Investment and funding needs for the Digital Decade connectivity targets

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1 Executive summary

The EU has established ambitious targets under the Digital Decade Policy Programme 2030[1] that by 2030 all European households should be served by a Gigabit network, and all populated areas covered by next generation wireless high speed networks offering performance at least equivalent to that of 5G.[2]

Achieving these goals will require substantial investments from the private sector as well as support from State Aid and public funding from EU programmes such as CEF Digital[3] and the Recovery and Resilience Facility.[4]

In this study, through the use of WIK-Consult's cost and viability model, we seek to provide an estimate of the costs of achieving the recently adopted Digital Decade goals, taking into account the progress that has been made thus far in deploying high speed fixed and mobile networks,[5] and provide a high level assessment of the public subsidies that may be needed to address remaining coverage gaps.

We estimate that around €114bln in investment will be required to achieve the fixed Gigabit coverage goal using Fibre-to-the-Premise (FTTP), of which around €40bln would be needed in public funding. The total investment needed to meet this goal could be reduced to around €108bln including €29bln in subsidies if the most rural households (in areas with a population density of less than 30 inhabitants per square km) are served using 5G Fixed Wireless Access (FWA) connections.[6]

The estimates suggest that relatively limited additional investment[7] will be needed to complete the roll-out of 5G mobile networks with a basic level of service quality (so-called "basic 5G") to all populated areas in the EU.[8] However, for European citizens and businesses to benefit from the full capabilities that can be offered by 5G mobile networks (so-called "full 5G"), we estimate that investments of at least €33.5bln may be required to install additional base stations and small cells that are needed to provide additional bandwidth and support higher quality and more reliable mobile connectivity.[9]

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[1] Decision (EU) 2022/2481 establishing the Digital Decade Policy Programme 2030 https://eur-lex.europa.eu/eli/dec/2022/2481/oj

[2] Article 4

[3] https://digital-strategy.ec.europa.eu/en/activities/cef-digital

[4] https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en

[5] As of 2021, 70% households had access to a Gigabit-capable fixed network and 66% 5G. EC report Broadband coverage in Europe in 2021 https://digital-strategy.ec.europa.eu/en/library/broadband-coverage-europe-2021

[6] This estimate assumes that the latest technologies are used to extend the range of 5G FWA see e.g. https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/closing-the-digital-divide-with-mmwave-extended-range-for-fwa. If smaller cell radii are needed to deploy 5G FWA, the cost would approach that of deploying FTTP for the most rural households.

[7] The cost of achieving full coverage of "basic" 5G through upgrades of existing 4G base stations may require around €11.5bln of additional investment, with minimal need for public subsidies.

[8] Nearly all 5G today has been deployed by upgrading existing 4G base stations and operating the 5G core network on top of the 4G network (5G non-standalone). This offers higher broadband speeds than were available over 4G, but does not offer the full capabilities of 5G including ultra-low-latency and support for massive machine to machine communications.

[9] Providing higher quality 5G mobile services will necessitate the use of midband 3.6GHz and millimetre-wave 26GHz spectrum in areas of high demand. More cell sites will be needed because these higher frequencies

Our modelling also shows that synergies can be achieved by deploying FTTP and full 5G mobile networks in tandem. A joint fixed and mobile deployment meeting both of the Digital Decade connectivity targets would require around €120bln in investment including €33bln in subsidies.[10] This would save around 20% in investment costs compared with a scenario where FTTP and full 5G networks are deployed independently.[11] However, even with these savings, existing EU funds alone, which currently amount to around €19bln, are unlikely to fully address the connectivity gap, and will need to be supplemented with national and regional funding.[12]

A further €26bln in investment on top of the investments required to achieve FTTP and 5G household coverage may be required to ensure full coverage of transport paths including roads, railways and waterways. Some studies[13] also suggest that additional investments (and subsidies) may be required to extend the 5G mobile network beyond populated areas to support 5G industrial use cases such as smart agriculture.

offer less coverage than the lower frequencies such as 700MHz that have predominantly been used to achieve 5G coverage today. In addition the 5G core network should be operated on a standalone basis rather than overlaid on 4G (5G standalone).

[10] These subsidy requirements are likely to be an underestimate as it is based on calculations for NUTS3 areas, and would thus allow more cross-subsidisation between profitable and unprofitable areas than is likely to be possible with State Aid which is targeted solely at unprofitable zones. Moreover, in the base case, only one mobile network is modelled, capturing all available revenues. If the mobile network is able to capture only around 30% of revenues, additional subsidies of around €2.5bln are estimated to be required to support full 5G deployment.

[11] In this case, around €148bln of CAPEX would be required including subsidy needs of at least €43bln

[12] €19bln has been assigned under EU funding for investments in connectivity under the Recovery and Resilience Facility (RRF), and under the 2021-2027 programme for the ERDF and EAFRD The calculations for EU funding do not include national and regional funds.

[13] This has in particular been the subject of research by Analysys Mason on behalf of Ericsson and Qualcomm in 2020 and 2021 studies

2 Introduction

The EU has established ambitious targets under the Digital Decade Policy Programme 2030[14] that by 2030 all European households should be served by a Gigabit network, and all populated areas covered by next generation wireless high speed networks offering performance at least equivalent to that of 5G.[15]

These build on previous goals, established in the 2016 EC Gigabit Society Communication[16] that by 2025 all European households should have access to an Internet connection offering at least 100Mbit/s, upgradable to Gigabit, and that all urban areas and major terrestrial transport paths should have uninterrupted 5G coverage.

Achieving these goals will require substantial investments from the private sector as well as support from State Aid and public funding from EU programmes such as CEF2 Digital and the Recovery and Resilience Facility. In a 2018 study: “Reaching the objectives of the Gigabit Society: Assessment of the investment gap”[17], the European Investment Bank estimated that around €185bln would be needed to achieve universal coverage Gigabit-capable connections, while they estimated that €52bln would be needed to achieve the intermediate (2025) goals of achieving 5G coverage in urban areas and along major transport paths.

Since that calculation was made, significant progress has been made in achieving the Gigabit targets. According to data published by the EC[18] as of 2021, 50% of households had access to an FTTP connection, while 70% had access to a Gigabit-capable connection when DOCSIS 3.1 was also taken into account. 5G coverage was also estimated to have reached 66% of households, up from just 14% the previous year.

It is necessary to update the projections regarding the cost of achieving Gigabit coverage to households and transport paths to take into account deployments that have taken place in recent years. Moreover, as further improvements to mobile network quality as well as support for new 5G use cases will depend on the deployment of 5G using mid-band and millimetre wave frequencies, it is necessary to understand the costs involved in upgrading 5G networks to “full 5G”, including the costs of deploying small cells as well as dark fibre backhaul.

In this study, through the use of WIK-Consult’s cost and viability model, we seek to estimate the costs of achieving the Digital Decade goals, taking into account the progress made thus far, and to assess, at a high level, the degree to which public subsidies may be needed to address remaining coverage gaps. We also compare the outputs from the WIK model with

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[14] Decision (EU) 2022/2481 establishing the Digital Decade Policy Programme 2030 https://eur-lex.europa.eu/eli/dec/2022/2481/oj

[15] Article 4

[16] https://digital-strategy.ec.europa.eu/en/library/communication-connectivity-competitive-digital-single-market-towards-european-gigabit-society

[17] EIB, 2018, Reaching the objectives of the Gigabit Society: Assessment of the investment gap

[18] EC report Broadband coverage in Europe in 2021 https://digital-strategy.ec.europa.eu/en/library/broadband-coverage-europe-2021

other cost estimations and provide an overview of FTTP and 5G coverage forecasts, to identify potential gaps which may require public support.

- Chapter 3 provides an overview of the methodology and main results from WIK’s cost and viability modelling
- Chapter 4 provides a summary of other studies which have sought to estimate deployment costs and provide deployment forecasts for Gigabit broadband and 5G
- Conclusions are presented in chapter 5

A more detailed description of the cost modelling methodology is provided in the Annex.

3 Results from WIK's modelling

3.1 Assumptions used in the modelling

3.1.1 Network architecture

The network architecture used for all households connected through fibre is point-to-multipoint (PtMP). The underlying technology is assumed to be XGS.PON with OLT in the central office (MPoP), a splitter in the distribution point and an ONU/ONT in the customer's premise.

For scenarios involving mobile deployment, the network architecture used for the connection of networking equipment, including 5G base stations, 5G small cells or FWA base stations is point-to-point (PtP). The underlying technology is assumed to be an active network with switches in the central office (MPoP) and 5G equipment at the base station location.

3.1.2 Frequencies and Radii

Regarding mobile coverage, it is assumed that in rural regions spectrum in the 700-900 MHz frequency band range is used in order to achieve maximum reach. In mid-density (suburban) regions spectrum in the 1.5-2.6 GHz frequency bands is used to achieve a good balance between reach and bandwidth. In dense (urban) regions spectrum in the 3.6 GHz band is used to support bandwidth requirements and low latency.

For fixed wireless access (FWA) a frequency within the 26 GHz band is used to achieve Gigabit-capable connectivity.

For mobile coverage along transport corridors (roads, railways and waterways) spectrum in the 3.6 GHz band is used to support ultra-low latency transport applications.

In urban settings, alongside base stations, spectrum in the 26 GHz band is used to deploy small cells to increase the capacity of mobile services. Small cells are only installed to enhance capacity at dedicated locations, as wider coverage is achieved by base stations operating in low and mid bands.

Table 3-1 Radii for base stations[19]

Regio Type	Frequency	Radius
Rural	± 0,7 GHz	7 km
Sub-Urban	± 1,5 GHz	2 km
Urban	± 3,5 GHz	0,5 km
FWA	± 26 GHz	4 km
Transport corridors	± 3,5 GHz	0,5 km

Source: WIK estimates based on radio emission models

[19] See WIK (2022) Estimation of additional 5G antenna mast locations for 3.6 GHz for filling gaps between existing antenna locations https://www.wik.org/en/publications/publication/wik-research-brief-estimation-of-additional-5g-antenna-mast-locations-for-36-ghz-for-filling-gaps-between-existing-antenna-locations

The number of base stations required to achieve coverage per NUTS3 region is determined following the radii assumptions displayed in Table 3-1, and taking into account the population density of the region concerned. For FWA an additional threshold of 200 households per FWA basestation is applied[20]. Small cells are added to meet capacity requirements within the covered 5G areas. Assumptions regarding the radii for small cells that will be required to address capacity needs in different area types is shown in Table 3-2.

Table 3-2 Radii for small cells[21]

Regio Cluster	Radius [km]
1 Dense Urban	0,25
2 Urban	0,30
3 Less Urban	0,40
4 Dense Suburban	0,50
5 Suburban	0,70
6 Less Suburban	0,90
7 Dense Rural	0,95
8 Rural	1,00

Source: WIK estimates based on radio emission models

3.1.3 Cost for mobile appliances[22]

For the cost of 5G macro cell implementation two different scenarios apply. For new sites, a new P2P fibre backbone connection is installed, as well as 5G equipment. In the scenario where an existing 4G base station is updated to 5G, the 4G equipment is upgraded and a new or improved backbone connection deployed.

Small cells and FWA base stations are always assumed to be new and equipped with a new P2P fibre backbone connection. The estimated costs are shown below.

[20] For FWA both thresholds (radius and maximum number of households per basestation) apply simultaneously for NUTS3 regions with less than 30 households per km², but only for the very rural households within the NUTS 3 region. The number of basestations for FWA per NUTS3 region is determined based on whichever criterion results in a higher number of basestations. The report "Fixed Wireless Access using mmWave extended range" by Ericsson (https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/closing-the-digital-divide-with-mmwave-extended-range-for-fwa) indicates that with modern technology, 5G FWA can deliver gigabit capabilities to the customer over extended distances. In practice, a very low number of households (only approx. 0,013%) would be connected with FWA, as other households are either not located in low density areas or are already connected with FTTP or DOCSIS 3.1

[21] For coverage it is assumed that the whole area of each NUTS3 region is covered via macro cells. It is assumed that in the built up areas small cells are added to provide additional capacity. Estimates regarding the number of small cells needed vary. The WIK (2022) study "Estimation of additional 5G antenna mast locations for 3.6 GHz for filling gaps between existing antenna locations" https://www.wik.org/en/publications/publication/wik-research-brief-estimation-of-additional-5g-antenna-mast-locations-for-36-ghz-for-filling-gaps-between-existing-antenna-locations suggests that there may be limited additional capacity needs in the coming years. Thus, projections for small cell deployment could be an over-estimate, although under-estimation is also possible depending on the evolution of bandwidth demand.

[22] Reduction in cost might be possible through the use of Open RAN, but is not assumed in the present calculations

Cost for new 5G macro cells per base station	110.000 €
Cost for updated 5G macro cells per base station	40.000 €
Cost for new 5G small cells per base station	34.000 €
Cost for FWA base station	160.000 €

Source: WIK estimates based on WIK benchmarks

These sums include investments for the network element as well as the CAPEX required for construction and installation.

