A STUDY ON THE DEPLOYMENT OF HIGH-SPEED BROADBAND NETWORKS IN NUTS3 REGIONS WITHIN THE FRAMEWORK OF DIGITAL AGENDA FOR EUROPE

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Abstract

This paper investigates the high-speed broadband situation in the EU and its prospects. It uses a deployment model to estimate the investment required to meet the Digital Agenda for Europe (DAE) broadband targets set by the European Commission in its Europe 2020 strategy at different stages: as of 2016, after expected operators' deployment, after public subsidies and leveraged investment, and as expected in 2020. The model uses data at the NUTS3 level, which is the most granular level that has data available on the status of broadband deployment, to arrive at a coherent and comparable framework. From the different perspectives on the investment to meet DAE targets, the paper concludes on the need for an appropriate combination of incumbent and alternative operators investments, public subsidies and leveraged investments, and new investments, both public and private and non-existing as of 2016, examining their feasibility and the impact of different regulatory, technical, and policy strategies.

Keywords

Ultra-broadband; next-generation networks; public–private partnerships; rural areas; FTTH; FTTx; LTE; network deployment; high-speed broadband

Background

High-speed broadband as a means to access and use the Internet has become a pervasive and fundamental part of daily life. Its general socio-economic impact[1] and specific relevance in areas such as community, education, employment, environment, equality, finance, healthcare, income, multimodal communications, retail, travel, tourism, well-being, and a long list of other activities have been thoroughly researched.[2] Within this framework, the European Commission presented the Digital Agenda for Europe (DAE)[3] in May 2010 with the objective of a better exploitation of the potential of information and communication technologies (ICTs) to foster innovation, economic growth, and progress (European Commission, 2010). DAE includes several topics and actions, but with regard to the development of broadband infrastructures in the EU, it specified two high-speed broadband targets: to enable access to much higher Internet speeds (30 Mbps or above) for all Europeans by 2020 (Target 2, T2) and to ensure

[1] See Gruber et al. (2014) for an evaluation of the net economic benefits from the implementation of the broadband infrastructure deployment targets by 2020 as entailed by the Digital Agenda for Europe. See Wee et al. (2015) for an example of the calculation of indirect benefits. See Mansell (2011) for an assessment of the influence of policy in society vis-a-vis market interests.

[2] See Analysis Mason & Tech4i2 (2013) for a review. The same authors present an estimation of the benefit–cost ratio of 2.7:1 for the amount of broadband investment presented in this paper.

[3] The digital agenda presented by the European Commission forms one of the seven pillars of the Europe 2020 Strategy, which sets objectives for the growth of the EU by 2020.

that 50% or more of European households subscribe to Internet connections above 100 Mbps by 2020 (Target 3, T3).

Starting with a brief analysis of the situation regarding T3, and according to the EC database on the DAE[4], by mid-2015 wired broadband adoption (subscriptions as a percentage of population) in EU member states reached 31.6%. From this figure, 30% were high-speed broadband connections, that is, above 30 Mbps. Adoption of broadband data rates of 100 Mbps or above, the so-called ultrafast–broadband, was a mere 3.4% in the EU on average. In regard to technologies, VDSL share was 29% of the total high-speed broadband connections in the EU. Cable accounted for 45%, FTTB technologies accounted for 11%, and FTTH technologies accounted for 14%. Exhibit 1 below shows the evolution of high-speed adoption in the EU from 2013 to 2015, displaying how it falls very far behind expectations,[5] even though there are still five years left to reach T3.

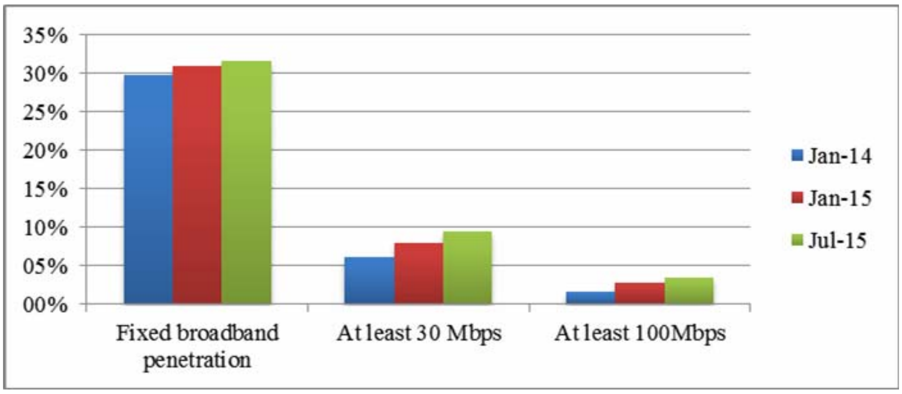

Exhibit 1. Evolution of high-speed broadband adoption in the EU from 2013 to 2015 (subscriptions as percentage of population). Source: DAE database

According to the same DAE database and now looking into coverage, at mid-2015 the wired broadband coverage (percentage of population) in EU member states was 97.4%. High-speed broadband coverage[6] was 70.9%. Coverage of broadband data rates of 100 Mbps or above was 47.6% at the end of 2014. With regard to technologies, VDSL coverage was 41.0%, cable DOCSIS coverage accounted for 43.1%, FTTP[7] technologies reached 20.8% coverage, and LTE accounted for 85.9%. Exhibit 2 below shows the evolution of high-speed broadband coverage in the EU from 2013 to 2015, also displaying how there was still a considerable gap to reach T2 as of 2015 (i.e. 100% coverage of NGA).

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[4] https://ec.europa.eu/digital-single-market/en/download-data

[5] According to Eurostat (see http://ec.europa.eu/eurostat/statistics-explained/index.php/Household_composition_statistics), the average household size was 2.3 members in 2014; therefore, existing ultra-fast broadband penetration would translate to about 7.8% household adoption. Linearly extrapolating past behaviour, the rate of adoption in 2020 would be equivalent to 23.9% household adoption, which is still extraordinarily far from DAE T3.

[6] Also usually termed next-generation access (NGA); see Feijoo (2016) for a detailed definition.

[7] FTTP is either FTTH or FTTB.

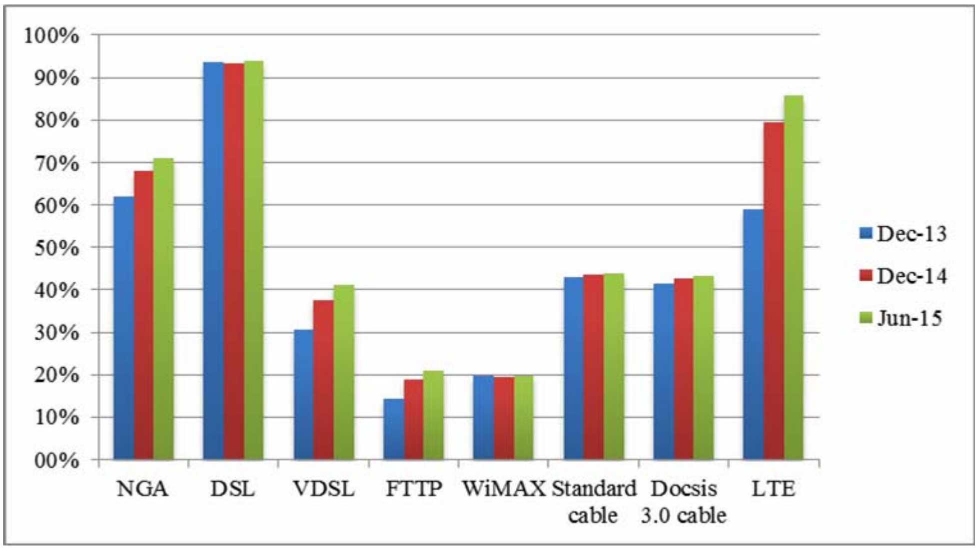

Exhibit 2. Evolution of high-speed broadband coverage in the EU from 2013 to 2015 (percentage of population). Source: DAE database

In addition, an analysis of the EU broadband situation regarding different geotypes shows that the big challenge for high-speed broadband availability in the EU is mostly in the rural areas of the countries: NGA coverage in urban areas was 68.1% of premises but only 25.1% in rural areas in 2014 (IHS & VVA Consulting, 2015). The latest available figures from mid-2015 display a similar pattern: 70.9% NGA urban coverage vs. 27.8% rural.

Therefore, in many EU countries high-speed broadband deployment and adoption proceed at a much slower pace than expected to meet DAE targets. In fact, according to a 2016 report for the European Parliament (Rivera et al., 2016), the level of broadband investments from 2004 to 2013 has been substantially lower in the EU compared to other developed economies, and the situation worsened in 2014 and 2015. In 2013 investments per capita in countries such as Australia, the US, and Canada were twice that of the EU. According to the same report, and as is obvious from the exhibits above, the demand for ultra-fast broadband services is growing at a much slower pace than the supply. As a result, Internet access speeds in Europe are, for instance, about three times lower than in Korea and Japan.

Within this framework, it is not surprising that research on the conditions for investment in broadband in general and high-speed broadband in particular has attracted a considerable attention from academicians, industry analysts, and policy-makers for more than a decade. Inside this domain, earlier attempts at introducing models for and making calculations on the cost of NGA deployment were mainly aimed at modelling the deployment situation due to the absence of real-life data (see, for instance, the Euroland approach for the EC in Forge et al. [2005] or the NGA calculations also based on the Euroland approach in De-Antonio et al. [2006]), which then could be used to assess different scenarios or be adapted to different country settings. In fact, the lack of long-enough data series and granular-enough models at the start of the high-speed broadband deployments deterred reaching definitive conclusions on the best approaches to encourage investments from the analysis of empirical studies (Cambini & Jiang, 2009). At the time it was already pointed out that this type of analysis requires micro-data, ideally at exchange level, in order to estimate the evolution over time of the investments and also that there was no comprehensive model covering both wired and wireless broadband provision.

The next strand of research tried to come out with more precise figures in specific geographies with the objective of evaluating financial perspectives and ultimately identifying potential sources of funding in an institutional setting (see, for example, the OECD or European Investment Bank studies (EIB, 2011; OECD, 2009)] or studies for countries such as the United Kingdom (Analysis Mason, 2008)] or Spain [Feijóo & Gómez-Barroso, 2010]). The approach has become more sophisticated, including more elaborate models for both the supply and demand sides, a wider geography, and increased use of available evidence[8] (Analysis Mason & Tech4I2, 2013; FTTHCE, 2012; IDATE, 2013; Point Topic, 2013), mostly with the explicit or implicit aim of influencing the process of decision-making in the broadband domain. At this point it is worthy to remind that it was relatively early acknowledged in the literature that diverse variations on real options methodology should be used to decide on telecoms investments rather than the traditional net present value formulation (Angelou & Economides, 2009; Ramirez, Harmantzis, & Tanguturi, 2007). However, these methodologies require a deeper analysis of alternatives and until now are only suited to deployments in specific locations; therefore the general preference for net present value calculations in telecoms deployment prospects.

