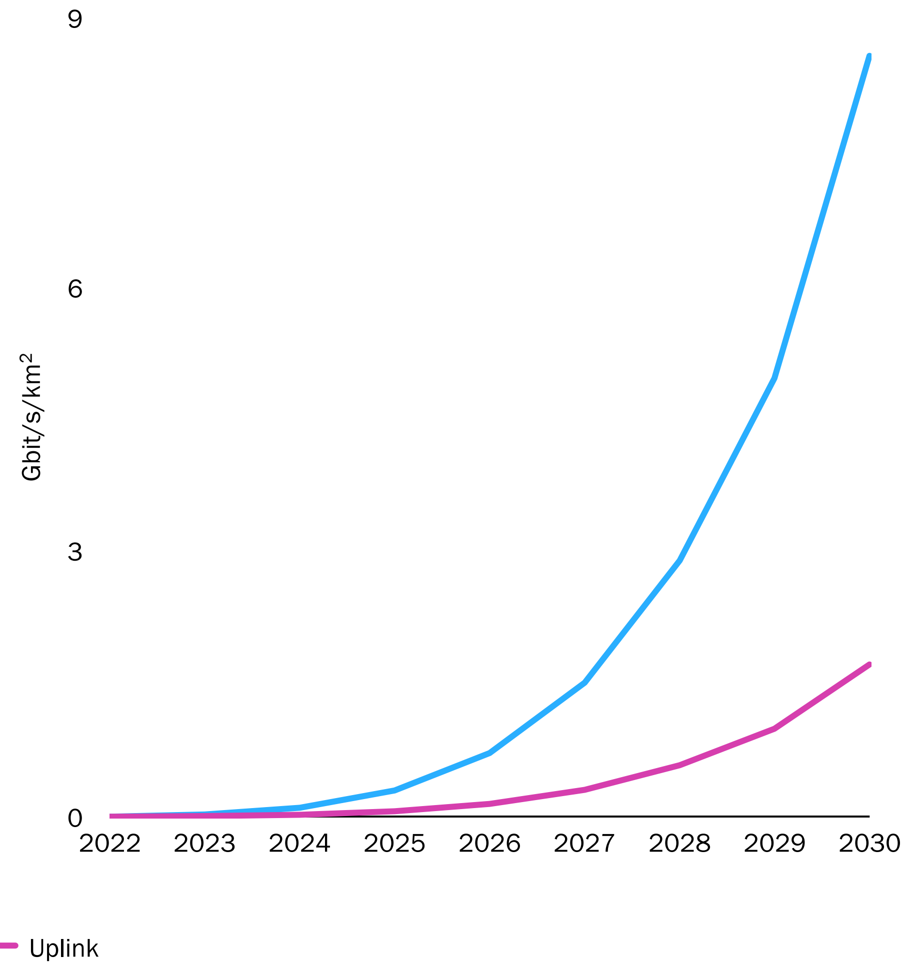
Rural town or village results – required capacity