After calculating the investment required annualised CAPEX, OPEX[23] and revenues are taken into account in order to determine the unprofitable regions and the resulting subsidy requirements. No distinction has been made between 4G and 5G electrical power consumption per antenna, on the basis that increased energy efficiency of 5G is likely to be counteracted by increased data consumption.

3.1.4 Base parameters for NGA network setup

For fixed network cost and viability modelling, the following assumptions apply regarding the type of deployment (aerial or ducted), degree of infrastructure re-use and associated costs. These parameters are drawn from option 0 (the status quo) scenario modelled in the context of the WIK et al study for the Commission on the Review of the Broadband Cost Reduction Directive (BCRD). In a scenario where additional measures are taken to support infrastructure re-use the overall cost for FTTP deployment would be lower.

Table 3-3 Base parameters

Market Share	70%
Share of deployment	
Ducted (drop)	80%
Aerial (drop)	10%
Use of empty ducts (drop)	5%
Use of existing poles (drop)	5%
Ducted (feeder)	95%
Aerial (feeder)	0%
Use of empty ducts (feeder)	5%
Use of existing poles (feeder)	0%
Price for empty duct access per meter of microduct and month	0,05 €
Price for existing pole access per meter and month	0,04 €
Cost of in-building infrastructrue	200 €
% premises with reduction for in-building infrastructure	10%
% cost reduction compared with newly built in-building infrastructure	30%

Source: WIK et al Review of the BRCD (2022)[24]

[23] OPEX for active equipment and backhauling for 5G basestations is taken into account via a mark-up for the subsidy calculation (but is not included in the investment calculation). OPEX calculations might be higher if calculated in the context of a detailed model of the mobile network. The cost of spectrum licenses are not considered, as these vary significantly between countries and operators, and in some cases have not yet been assigned. High spectrum license costs would likely result in higher subsidy requirements.

[24] The €200 for inbuilding infrastructure per home connected is based on an average of the cost estimates provided by electronic communication network operators in interviews and an online survey conducted

3.2 Fixed connectivity scenarios

For fixed connectivity, we model two scenarios: (1) the cost of deploying FTTH to reach 100% of households; and (2) the cost to deploy FTTH with 5G FWA used to serve households in the least densely populated areas. Results are shown below.

(1) FTTH stand alone: FTTH coverage to 100% households

The first scenario calculated is an FTTH standalone case, where the cost of fixed deployment to households is assessed independently from the cost of deploying 5G FWA. The topology modelled is a Point-to-Multipoint (PtMP) network, provided through XGS.PON technology. Although this is less future proof architecture than point to point, PtMP achieves some cost savings which are estimated through WIK-Consult's cost models at approximately 10% of the total investment. In order to provide gigabit capabilities a splitting-factor of 1:32 is used, as the feeder section of the network is a shared medium. With this splitting-factor 1.5 Gigabit/s downstream and upstream can be achieved in the busy hour by 20% simultaneous users[25]. A splitting factor of 1:64 would halve this figure, and thus not meet the 1 Gbit/s goal. This splitting factor is also chosen to provide a future proof modelling approach to the PtMP architecture.

The required investments and subsidies are calculated on the assumption that only households need to be served, that presently are not covered by FTTH or DOCSIS 3.1 or higher. Existing coverage data per NUTS3 area from the European Commission is used to exclude households which are already served with Gigabit technologies.

The following table shows the results of the calculation for the 27 member states. The investment requirements are approximately 114 bln € and the subsidy requirements amount to approximately 40 bln €[26]. It should be noted that the estimates regarding required subsidies should be taken as a rough estimate and cannot replace the need for detailed calculations within the Member States. Specifically, the estimation of costs at NUTS3 level may lead to greater levels of cross-subsidisation of fibre costs between different area types (and therefore lower subsidy requirements) than would be considered in the context of state aid, where smaller geographic areas are typically defined (sub-NUTS3) in order to target funding at households which are not economically viable.

in the context of a study for the European Commission regarding the review of the Broadband Cost Reduction Directive.

[25] An simultaneous usage of 20% was outlined in the draft version of the EC state aid guideline available during the preparation of this study. The value has been reduced to 10% in the final EC state aid guideline by end of 2022. The effect on the investment needs is estimated to be less than 1% if the networks will be designed in the poorer quality option now admitted.

[26] These investments cover 57.3 mln. Households not yet served with 1 Gbit/s capable fixed access (as of 2022)

Table 3-4 FTTH stand alone: FTTH coverage to 100% households[27]

Country	Fixed Only Invest [Bln€]	Fixed Only Subsidy [Bln€]
Austria	5,473	2,017
Belgium	3,392	0,367
Bulgaria	0,574	0,705
Croatia	1,023	
Cyprus	0,302	
Czechia	2,982	1,533
Denmark	0,376	0,078
Estonia	0,268	
Finland	2,678	2,365
France	26,34	9,18
Germany	22,859	5,331
Greece	5,29	
Hungary	1,306	0,892
Ireland	0,513	0,23
Italy	24,993	6,91
Latvia	0,133	0,277
Lithuania	0,382	0,5
Luxembourg	0,024	0,004
Malta		
Netherlands	1,414	0,161
Poland	5,95	4,081
Portugal	0,609	0,087
Romania	1,261	1,156
Slovakia	0,868	0,582
Slovenia	0,348	0,191
Spain	2,266	1,763
Sweden	2,736	1,764
Sum EU 27	**114,359**	**40,173**

Source: WIK calculations

(2) FTTH with 5G FWA in the most rural areas

The second scenario calculated is an FTTH standalone case (i.e. fixed network is calculated independently from mobile), where all households are connected with FTTH except for households in areas with less than 30 households (around 100 inhabitants) per km² which are connected via 5G fixed wireless access (FWA) technology instead of being connected with fibre. Again, the fixed part of the access network is modelled as a passive point-to-multipoint (PtMP) architecture. The part of the network serving to connect the FWA base

[27] In a few cases the operation of a fully subsidized network is still not profitable. This results in subsidy requirements larger than the investment needs

stations is assumed to be based on point-to-point (PtP) deployment to the base stations, in order to maximise capacity available to the wireless network.

As before, the required investments and subsidies are calculated on the basis that only households which are not currently served with Gigabit technology should be included in the calculation.

The following table shows the results of the calculation for the 27 member states. The investment requirement amounts to approximately 108 bln € and the subsidy requirement is around 29 bln €. The replacement of fibre access lines for the most rural areas with FWA therefore reduces the investment needs by ca. 6 bln € and subsidisation requirements by around 11 bln € compared with a full fibre roll-out to all households.

Table 3-5 Results FTTH with 5G FWA in the most rural areas

Country	Fixed Only FWA for rural Invest	Fixed Only FWA for rural Subsidy
Austria	5,013	1,416
Belgium	3,352	0,307
Bulgaria	0,467	0,322
Croatia	0,794	
Cyprus	0,302	
Czechia	2,936	1,231
Denmark	0,372	0,048
Estonia	0,201	
Finland	2,154	0,909
France	24,606	7,813
Germany	22,47	4,097
Greece	4,084	
Hungary	1,1	0,528
Ireland	0,412	0,109
Italy	24,74	5,141
Latvia	0,204	0,3
Lithuania	0,237	0,125
Luxembourg	0,024	0,003
Malta		
Netherlands	1,414	0,111
Poland	4,992	2,448
Portugal	0,441	0,032
Romania	1,243	0,826
Slovakia	0,884	0,602
Slovenia	0,319	0,134
Spain	2,677	2,126
Sweden	2,464	0,369
Sum EU 27	**107,903**	**28,997**

Source: WIK calculations

3.3 Mobile connectivity scenarios

For mobile connectivity (5G), we model three scenarios: (3) an upgrade of existing 4G sites to 5G, (4) upgrade to 5G and deployment of new sites including small cells; and (5) deployment along transport links. The results are described below.

(3) Upgrade of existing 4G sites to 5G.

This scenario involves the upgrade of 4G sites with 5G equipment and fibre backhaul. The backhauling part of the network is modelled as point-to-point (PtP) network, to maximise capacity to the base stations. Cost estimations assume a stand-alone deployment (i.e. they do not take into account parallel deployment of an FTTH network).

The investments and subsidies required are calculated on the basis, that only base stations that are not currently upgraded to 5G (as estimated on the basis of 2021 coverage data from the EC) need to be equipped with fibre backhaul and 5G equipment[28].

The following table shows the results of the calculation for the 27 member states. The investment requirement is approximately 11.5 bln € and the subsidy needs are approximately 19m €. Mobile networks are able to generate more revenues than fixed networks as in a given household multiple end users can share the same fixed broadband contract while for mobile end customer devices each device typically[29] needs its own subscription. Deployment costs are also lower for mobile than for fixed networks. Thus, mobile networks typically require less subsidization than fixed broadband networks.

[28] We assume similar deployment of frequencies under 4G as under 5G, i.e. we assume that current 700 – 800 MHz as well as 1,800 MHz deployment as applied in 4G networks is not significantly different from the assumed 700 MHz and 1.5 GHz 5G frequencies in terms of coverage. Therefore for these 5G frequencies we account for equipment updates but not the deployment of new base stations. On the other hand, for 3.6 GHz we assume a new roll-out. For all base stations, we assume that fibre cables are deployed to the base station locations, irrespective of their frequencies.

[29] Mobile routers are an exemption of the SIM-card association per device, thus may reduce the mobile ARPU (Average Revenue per User)

Table 3-6 Results (3) Upgrade of existing 4G sites to 5G

Country	Mobile Only update, no small cells Invest [Bln€]	Mobile Only update, no small cells Subsidy [Bln€]
Austria	0,302	
Belgium	0,195	
Bulgaria	0,145	
Croatia	0,086	
Cyprus	0,013	
Czechia	0,207	
Denmark	0,154	
Estonia	0,083	
Finland	1,033	
France	1,859	0,019
Germany	1,685	
Greece	0,302	
Hungary	0,216	
Ireland	0,164	
Italy	0,909	
Latvia	0,113	
Lithuania	0,096	
Luxembourg	0,005	
Malta	0,002	
Netherlands	0,228	
Poland	0,499	
Portugal	0,191	
Romania	0,327	
Slovakia	0,065	
Slovenia	0,034	
Spain	1,141	0,001
Sweden	1,463	0
Sum EU 27	**11,517**	**0,019**

Source: WIK calculations

(4) Expansion and densification of the 5G network

In this scenario, 4G sites are equipped with 5G antennas and transceiver equipment (as in scenario (3), and in addition, new 5G sites are built to satisfy the need for better coverage and more bandwidth in particular in urban areas. In addition, small cells are deployed in urban areas to increase capacity and support QoS levels of 100Mbit/s download speeds at peak time conditions. The backhauling part of the mobile network is modelled as point-to-point (PtP) network for macro as well as for small cells, as full fibre capacity is needed to support 5G capabilities for base stations and small cells. Like the previous scenario, this scenario involves deployment of an independent mobile network.

The cost calculation takes into account pre-existing 5G coverage for base stations (as reported in 2021 data for the EC). Otherwise, it assumes that existing 4G base stations are upgraded to 5G and new 5G base stations are installed to serve urban areas with 3.6 GHz as this frequency band requires additional base stations due to the reduced coverage area of each base station. We assume that no small cells exist yet, and thus all small cell deployment is considered to require new investments, a conservative assumption that may result in higher investment requirements in the event that small cells have already been deployed in some areas.

The following table shows the results of the calculation for the 27 member states. The investment requirement is approximately 33.5 bln € and the subsidy requirement is approximately 2.7 bln €.

As previously noted, calculations are conducted at the level of NUTS3 regions, which allows for cross-subsidisation within these rather large areas. However, typically, subsidisation is tendered for smaller areas that do not include profitable regions for network deployment. Thus, projects in Member States which involve areas smaller than NUTS3 are likely to require additional public funding than is suggested by the model.

Table 3-7 Results Expansion and densification of the 5G network

Country	Mobile Only Invest [Bln€]	Mobile Only Subsidy [Bln€]
Austria	0,835	
Belgium	0,536	
Bulgaria	0,374	
Croatia	0,225	
Cyprus	0,035	
Czechia	0,453	
Denmark	0,475	
Estonia	0,228	
Finland	2,966	0,686
France	5,598	0,603
Germany	5,394	
Greece	0,776	
Hungary	0,486	
Ireland	0,486	
Italy	2,741	
Latvia	0,325	
Lithuania	0,258	
Luxembourg	0,024	
Malta	0,012	
Netherlands	0,796	
Poland	1,428	
Portugal	0,523	
Romania	0,81	
Slovakia	0,176	
Slovenia	0,097	
Spain	3,221	0,235
Sweden	4,232	1,223
Sum EU 27	**33,508**	**2,746**

Source: WIK calculations

(5) Comparison of Standalone vs Combined network rollout

The scenarios previously calculated assume that fixed broadband and mobile networks are rolled out independently. However, major savings are possible, both in investments and in subsidies, if fixed and mobile deployment is coordinated (in particular if the digging and cabling is combined and uses the same ducts and trenches where possible).

The following table shows the results of the calculations for the 27 member states comparing an independent and co-ordinated fixed and mobile deployment. The investment requirement for independent deployment of both fixed and mobile networks would amount to 148 bln € with subsidy requirements of around 43 bln €. In contrast, a combined roll out would require only 120 bln € investment (a saving of €28 bln or 19%) and 32.7 bln € in subsidies.