More recently, a number of academic papers have started to build techno-economic models to explore beyond the mere broadband deployment so that relevant issues such as public-private partnerships (Falch & Henten, 2010; Nucciarelli, Castaldo, Conte, & Sadowski, 2013), energy consumption (Coomonte et al., 2013), index of impact of digital agendas (Katz, Koutroumpis, & Martin Callorda, 2014), quality levels of service (Ovando et al., 2015), indirect benefits (Van Der Wee, Verbrugge, Sadowski, Driesse, & Pickavet, 2015), last-mile wireless deployments (Katsigiannis & Smura, 2015) or digital divide inside rural areas (Rendon Schneir & Xiong, 2016) can also be addressed. All of them provide interesting insights on diverse formulations of costs and benefits for broadband deployment but are circumscribed to particular geographies (regions in the EU in most of the cases mentioned above) and/or do not provide cost calculations for broadband deployments.

Therefore, it can be concluded that a common theme from both the analysis of the high-speed broadband deployment situation and the brief literature review presented above is the need to periodically assess the amount of broadband investment required and the feasibility of targets in light of the evolution of technology, funding availability, and policy goals. At the same time, the analysis must cover a diverse range of geographies with different departing points, mix of technologies, and market situation.

In particular, the main issue at stake in the EU case is what exactly is the gap between a realistic prospect of the broadband deployment situation in 2020 and the DAE policy goals, and whether this gap can be addressed before 2020 with a combination of business-as-usual deployments and diverse types of existing schemes for public support, or whether some new measures would be necessary to fill it and achieve the DAE targets. Thus, the aims of this paper are to calculate the 2016 gap, its evolution into the 2020 gap, and the potential impact of different technological and policy options, and to elaborate on some of their consequences. The next section explains the methodology and model followed to calculate the DAE gap in 2020, departing from the situation as of 2015 and at the same time analysing in more detail the departing situation for the EU regarding broadband and some of the implicit strategic choices. Section 3 displays and briefly discusses the resulting gaps, including different scenarios and potential further measures. The paper closes with a general assessment of the expected high-speed broadband situation in 2020 and its implications.

Methodology with further analysis of high-speed broadband situation

The assessment of the gap to complete T2 and T3 of the DAE in 2020 is composed of nine steps: i) geographical framework for the analysis; ii) status of deployment and adoption of technologies relevant to achieve T2 and T3 in each of the regions in the EU, i.e. the 'departing point' of the calculations; iii) level of coverage of high-speed broadband needed to meet DAE targets, i.e. 'the coverage goal'; iv) choice of technologies to meet DAE targets in each country; v) cost of the deployments needed to meet the DAE targets as of 2016; vi) prospective deployments from incumbents and alternative operators up to 2020;

[8] In this regard, there is a notorious gap in availability of broadband deployment data at a sufficient granular level, such as at NUTS3 level (see below for an explanation on NUTS classification). The lack of data is difficult to understand when both the EC and national regulatory agencies in the EU have commitments to increase transparency and support competition in the telecom markets. Usual blurred arguments because it is commercially sensitive information look rather squalid and against public interest when we are talking about percentage of coverage at the NUTS3 level. In fact, in the few cases in which information is available (Spain, as a main example), nothing relevant has happened.

vii) comparison with 2015 footprint of existing fixed technologies to identify remaining 'white areas' without high-speed broadband infrastructures; viii) prospective deployments derived from existing public subsidies up to 2020; and ix) estimation of the DAE gap in 2020. Steps vi to ix constitute a 'waterfall' of investment in which the initial 2016 gap is orderly discounted of incumbent and alternative operators investments, overlapped coverage with existing fixed technologies, and public subsidies and their linked investments. In the following, each of these steps is presented in detail while at the same time analysing the departing situation of high-speed broadband in Europe.

a. *Geographical framework*

The geographical framework is based on EU regional data at the NUTS3 level.[9] This is the deepest level for which consistent and reliable socio-economic data is available across the EU.[10] Data are taken from the Eurostat database[11] and refer to the year 2012. The basic data consist of population density, number of households,[12] and land area. Data on the number of households is transformed into data of number of premises — households and businesses offices — following available EC statistics (Analysis Mason & Tech4I2, 2013), as the latter is regarded as more representative of the broadband connectivity gap. From here, each region is classified into five different types according to its average population density: above 500 inhabitants/km^2, 100 to 500 inh/km^2, 50 to 100 inh/km^2, 10 to 50 inh/km^2, and up to 10 inh/km^2. Next, each NUTS3 region is assumed to be a combination of five different geotypes: urban, suburban, semi-rural, rural, and extreme rural. This classification uses LAU2 data (sometimes called NUTS5)[13] from EC (Dijkstra & Poelman, 2014). The use of a double classification into population density and share of geotype offers a deeper understanding of the geographic morphology within a given NUTS3 region and therefore allows estimating the high-speed broadband gap with higher precision, particularly in low-density areas where the gap could be more relevant. This is an agreement with latest rural costing models that highlight the difference in investments required out of town vs. town in rural areas (Rendon Schneir & Xiong, 2016). The aggregated results for the EU using this geographical framework are presented in Table 1 below.

Table 1. Distribution of NUTS3 regions according to population density and geotype

[9] The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard for referencing the subdivisions of countries for statistical purposes. There is a hierarchy of three NUTS levels. The first level is the region or group of regions, the second is generally some type of regional division, and the third is typically a county, district, or department. The 2010 NUTS classification for EU-28 lists 28 countries, 98 regions at NUTS1 level, 273 regions at NUTS2 level, and 1,316 regions at NUTS3 level.

[10] It is worth noting that the 1,316 regions at NUTS3 level (558 of them included in the cohesion priority regions) are rather inhomogeneous regarding size. In member states such as Spain or Finland, the areas are considerably bigger than in countries like Belgium or Germany.

[11] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_d3area&lang=en

[12] Households are obtained from Eurostat data for the number of persons per household at the country level. Eurostat does not provide data on regional variations. Usually, rural households have a higher number of persons than urban households; therefore, the number of rural households, and hence the cost of providing broadband, tends to be higher than real.

[13] A local administrative unit (LAU) is a low-level administrative division of a country that is typically ranked below a province, county, district, or department. In the EU, it belongs to the NUTS classification where two levels are defined, LAU1 and LAU2, which were previously called NUTS4 and NUTS5. LAU2 typically refers to municipalities.

Pop. density	No. of NUTS3 regions	Pop. (m)	No. of premises (m)	Urban geotype (%)	Suburban geotype (%)	Semi-rural geotype (%)	Rural geotype (%)	Extreme -rural geotype (%)
up to 10 inh/km^2	14	2.23	1.08	6.4%	7.8%	5.3%	40.8%	39.8%
10 to 50 inh/km^2	193	37.77	17.72	17.0%	18.3%	19.3%	37.3%	8.0%
50 to 100 inh/km^2	298	95.85	43.12	21.2%	22.5%	31.5%	19.3%	5.4%
100 to 500 inh/km^2	546	229.43	105.07	27.5%	41.3%	26%	4.5%	0.8%
above 500 inh/km^2	265	153.37	70.64	79.3%	18.4%	2.1%	0.2%	0.0%
Total	1,316	518.65	237.64	41%	30%	20%	8%	2%

Source: own calculations from Eurostat data

The table shows how there is a correspondence between population density and the usual descriptors of urban, suburban, and rural geotypes, and in terms of premises in the EU-28 there is a 30% share belonging to rural areas on average. But it also points to the fact that within a given region there is a combination of geotypes and that an oversimplification directly linking population density and geotypes can be considerably misleading. Even areas generally regarded as suburban, with a relatively high population density, keep within them about a 30% share of rural areas. On the contrary, very rural and remote areas have a considerable share of urbanisation, 14% and 33%, respectively, which is a relevant difference for broadband deployment calculations.

b. *Status of high-speed broadband*

The other basic set of parameters required at the NUTS3 level are those related to existing high-speed broadband deployment in 2015: the coverage in terms of population at both 30 Mbps (superfast) and 100 Mbps levels (ultrafast) and the adoption at 100 Mbps level. Coverage at 30 Mbps and above equals the maximum footprint of FTTx, VDSL or other advanced DSL technologies, and DOCSIS 3.x. Coverage and adoption at 100 Mbps have been made equal to the deployment of FTTH, FTTB/C when used in combination with advanced DSL techniques,[14] and DOCSIS 3.x. LTE-A is considered in extreme-rural areas as a potential candidate for 100 Mbps, and LTE as a technology is suitable to provide 30 Mbps in rural areas.[15]

The data regarding coverage and adoption were obtained from multiple sources and own estimations. The process was the following. At the country level, data were obtained from the European Commission (Digital Agenda database) for 2012 and 2015. At the NUTS3 level, data were obtained from Point Topic research[16] for the year 2012. Data at NUTS3 level were extended into 2015 using an extrapolation weighting the increase in broadband coverage at the country level from 2012 to 2015 by the population density of the area. Therefore high-density areas grew more in coverage than low-density areas, see additional details in the Annex. The resulting values in each NUTS3 area were grouped by

[14] We refer to technologies that fully or partially use existing copper wire legacy infrastructures. Some of the technologies include G.fast over copper and bonding and vectoring techniques. Deployments show that these technologies could reach up to hundreds of Mbps at distances up to 1 Km, see Lemstra (2016) for an account of its implications for the industry.

[15] As this is a prospective exercise, technologies such as satellite or fixed wireless over microwave links have been excluded from the analysis.

[16] See http://point-topic.com/free-analysis/mapping-broadband-coverage-europe-2012/

geotype. In a last step the data were validated with the information publicly available from responsible bodies in each of the EU countries and in particular from the report ‘Broadband coverage in Europe 2014: Mapping progress towards the coverage objectives of the Digital Agenda’ (IHS & VVA Consulting, 2015).

Table 2 below summarises the results and displays the status of deployment of the main technologies relevant for DAE targets. There are two thresholds where fixed networks — both fibre and cable — drop dramatically: from urban into suburban, and from suburban into semirural geotypes. Wireless networks have almost full coverage in urban and suburban geotypes and as of 2015 drop only at rural and extreme-rural geotypes. It is also worth noting the leading role of cable-based technologies in the early stages of ultrafast broadband development.