Rural town or village required MBB capacity



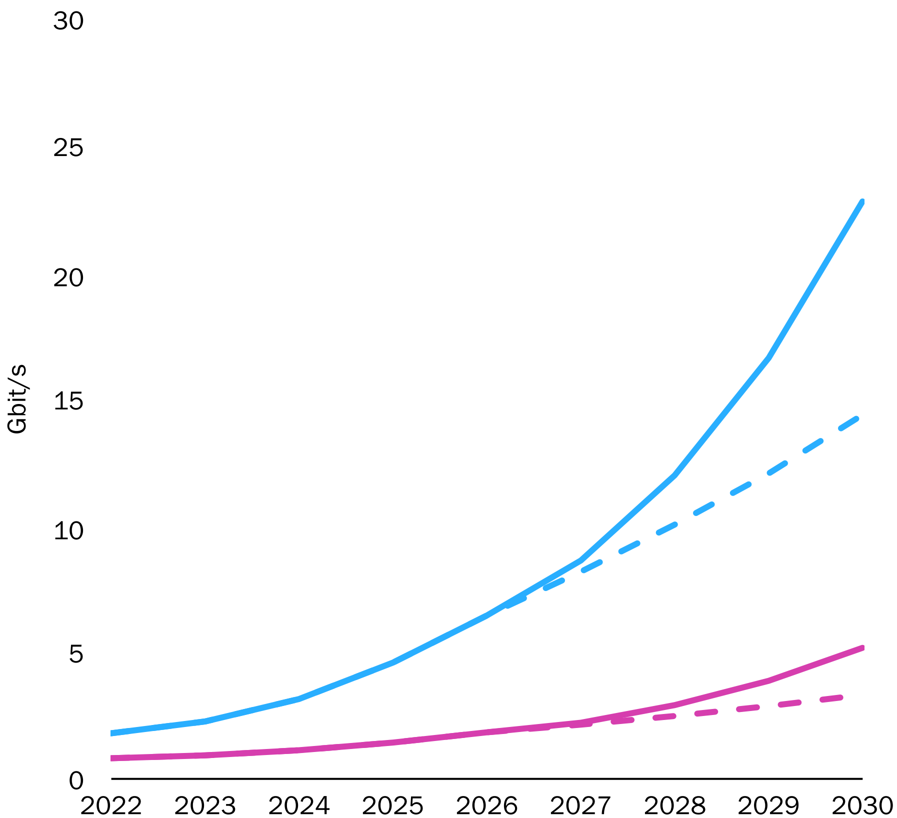
Rural town or village required FWA capacity