To provide context, the following table also shows the EU funding allocated for connectivity investments per country as of September 2022. A comparison of the amounts shows that the allocated funding is around. € 13.5bln lower than the subsidy requirements that the model suggests might be required. The actual shortfall might be higher because the use of NUTS3 areas for the modelling could result in an underestimation of subsidy requirements.[30] Moreover the subsidy calculations for mobile deployment may also be underestimated because they assume the deployment of a single network which can capture all subscribers, when in practice the revenue share of mobile operators could be lower if more than one network is deployed. These factors may also explain why, for certain countries the EU funding that has been allocated as of 2022 exceeds the estimated funding requirements as determined by our modelling. For the majority of countries where a shortfall is indicated, this may need to be addressed through the use of supplementary EU, national or regional funds, if not already addressed through national or regional funding programs, which are not included in the calculation of actual subsidies allocated.

Table 3-8 Comparison of Standalone vs Combined network rollout

Country	Fixed Only Invest [Bln€]	Fixed Only Subsidy [Bln€]	Mobile Only Invest [Bln€]	Mobile Only Subsidy [Bln€]	Combined Invest [Bln€]	Combined Subsidy [Bln€]	Actual Total EU Funding [Bln€]
Austria	5,473	2,017	0,835		5,604	1,655	0,8912
Belgium	3,392	0,367	0,536		3,52	0,314	0,0898
Bulgaria	0,574	0,705	0,374		0,669	0,617	0,2696
Croatia	1,023		0,225		1,071		0,2076
Cyprus	0,302		0,035		0,309		0,053
Czechia	2,982	1,533	0,453		3,084	1,18	0,4099
Denmark	0,376	0,078	0,475		0,449	0,058	0,013
Estonia	0,268		0,228		0,303		0,088
Finland	2,678	2,365	2,966	0,686	2,951	2,324	0,0728
France	26,34	9,18	5,598	0,603	27,131	7,461	0,6665
Germany	22,859	5,331	5,394		24,001	3,941	0,2887
Greece	5,29		0,776		5,452		1,6791
Hungary	1,306	0,892	0,486		1,482	0,708	0,2075
Ireland	0,513	0,23	0,486		0,586	0,201	0,019
Italy	24,993	6,91	2,741		25,559	5,129	6,791
Latvia	0,133	0,277	0,325		0,196	0,279	0,0457
Lithuania	0,382	0,5	0,258		0,431	0,461	0,0985
Luxembourg	0,024	0,004	0,024		0,028	0,003	0
Malta			0,012		0,006		0
Netherlands	1,414	0,161	0,796		1,6	0,111	0
Poland	5,95	4,081	1,428		6,434	3,293	3,3657
Portugal	0,609	0,087	0,523		0,728	0,091	0,167
Romania	1,261	1,156	0,81		1,472	0,957	0,094
Slovakia	0,868	0,582	0,176		0,906	0,47	0,1121
Slovenia	0,348	0,191	0,097		0,366	0,155	0,0497
Spain	2,266	1,763	3,221	0,235	2,833	1,629	3,0801
Sweden	2,736	1,764	4,232	1,223	3,104	1,677	0,4909
Sum EU 27	**114,359**	**40,173**	**33,508**	**2,746**	**120,276**	**32,713**	**19,2504**

Source: WIK calculation for modelling results and Schumann Associates for subsidy intelligence

[30] Due to data availability limitations, our subsidisation forecast was computed for the administrative regions of NUTS3 areas which mathematically allows for cross-subsidisation within these areas. The administrative size of NUTS3 regions is typically larger than areas targeted for public funding, as subsidy zones typically focus only on regions that are unprofitable and often leave out neighbouring areas that are viable for private investments.

A more detailed overview of the source of EU funding is shown in the following Table 3-9.

Table 3-9 RRF & 2021-2027 ERDF/ EAFRD funding for connectivity investments[31]:

	TOTAL EU FUNDING [Bln€]	RRF [Bln €]	2021-2027 ERDF [Bln€]	2021-2027 EAFRD [Bln€]
Austria	0,8912	0,8912	/	/
Belgium	0,0898	0,0898	/	/
Bulgaria	0,2696	0,2696	/	/
Croatia	0,2076	0,1576	0,05	/
Cyprus	0,053	0,053	/	/
Czechia	0,4099	0,2272	0,1826	/
Denmark	0,013	0,013	/	/
Estonia	0,088	0,2429	0,6372	/
Finland	0,0728	0,05	/	0,0227
France	0,6665	0,54	0,1265	/
Germany	0,2887	/	0,264	0,0246
Greece	1,6791	1,433	0,2461	/
Hungary	0,2075	/	0,2075	/
Ireland	0,019	0,019	/	/
Italy	6,791	6,722	0,0689	/
Latvia	0,0457	0,0165	0,0292	/
Lithuania	0,0985	0,0735	0,025	/
Luxembourg	0	/	/	/
Malta	0	/	/	/
Netherlands	0	/	/	/
Poland	3,3657	2,6	0,7657	/
Portugal	0,167	0,01	0,157	/
Romania	0,094	0,094	/	/
Slovakia	0,1121	/	0,1121	/
Slovenia	0,0497	0,03	0,0196	/
Spain	3,0801	2,887	0,1931	/
Sweden	0,4909	0,464	0,0269	/
TOTAL	**19,2504**	**16,6647**	**2,5381**	**0,0474**

Source: Schumann Associates

[31] Based on publicly available (draft) programming documents, September 2022

(6) Sensitivity calculation of mobile scenarios with reduced market share

In order to assess the potential impact of mobile network competition on subsidy requirements, we have conducted a sensitivity calculation for the scenarios of basic 5G roll-out (3) and full 5G roll-out (4). In these sensitivity calculations we assume that the mobile captures only 30 % of total mobile market revenues instead of capturing all subscribers in the relevant area. The results of these calculations are shown in Table 3-10.

Table 3-10 Results of the sensitivity calculations of the mobile scenarios (3) and (4) assuming a subscriber share of 30%

Country	Mobile Only Invest [Bln€]	Mobile Only Subsidy [Bln€]	Mobile Only update, no small cells Invest [Bln€]	Mobile Only update, no small cells Subsidy [Bln€]
Austria	0,835	0,005	0,302	0
Belgium	0,536		0,195	
Bulgaria	0,374		0,145	
Croatia	0,225		0,086	
Cyprus	0,035		0,013	
Czechia	0,453		0,207	
Denmark	0,475		0,154	
Estonia	0,228		0,083	
Finland	2,966	1,465	1,033	
France	5,598	0,739	1,859	0,019
Germany	5,394		1,685	
Greece	0,776		0,302	
Hungary	0,486		0,216	
Ireland	0,486	0,112	0,164	0,001
Italy	2,741		0,909	
Latvia	0,325		0,113	
Lithuania	0,258		0,096	
Luxembourg	0,024		0,005	
Malta	0,012		0,002	
Netherlands	0,796		0,228	
Poland	1,428		0,499	
Portugal	0,523		0,191	
Romania	0,81	0,103	0,327	0
Slovakia	0,176		0,065	
Slovenia	0,097		0,034	
Spain	3,221	1,192	1,141	0,003
Sweden	4,232	1,737	1,463	0
Sum EU 27	**33,508**	**5,353**	**11,517**	**0,022**

Source: WIK calculation

It is worth noting that conducting a sensitivity analysis in relation to market shares affects the expected level of subsidy required but not the investment requirements.

In the “basic 5G roll-out”, i.e. only upgrades of existing 4G base stations, we see limited effect on subsidisation, as subsidy needs increase from € 19mln in the original calculation to € 22mln in the sensitivity calculation.

However, in the “full 5G” scenario (including network densification with small cells), we see a major effect on subsidisation requirements: While in the original results subsidy requirements were € 2.746bln, they nearly double to € 5.335bln subsidy needs when the mobile market share is reduced to 30%. The absolute amount of subsidy required for mobile network deployment however remains significantly less than that projected for fixed. These amounts could also be reduced if mobile operators engage in network sharing in less densely populated areas, and thus split the deployment costs between them.

(7) Deployment of 5G mobile along main transport corridors.

The fifth scenario calculated is a mobile only case, where new 5G sites operating in 3.6 GHz are built in order to satisfy the need for more bandwidth and low latency infrastructure along major transport corridors (roads, railways and waterways). The backhauling part of the network is modelled as a point-to-point (PtP) fibre network, as full fibre capacity is required to support the 5G capabilities of the base stations. The network modelled assumes the installation of new base stations, without additional network densification using small cells.

The country specific investment values of the fourth scenario are used for the calculation of fibre backhaul deployment costs.

We also consider a combined scenario where it is assumed that the rollout along major transport corridors would take place simultaneously with the rollout of a fixed FTTH network. This case may not be realistic as transport paths typically extend well beyond populated areas. However, it illustrates the savings that could be achieved if combined deployment takes place, at least in areas where this is possible. [32]

[32] The use of satellites or HAPS (high altitude platform stations) was not in the scope of the study, but additional information on this topic can be found here: https://www.wik.org/fileadmin/Studien/2021/Kurzstudie_HAPS_deutsch.pdf

Table 3-11 Results Deployment of 5G mobile along main transport corridors

Country	Waterways [km]	Roads [km]	Railways [km]	Total [km]	Investment needs Scenario Standalone [Mio €]	Investment needs Scenario Combined [Mio€]
Austria	343	1.814	2.989	5.146	2.086	577
Belgium	1.071	1.845	2.226	5.142	1.715	577
Bulgaria	469	2.580	2.245	5.294	1.368	589
Croatia	541	1.573	1.589	3.703	1.039	413
Cyprus	0	445	0	445	129	50
Czechia	333	1.976	2.945	5.254	1.372	582
Denmark	0	1.625	1.051	2.676	1.010	300
Estonia	0	1.355	986	2.341	796	262
Finland	595	5.192	3.572	9.359	4.709	1.060
France	2.317	14.612	17.949	34.878	13.581	3.923
Germany	4.260	11.348	14.708	30.316	9.471	3.370
Greece	0	4.656	2.926	7.582	2.337	845
Hungary	405	2.545	3.867	6.817	1.722	757
Ireland	0	2.220	1.512	3.732	1.456	420
Italy	916	10.707	10.337	21.960	6.755	2.449
Latvia	0	1.680	1.541	3.221	1.003	360
Lithuania	265	2.179	1.583	4.027	1.240	450
Luxembourg	37	90	216	343	119	39
Malta	0	117	0	117	23	13
Netherlands	1.379	1.951	2.099	5.429	1.557	603
Poland	65	7.751	7.979	15.795	3.898	1.757
Portugal	275	2.822	2.956	6.053	1.763	676
Romania	1.285	4.838	5.352	11.475	2.900	1.276
Slovakia	413	1.567	1.389	3.369	921	376
Slovenia	0	643	871	1.514	487	169
Spain	92	12.030	14.256	26.378	8.801	2.955
Sweden	672	6.448	5.861	12.981	6.655	1.473
Total	**15.733**	**106.609**	**113.005**	**235.347**	**78.912**	**26.321**

Source: EC data for pathway km and WIK calculations

The results displayed in Table 3-11 are again computed based on the deployment of new base stations making use of 3.6 GHz frequency along major European transport paths, without the additional installation of small cells. These results do not take into account potential overlapping usage of these base stations for wider 5G coverage.

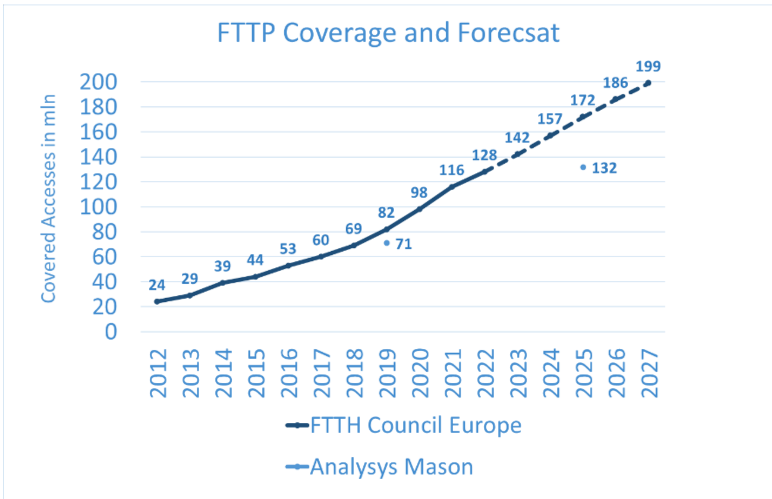
4 Desk research findings

Besides WIK-Consult's calculations, there are a number of other studies which have provided forecasts concerning FTTH deployment and estimated the cost of deploying FTTH and 5G to unserved households. In this chapter, we summarise the results from these studies and compare the investment requirements highlighted in other studies with those estimated through the WIK model.