Table 2. Deployment of high-speed broadband technologies (% pop) by geotype (2015)

Geotype	FTTH/B	DOCSIS	LTE
Urban	58.1%	69.6%	99.7%
Suburban	30.7%	34.8%	98.5%
Semi-rural	4.9%	6.8%	79.6%
Rural	3.4%	6.2%	42.5%
Extreme rural	0.2%	7.7%	26.3%

Source: own estimations

c. *High-speed broadband coverage targets*

The next step is the specification of the high-speed broadband coverage required to meet DAE targets. T2 does not require any interpretation, and the ubiquitous coverage of 30 Mbps is immediately translated into 100% coverage of the population. However, T3 is somewhat problematic: it refers to 50% take up (adoption) of 100 Mbps broadband. The most logical interpretation is that coverage higher than 50% is required to achieve this take-up target on a country-by-country basis. But at which level set the coverage target to ensure 50% take-up? This paper supposes that the relationship between take up and coverage is similar to the level of conventional broadband coverage that was required to achieve 50% take up of this conventional type of broadband. At the EU level, this was achieved when coverage of the basic broadband type reached 87.1%.[17]

d. *Choice of high-speed broadband technologies*

It is not only a matter of a coverage goal but also the key technologies to provide such coverage. In the case of T3, the assumptions about the technologies deployed are country-specific and depend on the preferred route for rolling out broadband coverage by incumbent and alternative providers in each country. In some countries there has been a clear preference for using FTTB/C technologies. In other countries there has been a clear preference for FTTH technologies. There are some cases in which the choice of technology depends on the geotype. Table 3 summarises the situation in the EU as of 2015 and the sources for information are compiled in an Annex.

Table 3. Technology choices to meet DAE T3 in the EU (2015)

[17] This is obviously a simplification, but the alternative of considering specific thresholds for each country would require a detailed study of the drivers of high-speed broadband adoption in each country, gathering relevant data on a country basis, and running an uncertain model without providing ground for different conclusions from those presented here. Other studies have used a similar approach, such as BCG (Bock et al., 2015) with 85.1% coverage to reach 50% take up.

Technology	Countries
FTTH	Croatia, Cyprus, Estonia, France, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Portugal, Romania, Slovakia, Spain, Sweden
FTTB/C	Austria, Belgium, Bulgaria, Czech Republic, Denmark, Germany, Greece, Italy
FTTH/B/C	Finland, Netherlands, Poland, United Kingdom

Source: own estimations from publicly available information at country level

T2 technology choice has been supposed to be the same for all EEA countries, with preference for LTE[18] in the extreme-rural geotype and in 50% combination with FTTC in the rural geotype.

The quantitative gap analysis estimates the broadband investments in each country by geotype and technology required to meet the targets. It provides results at the NUTS3 level. The analysis starts from the deployment situation of high-speed broadband as of 2015 to estimate the broadband investments from 2016 ('the 2016 investment gap'). The gap estimation process first calculates the required deployments to meet T3 and only then T2. The model iteratively estimates the coverage required to meet T3 using for that calculation the fixed preferred technology by the incumbent in each country; then it estimates whether any incremental coverage is needed over this level to meet T2. Therefore, T2 has just a secondary role in deployment cost calculations, and it is typically only relevant for rural geotypes.

e. *Deployment costs*

The deployment costs for each technology are based on relevant reports and academic papers on NGA deployment and depend on technology and geotype. They include previous studies on NGN deployment from different institutions and organisations (EIB, 2011; FCC, 2010; FTTHCE, 2012; OECD, 2009), forecasts regarding the evolution of high-speed broadband networks from main market analysts (Analysis Mason & Tech4I2, 2013; IDATE, 2013; Point Topic, 2013), and available academic literature on the subject (Feijóo & Gómez-Barroso, 2013; Han et al., 2013; Ovando et al., 2015; Tselekounis & Maniadakis, 2012). The costs have been combined in a weighted average for each of the technologies and geotypes and adapted for each country, see Annex on further details on calculations. For this, it has been considered that deployment requires on average 70% of civil works, and this cost has been adapted into the labour force in each member state from the Eurostat database 2013. With the exception of CPE, costs display the capital expenditure of network rollout to pass subscribers' premises and do not include elements from the core, backbone, transport, or aggregation networks. Costs are expressed in euros at 2016 prices. Table 4 below summarises average EU deployment costs.

Table 4. EU average deployment costs (€ per premise passed)

	Urban	Suburban	Semi-rural	Rural	Extreme rural
FTTH[19]	565	1,388	2,054	2,609	6,711
FTTB	416	838	1,375	2,134	2,467
FTTC	283	476	816	1,380	1,549
Update to FTTH	188	463	685	870	2,237
LTE-A (for T3)	374	374	582	91	1,163
LTE-A (for T2)[20]	59	104	207	641	817

Source: own calculations from meta-analysis of relevant literature, see above

[18] LTE coverage is extended to 2020 using a Gompertz technology diffusion model, with most countries achieving rates of 100%.

[19] FTTH-GPON has been preferred for cost calculations to FTTH P2P due to its prevalence in the EU.

[20] LTE-A for T2 requires a less dense network deployment, as the data rates per user are lower.

In addition to capital investments (capex), the model makes assumptions for operating expenses (opex), maintenance of assets (set at 25 years), inflation (2% per year), decrease of equipment prices due to increase in technology efficiency (1% per year), and WACC for the telecom industry (set at 10%) and used for net present value (NPV) calculations.[21]

f. *Deployments from operators*

Next, based on the country desk research, the 2016 gap is adjusted to reflect investments expected to be made by incumbents (the 'incumbent adjusted investment gap'). Incumbent investment in the period 2016–2020 is compiled from publicly available commitments or, when this was not possible, from an average of the last two years of investments in fibre-based technologies. Exhibit 3 summarises the per-capita expected investments from operators averaged yearly in the period 2016–2020.

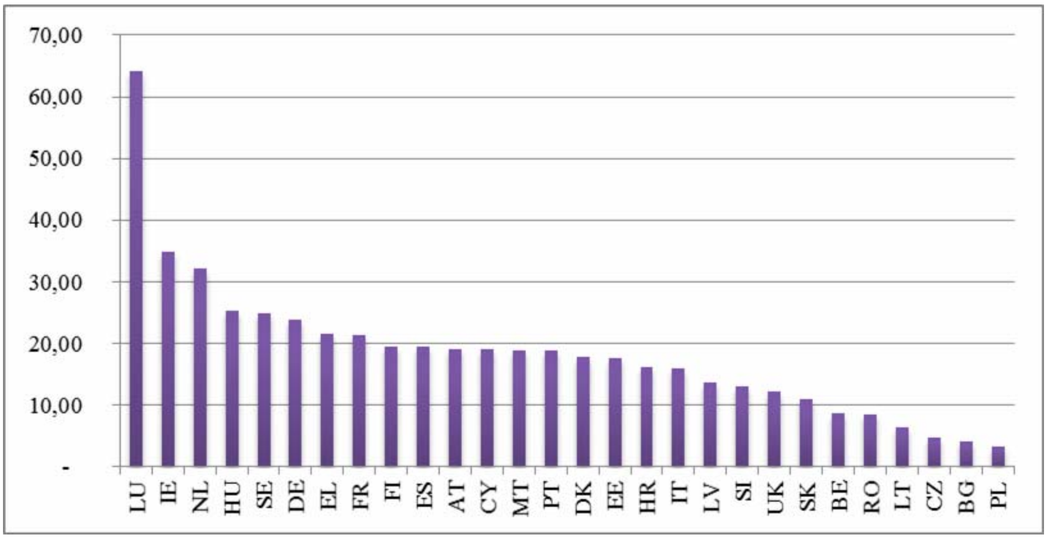

Exhibit 3. Expected per-capita yearly investment by operators in the period 2016–2020 in fibre-based technologies (€). Source: own estimations from publicly available data at country level

g. *Technology overlaps*

The model considers fixed technology overlaps, as market developments show that fixed technologies compete in the same areas. This is the case, for example, of incremental fibre-based rollout promoted by incumbents that target the same areas in which cable providers operate with DOCSIS 3.0 solutions. In this sense, existing DOCSIS3.0 and/or fibre-based infrastructures are taken into account to calculate the corresponding coverage gap to meet DAE targets in a further step, the so-called 'white areas investment gap'. It is assumed that in 2015 DOCSIS3.0 could widely support 100 Mbps broadband. But later generations of the technology due to be rolled out (DOCSIS3.1) could fully support 100 Mbps. In all country cases, only fibre-based technologies are considered for new rollout; therefore, no further cable deployment from the existing coverage footprint in 2015 is forecasted.[22] This is consistent with the market logic of incumbents that reuse technologies where possible but invest in new infrastructures able to provide the highest flexibility and features for broadband services provision, a result already reported in the critical review of Cambini & Jiang (2009).

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[21] The authors ackowledge that a more realistic approach to operators' decisions on investment is based on some variation of real options approach adapted to telecoms, see for instance Angelou & Economides (2009). However, since these methodologies require a considerably deeper analysis of alternatives and since the main objective of the paper is assessing the overall broadband deployment situation in comparative terms, therefore in authors' opinion a traditional NPV approach would suffice to this aim.

[22] With the exception of the UK, where the cable operator has announced plans for extending its cable footprint.

h. *Public subsidies and leveraged investment*

The next step considers existing public subsidies for underserved (white) areas. The source for this information is publicly available information in each country at the national, regional, or municipal level. The calculation of additional funding linked with these public subsidies relies on the share of additional investment to achieve NPV zero in 20 years capped at the maximum share of public funding as specified in the public subsidy conditions. The analysis is based on a discounted cash flow model. Exhibit 4 summarises the per-capita expected public subsidies in the period 2016–2020 together with the per-capita expected investment leveraged in the same period.