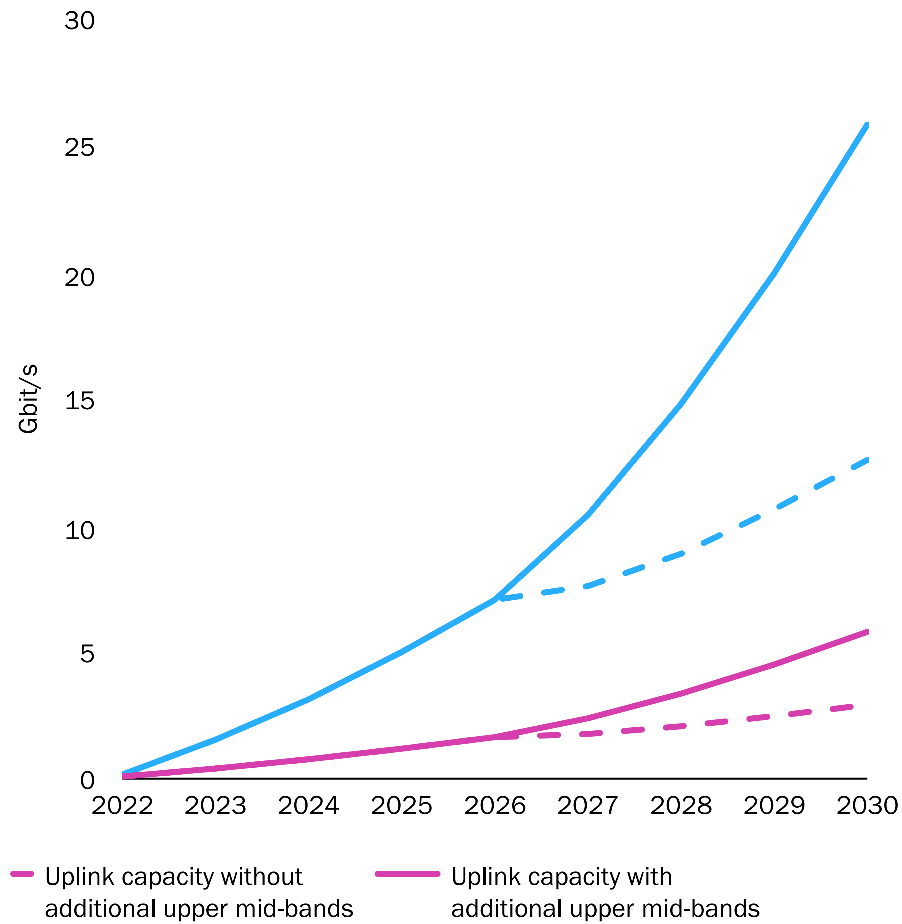
Source: Analysys Mason

Rural town or village results – capacity supply

Maximum MBB capacity supply per macro site for rural town or village



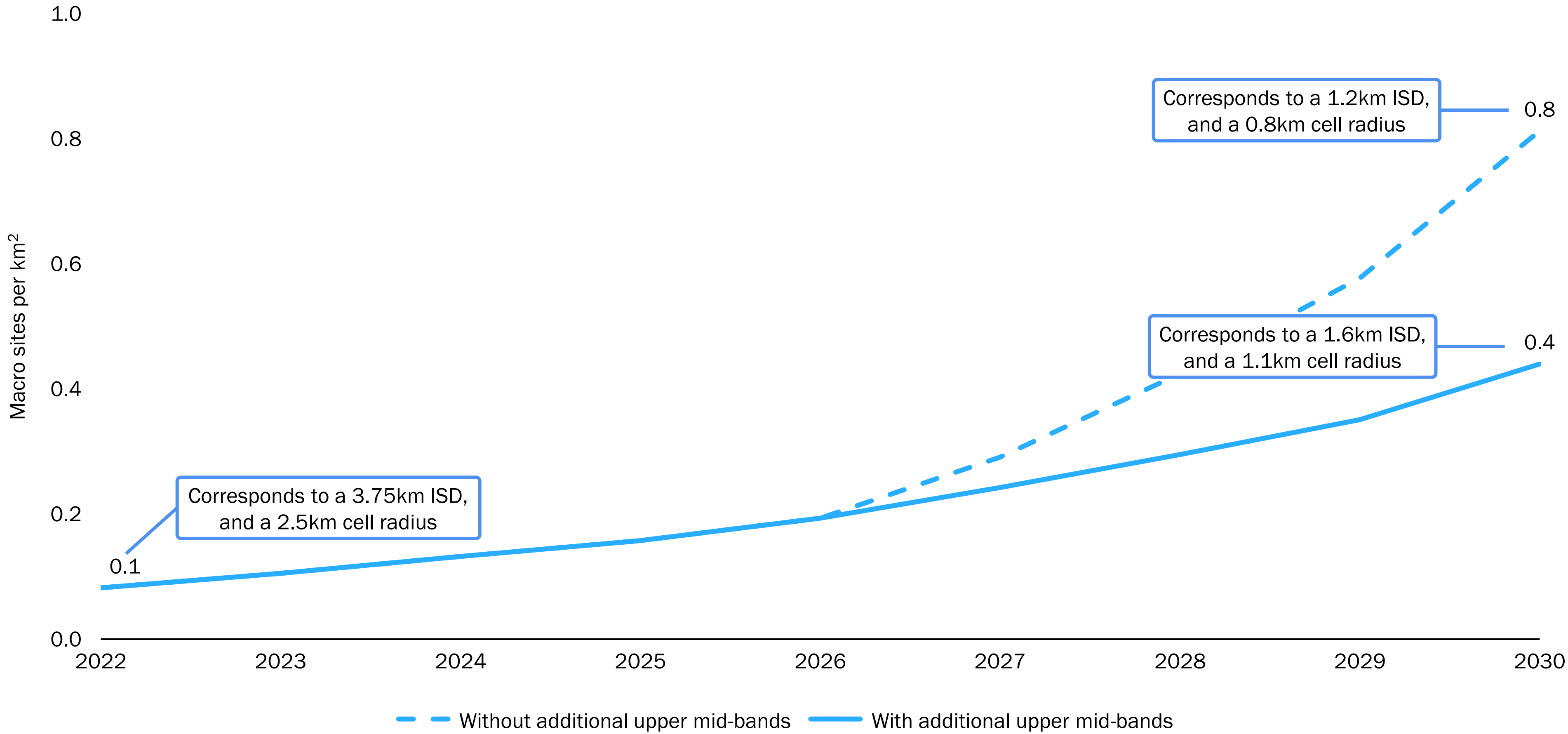
Maximum FWA capacity supply per macro site for rural town or village



Source: Analysys Mason

Rural town or village results [1/3]