4.1 Fixed connectivity

Analysys Mason (2020) and IDATE on behalf of the FTTH Council Europe (2022) have provided forecasts for FTTP coverage in Europe up to 2025 and beyond. The following figure illustrates the baseline FTTP coverage as reported in these studies (respectively from 2019 and 2022) as well as the forecasts made in terms of absolute numbers of households accessible with FTTP in the EU27 + UK[33].

Figure 4-1 Comparison of FTTP coverage and forecast for EU27 + UK



Source: Analysys Mason, 2020a; FTTH Council Europe (IDATE), 2022; own calculation

It is notable that there are differences in the absolute values reported for the baseline. For example, while Analysys Mason observe a coverage of 71m households covered by FTTP in 2019, the FTTH Council Europe observes 82m in 2019, and the EC BCE reports FTTP coverage of 74.7m (71.6m excluding the UK). The difference between the Analysys Mason/EC and IDATE/FTTH Council Europe values may be due to different interpretations of FTTP (and the treatment of cable/FTTB) in this regard. In addition to reporting a higher baseline coverage, IDATE is more optimistic about the progression of FTTP coverage in Europe in the coming years, predicting growth rates in access lines from 2019 to 2025 of 110% compared with Analysys Mason's projection of 86%. By 2025, total FTTP coverage of EU27+UK would reach 59% according to Analysys Mason's forecast and 77% according to IDATE / FTTH Council Europe.

As regards the cost of closing the coverage gap, the most recent estimate comes from research by Ferrandis et al. (2022) "Deployment of high-speed broadband in rural areas in the EU: Evolution of the investment gap and alternatives to reduce it". The study assesses

[33] For this purpose, Percentage data from Analysys Mason was transformed into absolute values using household information of the years 2022 for EU27 and 2020 for the UK.

the additional investment required to meet the four broadband goals of the EU (i) 5G availability to commercial usage in at least one major city in every European country, (ii) 5G coverage of all urban areas and major pathways, (iii) Gigabit connectivity for all socio economic drivers and (iv) coverage of 100 Mbit/s upgradable for to gigabit connectivity for all European households, rural and urban.[34]

The authors conclude that €83.8 bln of additional investment is needed in order to achieve goal (iii) (socio-economic drivers) and that an additional €140.2 bln is needed to achieve the full coverage goal of delivering 100Mbit/s downstream to all European households, upgradable to 1 Gbit/s. The authors make these calculations with an aggregation level of NUTS3 (as in WIK's approach) and assign each NUTS3 region to one of five regio type clusters ranging from urban, suburban, semi-rural, rural and extremely rural depending on area, population and degree of urbanisation. The authors take into account the degree of existing infrastructure. They base existing coverage on data from the EC, and (like WIK) consider that DOCSIS 3.1[35] as well as FTTP do not require further upgrades to achieve the goal of 100 Mbit/s downstream upgradable to 1 Gbit/s. To achieve goal (iv), 100 Mbit/s availability to all EU27 households, upgradable to 1 Gbit/s, FTTH is the chosen technology except for the most rural geotype deployment, which is assumed to be based on 5G only. For each technology they assess deployment costs based on a literature review, institutional studies and industry references. The gap between the existing infrastructure and the infrastructure coverage required is then applied to estimate the additional investments needed to achieve the goal under consideration.

The authors start their estimation with the most recent coverage data that was available from the EC at that time (2019) and also make calculations based on coverage data from 2017 for a sensitivity analysis. They find that of the investment required to fulfil broadband goals (iii) and (iv) declines from €99.7 bln (2017 existing coverage database) to € 83.8bln (2017 existing coverage database) and € 173.2 bln to € 140.2 bln respectively.

The results of the authors regarding goal (iv) "full coverage of all European households with access technologies that are capable of 100Mbit/s and are upgradable to 1 Gbit/s are comparable with our results for the cost of FTTH PTMP roll-out with FWA being deployed in the least densely populated areas. We predict outstanding investment requirements of circa € 107.9bln whereas the authors Ferrandis et al. suggest an investment needs of € 140.2 bln. However, the difference in the amounts can be explained by the date of the coverage estimate. While Ferrandis et al.'s most recent data source for coverage is mid 2019, our data is from 2021. Progress in the deployment of fixed Gigabit-capable broadband across the EU has led to a decrease in the investments required to achieve the stated broadband goal compared with the levels forecast three years ago. This effect is confirmed by the decline in investment needs between 2017 and 2019 as estimated by Ferrandis et al. themselves. Another reason for possible discrepancies may be that

[34] Ferrandis et al. 2022, Deployment of high-speed broadband in rural areas in the EU: Evolution of the investment gap and alternatives to reduce it

[35] Although the study of Ferrandis et al. 2022 does not specify the technical details, it is worth mentioning that the frequency band for transmission on coaxial cable for DOCSIS 3.1 is 1.218 GHz and may be upgraded to 1.794 GHz. Such upgrade within DOCSIS 3.1 may be conducted based on demand. With this upgrade, individual downstream capacities could reach 10 Gbit/s and 1 Gbit/s. The update of DOCSIS 3.1 to Release 4.0, which is likely to be available around 2023, will support full duplex, 10 Gbit/s symmetrically. Upstream and downstream frequency bands of up to 1.794 GHz can be used simultaneously, used by the end customers connected to the same coax string (fibre node) in a shared manner per direction. Due to the complexity of the full duplex architecture, fibre node capacity would be limited to 40-50 end users. (see Plückebaum et al, 2019, Potenziell anzunehmende Vorleistungsprodukte in Kabelnetzen auf der Basis von DOCSIS, Study for BNetzA, p. 7-9 and Kroon et al, 2017, Study into the current and future technological access options to all fixed telecommunication infrastructures in the Netherlands; Study for ACM, p. 42 et sqq.)

estimates on costs of technology deployment may differ between studies. Given that available data on deployment costs are taken from models and literature reviews, anticipated values may differ as they are subject to assumptions. Thirdly, the number of clustered regional types could affect the outcomes of calculations. While Ferrandis et al. assign five regional clusters, we assign eight which may increase the granularity of results. Furthermore, the authors do not elaborate which FTTH topology they assume in their modelling. In case they estimate deployment costs for a PtP infrastructure, while we assume PtMP deployment, a share of investment savings could be explained by the chosen architecture[36]. Another difference is that, Ferraris et al. appear to assume a wider deployment of 5G as an alternative to FTTP than is assumed in the WIK model. Whereas Ferraris et al. assume 5G roll-out instead of fixed broadband roll-out in the most rural regional cluster, we only assume the use of 5G FWA for the most rural share of the least densely populated regional cluster (out of the eight assessed), while Ferraris et al. have five clusters, which would tend to lead to more access links in the lowest density cluster than in the WIK model.

Following their cost assessment, Ferrandis et al. discuss how investment needs could be decreased. they conclude that the use of public private partnership (PPP) vehicles for Gigabit broadband deployment will not enable countries to achieve broadband goals at lover investment costs, but that private wholesale only providers and the application of differentiation in access regulation between rural and urban areas could have a positive impact on investment requirements and investment incentives.

Another report on the estimation of investment needs to fulfil the European broadband goals as of 2025 is the report “Reaching the objectives of the Gigabit Society: Assessment of the investment gap” of the European Investment Bank from 2018[37]. As in the previously described study, the authors seek to estimate investment needs to meet the European broadband goals for 2020 and 2025 with a starting point for the analysis of 2017. The authors analyse six broadband goals, (i) access to download speeds of 30 Mbit/s to every European by 2020, (ii) ensuring that by 2020 50 % of European households subscribe to Internet services of at least 100 Mbit/s download speed by 2020, (iii) 5G coverage for commercial use in at least one major city of every EU country, (iv) 5G connectivity for all European urban areas as well as major transport paths, (v) gigabit connectivity to all socio economic drivers and lastly (vi) coverage of access technologies of 100 Mbit/s downlink speed to all European households upgradable to 1 Gbit/s. The last goal is comparable with our approach of determining the investment requirements for fixed FTTH coverage with FWA for the most rural accesses.

The study suggests the following investment needs for each of the six goals, not including the UK:

[36] Experience of the authors of this study show that cost savings may only be around 5-10 %

[37] EIB, 2018, Reaching the objectives of the Gigabit Society: Assessment of the investment gap

Table 4-1 Investment needs per Broadband Goal according to the EIB study, 2018

Goal	Keyword	Investment needs
(i)	30 mbps downlink coverage	42.9 bln €
(ii)	50 % 100 mbps subscriptions	112.2 bln €
(iii)	5G in one city per country	12.7 bln €
(iv)	5G in all urban areas and transport paths	36.4 bln € + 16,4 bln €
(v)	Gigabit connectivity to all socio economic drivers	104 bln €
(vi)	100 mbps ugradable to all European households	184.6 bln €

Source: EIB, 2018

The authors describe their methodology as following seven steps: Firstly, they divided European NUTS3 regions into five clusters by population density. Within the clusters, again by drawing on population density, in a second step of clustering they further divided regions into urban, suburban, semi rural, rural and extremely rural. Secondly, they accounted for the level of existing deployment. The information on existing infrastructure coverage dates from 2017 and was obtained on the level of NUTS3 regions from IHS Markit & Point Topic study for the EC and thus is likely to be the same data source as that used by Ferrandis et al. as applied for 2017. Thirdly, for each of the six goals listed, the authors defined what level of NGA technology coverage would be required in order to achieve the respective goal. For the determination of the required level of coverage in order to reach a 50 % subscription level of all accesses, they made a linear extrapolation of data from 2012-2018. Fourthly, for each of the listed goals they determined which technologies would be needed to achieve the stated goals. For the sixth goal of full availability of 100 Mbit/s downstream accesses for every European household, upgradable to 1 Gbit/s, FTTH in a point-to-multipoint architecture was chosen as the most suitable technology as it was prevalent in Europe at that time (as now). For the most rural cluster 5G was chosen to achieve the desired download rates. The authors also provide a sensitivity calculation where the last three geo types are served with 5G instead of FTTH, thereby reducing investment needs by 53 %. In a further step, they estimated deployment costs for each technology through an academic literature review. Their estimate reflects the assumption that 70 % of the deployment costs of fixed broadband infrastructures are subject to civil works and they adapt prices for each country in accordance with the cost of labour in each member state. Furthermore, they deploy a correction factor for deployment cost ranging from +30 % to -30 % to take into account socio demographic factors, national landscape, the predominant form of buildings and regulation and commercial practices prevailing in the countries concerned such as prevalence of infrastructure sharing. In a fifth step, the authors describe extrapolating past investments of investors before lastly determining the investment requirements per country. The results are shown in Table 4-1. While the EIB study provide results for EU28 (including UK) as well, only the results of EU27 are illustrated in this comparison as it forms the basis for comparability with the WIK study as well as with other studies estimating the investment requirements for fibre coverage in the EU.

The result of the EIB study for the investment needed to achieve the sixth stated goal is comparable with our results for the investment cost required to achieve Gigabit coverage across all European households – through FTTH and FWA in the most rural NUTS3 regions - taking into account the existing level of deployment of FTTH and DOCSIS 3.1. While we state a result of around € 107.9bln of investment needs, the EIB states € 184.6bln. The main reason for the difference is likely to be the date of the coverage data. Whereas the EIB uses coverage data from 2017, WIK's coverage data stems from 2021. The investments completed in the meantime between 2017 and 2022 have reduced the investments required to achieve the goal of 100 Mbit/s downstream for all European households. The time reference to 2017 makes the EIB study somewhat comparable to the results that Ferrandis et al. as regards investment requirements using the 2017 dataset 2017. Ferrandis et al. derive investment needs of € 173.2bln as opposed to € 184.6bln stated in the EIB, a divergence of only 6.5 %. Therefore, assuming that this result may be seen as somewhat robust and given that Ferrandis et al. derive reduced investment needs of € 140.2bln when referring to the coverage availability data from 2019, we view the WIK estimate as being in line with these results, as our data source stems from 2022. The use of NUTS3 regions, segmentation into regional types (5 in the case of Ferrandis et al and EIB (also with sub-segments) and 8 in the case of WIK), and the assumed use of 5G to serve the least dense areas is common to all studies. WIK also makes use of in-house detailed technology and architecture-specific cost modelling in place of the literature review relied on by the other studies.