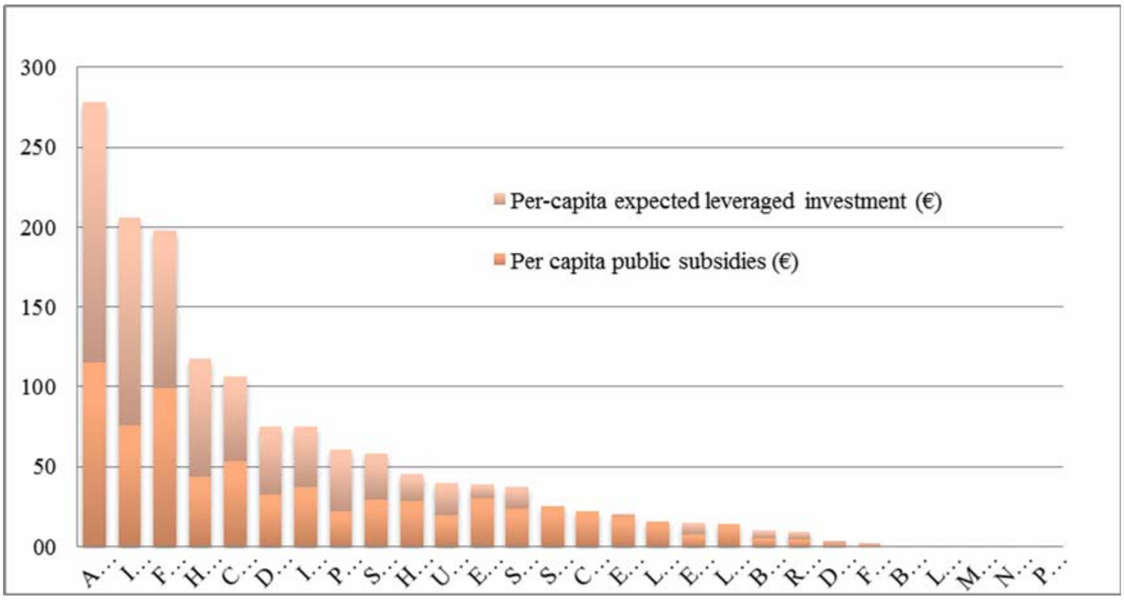


Exhibit 4. Expected per-capita public subsidies and leveraged investment in the period 2016–2020 (m€). Source: own estimations from publicly available data at country level

i. *Estimation of 2020 investment gap and additional assumptions*

The last step in the methodology consists of the estimation of the 2020 investment gap. From the departing 2016 investment gap, the model orderly discounts incumbent and alternative operators' expected investment, overlap with existing fixed technologies, and public subsidies linked with additional investment to finally arrive at the remaining investment gap. This final gap consists mostly of rural areas where broadband infrastructure projects will not be economically viable absent public subsidy.

The NPV calculations and discounted cash flow model require a set of additional assumptions. In particular, the model assumes that the broadband provider is an integrated operator and therefore deploys infrastructures and provides services to final customers. This is equivalent to assuming that the operator receives retail revenues and incurs retail costs. In this regard, revenues for ultrafast broadband are obtained from median levels for superfast broadband ARPU, including voice and line rental, and are country-specific.[23] Revenues for LTE-A are obtained from median levels for mobile broadband ARPU and are country-specific.[24] Both fixed broadband and mobile broadband revenues are assumed to decrease 1% per year, in line with past trends. The model also assumes that the take-up rate in urban areas (where there is competing technology) is 12% per year as users gradually migrate to the new technology. In rural areas (where there is no competing technology), the model assumes a stepped take-up assumption, with a

[23] European Commission (2015a). Broadband Internet access cost (BIAC 2015) prices as of February 2015. Retrieved from https://ec.europa.eu/digital-single-market/news/study-retail-broadband-access-prices-february-2015

[24] European Commission (2013). Digital Agenda Scoreboard - LTE ARPU data year 2013. Retrieved from http://digital-agenda-data.eu

20% increase in take up in years one and two (to represent currently unmet demand), then slowing to 10% per year. Taxes are country-specific.[25]

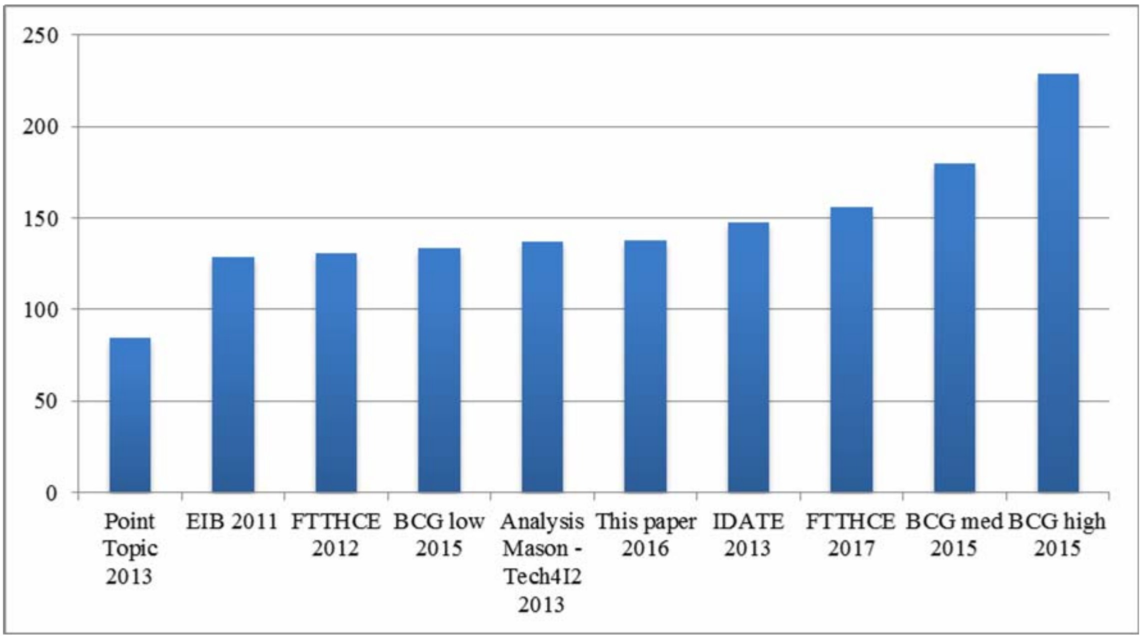
A final remark/disclaimer on the methodology from the authors' perspective is that its goal is not to provide the ultimate figures for the DAE 2020 investment gap but to provide a rational and coherent framework to address the order of magnitude of the gap and some main insights into its nature, and to test the impact of different alternatives to address it. The error margin of the assessment of the investment gap derives from three main sources: lack of granularity of data on the coverage and adoption of technologies, projections on operators and public subsidies-related investments, and projections on deployment costs and revenues. The authors' intention was to collect the most updated information in those three areas. In any case, the figures in this paper must be interpreted with great caution and only within the framework of the assumptions made.

Results and discussion

This section displays the results obtained from applying the methodology above to NUTS3 regions in Europe. They are presented in the order introduced in the methodology section: first the results on the 2016 investment gap, then on the gap after operators' expected deployment, followed by the white areas investment gap and the final expected 2020 investment gap. A second set of results introduces several alternative situations, namely greenfield and neutral operators, as well as modifications in the choice of high-speed broadband technologies and the influence of different types of simple policies.

a. *2016 investment gap*

The model estimates a total 2016 investment gap to achieve DAE targets in 2020 of 137.5 b€. This is a value that falls within the available estimations of market analysts at the EU level adapted to the time (2016) and geographical conditions of this study (EU-28). See Exhibit 5 for a compilation of estimations in b€ from available reports on this same gap.[26]



[25] Sources: KPMG (2016). *Corporate tax rates table*. Retrieved from https://home.kpmg.com/xx/en/home/services/tax/tax-tools-and-resources/tax-rates-online/corporate-tax-rates-table.html and REDTEL (2012). *Impacto de la tributación específica en el sector de las telecomunicaciones* (in Spanish).

[26] Point Topic's estimation just considers 30 Mbps technologies. BCG's high estimation considers a full fibre scenario.

Exhibit 5. Estimations of 2016 investment gap to achieve DAE targets (b€). Sources: own calculations; Analysis Mason & Tech4I2, 2013; Bock, Soos, Wilms, & Mohan, 2015; EIB, 2011; FTTHCE, 2012, 2017; IDATE, 2013; Point Topic, 2013.

In terms of premises, the model shows that there is still a 67% gap (159 m premises) without DAE targets coverage as of 2016.

The 2016 investment gap can also be analysed as a function of geotype, as shown in Table 2 before and in Table 5 below. As expected, the gap is higher in rural areas, and it is also in these rural areas where the most advanced fixed technologies are missing, FTTH in particular. Also, while the share of the gap in rural areas is 35% of premises vs. 31% in urban areas, its weight in terms of investment is much higher, a 58% share vs. a 12% share in urban areas. Point Topic (2013) reports a 63% share for rural areas vs. a 9.8% share in urban areas for this gap. The difference between urban and rural areas is also highlighted through the change in the cost per premise from urban areas into rural areas, which is 4.8 times higher. The cost of extreme-rural areas is less than semi-rural and rural areas, since the model assumes LTE deployment in this geotype. The wireless effect is also present to some extent in rural areas, since part of them may be covered with LTE. (Note that the deployment cost increase with regard to semi-rural areas is relatively modest.)

Table 5. 2016 investment gap by geotype

	Urban	Suburban	Semi-rural	Rural	Extreme rural
Share of gap in no. of premises (%)	31%	35%	23%	10%	2%
Share of gap in terms of investment (%)	12%	31%	39%	17%	2%
Total investment (b€)	16	42	52	24	2
Average investment per premise (€)	322	753	1,412	1,548	720

Source: own calculations

In terms of countries, as of 2014 Malta remained the only country to report complete coverage for NGA technologies, followed by Belgium, the Netherlands, Lithuania, Luxembourg, and Denmark, all above 90% (IHS & VVA Consulting, 2015). According to the model used in this paper, in 2016 the only two countries to achieve the DAE targets already are Malta and the Netherlands, a result coincident with the report cited above.

b. *Incumbent adjusted investment gap*

After incumbent and/or alternative operators roll out in the period 2016–2020, the model estimates that the remaining gap to achieve DAE targets in 2020 amounts to 107.5 b€ and encompasses 95.0 m premises. Therefore, deployment from existing operators is expected to reduce the high-speed broadband investment gap by 22 percentage points compared to the 2016 investment gap. In terms of premises, it implies that there is still a 40% gap with regard to the total number of premises.

The total amount of investment from operators is expected to be 44.7 b€ in the 2016–2020 period, or equivalently, it is expected that operators will invest 10.4 b€ per year in the 2016–2020 period. This is slightly higher than previous estimates of 9.6 b€ of operator investment per year (Analysis Mason & Tech4I2, 2013) and lower than BCG estimations at 14.1 b€ per year (Bock et al., 2015). Note that the operators invest 44.7 b€, but the gap only diminishes by 30 b€. Therefore, almost one-third of the operators' investment is not conductive to decrease the high-speed broadband, as it takes place in areas where there are already investments from the same or a similar type of operators in alternative technologies, such as FTTH deployments in areas with VDSL coverage.

The incumbent adjusted investment gap is shown in Table 6 below as a function of geotype and technology. The comparison of these values with those of the 2016 investment gap highlights how the operators mostly aim at urban and suburban areas, which are potentially more profitable, and help to fill the investment gap in these areas. However, rural areas are mostly left aside in the period 2016–2020. Note that DOCSIS coverage increases as the model assumes that all the cable deployed in the EU will be upgraded to DOCSIS before 2020, and therefore the cable and DOCSIS footprints will be equal.