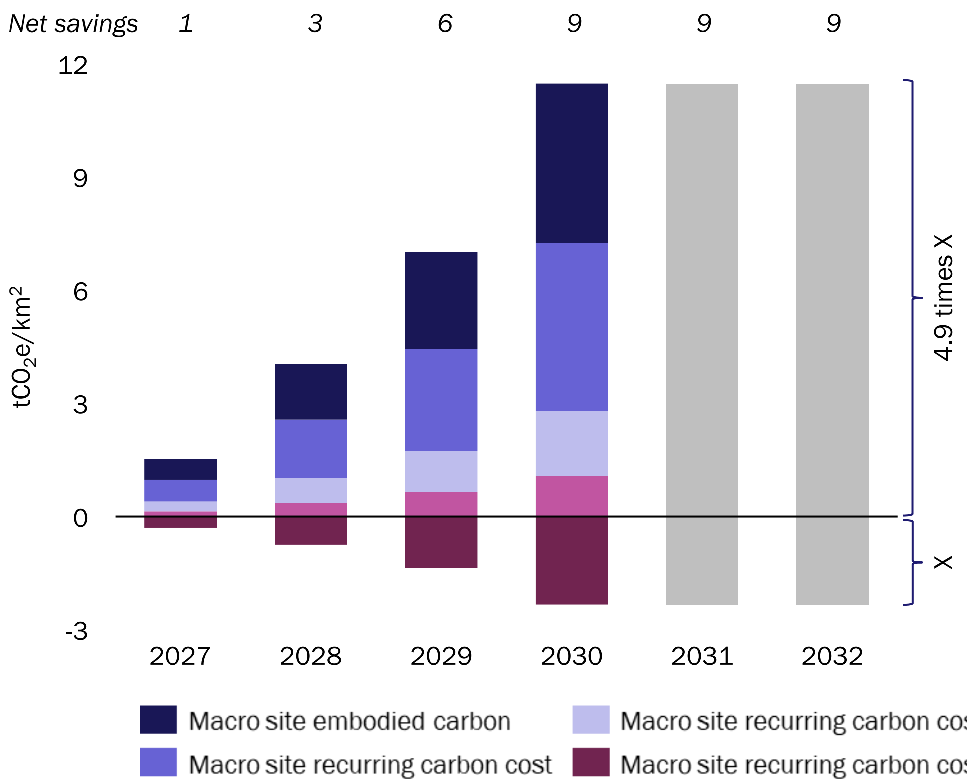
Density of macro sites for rural towns or villages

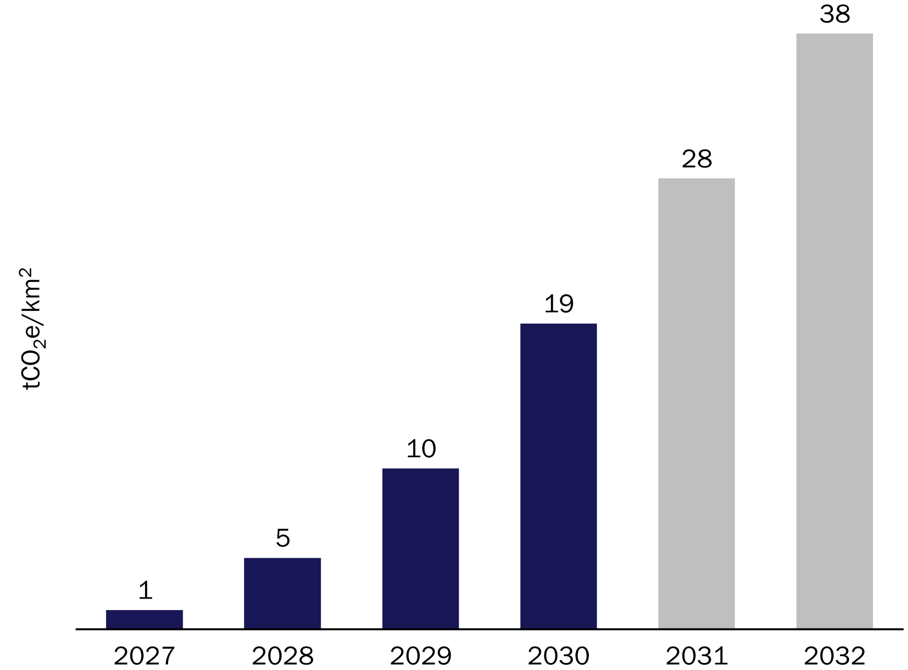


- There is significant macro site densification without additional upper mid-bands