A further report from 2021 from the European Telecommunications Network Operators' Association (ETNO) titled "Connectivity & Beyond - How Telcos can Accelerate a Digital Future for All" identifies total investment needs of € 150bln in order to achieve a fixed broadband upgrade to 1 Gbit/s downstream for all Europeans. The report does not provide details regarding the methodology used to derive this estimate and therefore it is not possible to provide a comparison of results and methodology. Nevertheless, this result appears to be broadly in line with the other results. [38]

The following table provides an overview of studies estimating investment needs for fixed Gigabit-capable broadband:

Table 4-2 Comparison of results of studies on investment needs for fixed broadband coverage

Result source	Data source year for availability	Goal - Definition Keywords	Result of investment needs
WIK, 2022	2022	FTTH PtMP Coverage with 5G FWA in most rural NUTS3 regions	107.9 bln €
Etno, 2021	2020?	Gigabit Coverage	150 bln €
Ferrandis et al., 2022 a)	2019	FTTH Coverage with 5G in most rural cluster	140.2 bln €
Ferrandis et al., 2022 b)	2017	FTTH Coverage with 5G in most rural cluster	173.2 bln €
EIB, 2018	2017	FTTH Coverage with 5G in most rural cluster	184.6 bln €

Source: WIK, 2022; Etno, 2021; Ferrandis et al, 2022; EIB, 2018; own illustration

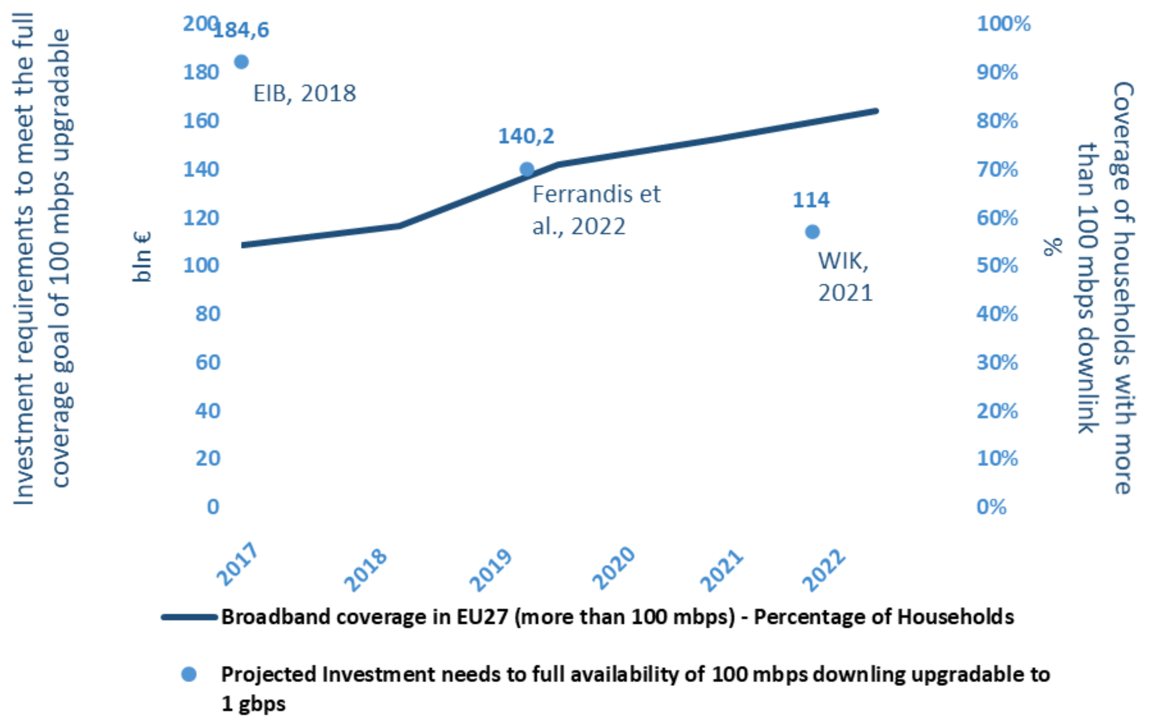
The table shows that, although there are some methodological differences between the studies, it can be seen that the newer the data set is, the lower is the required investment to achieve the Gigabit-capable fixed broadband goal. This is due to the fact that newer data sets reflect increases in coverage that have been achieved in Gigabit-capable broadband over the years.

This observation was made in the study by Ferrandis et al. 2021 and is illustrated in the following graph which shows in light blue dots the predicted investment required to reach

[38] European Telecommunications Network Operators' Association (ETNO), 2021, Connectivity & Beyond - How Telcos can Accelerate a Digital Future for All

full gigabit-capable coverage a given time specific on the left axis[39] and (on the right axis) the corresponding existing coverage of networks enabling at least 100 Mbit/s download speed as a % of households. The graph shows that with increasing availability of access technologies granting at least 100 Mbit/s downlink capacity, lower investment requirements have been modelled at the respective times. The coverage data and projected investment requirements exclude the UK.

Figure 4-2 Actual coverage of 100 Mbit/s downlink capacity to EU accesses in % as opposed to predicted investment needs at given existing coverage



Source: EIB,2018; Ferrandis et al, 2022; WIK calculation; ESTAT dataset SOC_CBS$DEFAULTVIEW, accessed on 16/09/2022; own illustration

4.2 Mobile connectivity

Ericsson describes the 5G network as the “fastest-deployed mobile communication technology in history” and predicts that it will reach 75% coverage of the world population by 2027 as compared with 25% coverage in 2021[40]. EU data indeed shows that, while late in starting in some countries in part due to delays in spectrum awards, 5G deployment has been rapid.

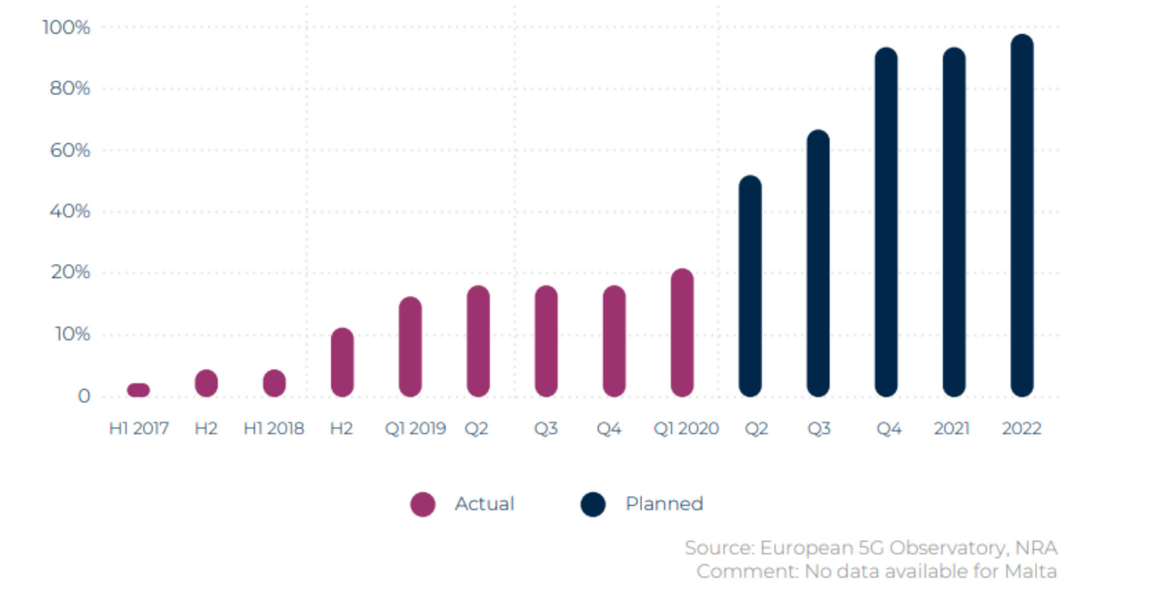
However, a large part of reported 5G coverage is understood to be on the basis of lower frequencies (basic 5G). In this context, Analysys Mason in a 2021 report for Ericsson and Qualcomm predict that by 2026 the 700 MHz 5G pioneer band will be deployed in all countries to cover 99 % of population or around 80 % of geographical coverage.

[39] Note that the prediction is marked at the spots of the data referral these studies have nut their date of publication

[40] Ericsson, 2022, Network coverage outlook, https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/network-coverage, accessed Sep. 26th 2022

However, while projections show that mid-band spectrum is due to be awarded in nearly all Member States by the end of 2022 (see below), it is less clear to what extent these frequencies will be commercially deployed in the medium term.

Figure 4-3 Availability of Mid Band (3-5 GHz) Spectrum in EU-27 (share of EU-27 Member States, %)

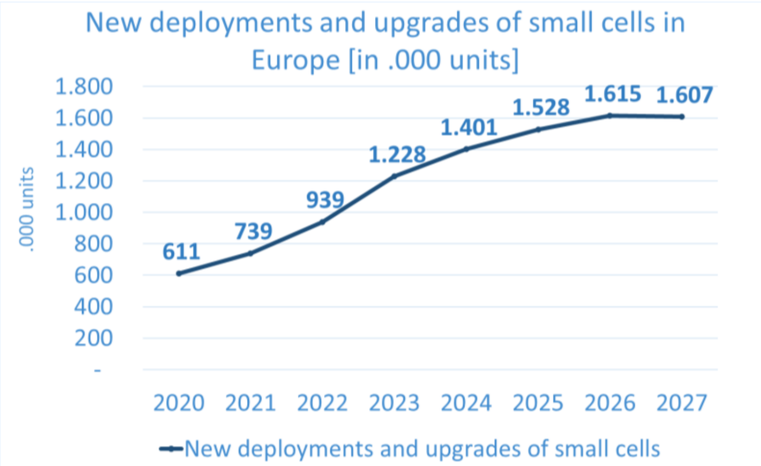


Source: ERT & Global Counsil, Assessment of 5G Deployment Status in Europe, 2020

Analysys Mason (2021) project that base stations with 3.6 GHz cells will be deployed to a population coverage of around 30-60 % covering less than 10 % of geographic coverage.[41]

Another perspective comes from the Small Cell Forum, which provides an overview and forecast of new deployments and upgrades of small cells as shown in the following graph.

Figure 4-4 New deployments and upgrades of small cells in Europe according to Small Cell Forum, 2022



Source: Small Cell Forum, 2022[42]

[41] Analysys Mason, Costs and benefits of 5G geographical coverage in Europe, 2021

[42] Small Cell Forum, 2022, SCF market forecast 2022, p. 9

According to this prediction, the number of newly deployed and upgraded small cells in Europe will increase from 611,000 in 2022 to 1,528,000 in 2025 and 1,607,000 in 2027 which corresponds to an increase of 150 % and 163 % correspondingly. However, it is not known to what extent small cell deployment by different operators will overlap, and what figures such as these may mean for the coverage of mid-band and mmWave 5G.

In terms of investments required to achieve wider coverage of 5G, the previously described studies concerning fixed broadband roll-out also include estimates on 5G coverage to varying degrees. Additionally, some studies focus solely on assessing 5G investment requirements. In the following paragraphs, we describe several of these studies and compare their results. However, it should be noted that comparisons regarding the cost required for mobile coverage are more difficult than those for fixed, due to the wide range of assumptions that are possible regarding the levels of investment required for new base stations and upgrades, the frequencies used, the degree of coverage assumed for small cells and the radius of coverage assumed, as well as the technology used and associated cost for backhauling.

As most of the studies do not provide details regarding deployment assumptions or frequencies used, comparability of results may be limited.

The previously described study of Ferrandis et al. in 2022 covers investment requirements for the two goals of (i) 5G availability for commercial use in at least one major city in every European country and (ii) 5G coverage of all urban areas and major pathways.

For the first goal they predict investment needs of € 12.7bln based on coverage data from 2019 and € 12.8bln when referring to coverage data from 2017. The limited difference reflects the fact that 5G coverage levels have only recently begun to expand. These estimates should therefore be seen as a “baseline” for coverage in major cities starting from negligible levels. For the second goal, the authors predict investment needs of € 52.5bln based on 2019 5G coverage and € 52.3bln based on 2017 coverage data. The slight increase in investment needs over time is explained by the authors by an increase of households in urban areas and an increase in labour costs. The study does not specify whether it accounts for co-ordinated roll-out of 5G and fibre infrastructure which can have a significant impact on reducing deployment costs. For example, the FTTH Council Europe states “the range of cost savings for the FTT-5G network due to convergence can reach between 65% and 96%”[43]. Given that the authors estimate 5G investment costs as well as fibre deployment we assume that figures are based on a combined roll-out of both infrastructures, 5G and FTTH. However, due to the lack of detail regarding the methodology, it is not clear to what extent the figures are comparable with WIK’s analysis.

Further information concerning the cost of serving major transport paths, can be derived from a previous study by Ferrandis et al. from 2021[44]. In this study they note that € 16.9bln will be required to meet the goal of 5G coverage along major transport paths. They also observe that if 5G quality is increased (although the meaning is not specified - this may refer to the use of mid-band frequencies), this investment need increases to € 23.0bln.

The study by the EIB on “Reaching the objectives of the Gigabit Society: Assessment of the investment gap” from 2018 also addresses 5G network investment requirements explicitly in two of the stated goals: (ii) 5G availability in at least one major city per EU member state

[43] FTTH Council Europe, Fibre and 5G Convergence, https://www.ftthcouncil.eu/committees/policy-regulation/fibre-and-5g-convergence, accessed on Sep 27th 2022

[44] Ferrandis et al., 2021, An assessment of estimation models and investment gaps for the deployment of high-speed broadband networks in NUTS3 regions to meet the objectives of the European Gigabit Society

and (iii) 5G availability in all urban areas and along major transport paths (see also Table 4-1). The estimated investment needs for achieving goal (ii) is € 12.7bln and for goal (iii) it is € 36.4bln for 5G coverage of all European urban areas and additional € 16.4bln for the coverage of main transport paths. This results in a total estimate of € 52.8bln for their base case scenario. In a sensitivity analysis assuming higher demands for 5G quality, the EIB study estimates € 21.5bln instead of 16.4bln € for the deployment among the major European transport paths.