Table 6. Incumbent adjusted investment gap (% pop) by geotype and technology

Geotype	FTTH/B	DOCSIS	LTE
Urban	67.5%	73.2%	99.7%
Suburban	39.3%	38.7%	98.5%
Semi-rural	12.2%	7.3%	79.6%
Rural	8.5%	0.7%	42.5%
Extreme rural	7.1%	0.3%	26.3%

Source: own calculations

The incumbent adjusted investment gap can be also analysed as a function of geotype, as shown in Table 7 below. From the 2016 investment gap, the share of the gap in rural areas has increased 8 percentage points to 43%. Its weight in terms of investment is also higher: 61% share in rural areas vs. 8% share in urban areas. All the costs per premises are higher than in the 2016 analysis, with a growth of 40% in the urban geotype and 17% in the rural geotype.

Table 7. After incumbent deployment investment gap by geotype

	Urban	Suburban	Semi-rural	Rural	Extreme rural
Share of gap in no. of premises (%)	20%	37%	31%	10%	2%
Share of gap in terms of investment (%)	8%	31%	43%	17%	1%
Total investment (b€)	9	33	47	18	1
Average investment per premise (€)	450	944	1,591	1,816	784

Source: own calculations

c. *White areas investment gap*

The model estimates 92.4 b€ for the white areas investment gap. The gap calculation considers both incumbent and/or alternative operators' roll out in the period 2016–2020 and the existing footprint of fixed technologies (mostly cable DOCSIS) to keep the higher value among them in terms of coverage. Therefore, existing fixed technologies contribute to reduce the high-speed broadband gap by 33 percentage points compared to the 2016 investment gap, with 11 percentage points exclusively due to coverage from previously existing (mostly cable) technologies. In terms of premises, this implies that there will still be a 31% gap of underserved premises with regard to the total number of premises. Other reports estimate that the white areas gap regarding 100 Mbps technologies in terms of coverage will be somewhat higher at 37% in 2020 (Analysis Mason & Tech4I2, 2013). The white areas investment gap as a function of geotype and technology is shown in Table 6, as there have not been new deployments.

The white areas investment gap can be also analysed as a function of geotype, as shown in Table 8 below. From the investment gap after incumbent deployment and comparison with the footprint of existing fixed technologies, the share of the gap in rural areas has increased 18 percentage points to 53% from the 2016 situation, whereas the urban share has decreased 18 percentage points to a mere 13% share.

Also, the rural weight in terms of investment is much higher: 10 percentage points more than in 2016 to a 68% share. Urban weight in terms of investment is just 5% for white areas, compared to 12% in 2016. The estimated total investment for rural white areas is estimated to amount to 63 b€. These are the areas where public subsidies and leveraged investment are generally aimed at, as discussed in the next sub-section.

Table 8. White areas investment gap by geotype

	Urban	Suburban	Semi-rural	Rural	Extreme rural
Share of gap in no. of premises (%)	13%	33%	38%	13%	2%
Share of gap in terms of investment (%)	5%	26%	48%	19%	1%
Total investment (b€)	5	24	44	18	1
Average investment per premise (€)	494	1,000	1,578	1,843	784

Source: own calculations

d. *2020 investment gap*

From the white areas investment gap, the model considers public subsidies and their linked investment to arrive at the estimation of the 2020 investment gap to meet DAE targets across the EU. Thus, the model estimates 48.8 b€ for the resulting final gap in 2020, with public subsidies estimated to amount to 19.5 b€ and their leveraged investment to 24.3 b€ — a ratio of 1.24 between public subsidies and leveraged investment. Analysis Mason & Tech4I2 (2013) estimate 26 b€ of public subsidies in their modest public intervention model, a ratio of 2.14 with regard to leveraged investment, and a total gap of 60 b€. Bock et al. (2015) estimate 20.8 b€ of public subsidies for the period 2016–2020 and a final 2020 gap of 75 b€.

In terms of premises, the result implies that there is still a final 14% gap with regard to the total number of premises, equivalent to 32.5 m premises, and an average cost per premise of 1,566 €. Analysis Mason & Tech4I2 (2013) estimated a higher gap at 24%.

The 2020 investment gap is shown in Table 9 below as a function of geotype and technology. It has been assumed that public subsidies have been aimed to reduce the gap equally in terms of population in all the remaining areas, as existing policies are aimed at white areas in general and do not follow a logic related to population density or preference for expected profitability. In any case, the comparison of these values with those of the 2016 investment gap highlights how rural areas are still devoid of fibre and will have to rely mostly on wireless technologies.

Table 9. 2020 investment gap (% pop) by geotype and technology

Geotype	FTTH/B/C/AdvDSL	DOCSIS	LTE
Urban	80.4%	73.2%	97.3%
Suburban	58.9%	38.7%	93.7%
Semi-rural	34.0%	7.3%	92.0%
Rural	26.1%	0.7%	80.6%
Extreme rural	20.4%	0.3%	78.2%

Source: own calculations

The 2020 investment gap can also be analysed as a function of geotype, as shown in Table 10 below. Departing from the 2016 analysis and after incumbent deployment, comparison with the footprint of existing fixed technologies, and use of public subsidies and leveraged investment, the share of the gap in rural areas has increased 47 percentage points to 82%. Also, its weight in terms of investment is even higher — 93% share of rural areas vs. just 1% for urban areas — with the cost of deployment per premise increased in all rural geotypes with regard to the previous investment gaps analysis.

Table 10. 2020 investment gap by geotype

	Urban	Suburban	Semi-rural	Rural	Extreme rural
Share of gap in no. of premises (%)	6%	12%	52%	27%	3%
Share of gap in terms of investment (%)	1%	6%	58%	33%	2%
Total investment (b€)	0	3	28	16	1
Average investment per premise (€)	226	698	1,672	1,879	895

Source: own calculations

This same 2020 gap can be further analysed per NUTS3. Exhibit 6 below shows the histogram of the gap in percentage of premises. From the total 1,316 NUTS3 areas in the EU-28, it is expected that there will be 299 with no gap at all, and an additional 478 with a gap less than 25% of premises. On the opposite side, there will be 33 regions with a gap higher than 50% of their premises, and a further 506 with a gap between 25% and 50% of premises in terms of 2020 broadband DAE targets. The population living in NUTS3 areas with no gap is expected to be 25% of the EU-28, 27% in NUTS3 areas with a 2020 gap less than 10%, 22% of the EU population living in NUTS3 areas with a gap between 10% and 25%, 26% of the EU population with a gap between 25% and 50%, and 1% of the population living in NUTS3 regions with a gap higher than 50%. Cohesion regions have an average gap of 21%, compared to 16% for non-cohesion regions.

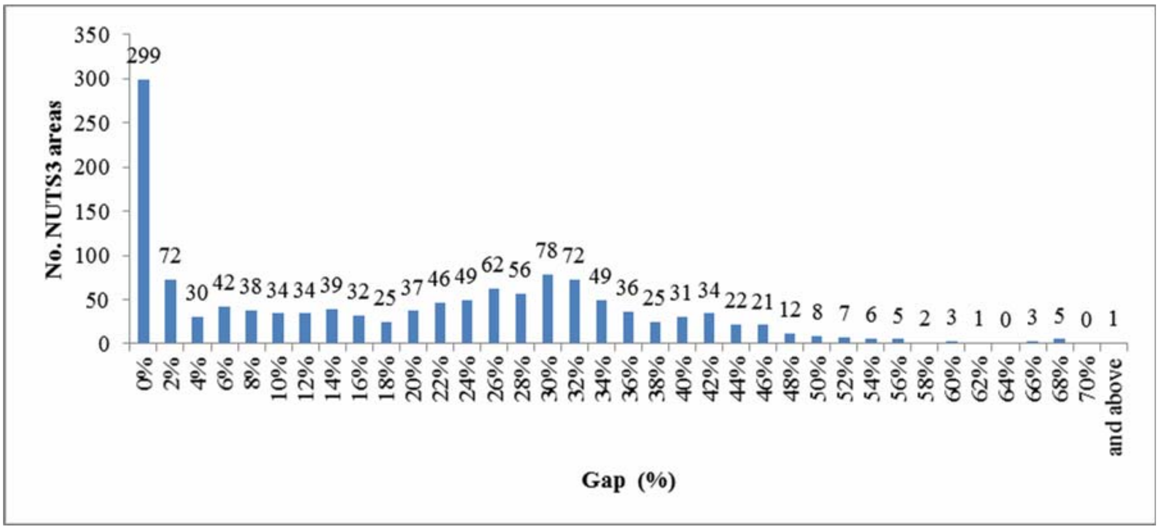


Exhibit 6. Histogram of number of NUTS3 regions as a function of the 2020 investment gap (% premises) in the EU

The gap can be analysed per country. There are nine countries where no gap at all or a gap below 0.5% is expected in 2020: Belgium, Denmark, Estonia, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, and Portugal. Seven countries are expected to have a gap below 10%: Croatia, Cyprus, Finland, Hungary, Italy, Slovakia, and Slovenia. Five countries are expected to have a gap below 15%: the Czech Republic, Germany, Greece, Spain, and Sweden. A 15% to 25% gap is expected in five countries: Austria, France, Ireland, Romania, and the United Kingdom. Finally, two countries are expected to be beyond the 25% gap: Bulgaria and Poland. Five countries account for 79% of the total gap in terms of premises: France, Germany, Poland, Spain, and the United Kingdom. The report from Point Topic (2013) shows similar results in terms of countries: the five biggest countries of Europe would require 72% of the total funding.

Another analysis of interest is the amount of non-recoverable public subsidy that would be necessary to close the 2020 investment gap. Assuming an objective of NPV zero in 20 years, the total amount of public subsidies would be 27.6 b€; in other words, the 'pure' subsidy should amount to 57% of the 2020 investment gap. The remaining 43% would be investments leveraged by means of the public subsidy. There are considerable differences between countries in their proportion between subsidies and leveraged investment due to their different prospects of profitability, with three quarters of countries requiring between 44% and 74% of the public subsidy share. Cases of interest requiring a very high percentage of subsidy (above the third quartile) are Finland, Romania, and Sweden. Cases below the first quartile (i.e. countries with rather low levels of subsidy share) are Germany, Greece, and the United Kingdom.

e. *Alternative scenarios: Operators*

Two alternative scenarios are considered here. The first uses a 'greenfield' operator, which is an operator that cannot reuse existing infrastructures for the deployment. Its main effect is a premium of 16% in the overall size of the 2020 investment gap.

The second scenario assumes a neutral operator, which is an operator that can only provide wholesale services. This is aligned with broad provisions aimed at open access public (or publicly supported) operators within the EC regulation. A neutral operator incurs the same costs of a regular operator; however, it only gains wholesale revenues and cannot access retail revenues. Therefore, the effect of a neutral operator is an increase of the possible public subsidies share to fill the 2020 investment gap, which now would amount to 79% on average vs. 21% of the hypothetical leveraged investment.

f. *Alternative scenarios: Technologies*

Two alternative scenarios are considered in this section. The first assumes that the technology to be deployed is FTTH — or FTTB/C in combination with advanced DSL techniques, if this is the strategic choice of the country — in every region irrespective of geotype. This is equivalent to suppose that T3 is only achieved with 100% of coverage. If this would be the case, the 2020 investment gap would increase to 82.7 b€, which is 98.3% above the baseline scenario.