Source: Analysys Mason

Rural town or village results [2/3]





For a 10km^2 town 380tCO_2e would be saved by 2032 if the upper 6GHz band was available to mobile networks, this corresponds to:


6 million km of car travel[1]

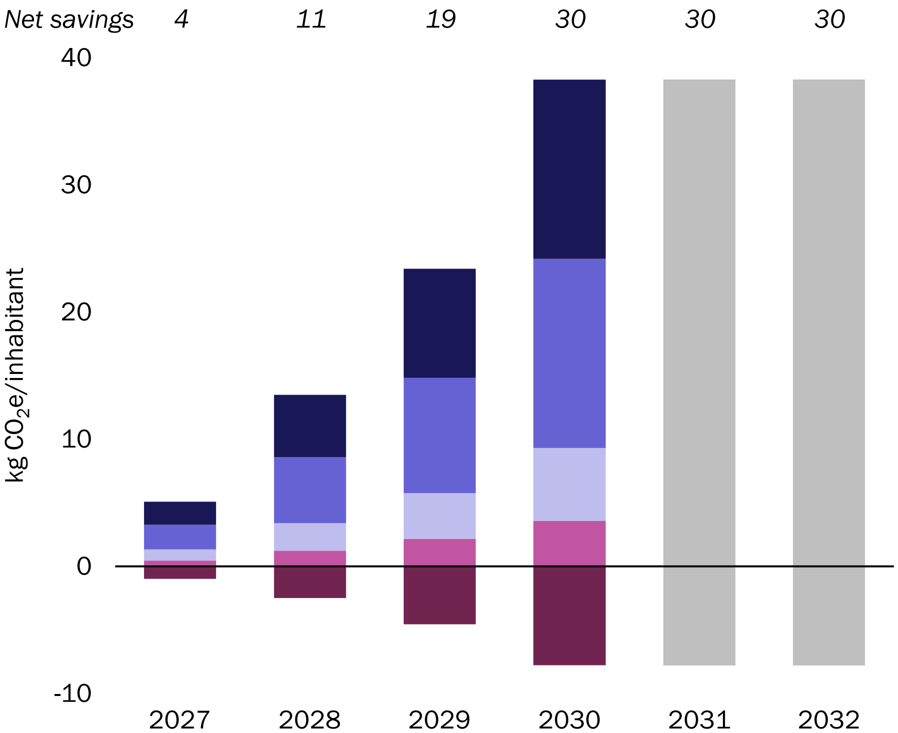
209 round-trip London - New York flights[2]