Comparing the results from the EIB 2018 study and the study results of Ferrandis et al., 2022 computed for coverage data from 2017 it can be seen that the results of 5G coverage for at least one major European city match perfectly as both studies derive exactly the same figure of € 12.7bln. The estimates of investment requirements of full urban coverage plus coverage of major transport paths also correspond with a total of € 52.8bln predicted by EIB and € 52.3bln by Ferrandis et al.

The investment needs predicted by the EIB study for 5G provisioning along major transport paths is comparable to our approach that results in a prediction of € 26.3bln for 5G coverage of European main transport paths[45]. As the study of EIB itself states, in the base case, 5G is not assumed to be deployed at highest quality. The study defines “high quality” as 1 Gbit/s of download rate available at more than 80 % of the time and a contention rate at peak hour of 10:1 or better yet does not elaborate further by which means this quality is achieved in the modelling approach.[46] In our context, quality may inter alia be indirectly inferred in relation to the frequency deployed. As our study models 5G deployment along major transport paths at 3.6 GHz, we assume the EIB’s sensitivity calculation of “higher 5G quality” to be more comparable to our approach. Consequently, the EIB’s prediction of € 21.5bln would be a more suitable value to compare with our forecast of €26.3bln. Again, the findings of Ferrandis et al, the EIB 2018 study as well as the modelling results of this present study can be seen to be relatively consistent, ranging from € 21.5bln (EIB) to € 23.0bln (Ferrandis et al.) to € 26.3bln predicted by WIK.

Differences in results could be explained by the interpretation of “major” transport paths, and the resulting length of networks to be deployed or assumptions regarding the overlap of transport infrastructures. For example, WIK’s calculations include waterways, which may not have been covered in the other calculations. Other deviations may be caused by different assumptions on investment per network element or on the effective reach of frequencies.

Another study which focuses solely on 5G is that by Analysys Mason (2020) on behalf of Ericsson and Qualcomm: “5G action plan review for Europe”.[47] The aim of the study is to illustrate the economic advantages compared with the costs of deploying 5G, considering scenarios involving basic as well as “full” (mid-band) 5G.

For a full 5G network deployment in Europe, the study estimates investment requirements of € 46bln taking into account existing coverage. This result is not entirely comparable with our figure for full 5G deployment as the figure of Analysys Mason includes coverage in Switzerland, Norway and the UK. Existing coverage data on 5G and upgradable 4G infrastructure dates from Q2 2020 and is taken from GSMA intelligence as stated by the

[45] Neither the study of Ferrandis et al, 2022, nor the EIB study from 2018 specify whether small cells are used among major transport paths. As this result is comparable to the results of the two described studies (€ 23bln and € 21.5bln respectively) it seems reasonable to assume that the other studies also assume 5G deployment along transport routes using base stations alone.

[46] Quality features may refer to product specifications like eMBB, URLLC, eMMC (Bandwidth, Reliability, Latency)

[47] Analysys Mason, 2020b, 5G action plan review for Europe

study. Analysys Mason estimates investments by use case and assigns them to four clusters of "smart urban", "smart public services", "smart production" and "smart rural". The following table illustrates how use cases are assigned to the different clusters:

Table 4-3 5G Use Cases to Cluster Assignment according to Analysys Mason, 2020

	Cluster			
	Smart Production	Smart Rural	Smart Urban	Smart Public Services
Use Case	Mining	Agriculture	Construction	Healthcare and hospit
	Smart factories	FWA	Urban hotspots	Municipal buildings
	Ports		Stadiums	Education
	Airports		Smart automotive.	Tourism.

Source: Analysys Mason, 2020b

Analysys Mason notes that they model the deployment of 700 MHz, 3.4-3.8 GHz frequencies depending on the use case and 26 GHz for FWA. For each use case the authors define the required capacity and take into account existing infrastructure to derive the additional equipment and associated investment needed. This includes macro cells operated at 700 MHz or 3.4-3.8 GHz and FWA base stations operated at 26 GHz as well as requirements for small cells (frequencies not further specified) and roadside units operated at 5.9 GHz.

In a further (2021) report for Ericsson and Qualcomm "Costs and benefits of 5G geographical coverage in Europe", Analysys Mason change certain assumptions and update their calculations. Specifically, they assume that in addition to the usage of 700 MHz, 3.6 GHz and 26 GHz for 5G as described for their previous study, the bandwidths of 800 MHz, 900 MHz, 1800 MHz and 2100 MHz bands will be used progressively for 5G. Additionally, they assume that the frequencies of 2.6 GHz, 1400 MHz and 2300 MHz bands to be made available for 5G and apply it to 60 % of the sites starting from 2024. The study covers the same use cases as the previously described study. The amendments to the modelling approach leads to a slightly lower total investment sum of € 42bln compared with the previous result of € 46bln. In this study, they predict € 1.2bln of public funding will be needed out of the total investment of € 2.9bln for 5G FWA coverage (i.e. 41% of the total). For smart agriculture, they predict total investment requirements of 5.7 bln € of which 2.4 bln € of public funding would be needed. For road and rail coverage they suggest 3.4 bln € out of a total of 8.3 bln € of deployment investments required may be subject to public funding needs, or 41%. For healthcare, hospital and municipal buildings deployment they expect 100% of a total of 2 bln € investment needs to be subject to public funding. As a result, they predict that out of the projected costs of €42 bln, €10 bln of public funding will be needed, i.e. 24% of the total.

From a methodological perspective, the approaches of the previously described studies as well as our results presented in this study differ from the approach of Analysys Mason as Analysys Mason's calculations are based on a use case approach (which focuses on specific vertical and IoT applications) while the other studies centre on the delivery of 5G to households and businesses and pursue a regionally clustered approach based on population density. In general, we view the results of 5G roll-out from Analysys Mason as complementary rather than as offering a direct comparison to figures regarding the cost of achieving 5G in given areas. Other assumptions such as assumptions regarding frequencies deployed broadly correspond with our assumptions as does the deployment of small cells to enhance capacity where needed. However, one difference is that our approach does not foresee additional road side units operated on 5.9 GHz band.

Finally, a study from EY Parthenon from 2019 titled "The economic contribution of the European tower sector – A report for European Wireless Infrastructure Association" highlights the advantages of independent tower operators in cost reduction for mobile network roll-outs and competition of mobile network operators. They estimate an investment requirement of € 56blnto upgrade the existing 4G network to 5G[48]. They identify the following main cost drivers: [49]

- Network upgrade,
- Network densification,
- Network visualisation, and
- Fibre backhaul.

The major difference in their estimate of € 56 bln and our figure of € 33.5bln is that the report speaks of upgrades of multiple mobile networks therefore includes additional costs associated with competing networks while we consider the investment requirements to reach the required coverage goals with a single network.

[48] Resulting from analyses conducted in cooperation with Analysys Mason

[49] Y Parthenon, 2019, The economic contribution of the European tower sector – A report for European Wireless Infrastructure Association

5 Conclusions

A review of cost estimates made over time shows that the investment requirements needed to achieve Europe's Digital Decade Goals have reduced as deployments have progressed in both FTTP and 5G networks. However, our cost modelling shows that significant investments are still required to reach the remaining 30% of households (mostly in less dense areas) which do not have access to a Gigabit-capable connection. We estimate that around €114bln is still required to achieve complete coverage of FTTP, of which around €40bln would be needed in public funding. These requirements could be reduced to around €108bln in investment and €29bln in subsidies if the most rural households (in areas with a population density of less than 30 inhabitants per square km) are served using 5G Fixed Wireless Access.

For European citizens and businesses to benefit from the full capabilities that can be offered by 5G (so-called "full 5G"), we estimate that investments of around €33.5bln may be needed to install additional base stations and small cells which can support the deployment of mobile services through mid-band and millimetre wave frequencies in cities along with the associated fibre backhaul.[50] This would result in a total investment requirement of around €148bln and subsidy needs of around €43bln if fixed and mobile networks are deployed independently. However, we find that the overall investment and subsidy levels could be significantly reduced if full 5G deployment is conducted in tandem with a full FTTP deployment, requiring only €120bln in investment (a saving of around 20%) and around €33bln in subsidies for a combined FTTP and full 5G deployment to populated areas. A further €26bln in investment may be required to ensure full coverage of transport paths including roads, railways and waterways.

Estimates from other literature regarding fixed and mobile Gigabit connectivity for citizens and along transport paths are broadly consistent with WIK's cost estimates. Some studies[51] also suggest that additional investments (and subsidies) may be required to support 5G use cases in more rural areas such as smart agriculture and advanced healthcare applications.

[50] The cost of achieving full coverage of "basic" 5G through upgrades of existing 4G base stations is by comparison much less significant and may require around €11.5bln of additional investment, with minimal need for public subsidies.

[51] This has in particular been the subject of research by Analysys Mason on behalf of Ericsson and Qualcomm in 2020 and 2021 studies

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6 Annex: Methodology

6.1 Overall approach

The modelling for the study is based on the WIK-NGA model, which was developed to calculate investments, costs and profitability of a fibre optic roll-out up to buildings. Bottom-up cost modelling is carried out for Germany in detail (taking advantage of information available to the study team from its development of regulatory cost models). The cost estimations for Germany are then extrapolated to other countries, taking into account different degrees of Gigabit infrastructure coverage, and differences in labour costs, WACC, and geotypes present in the different regions of Europe.

The profitability of fibre optic roll-out depends to a large extent on the costs of the access network per subscriber alongside the ARPU. We take into account different national broadband ARPUs along with different regional population densities (and degree of existing coverage) to estimate the degree to which subsidies may be required to meet investment needs.

For this modelling exercise, we use an FTTH-PtMP (point-to-multipoint)[52] architecture in the access network while backhaul access for mobile and FWA base stations is modelled in a PtP-(point-to-point) architecture to each base station. Cost calculations are based on extensive processing of spatial data[53], based on a scorched node approach. This means that the existing central office (HVt) locations (access points to the Telekom Germany copper network) are retained in Germany and function as MPoP (Metropolitan Point of Presence) in a fibre optic world[54]. The results are only intended as a guide, as network architectures and possible access points may differ depending on the operator and the country concerned.

6.1.1 FTTH-PtMP and FTTH-PtP

In principle, fibre optic architectures can be distinguished in terms of the topology of the passive access network and the active network components that serve to light up the fibres in the central office and at the end customer. With a point-to-point (PtP) topology, all households or base stations are connected to the central office, the MPoP, with their individual own fibre strand. As in the previous copper connection network, this line does not have to be shared with other connections. The PtP architecture is considered as a passive network with switches in the MPoP and routers at the end customer site and no intermediate network components.

On the other hand, there is the so-called point-to-multipoint (point-to-multipoint, PtMP) topology, in which there is a dedicated individual fibre line for each customer connection in the terminating section between the end customer home and a fibre aggregation point (or fibre distribution point, if viewed from the MPoP perspective) somewhere on the path towards the MPoP (ODF) location. In this fibre distribution point the end customer fibres are connected by a passive optical splitter onto one single fibre strand towards the MPoP (respectively the ODF in the MPoP). The traffic of the customer connections is concentrated

[52] We only model the single-fibre variant of the FTTH network as the most cost-effective architecture and do not represent a multi-fibre approach.

[53] At the end of this process there are geocoded data for HVt (main distributor), buildings, streets, etc., with which the WIK route optimization tool can be started.

[54] Based on the geospatial data, for each MPoP, among other things, Data on the route lengths, the number of branching areas, the number of customers and buildings, as well as the subscriber density.

at the distribution point and transmitted together on one shared (commonly used) fibre to the MPoP, or vice versa the traffic from the MPoP is distributed to the individual end customers at this (Splitter) point. The fibre between the MPoP and the splitting point (distribution point) is called a feeder fibre. Due to the sharing of traffic on the feeder fibre additional electronic equipment is required to ensure that end customers' traffic does not interfere with each other. The OLT at the MPoP and the ONU at each customer's premise site organize and guarantee the time slots in which the end customer communication can be exclusively transmitted. In our model approach a splitting factor of 1:32 is assumed in order to ensure Gigabit capabilities of the network with the shared fibre. Hence, no more than 32 end customers can share the feeder fibre and its associated capacity. The PtMP architecture is considered as passive network as well, because the intermediate Splitter is a passive optical network component.

6.1.2 Bottom-Up-Modelling

For the NGA model, investments that are necessary to set up and operate an FTTH network are determined bottom-up. These include costs for:

- the access network from the MPoP to the end customer,
- the active or passive equipment (in the MPoP, the distribution point and at the end customer).

The model converts all investments into monthly cost values, taking into account the different lifetimes of assets and the weighted average cost of capital (WACC). The use of the WACC ensures that the costs already include an appropriate return on the capital employed. Operating costs are for the most part added to investment values by means of surcharges, but sometimes also explicitly calculated bottom-up (e.g. energy costs of active technology in the MPoP and square meter requirements of the MPoPs). Other items are included directly as costs and are not shown on the investment side. Overhead costs are included via a surcharge on investment and operating costs.