The second scenario supposes that the 2020 investment gap is only fulfilled with wireless LTE-A technologies. Under this alternative hypothesis, the 2020 investment gap would reduce to 6.8 b€, which is 83.8% less than the baseline scenario.

g. *Alternative scenarios: Policies*

It has been argued that policy intervention can help reduce the deployment costs, typically between 5% and 10%, thanks to a combination of measures such as coordination of civil works, reduction of the bureaucratic burden for local licensing, or tax exemptions and reductions. Assuming a decrease of 10% of deployment costs, the 2020 investment gap would reduce to 35.5 b€, which is 27.2% less than the baseline scenario.

Conclusions

From the different categories of barriers (WEF, 2016) to enjoy high-speed broadband (infrastructure availability, affordability, skills, awareness and cultural acceptance, local adoption, content and use), this paper focuses on the first of them, with the specific aims set forward in the DAE plan for 2020. Within this framework, the paper's main conclusion is that the EU in general is far from achieving the DAE targets in 2020 in terms of infrastructure deployment, with almost all the gaps taking place in rural geotypes, the white areas where there are no expected high-speed broadband deployments up to the year 2020.[27] In fact, it seems that there is a considerable consensus among market analysts and experts on these issues, putting the figure on the investments needed to fill the gap at around 50 b€ for the EU-28 beyond already expected public and private funding, with more than 90% of the pending investments in rural geotypes.

There is also a great deal of consensus about the need for additional policy interventions and more public funding in order to achieve the DAE targets. In simple terms, the private sector is reluctant to invest and close the gap, as investors in broadband infrastructure can only partially appropriate benefits due to the public good features of broadband connectivity (Gruber et al., 2014), a result also displayed in most of the theoretical and empirical studies available on the relationship between broadband deployment and regulatory measures (Cambini & Jiang, 2009). Thus, according to the model used in this paper, only an appropriate combination of i) incumbent and alternative operators investments, ii) public subsidies and investments linked to them, and iii) new investments, both public and private and non-existing as of 2016, would be able to meet the set targets.

Each of these sources of investments has its own set of requisites, which is also dependent on the particular country. Incumbent and alternative operators investments require sound business prospects, and probably a positive economic situation and a stable / renewed regulatory / policy framework in the mid to long term. Public subsidies, which considerably rely on EU structural funding, need to address how to leverage the additional funding from other public bodies, private parties, or a combination of both, which in turn implies a detailed business case to prove the long-term profitability of such an investment. Last but not least, new sources of funding, unknown and unavailable from the perspective of 2016, are needed for innovations able to increase the appeal of high-speed broadband investments.

This combination of instruments — private investments, public subsidies, and innovations able to attract new sources of investments — is nothing new, and, in fact, it is the conventional but difficult recipe to fill the broadband infrastructure gap. For instance, according to WEF (2016), governments can facilitate and encourage infrastructure investment when they have a clear long-term plan, a transparent regulatory framework, and a tax system that incentivises investment. It is also recommended as a best practice, given the substantial investment required, to use multiparty cooperation between the public and private sectors as well as innovation in technology, business models, and even regulation.

Of course, the policy and regulatory framework has been traditionally subject to extensive research looking for normative views on how to improve the unstable relationship among competition, innovation, and investment, or from the time perspective between static and dynamic efficiency of broadband markets, see the critical review in Cambini & Jiang (2009). Also already at the start of NGN deployment, Gómez-Barroso and Feijóo (2009) classified all the possible instruments that support the development of next-generation communications: public administrations' direct interventions, indirect interventions, and regulations with regard to the supply side, the demand side, or both. The existing EU regulatory framework, which entered into force by mid-2011 based on an open-access approach[28], and its relationship with broadband investments have also received/are receiving considerable attention. A telegraphic summary of this framework can be read as 'aiming to incentivise investments while promoting competition in network access', which is exactly the conundrum of broadband markets and the base of the doctrine on "essential facilities" (Renda, 2010). The launch of the Communication on a

[27] Note that the paper departs somewhat from the analysis into black, grey and white areas. The reason is that it is not a paper about level of competition in the market but about providing broadband to all Europeans, therefore with a social more than economic perspective. Having said that, there is a general coincidence on white areas (this is, those areas who lack infrastructures now and with business-as-usual also in 2020), while black and grey areas would require a specific analysis about the overlap of providers; an analysis beyond the scope of the paper.

[28] See Kongaut & Bohlin (2014) for an account of open access policy in OECD countries.

Digital Single Market for Europe (European Commission, 2015b) has highlighted again the contradictions between competition and investment / innovation. Recently, some revisited approaches have been proposed to update the regulatory framework with the aim of promoting investments in new-generation networks and, to a certain extent, putting direct benefits to consumers from increased competition in a secondary role. These approaches range from using tools in the current regime (functional separation of incumbent national providers to split their businesses into wholesale network supply and retail supply, review of the universal service concept) to broadening the current approach (EU regulator, coordination of spectrum at EU level) and to more aggressive changes in regulation, such as particular regulatory holidays for NGA (Ünver, 2015), symmetric regulation (Shortall & Cave, 2015), or even a move towards a competition-based, ex-post framework (Rivera et al., 2016).

Beyond regulation, innovations in policies and markets to attract additional investments have lately received particular attention. There are proposals for partnership between digital (content) providers and telecom operators (D'Annunzio & Reverberi, 2016); for full use of the wireless advantages in broadband (Ovando et al., 2015); for breaking network neutrality and charging for quality and/or content (Bock et al., 2015); for 'soft' EU policies such as broadband mapping, infrastructure registration and sharing, co-investment measures, streamlined administration, and standards development (Analysis Mason & Tech4I2, 2013); and for launching demand-side policies targeted at broadband consumers (Rivera et al., 2016), including specifically subsidised prices to consumers of 100 Mbps service (Analysis Mason & Tech4I2, 2013).

Only a handful of these measures seem timely enough to effectively contribute to close the gap before 2020, in particular those ensuring rapid changes in the broadband market behaviour and the extension of coverage. Among them, this paper shows that a combination of improved wireless technologies and support from policies aimed at reducing costs of deployments (supply-side measures) and/or subsidising the demand side can be used to achieve the DAE targets. Therefore, in spite of their exclusive market approach, operators play a fundamental role in meeting DAE targets. This is primarily the case because of their existing plans for further investment into high-speed broadband networks, which can reduce about one quarter of the 2016 investment gap, but also because of the impact of reusing their infrastructures for further deployment and counting on their economies of scale to attract new funding.

Existing public funding and expected leveraged investment attached to this funding also play a fundamental role, not only because they will help to close the gap existing in 2016 by about one third, but also because they are specifically targeted at white areas that otherwise will not receive such investment. Following the same rationale, it would also be possible to use additional public subsidies to completely close the expected 2020 gap. However, these new public subsidies will need to leverage new investment, which in turn requires a potentially profitable business case, even if in the long term. As the average cost of underserved areas increases as other, more profitable areas are already covered, the amount of non-recoupable subsidy should also increase to compensate for the lack of profitability. According to the model, the percentage of subsidy should amount to 57% on average for deployments to be profitable in 20 years' time, with the median case for a country at 65% and some relevant cases well above the 75% threshold.

On the other side of the coin, the expected 2020 gap can also become considerably higher than the baseline figure presented here. This paper has examined three main situations that can negatively impact the estimated 2020 gap: an extreme preference for fibre-based technologies in all geotypes almost doubles the size of the gap; a greenfield operation also increases the gap, although modestly, as there is not much opportunity for reusing existing infrastructures in the more remote geotypes; and a strict respect for the existing regulatory provisions of open access using a neutral operator will not increase the size of the gap *per se* but will increase the amount of subsidy relative to the leveraged investment, since the cost of deployment remains the same but the profitability of such operators is compromised by the decrease in potential revenues.

In addition to the general analysis, there is also the possibility of looking into the NUTS3 areas and the countries themselves, since there are a number of countries that have already achieved the DAE 2020 targets as of 2016, namely Malta and the Netherlands, and since there are also some countries that are expected to achieve them in 2020, namely Belgium, Denmark, Estonia, Latvia, Lithuania, Luxembourg, and Portugal. Regarding this list of countries, it is worth briefly exploring the reasons for their success. There are all types of situations, such as countries that have used past investments, mostly in cable (Belgium, Denmark, Malta, Portugal, the Netherlands), and countries that rely on existing investment plans for operators and support from the government as well as leveraged investments (Estonia, Latvia, Lithuania, Luxembourg).

There could be some temptations to explain these successes. All of them are relatively small countries with good departing coverage. Some are also highly urbanised and homogeneous with relatively high income: Belgium, Denmark, Luxembourg, and the Netherlands. Their rural sector is small in absolute terms. There are also other small countries in which cable technologies have a strong footprint, including the three countries just mentioned, but also Estonia, Latvia, Lithuania, Malta, and Portugal. These last five also have comparatively low cost levels for deployment. In taking the cable case further, however tempting uniformity could be, the differences are considerable. In Latvia, cable providers are seen as television providers with only limited high-speed broadband adoption. In Denmark, early attempts at an integrated fibre-cable network solution paved the way for the incumbent to provide cable television. In the Netherlands, a municipal initiative led to consolidation of cable provision in separated regional providers, creating a true infrastructure-based competition situation (see Lemstra and Melody [2015a] for a detailed account of differences in broadband dynamics across Europe). Neither general socio-economic conditions nor market behaviour explain all cases, as there is also room for new, strong public support, as the cases of those countries with an expected gap less than 10% prove (Croatia, Cyprus, Finland, Hungary, Italy, Slovakia, and Slovenia). Therefore, the most reasonable conclusion is that each country has its own path,[29] and much still depends on economic pre-conditions, market interest, and political will regarding high-speed broadband deployment.

From the perspective of NUTS3 areas, the results presented in this paper provide the grounds for further development of the so-called municipal broadband networks. These are deployments to fill gaps or provide substantial areas of service in regions, cities, or smaller towns and surrounding locations that are fully or partially facilitated, built, operated, or financed by local governments, public bodies, utilities, organisations, or co-operatives that have some type of public involvement (Mölleryd, 2015). The existence of a considerable premises gap in the mid to long term (2020 and beyond) in about one third of the NUTS3 regions in Europe (with about 20% of the EU population), the absence of fibre deployment in rural geotypes and the digital-divide-within-a-digital-divide in rural areas (Rendon Schneir & Xiong, 2016) will be foundational factors in triggering a local response to the lack of high-speed broadband deployment in these areas.