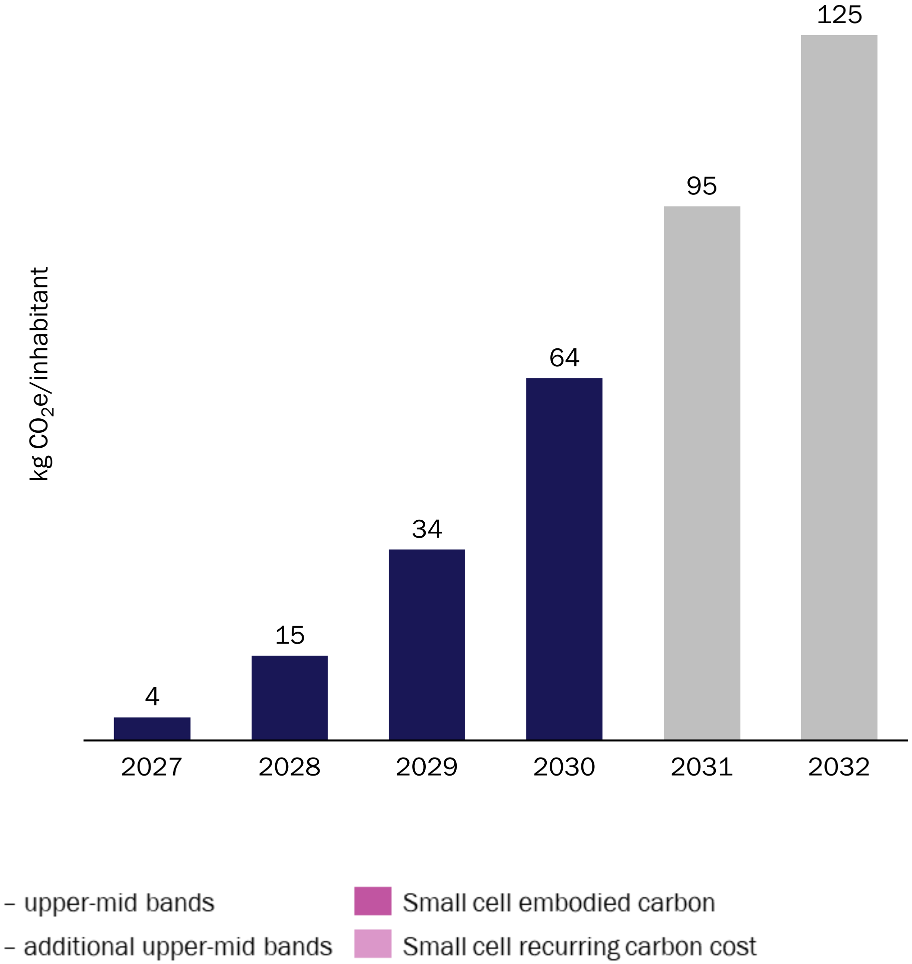
Annual energy for 94 Cambridge homes[3]

[1] Based on the EU target of 59.4gCO_2e/km by 2030 (https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics), [2] https://co2.myclimate.org/en/flight_calculators/new, [3] https://impact-tool.org.uk/footprint/footprint

Source: Analysys Mason

Rural town or village results [3/3]





Source: Analysys Mason

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Modelling the impact of additional 6GHz spectrum on the number of access points required to meet the EC's gigabit targets [1/3]

- The report also includes a discussion of the impact (in terms of the number of Wi-Fi access points needed) of meeting the European Commission Digital Decade policy programme target for all end users at fixed locations to have gigabit connectivity at least equivalent in speed to that of 5G
  - the analysis considers the target of 1Gbit/s within homes and business premises by 2030
  - the analysis assumes connectivity within homes and businesses uses Wi-Fi connected to a fixed broadband connection

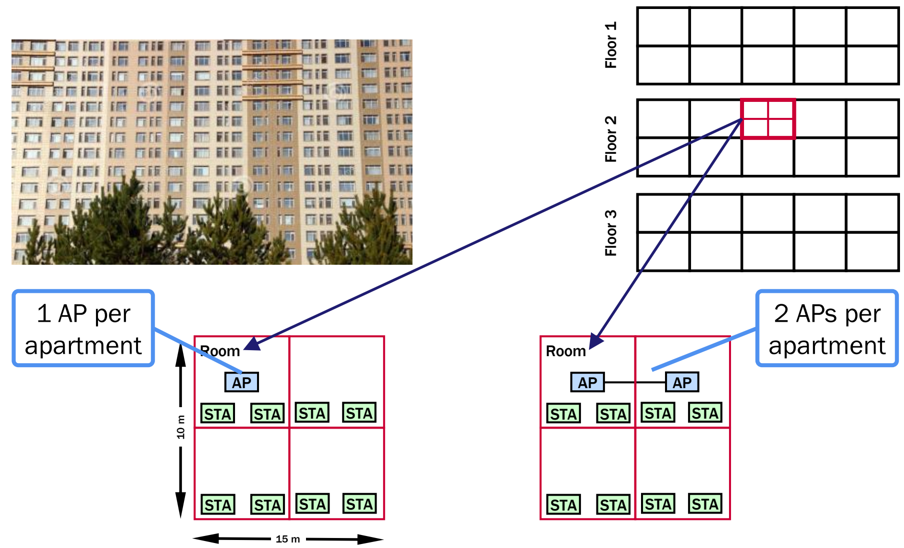
- Huawei has developed a model for the purpose of understanding the impacts on throughput in typical dense urban and rural premises of both the densification of Wi-Fi APs and the use of additional spectrum for Wi-Fi
  - this model simulates the operation of the latest type of Wi-Fi equipment, Wi-Fi 6, radios at the physical (PHY) and medium access control (MAC) layers, and accounts for the impact of co-channel and non-co-channel interference between APs in quantifying the achievable data throughputs