6.1.3 Steady State

The present model is based on a steady-state view, i.e. the gradual migration from e.g. copper to fibre optic access networks or the build-up phase are not taken into account. The focus of the analysis is based on a medium to long-term situation and the requirements for penetration and ARPU (Average Revenue per User), which result from the cost structure of fibre optic networks.

6.1.4 ARPU

The profitability of the fibre optic roll-out is determined using the costs per access line associated with the roll-out on the one hand and the expected income from realized services on the other. Within the NGA model an ARPU of 38,18 € is used for Germany. For the analysis performed in this study a more precise value is not needed here, as actual ARPU per country are used within the extrapolation exercise.

6.1.5 WACC

The WACC (Weighted Average Cost of Capital) is assumed to be 5.2% in the model. For the sensitivity analysis performed in this study, a more precise value is not needed, as only the relative delta results are considered. National WACCs used in the extrapolation exercise. These are taken from the BEREC RA database 2021[55,56].

6.1.6 Market Share

The maximum achievable demand per connection area is estimated at 70% of households. This reflects the fact that not all households will take up the lines of a fibre investor, including households without a broadband connection, those where only mobile broadband services are used and households which are served by an alternative FTTH or DOCSIS 3.1 connection. The relatively high assumed penetration rate of 70% assumes a situation in which the copper to fibre transition has been completed (a realistic scenario over a 2030 timeframe), and the deployment costs to be calculated are mainly in less urban and rural areas, where network duplication is expected to be limited. The market share for the calculated connections to base stations is 100%, which means that every established base station will be activated and connected by fibre to deliver mobile services.

6.1.7 In-house cabling

The model takes into account the cost of installation of optical fibres within the building, the in-house cabling, and assumes this cost is borne by the network operator, and should be covered by the ARPU. These costs are only incurred as soon as the first customer in the building has been acquired, and not during the deployment phase. This parameterization of the model therefore reflects the worst case, which is economically less favourable for the network operator, but is consistent with the medium-term steady-state approach taken to the model.

6.1.8 Cable laying

Civil engineering works generally make up the largest share of investments in the construction of a new network. For model results of high quality, it is therefore crucial to map this position as precisely as possible. Route lengths and prices for civil engineering and laying work, which represent relevant initial values for this, were included in the calculation of civil engineering investments. Expenses for branch sleeves, cable ducts and their average distance from one another are explicitly taken into account in the model as investment parameters.

According to our assessment, the determined price level as well as the structural parameters of the civil engineering installation differ from connection area to connection area. In sparsely populated areas, for example, the relative share of unpaved areas is higher, which lowers the average price per meter of laying compared to urban areas. It can also be assumed that there will be smaller cable ducts in rural areas, because the number of households and thus the number of fibres per km² will decrease here.

[55] BEREC, RA Report Chapter 5 – WACC.

[56] Data for Bulgaria was taken from the BEREC RA database from 2020 and data for Estonia from the BEREC RA database 2019 as no data was available for 2021 and 2020 respectively in the database.

The route lengths were determined in a route length determination model that uses an optimization algorithm[57]. Along the course of the road, this algorithm determines the optimal route length between the building and the central office or cabinet or man hole. It also optimizes the bilateral and one-sided laying along the road. The consideration that the cheaper alternative is always laying on one side of a road does not go far enough. For example, if there are buildings on both sides of the street, one-sided laying could be the more cost-intensive option, because here buildings on the other side of the street could only be connected with comparatively cost-intensive street crossings. Considerations like this make it clear with which accuracy route lengths were determined.

The route lengths were determined individually for each connection area of the network, so that a total of around 1,500 iterative calculations were included in the parameterization. Each connection area is assigned to one of 8 clusters according to its connection density.

Aerial cables are another option for fibre optic connections to buildings. Relatively low investments and higher operating costs are associated with this type of laying, which is relevant from the network operator's point of view.

6.1.9 Variable Costs per Customer

In general, we assume that a network operator will roll out a cluster to 100% of the addressable customers, because each could be won as a customer and its connection should not be delayed by long-lasting construction work (100% homes passed). Nevertheless, there are also variable costs for connecting the individual customers. The network operator only provides active equipment for implemented and connected customers (e.g. the subscriber port in the Ethernet switch of the MPoP (FTTH) and the OLT and ONU). The model therefore treats expenses for this equipment as variable investments. The costs for in-house cabling are also variable in the case of FTTH. With FTTH, the model records optical distributors in the MPoP in such a way that each household is stored on ports on the household side. The ports pointing to the network side, however, grow with the number of actually activated customers. If required, the operators install a port and a patch cable for each customer. The variable costs per customer differ depending on the architecture but are low in comparison with the costs that the basic roll-out (homes passed) requires in the roll-out area.

6.1.10 Number of MPoP

For the entire access network of Germany we have mapped a number of 7896 MPoP and thus access areas, parametrized and calculated individually.

6.1.11 Cable sizes, conduits and cable trenches

In principle, a standard trench is provided that can accommodate up to eight cables in ducts. The standard assumption here is installation in empty ducts. If there is more demand, the model endogenously determines the corresponding extensions.

[57] We use the Augmented Shortest Path Algorithm for this.

6.1.12 Greenfield- and Brownfield-Approach

The modelling is conducted on the basis of a greenfield scenario in which as a default all civil engineering work has to be carried out anew. However, the modelling allows for the re-use of ducts and poles for a given proportion of the deployment. These are considered to be rented at replacement costs. The proportion of re-used infrastructure derives from the base case assumptions used for FTTH cost modelling in the context of WIK-Consult's research on the review of the Broadband Cost Reduction Directive. If a higher proportion of infrastructure is re-used, because more of the still-to-be-constructed infrastructure is deployed by operators with pre-existing physical infrastructure, or if there is a greater use of access to existing physical infrastructure than estimated, then the projected investment costs and required subsidies would be lower.

6.1.13 5G Base Stations

Normally the WIK NGA-Model is only used to calculate investment, cost and profitability for a fibre network serving households and business with access to broadband. But it is possible to additionally calculate fibre connections to base stations of a mobile network and take into account the cost for the base station. To do this, the number and cost of base stations are estimated and parametrized in the model.

For the estimation of cost for the base stations we have estimated the number of required "regular base stations" as well as "small cells". With that information, we have performed a rough estimate of the mixed cost per base station.

The number of "regular base stations" is estimated on the basis of the number required to deliver basic coverage of the whole area, while the number of "small cells" reflects additionally needed capacity in residential areas. The number of "regular base stations" is estimated based on the assumed frequency for the individual area. For more dense areas (<550 inhabitants per km² [urban]) we have assumed a covered diameter of 1 km per base station. For medium dense areas (<2550 inhabitants per km² [suburban]) we have assumed a covered diameter of 4km per base station. For low density areas (>=2550 inhabitants per km² [rural]) we have assumed a covered diameter of 14 km per base station. The number of "small cells" required in addition to the "regular base stations" is estimated by using different radii depending on the household density of the area (regional type) and applied to built-up areas.

Basic coverage is driven by area coverage constraints. For network densification, the deployment of 5G small cells is assumed to cover all capacity requirements by applying the following radii per small cell, which varies depending on the regional cluster:

Regio Cluster	**Radius [km]**
1 Dense Urban	0,25
2 Urban	0,30
3 Less Urban	0,40
4 Dense Suburban	0,50
5 Suburban	0,70
6 Less Suburban	0,90
7 Dense Rural	0,95
8 Rural	1,00

Source: WIK estimates based on radio emission models

6.1.14 Model Outputs

The NGA model delivers output data in form of investments needed per access as well as investments required per access (MPoP) area. As described, investments as well as OPEX are converted into monthly costs in a steady state with the application of the WACC. Coupled with consideration of the ARPU, it can be determined if the deployment and operation of the infrastructure can be run profitably. The monetary profitability deficit is used to determine the subsidisation needs. As the subsidisation requirements are determined per access area, cross subsidisation within the area is assumed, meaning that profitable access lines in some parts of an access area decrease the subsidisation needs of unprofitable access lines within the same access area. Thus, the subsidies determined are lower than would be the case if only deficits from the unprofitable subareas within the NUTS3 areas were considered. The estimates produced in this study do not thus replace the need for more granular calculations to be conducted in each Member State for the purposes of assessing the need for and appropriately targeting State Aid or EU funds.

6.2 Calculations conducted with the WIK NGA Model

6.2.1 Fixed Only

In the Fixed Only-Scenario only fixed broadband access points are modelled without accounting for the access points of base stations for the provisioning of mobile services. An PtMP architecture is assumed and modelling conducted for 7896 German MPoP areas. It is then assessed whether ARPUs for fixed broadband services cover costs taking into account market share.

6.2.2 Fixed and Mobile – Combined PtMP

In this scenario fixed and mobile networks are rolled out simultaneously. All access points, like in the Fixed Only scenario, are modelled in a point-to-multipoint architecture. The number of required base stations is determined by taking into account the radii of mobile frequencies and the area of each access area. The number of small cells is estimated for the built-up areas.

On the revenue side, ARPUs for fixed broadband services are considered taking into account the assumed market share, as well as ARPUs for the lines connecting the base stations and small cells.

6.2.3 Fixed and Mobile – Combined PtP

In this scenario fixed and mobile networks are rolled out simultaneously. All access points, unlike in the Fixed Only scenario, are modelled in a point-to-point architecture. The number of required base stations is determined by taking into account the radii of mobile frequencies and the area of each access area. The number of small cells is estimated for the built-up areas.

On the revenue side, ARPUs for fixed broadband services are considered taking into account the assumed market share, as well as ARPUs for the lines connecting the base stations and small cells.

6.2.4 Mobile Only

In the Mobile Only scenario, only deployment (P2P fibre) to access points of mobile base station is modelled. No fixed access lines for fixed broadband services are modelled. On the revenue side, only the ARPU for the lines connecting base stations and small cells are considered.

6.3 Extrapolation to EU27

After the detailed calculations with the WIK NGA model have been performed for all of the approx. 8000 access areas of Germany, the results are assigned to 8 regional clusters. Then, for each of the calculations, estimation formulas are developed, based on household density:

- Investment per household or per mobile access
- Cost per household or per mobile access
- Subsidy need per household or per mobile access

During the application of the estimation formulas the country specific labour cost, WACC, fixed ARPU and mobile ARPU are taken into account.

6.3.1 Regional Clusters

Depending on the household density [HH/km²] each German access area as well as each EU27 NUTS3 region can be assigned to one of the eight Regional Clusters:

Regio-Cluster	Households/km²	
	min	max
1 Dense Urban	4000	∞
2 Urban	1600	4000
3 Less Urban	800	1600
4 Dense Suburban	470	800
5 Suburban	280	470
6 Less Suburban	150	280
7 Dense Rural	60	150
8 Rural	0	60

6.3.2 WACC

In order to determine the country specific adaption of the WACC all of the model calculations have been again calculated with a different WACC within the WIK NGA model. The result is an individual slope of the linear relationship regarding the WACC.

With this slope the extrapolated cost per household and month, based on the WACC for Germany, can be adapted to the country specific WACC.

6.3.3 ARPU

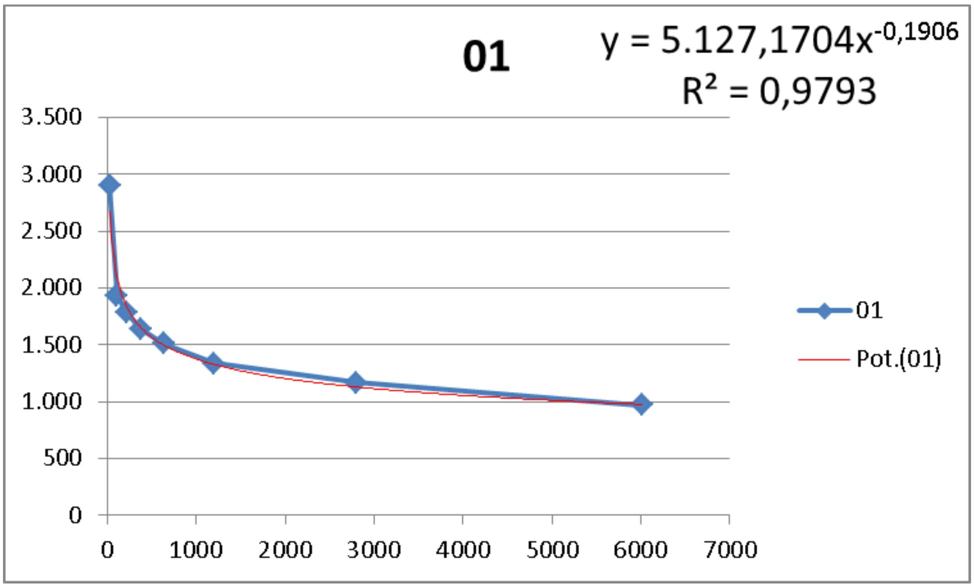
The national ARPU for FTTH networks stem from the European Commission's report on "Mobile and Fixed Broadband Prices in Europe 2021"[58] as a calculated average of the fixed broadband speeds of 30-100 Mbit/s, 100-200 Mbit/s and >200 Mbit/s for every country. For mobile national ARPUs, data stems from the same report and was calculated as an average of the mobile service categories of MBB5: "20 GB mobile data with no calls", "I5: 20 GB mobile data with 300 calls" and "I7: 20 GB mobile data with 100 calls".