All in all, the EU requires urgent action if the DAE targets are to be met. Telecommunications network deployments are slow by nature, as they require design, planning, coordination, and permission from local authorities, with typical projects requiring three or more years from the drawing table and financial agreements to deployment fruition. But it is not only a matter of deployment time, since the delay will increase the risk and amount of public subsidies needed, as this type of funding will be directed to less and less potentially profitable areas as the market evolves, and the ratio of subsidy to leveraged investment will be higher to compensate for the lack of profitability. Last but not least, the identification of new sources of investment and the case to attract them into the broadband business arena seems to be the final frontier for the fulfilment of EU high-speed broadband DAE targets.

[29] According to Lemstra and Melody (2015b), the broadband market dynamics depend on geography and demography, historical infrastructure deployment, institutional arrangements, time of joining the EU, market structure, distribution of market power, firm ownership, position and role of the regulator, political priorities and preferences, and the industrial setting.

Acknowledgements

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Annex – Further details on calculations

The extension of NUTS3 broadband data from 2012 to 2015 was carried out using Eq. (1) below.

$$BBNUTS3(2015)_i = BBNUTS3(2012)_i + \Delta BBCountry(2015-2012)_j * NPDNUTS3_i \quad \text{Eq. (1)}$$

where:

$BBNUTS3(year)_i$ is the broadband data in the i th NUTS3 region in a given year

$\Delta BBCountry(year2-year1)_j$ is the increase on broadband in the j th country between two given years

$NPDNUTS3_i$ is the normalized (0-1) population density of the i th NUTS3 region with regard to the distribution of population densities in the j th country.

The deployment costs have been calculated using the procedure described in the following. First data on deployment costs have been compiled from the literature described in the main text. Second all the prices have been transformed to 2015 using the corresponding inflation index. Third, deployment costs for each type of technology have been combined in a weighted average using weight "5" for specific projects / local / municipal deployment costs, weight "4" for NUTS3 regional deployment costs, weight "3" for NUTS2 regional deployment costs, weight "2" for country deployment costs and weight "1" for EU-wide deployment costs. These weights try to capture the reliability of costing data, from more reliable (specific deployments) to less reliable (EU general deployments). This heuristic procedure has also the advantage of incorporating new data as soon as they are available. In a last step the deployment costs are converted into country-specific costs using labour prices for the 70% of the cost (civil works). In any case, the authors would like to mention that the main interest of this study is the comparison of costs between different stages of deployment and not necessarily the absolute value of them.

Annex – Sources of information for specific countries

- Austria (AT)

Bundesministerium für Verkehr, I. und T. (2012). Breitbandstrategie 2020 - BBA2020. Retrieved from https://www.bmvit.gv.at/telekommunikation/publikationen/downloads/breitbandstrategie2020.pdf

Telecom Paper. (2015). Austria Public Investment 2015-2020 (press). Retrieved from http://www.telecompaper.com/news/austria-unveils-broadband-strategy-100-mbps-for-all-by-2020--1070538

- Belgium (BE)

Minister for Development Cooperation, Digital Agenda, Post and Telecommunictions (2015). Digital Belgium. Retrieved from http://www.digitalbelgium.be/en

- Bulgaria (BG)

Ministry of Transport, I. T. and C. (2014). National Broadband Infrastructure Plan for Next Generation Access. Retrieved from https://www.mtitc.government.bg/page.php?category=505&id=7036

- Croatia (HR)

Ministry of Maritime Affairs, Transport and Infrastructure (2011). Strategy for Broadband Development in the Republic of Croatia for 2012 – 2015, Retrieved from http://www.mppi.hr/UserDocsImages/w StrategyBB 5_12.pdf

Ministry of Public Administration. (2015). e-Croatia 2020 Strategy. Retrieved from https://uprava.gov.hr/UserDocsImages//e-Hrvatska//e-Croatia 2020Strategy %2820.01.2016.%29.pdf

- Cyprus (CY)

Ministry of Communications and Works. (2012). Digital Strategy for Cyprus. Retrieved from http://www.mof.gov.cy/mof/dits/dits.nsf/63e74b41e6109448c22577bd0027e112/107f3360ffee7f47c22577bd0027dc0c/$FILE/Digital Strategy for Cyprus.pdf

- Czech Republic (CZ)

Ministry of Industry and Trade. (2014). Operational Programme Enterprise and Innovations for Competitiveness 2014 – 2020. Retrieved from http://www.mpo.cz/dokument169167.html

- Germany (DE)

Breitbandausbau, D. (2015). Germany public investment 2018. Retrieved from https://www.bundesregierung.de/Content/DE/Artikel/2015/10/2015-10-21-breitbandausbau.html

Federal Ministry for Economic Affairs and Energy. (2014). Digitale Agenda 2014 – 2017 (Vol. 25). Retrieved from https://www.digitale-agenda.de/Content/DE/_Anlagen/2014/08/2014-08-20-digitale-agenda.pdf?__blob=publicationFile&v=6

- Denmark (DK)

Ministry of Business and Growth. (2013). Danish national broadband strategy. Retrieved from https://www.evm.dk/publikationer/2013/13-03-13-bedre-bredbaand-og-mobildaekning-i-hele-danmark

- Estonia (EE)

Ministry of Economic Affairs and Communications. (2014). Digital Agenda 2020 for Estonia. Retrieved from https://e-estonia.com/wp-content/uploads/2014/04/Digital-Agenda-2020_Estonia_ENG.pdf

National Audit Office of Estonia. (2015). Fast Internet may not get to every home from the information superhighway. Retrieved from http://www.riigikontroll.ee/Suhtedavalikkusega/Pressiteated/tabid/168/ItemId/803/amid/557/language/en-US/Default.aspx

- Greece (EL)

General Secretariat for Telecommunications and Post - Ministry of Economy, Infraestructures, S. and C. (2015). National Next Generation Broadband Access. Retrieved from http://www.yme.gr/getfile.php?id=6018

Ministry of Economy. (n.d.). Operational Programme "Competitiveness, Entrepreneurship and Innovation" (EPAnEK) 2014-2020. Retrieved from http://epan2.antagonistikotita.gr/uploads/Summary of EPANEK.pdf

- Spain (ES)

CNMC. (2014). Informe Económico de las Telecomunicaciones y del Sector Audiovisual 2014, 148. Retrieved from http://www.cnmc.es/Portals/0/Ficheros/Telecomunicaciones/Informes/Informes Anuales/2014/Informe Telecomunicaciones CNMC 2014.pdf

Ministerio de Industria, E. y T. (2013). Digital Agenda for Spain. Retrieved from http://www.agendadigital.gob.es/digital-agenda/Documents/digital-agenda-for-spain.pdf

Ministerio de Industria, E. Y. T., & Públicas, M. D. H. Y. A. (2014). Planes específicos de la Agenda Digital para España. Retrieved from http://www.agendadigital.gob.es/planes-actuaciones/Bibliotecaplanesconsolidados/Planes-Especificos-ADpE.pdf

- Finland (FI)

Advisory Ubiquotous and Information Society Board - Ministry of Transport and Ministry of Transport. (2011). Productive and inventive Finland - Digital Agenda for 2011–2020. Retrieved from http://www.oph.fi/download/135323_productive_and_inventive_finland.pdf

- France (FR)

France Très Haut Débit - French Broadband Strategy. (2013). Retrieved from http://www.francethd.fr/

ZDNet. (2013). France to invest €20bn in high-speed broadband for the entire country. Retrieved from http://www.zdnet.com/article/france-to-invest-eur20bn-in-high-speed-broadband-for-the-entire-country/

- Hungary (HU)

Ministry of Informatics and Communications. (2014). National Broadband Strategy. Retrieved from http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=4845

- Iceland (IS)

Post and Telecom Administration in Iceland. (2014). - Icelandic electronics communications market for 2012 – 2014. Retrieved from https://www.pfs.is/english/about-pta/news/news/2015/04/27/New-statistics-report-on-the-Icelandic-telecommunications-market-in-2014/

- Ireland (IE)

Deparment of Communications, E. and N. R. (2012). Delivering a Connected Society - A National Broadband Plan for Ireland. Retrieved from http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=4850

- Italy (IT)

Ministero dello Sviluppo Economico. (2011). Piano Nazionale banda larga: caratteristiche e modalità e attuative. Retrieved from http://ec.europa.eu/competition/state_aid/cases/242381/242381_1352102_93_2.pdf

Ministero dello Sviluppo Economico. (2014). The Italian strategy for next generation access network. Retrieved from http://www.agid.gov.it/sites/default/files/documentazione/next_generation_access_network_-_english_version.pdf

- Lithuania (LT)

National Digital Coalition of Lithuania 2014-2020. (2013). Retrieved from http://www.skaitmeninekoalicija.lt/en/documents.html#logo

- Luxembourg (LU)

Minisètere d´Etat, M. de l´Economie et du C. extérieur. (2010). National strategy for very high-speed networks, (April). Retrieved from hhttps://mygov.in/sites/default/files/user_submission/8ce8c1f97fe42a6f0b620a8925bd6f36.pdf

- Latvia (LV)

Government of Latvia. (2013). Latvia's national broadband strategy. Retrieved from http://tap.mk.gov.lv/mk/tap/?pid=40249838

- Malta (MT)

Government of Malta. (2014). Digital Malta - National Digital Strategy 2014 – 2020. Retrieved from http://digitalmalta.gov.mt/en/Pages/Content/DMDownload.aspx

- Netherlands (NL)

Ministerie van Economische Zaken, L. en I. (2011). Digital Agenda.nl. Retrieved from https://ecp.nl/de-digitale-agenda

- Norway (NO)

Ministry of Local Government and Modernization. (2013). Digital Agenda for Norway: ICT for Growth and Value Creation (Vol. 23). Retrieved from http://www.regjeringen.no/en/dep/kmd/documents/white/propositions/2012-2013/meld-st-23-20122013-2/4/4.html?id=729035

- Poland (PL)

Ministerstwo infrastruktury i rozwoju. (2014). Digital Poland for 2014-2020. Retrieved from https://www.polskacyfrowa.gov.pl/media/10410/POPC_eng_1632015.pdf

- Portugal (PT)

Governo de Portugal. (2012). Agenda Portugal Digital. Retrieved from http://www.portugaldigital.pt/index/

- Romania (RO)

Government of Romania. (2015). Digital Agenda for Romania 2020. Retrieved from https://ec.europa.eu/epale/sites/epale/files/strategia-nationala-agenda-digitala-pentru-romania-20202c-20-feb.2015.pdf

- Sweden (SE)

Ministry of Enterprise and Innovation. (2009). Broadband strategy for Sweden. Retrieved from http://www.government.se/reports/2009/11/broadband-strategy-for-sweden/

- Slovenia (SI)

Ministry of Education, S. and S. (2015). Digital Slovenia 2020. Retrieved from http://www.mizs.gov.si/si/delovna_podrocja/direktorat_za_informacijsko_druzbo/digitalna_slovenija_2020/