Modelling the impact of additional 6GHz spectrum on the number of access points required to meet the EC's gigabit targets [2/3]

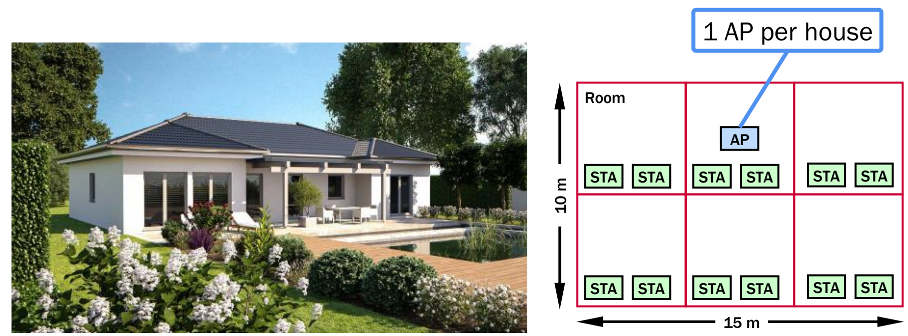
- Two types of premises are modelled, representative of typical dense urban apartments and detached households
  - a **middle-floor apartment**
    - four 5m × 5m rooms
    - Wi–Fi used in an apartment block that contains:
      - nine other similar apartments on the same floor
      - ten similar apartments on the floor above
      - ten similar apartments on the floor below
  - a **single-storey detached household**
    - six 5m × 5m rooms
- Regarding antenna technology, the model accounts for 4 × 4 MIMO in the Wi-Fi APs and 2 × 2 MIMO in the Wi-Fi terminals - a relatively conservative assumption

AP: Wi-Fi access point
STA: Wi-Fi station (user terminal)
Gbit ethernet cable
Walls

Dense urban apartments



Detached house



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Modelling the impact of additional 6GHz spectrum on the number of access points required to meet the EC's gigabit targets [3/3]

For dense urban apartments

- In 90% of model iterations, the target throughput of 1Gbit/s can be achieved with the spectrum currently available for Wi-Fi in the 2.4GHz, 5GHz and lower 6GHz bands
- To reach or exceed the target throughput of 1Gbit/s in 99% of iterations of the model would require two APs regardless of upper 6GHz availability

For detached households

- In 99% of model iterations, the target throughput of 1Gbit/s can be readily achieved with the spectrum currently available for Wi-Fi (2.4GHz, 5GHz and lower 6GHz bands)

Implications for the environmental impact

- The results of modelling show that:
  - the spectrum currently available to Wi-Fi in the 2.4GHz, 5GHz and lower 6GHz bands is sufficient to deliver the Digital Decade target
  - the use of additional spectrum such as the upper 6GHz band would not result in a lower carbon footprint for Wi-Fi installations
    - the same number of access points would be required to reach such a target, irrespective of the utilisation of the upper 6GHz band

Contents

Key findings

1 Making the upper 6GHz available for 5G mobile networks results in **significant carbon emission savings** relative to the alternative when meeting 2030 connectivity targets

In a 100km^2 city, 31–47 thousand tonnes of CO_2e are saved by 2032.
This is equivalent to:

- 524–800 million km of car travel[1]
- 17–26 thousand round-trip London - New York flights[2]
- energy for 7–12 thousand Cambridge homes per year[3]

In a 10km^2 town or village, 380 tonnes of CO_2e are saved by 2032.
This is equivalent to:

- 6 million km of car travel[1]
- 209 round-trip London - New York flights[2]
- energy for 94 Cambridge homes per year[3]

Beyond the higher environmental impacts associated with the required levels of densification in the absence of additional mid-band spectrum, such densification would be practically difficult, economically challenging and potentially technically unfeasible.