6.3.4 Labour Cost

The country specific labour cost is applied to the fraction of cost and investments that are mainly based on labour cost, such as digging of trenches (underground works). From the results calculated with the WIK NGA model for Germany a different fraction of underground works is applied for each of the eight regional clusters. Country specific labour costs are applied to the extrapolated investments for the regional clusters in other countries.

6.3.5 Investment

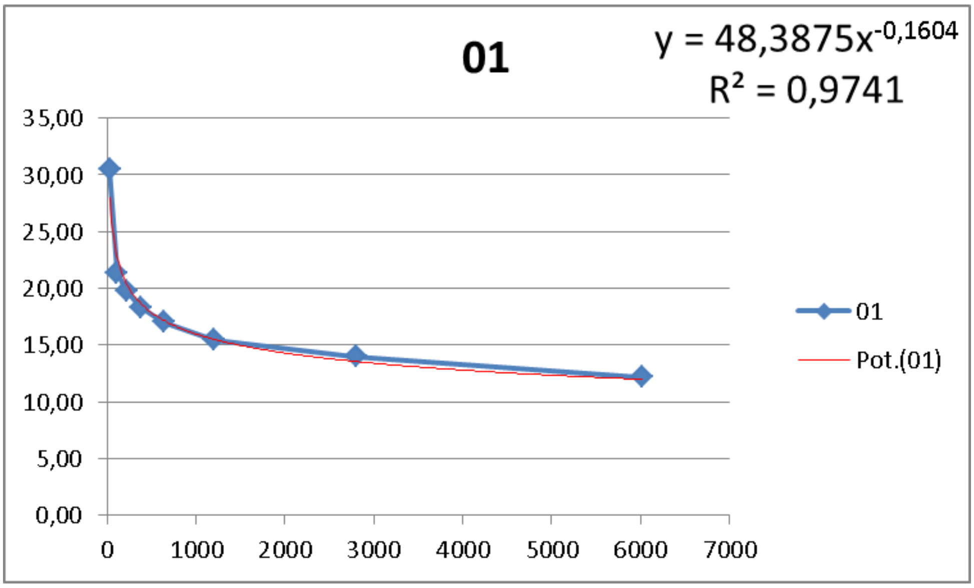
The estimation formula for Investment is developed for each of the 4 calculations (Fixed Only PtMP, Fixed and Mobile Combined PtMP, Fixed and Mobile Combined PtP and Mobile Only PtP). In the following graph the household density [HH/km²] is on the x-axis and the Investment per connection is displayed on the y-axis. Each of the dots represents a value for a regional cluster. The figure shows as an example the regression for calculation number 1 (Fixed Only PtMP):



58 European Commission DG Communications Networks, Content & Technology, Mobile and Fixed Broadband Prices in Europe 2021, 2022

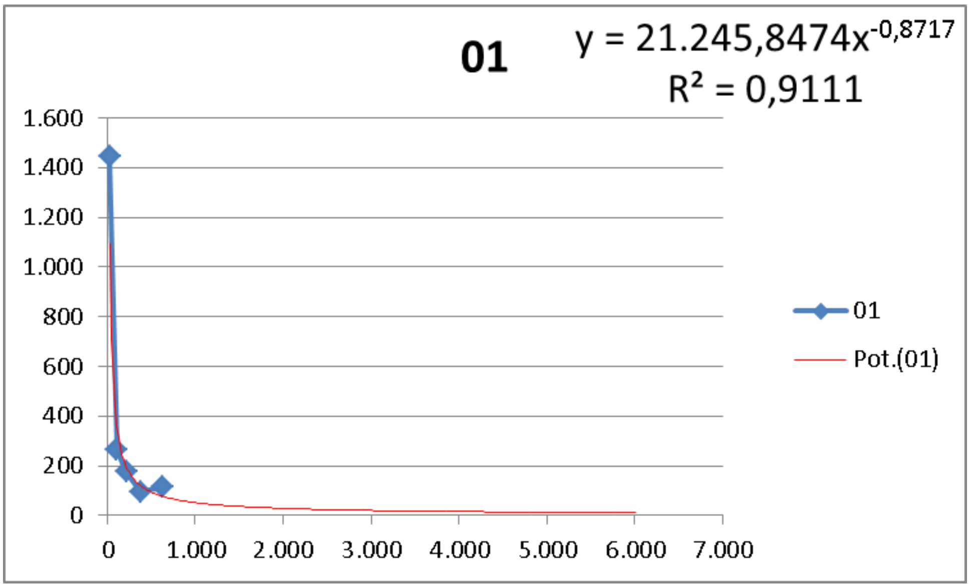
6.3.6 Cost

The estimation formula for Cost is developed for each of the 4 calculations (Fixed Only PtMP, Fixed and Mobile Combined PtMP, Fixed and Mobile Combined PtP and Mobile Only PtP). In the following graph, the household density [HH/km²] is on the x-axis and the Cost per connection is displayed on the y-axis. Each of the dots represents a value for a regional cluster. Here as an example is the regression for calculation number 1 (Fixed Only PtMP):



6.3.7 Subsidy

The estimation formula for Subsidy is developed for each of the 4 calculations (Fixed Only PtMP, Fixed and Mobile Combined PtMP, Fixed and Mobile Combined PtP and Mobile Only PtP). In the following graph the household density [HH/km²] is on the x-axis and the Subsidy per connection is displayed on the y-axis. Each of the dots represents a value for a regional cluster. Here as an example is the regression for calculation number 1 (Fixed Only PtMP):



6.3.8 Results for EU27

The extrapolation to the EU27 is based on individual calculations for each of the NUTS3 Regions. For each NUTS3 region the following data is available (at least available for the member state):

- NUTS3 Code
- Land area
- Total households
- Rural households
- Urban households
- Existing FTTH & DOCSIS coverage
- Existing 4G coverage
- Existing 5G coverage
- Labour Cost Index
- WACC
- Number of Mobile Users per Inhabitants
- Fixed ARPU
- Mobile ARPU

Based on the land area and the determined region type a number of existing 4G base stations, a number of required 5G base stations and a number of 5G small cells can be estimated.

Additionally based on the rurality information available, the number of households that could be served by FWA instead of FTTH can be determined. The threshold used is 30 households per km².

The following results were calculated in order to answer the questions raised in the study:

Country	Fixed Only Invest [Bln€]	Fixed Only Subsidy [Bln€]	Combined Invest [Bln€]	Combined Subsidy [Bln€]	Combined FWA for rural Invest [Bln€]	Combined FWA for rural Subsidy [Bln€]	Mobile Only Invest [Bln€]	Mobile Only Subsidy [Bln€]	Fixed Only FWA for rural Invest	Fixed Only FWA for rural Subsidy	Mobile Only, no small cells Invest [Bln€]	Mobile Only, no small cells Subsidy [Bln€]
Austria	5,473	2,017	5,604	1,655	5,147	1,416	0,835		5,013	1,416	0,302	
Belgium	3,392	0,367	3,52	0,314	3,482	0,307	0,536		3,352	0,307	0,195	
Bulgaria	0,574	0,705	0,669	0,617	0,564	0,322	0,374		0,467	0,322	0,145	
Croatia	1,023		1,071		0,844		0,225		0,794		0,086	
Cyprus	0,302		0,309		0,309		0,035		0,302		0,013	
Czechia	2,982	1,533	3,084	1,18	3,039	1,231	0,453		2,936	1,231	0,207	
Denmark	0,376	0,078	0,449	0,058	0,447	0,048	0,475		0,372	0,048	0,154	
Estonia	0,268		0,303		0,236		0,228		0,201		0,083	
Finland	2,678	2,365	2,951	2,324	2,437	0,909	2,966	0,686	2,154	0,909	1,033	
France	26,34	9,18	27,131	7,461	25,418	7,813	5,598	0,603	24,606	7,813	1,859	0,019
Germany	22,859	5,331	24,001	3,941	23,635	4,097	5,394		22,47	4,097	1,685	
Greece	5,29		5,452		4,249		0,776		4,084		0,302	
Hungary	1,306	0,892	1,482	0,708	1,278	0,528	0,486		1,1	0,528	0,216	
Ireland	0,513	0,23	0,586	0,201	0,486	0,109	0,486		0,412	0,109	0,164	
Italy	24,993	6,91	25,559	5,129	25,315	5,141	2,741		24,74	5,141	0,909	
Latvia	0,133	0,277	0,196	0,279	0,269	0,3	0,325		0,204	0,3	0,113	
Lithuania	0,382	0,5	0,431	0,461	0,287	0,125	0,258		0,237	0,125	0,096	
Luxembourg	0,024	0,004	0,028	0,003	0,028	0,003	0,024		0,024	0,003	0,005	
Malta			0,006		0,006		0,012				0,002	
Netherlands	1,414	0,161	1,6	0,111	1,604	0,111	0,796		1,414	0,111	0,228	
Poland	5,95	4,081	6,434	3,293	5,481	2,448	1,428		4,992	2,448	0,499	
Portugal	0,609	0,087	0,728	0,091	0,562	0,032	0,523		0,441	0,032	0,191	
Romania	1,261	1,156	1,472	0,957	1,457	0,826	0,81		1,243	0,826	0,327	
Slovakia	0,868	0,582	0,906	0,47	0,923	0,602	0,176		0,884	0,602	0,065	
Slovenia	0,348	0,191	0,366	0,155	0,337	0,134	0,097		0,319	0,134	0,034	
Spain	2,266	1,763	2,833	1,629	3,254	2,126	3,221	0,235	2,677	2,126	1,141	0,001
Sweden	2,736	1,764	3,104	1,677	2,845	0,369	4,232	1,223	2,464	0,369	1,463	0
Sum EU 27	**114,359**	**40,173**	**120,276**	**32,713**	**113,939**	**28,997**	**33,508**	**2,746**	**107,903**	**28,997**	**11,517**	**0,019**

6.4 Calculation for major transport paths

For the estimation of investment needs for the major transport corridors we used the national data available for waterways, roads and railways lengths and calculated the number of required base stations with a frequency at 3.6 GHz in a linear manner. The investment determined in the previous exercise was applied to the number of required base stations under two assumptions:

1.) The roll out along the transport corridors takes place independent from a roll out of a fixed network “Standalone”

2.) The roll out along the transport corridors takes place simultaneously with a roll out of a fixed network “Combined”

In the modelling of 5G coverage along major transport paths, we take into account deployment costs for the fibre access of base stations based on nationwide averages, modelled as described in chapter 3. We took into account projected 5G coverage of 3.4-3.8 GHz which peaks at 0.8 % in Germany and is lower for all other countries. We do not account for any parallelism of infrastructures, e.g. major roads running parallel to major railways, which is a conservative approach. What is more, unlike the 5G coverage of households, we do not account for additional small cell deployment as we consider 3.6 GHz BSA as sufficient to serve the broadband needs of travellers.

Country	Waterways [km]	Roads [km]	Railways [km]	Total [km]	Investment needs Scenario Standalone [Mio €]	Investment needs Scenario Combined [Mio€]
AUSTRIA	343	1.814	2.989	5.146	2.086	577
BELGIUM	1.071	1.845	2.226	5.142	1.715	577
BULGARIA	469	2.580	2.245	5.294	1.368	589
CROATIA	541	1.573	1.589	3.703	1.039	413
CYPRUS	0	445	0	445	129	50
CZECHIA	333	1.976	2.945	5.254	1.372	582
DENMARK	0	1.625	1.051	2.676	1.010	300
ESTONIA	0	1.355	986	2.341	796	262
FINLAND	595	5.192	3.572	9.359	4.709	1.060
FRANCE	2.317	14.612	17.949	34.878	13.581	3.923
GERMANY	4.260	11.348	14.708	30.316	9.471	3.370
GREECE	0	4.656	2.926	7.582	2.337	845
HUNGARY	405	2.545	3.867	6.817	1.722	757
IRELAND	0	2.220	1.512	3.732	1.456	420
ITALY	916	10.707	10.337	21.960	6.755	2.449
LATVIA	0	1.680	1.541	3.221	1.003	360
LITHUANIA	265	2.179	1.583	4.027	1.240	450
LUXEMBOUR	37	90	216	343	119	39
MALTA	0	117	0	117	23	13
NETHERLANI	1.379	1.951	2.099	5.429	1.557	603
POLAND	65	7.751	7.979	15.795	3.898	1.757
PORTUGAL	275	2.822	2.956	6.053	1.763	676
ROMANIA	1.285	4.838	5.352	11.475	2.900	1.276
SLOVAKIA	413	1.567	1.389	3.369	921	376
SLOVENIA	0	643	871	1.514	487	169
SPAIN	92	12.030	14.256	26.378	8.801	2.955
SWEDEN	672	6.448	5.861	12.981	6.655	1.473
TOTAL	**15.733**	**106.609**	**113.005**	**235.347**	**78.912**	**26.321**

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