- Slovakia (SK)

Ministry of Finance. (2014). Strategic Document for Digital Growth and Next Generation Access Infrastructure (2014-2020). Retrieved from http://www.informatizacia.sk/ext_dok-strategicky...2014_2020.../16622c

- United Kingdom (UK)

Analysys Mason. (2015). Report for BT International benchmarking report. Retrieved from http://www.analysysmason.com/About-Us/News/Press-releases/Broadband-benchmarks-Sept2015/

Innovate UK (Technology Strategy Board). (2015). Digital economy strategy. Retrieved from https://www.gov.uk/government/publications/digital-economy-strategy-2015-2018

National Audit Office UK. (2015). The superband rural broadband Progrmame update. Retrieved from https://www.nao.org.uk/wp-content/uploads/2015/01/The-Superfast-Rural-Broadband-Programme-update.pdf

UK Government. (2015). Broadband delivery UK (BDUK). Retrieved from https://www.gov.uk/guidance/broadband-delivery-uk

References

Analysis Mason. (2008). The costs of deploying fibre-based next-generation broadband infrastructure. London: Final report for the Broadband Stakeholder Group. Retrieved from http://www.broadbanduk.org/component/option,com_docman/task,doc_view/gid,1036/Itemid,63/

Analysis Mason, & Tech4I2. (2013). *The socio-economic impact of bandwidth*. Brussels. Retrieved from https://ec.europa.eu/digital-single-market/en/news/study-socio-economic-impact-bandwidth-smart-20100033

Angelou, G. N., & Economides, A. A. (2009). A compound real option and AHP methodology for evaluating ICT business alternatives. *Telematics and Informatics*, *26*(4), 353–374. http://doi.org/10.1016/j.tele.2008.02.004

Bock, W., Soos, P., Wilms, M., & Mohan, M. (2015). *Five Priorities for Achieving Europe's Digital Single Market*.

Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, *33*(10–11), 559–574. http://doi.org/10.1016/j.telpol.2009.08.007

Coomonte, R., Feijóo, C., Ramos, S., & Gómez-Barroso, J.-L. (2013). How much energy will your NGN consume? A model for energy consumption in next generation access networks: The case of Spain. *Telecommunications Policy*, *37*(10), 981–1003. http://doi.org/10.1016/j.telpol.2013.09.002

D'Annunzio, A., & Reverberi, P. (2016). Co-investment in ultra-fast broadband access networks: Is there a role for content providers? *Telecommunications Policy*, *40*(4), 353–367. http://doi.org/10.1016/j.telpol.2015.11.012

De-Antonio, J., Feijóo, C., Gómez-Barroso, J. L., Rojo, D., & Marín, A. (2006). A European perspective on the deployment of next generation networks. *The Journal of the Communications Network*, *Vol 5*, *pa*(April – June), 47–55.

Dijkstra, L., & Poelman, H. (2014). *Regional Working Paper 2014. A harmonised definition of cities and rural areas : the new degree of urbanisation*. Brussels. Retrieved from http://dx.doi.org/10.1016/j.apgeog.2012.01.009%5Cnhttp://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf

EIB. (2011). *Investigation of the Telecommunications Investment Targets*. Luxembourg.

European Commission. (2010). A Digital Agenda for Europe. Brussels: COM(2010) 245.

European Commission. (2013). *Digital Agenda Scoreboard - LTE ARPU data year 2013*. Brussels.

European Commission. (2015a). *Broadband Internet access cost (BIAC 2015) prices as of February 2015*. Brussels. Retrieved from https://ec.europa.eu/digital-single-market/news/study-retail-broadband-access-prices-february-2015

European Commission. (2015b). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Digital Single Market Strategy for Europe*. Brussels. Retrieved from http://ec.europa.eu/priorities/digital single market/docs/dsm communication_en.pdf

Falch, M., & Henten, A. (2010). Public private partnerships as a tool for stimulating investments in broadband. *Telecommunications Policy*, *34*(9), 496–504.

FCC. (2010). The broadband availabilty gap. OBI technical paper No 1. Washington: Federal Communications Commission. Retrieved from http://www.broadband.gov/plan/broadband-working-reports-technical-papers.html

Feijoo, C. (2016). Next Generation Access Networks. In *Encyclopedia of Law and Economics*. Berlin: Springer.

Feijóo, C., & Gómez-Barroso, J.-L. (2013). El despliegue de redes de acceso ultrarrápidas: un análisis prospectivo de los límites de mercado. *Papeles de Economía Española*, (136), 116–129.

Feijóo, C., & Gómez-Barroso, J. L. (2010). A prospective analysis of the deployment of next generation access networks: looking for the limits of market action. The case of Spain. Madrid, Spain: NEREC.

Forge, S., Blackman, C., & Bohlin, E. (2005). The demand for future mobile communications markets and services in Europe. *Technical Report Series*. Institute for Prospective Technological Studies - JRC - EC. Retrieved from http://ftp.jrc.es/eur21673en.pdf

FTTHCE. (2012). *The Cost of Meeting Europe' s Network Needs*. Brussels.

FTTHCE. (2017). Cost Study: Deploying FTTH throughout EU. Retrieved February 17, 2017, from http://www.ftthcouncil.eu/home/latest-news/cost-study-deploying-ftth-throughout-eu

Gómez-Barroso, J.-L., & Feijoo, C. (2009). Policy tools for public involvement in the deployment of next generation communications. *Info*, *11*(6), 3–13.

Gruber, H., Hätönen, J., & Koutroumpis, P. (2014). Broadband access in the EU: An assessment of future economic benefits. *Telecommunications Policy*, *38*(11), 1046–1058. http://doi.org/10.1016/j.telpol.2014.06.007

Han, S., Sung, K. W., & Zander, J. (2013). An Economic Cost Model for Network Deployment and Spectrum in Wireless Networks. In *24th European Regional International Telecommunications Society Conference*. Florence, Italy.

IDATE. (2013). *Deployment costs & access market revenue*. Montpellier.

IHS, & VVA Consulting. (2015). *Broadband coverage in Europe 2014. Mapping progress towards the coverage objectives of the Digital Agenda*. European Commission - DG Communications Networks, Content and Technology. Brussels.

Katsigiannis, M., & Smura, T. (2015). A cost model for radio access data networks. *Info*, *17*(1), 39–53. http://doi.org/10.1108/info-09-2014-0036

Katz, R., Koutroumpis, P., & Martin Callorda, F. (2014). Using a digitization index to measure the economic and social impact of digital agendas. *Info*, *16*(1), 32–44. http://doi.org/10.1108/info-10-2013-0051

Kongaut, C., & Bohlin, E. (2014). Unbundling and infrastructure competition for broadband adoption: Implications for NGA regulation. *Telecommunications Policy*, *38*(8), 760–770. http://doi.org/10.1016/j.telpol.2014.06.003

KPMG. (2016). *Corporate tax rates table*.

Lemstra, W. (2016). *An Integrated Regulatory Framework for Digital Networks and Services*. Brussels.

Lemstra, W., & Melody, W. H. (2015a). Cross-case analysis. In W. Lemstra & W. H. Melody (Eds.), *The dynamics of broadband markets in Europe. Realizing the 2020 Digital Agenda* (p. 409). Cambridge: Cambridge University Press.

Lemstra, W., & Melody, W. H. (2015b). Research context and perspective. In W. Lemstra & W. H. Melody (Eds.), *The dynamics of broadband markets in Europe. Realizing the 2020 Digital Agenda* (p. 409). Cambridge: Cambridge University Press.

Mansell, R. (2011). New visions, old practices: Policy and regulation in the Internet era. *Continuum*, *25*(1), 19–32. http://doi.org/10.1080/10304312.2011.538369

Mölleryd, B. G. (2015). *Development of High-speed Networks and the Role of Municipal Networks*. Technology and Industry Policy Papers. OECD Publishing. Paris. Retrieved from http://dx.doi.org/10.1787/5jrqdl7rvns3-en

Nucciarelli, A., Castaldo, A., Conte, E., & Sadowski, B. (2013). Unlocking the potential of Italian broadband: Case studies and policy lessons. *Telecommunications Policy*, *37*(10), 955–969. http://doi.org/10.1016/j.telpol.2013.05.008

OECD. (2009). *Network Developments in Support of Innovation and User Needs*. Paris.

Ovando, C., Pérez, J., & Moral, A. (2015). LTE techno-economic assessment: The case of rural areas in Spain. *Telecommunications Policy*, *39*(3), 269–283. http://doi.org/10.1016/j.telpol.2014.11.004

Point Topic. (2013). *Europe' s broadband investment needs: Quantifying the investment needed to deliver superfast broadband to Europe*. London. Retrieved from http://point-topic.com/free-analysis/europes-broadband-investment-needs/

Ramirez, W., Harmantzis, F. C., & Tanguturi, V. P. (2007). Valuing wireless data services solutions for corporate clients using real options. *International Journal of Mobile Communications*, *5*(3), 259–280. http://doi.org/10.1504/ijmc.2007.012394

REDTEL. (2012). *Impacto de la tributación específica en el sector de las telecomunicaciones (in Spanish)*. Madrid.

Renda, A. (2010). Competition-regulation interface in telecommunications: What's left of the essential facility doctrine. *Telecommunications Policy*, *34*(1–2), 23–35. http://doi.org/10.1016/j.telpol.2009.11.005

Rendon Schneir, J., & Xiong, Y. (2016). A cost study of fixed broadband access networks for rural areas. *Telecommunications Policy*, *40*(8), 755–773. http://doi.org/10.1016/j.telpol.2016.04.002

Rivera, R., Villar, J., & Jose-Luis Gomez-Barroso. (2016). *Reforming EU Telecoms Rules to create a Digital Union* (Vol. IP/A/ITRE/). Brussels. Retrieved from http://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_STU(2016)570011

Shortall, T., & Cave, M. (2015). Is symmetric access regulation a policy choice? Evidence from the deployment of NGA in Europe. *Digiworld Economic Journal*, (98), 17–41.

Ünver, M. B. (2015). Is a fine-tuning approach sufficient for EU NGA policy? A global review around the long-lasting debate. *Telecommunications Policy*, *39*(11), 957–979. http://doi.org/10.1016/j.telpol.2015.09.002

Van Der Wee, M., Verbrugge, S., Sadowski, B., Driesse, M., & Pickavet, M. (2015). Identifying and quantifying the indirect benefits of broadband networks for e-government and e-business: A bottom-up approach. *Telecommunications Policy*, *39*(3–4), 176–191. http://doi.org/10.1016/j.telpol.2013.12.006

WEF. (2016). *Internet for All. A Framework for Accelerating Internet Access and Adoption*. Geneva, Switzerland. Retrieved from https://www.weforum.org/reports/internet-for-all-a-framework-for-accelerating-internet-access-and-adoption