2 When the upper 6GHz is available for 5G mobile networks, the carbon emission savings from having less network densification are **at least 2.9 times greater** than the carbon emission costs of deploying and operating new mid-band radios

3 The availability of the upper 6GHz band for Wi-Fi would not translate into any reduction in carbon emissions when targeting an aggregated throughput of at least 1Gbit/s per premises

[1] Based on the EU target of 59.4gCO_2e/km by 2030 (https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics), [2] https://co2.myclimate.org/en/flight_calculators/new, [3] https://impact-tool.org.uk/footprint/footprint

Source: Analysys Mason

General conclusions

- Overall, the analysis demonstrates that, from a carbon footprint standpoint, **it would be more beneficial to make additional mid-band spectrum available to 5G macro cellular networks than to rely exclusively on network densification** to meet future connectivity targets
- More specifically, **with reference to the 5G network modelling:**
  - carbon emission savings from having less network densification outweigh the incremental carbon emission costs of deploying and operating new mid-band radios on existing sites
    - this holds true regardless of densification method (primarily via macro sites vs primarily via small cells)
  - increasing the activity factor for MBB use in the dense urban environment increases the carbon savings
  - increasing the high-band offloading decreases the carbon savings
    - however, such offloading is only needed at specific locations where demand is highest
- Whilst densifying either macro sites or small cells enables operators to meet increased demand, both options present practical issues in their design, implementation and cost, especially at the levels of densification that would be required to meet the connectivity targets in the absence of additional mid-band spectrum
- While results have been modelled assuming the upper 6GHz band as additional mid-band spectrum, conclusions may apply to other mid-band spectrum, provided that the alternative additional mid-band spectrum exhibits similar characteristics to those modelled here
- **With reference to the Wi-Fi deployment modelling:**
  - based on simulations for dense urban apartments and detached households, and considering the future connectivity targets for fixed broadband (i.e. an aggregated throughput of more than 1Gbit/s per premises), the availability of the upper 6GHz band for Wi-Fi would not translate into any reduction in carbon emissions, given that such targets can be met via the latest Wi-Fi technology using the spectrum bands already available for Wi-Fi use in Europe (2.4GHz, 5GHz and lower 6GHz)

Power efficiency measures in mobile network architectures

- 5G mobile network equipment vendors are evolving their systems to limit the carbon footprint of their clients' networks
- The following technology features might be used, among others, in 5G mobile networks to manage power consumption and energy efficiency (these features are vendor-specific, specific vendor solutions indicated in the footnote):
  - **transmission on demand** (e.g. dynamic on–off functions in antennas and radio frequency (RF) chains); these features can be assisted by artificial intelligence and/or user feedback to anticipate user and traffic patterns and to enable real-time network
  - **more efficient power control** in networks and devices, adjusting radiated power to actual coverage needs
  - **innovative solutions for massive MIMO antennas** to increase deployment efficiency and lower power consumption (e.g. through novel optimisation algorithms) (*)
  - **real-time capture and evaluation of network key performance indicators** (KPIs) as an input to network planning, rather than more traditional methods for non-real-time capture of KPIs (e.g. through drive testing).
- Other non-technology-related approaches to reduce the carbon footprint of 5G mobile networks may include:
  - **use of complementary renewable energy** power sources (e.g. solar or wind power) to limit the use of grid power and replenish back-up batteries
  - **power efficiency through spectrum assignment**, such as considering the most efficient way to assign spectrum for new mobile technologies (e.g. energy efficiency from wider contiguous carriers rather than aggregation of narrower carriers)

(*) www.huawei.com/en/news/2021/9/most-sustainable-network-solution; www.verdict.co.uk/huawei-intelligentran-5g/; www.zte.com.cn/global/about/magazine/zte-technologies/2021/1-en/Press-Clipping/1.html; www.ericsson.com/en/press-releases/2022/2/ericsson-5g-portfolio-update-puts-energy-efficiency-center-stage; www.nokia.com/about-us/news/releases/2022/02/22/nokia-launches-intelligent-ran-operations-to-manage-the-power-of-5g-with-machine-learning-mwc22/

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