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# KEYS AND CHALLENGES TO CLOSE THE RURAL BROADBAND GAP. THE ROLE OF LTE NETWORKS IN SPAIN.

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## Keywords

Rural broadband, public policies, New Generation Access Networks, Long Term Evolution, techno-economic analysis

## Abstract

This paper presents a techno-economic analysis to evaluate the feasibility of a Long-Term Evolution (LTE) radio access network to provide fixed wireless 30 Mbps broadband access services in the rural areas of Spain. The results are compared to those of Fiber-To-The-Home (FTTH) technology and conclude that FTTH networks could reach up to 74% households for 2020 and the proposed LTE network could expand this coverage up to 94.4% households, playing an important role to close the broadband gap with regard to one of the key targets of the Digital Agenda for Europe.

## 1. Introduction

Broadband network public policies have always been one of the cornerstones of the digital agendas settled both at national and supranational levels. The Digital Agenda for Europe [1] sets two main objectives for 2020: universalizing the access of 30 Mbps networks and reaching 50% penetration of services of at least 100 Mbps. On the other hand, the Digital Agenda for Spain [2] endorse these targets establishing intermediate milestones within its temporal scope.

Everyone is aware of the importance of fulfilling these objectives since it has been widely acknowledged that a wide broadband coverage significantly contributes to the economic development and social welfare of a country. There is also consensus about the important challenges that these objectives draw, given the required investments, which will only be achieved through strong commitment of all stakeholders: political power and private sector.

Fiber to the home deployments have attracted great attention at international level, but specially in Spain, due to the competitive structure of its market, with operators of high investment power, and to a regulatory environment which have promoted investment, both through the new General Telecommunication Act and to competition regulation regarding ultrafast broadband. FTTH deployments have this way constituted the fundamental technology for new generation access deployments, since they are future-proof for new standards and due to their capacity to provide more and better services, besides their lower operational costs.

This circumstances have led Spain to be one of the leader countries in FTTH deployments, but at the same time being laggard regarding rural New Generation Access (NGA) networks in comparison to other countries such as Germany or United Kingdom, whose operators have

decided reusing part of the current infrastructure, by adopting Fiber-To-The-Node (FTTN) architectures<sup>1</sup>. Consequently, coverage of 100 Mbps broadband access services has increased 4% during the last year in Spain; while that for 30 Mbps services did just 1%.

Nonetheless, overall NGA coverage indicators are positive for Spain, partially due to the deployments historically undertaken by cable operators. Therefore, HFC Docsis 3.0 nowadays reach 46% of Spanish population, while FTTH and LTE reach 26% and 48%, respectively, though increasing rapidly.

Despite legacy infrastructure and FTTH benefits, 2020 objectives will not be reached but relying on a technology compendium, which seeks for the maximum efficiency in each case. The European Commission has acknowledged the different role of each technology several times, aware of their complementarity.

Technological neutrality has constituted one of the flagships in telecommunication public policies. Governments of all Europe are granting State Aids to the deployment of New Generation Access Networks in any of its forms, imposing at the same time coverage obligations within the spectrum awards, clearly aligned with the Agendas.

This paper aims at analyzing keys and challenges to close the rural broadband gap with regard to next generation networks. As stated above, there are different technologies available to provide access to fast and ultrafast broadband networks, whose characteristics notably differ. Thus, the one being more appropriated will depend on circumstances of the deployment considered.

This work analyzes the feasibility of a fixed wireless Long-Term Evolution (LTE) access network to provide 30 Mbps broadband access services in the rural areas of Spain, as an alternative for the extension of fast broadband access networks. Thus, we compare the prospective coverage footprint of FTTH deployments for 2020 to that of the proposed LTE network, according to their feasibility.

Comparing technologies is always complex. The nature of optical fiber networks results radically different from that of wireless communications, exposed to higher communication channel variability, and which need radio spectrum and thus count on smaller bandwidth. Nonetheless, depending on the performance required, the differences in deployment costs between FTTH and LTE could be remarkable, so that the latter might be a feasible alternative to fiber deployments for the rural areas.

The rest of the paper is structured as follows. Section 2 presents the techno-economic methodology applied and describes both the technical model to dimension the proposed LTE network and the economic model developed; in addition the main assumptions for the case under study are listed, including detailed service penetration. Section 3 contains the main results assessing the role of LTE technology in closing the fast broadband gap in rural areas in Spain, comparing its feasibility to that of FTTH networks. Finally, section 4 draws some conclusions.

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<sup>1</sup> Nonetheless, the strategy adopted for NGA extension to rural areas has been tackled in a very different way in the different European countries, since legacy infrastructure and competitive structure notably differ from case to case.

## 2. Techno-economic methodology

The methodology used for this work consists in a techno-economic analysis, which has already been widely used for technology research programs and by regulators (see e.g. [4] and [5]). Bottom-up techno-economic models have been developed for FTTH and LTE access technologies and applied to all the Spanish municipalities. The GPON FTTH model used here has been presented in [3], while the one for LTE is described next.

We have carried out a prospective analysis on the ability of these technologies to close the digital divide for the particular case of Spain. Nonetheless, the methodology could be replicated to obtain case studies of any other country.

On the one hand, a data base has been created with the 30 Mbps coverage for each municipality, as well as other data such as population, number of households, area, etc., as it is shown in Figure 1.

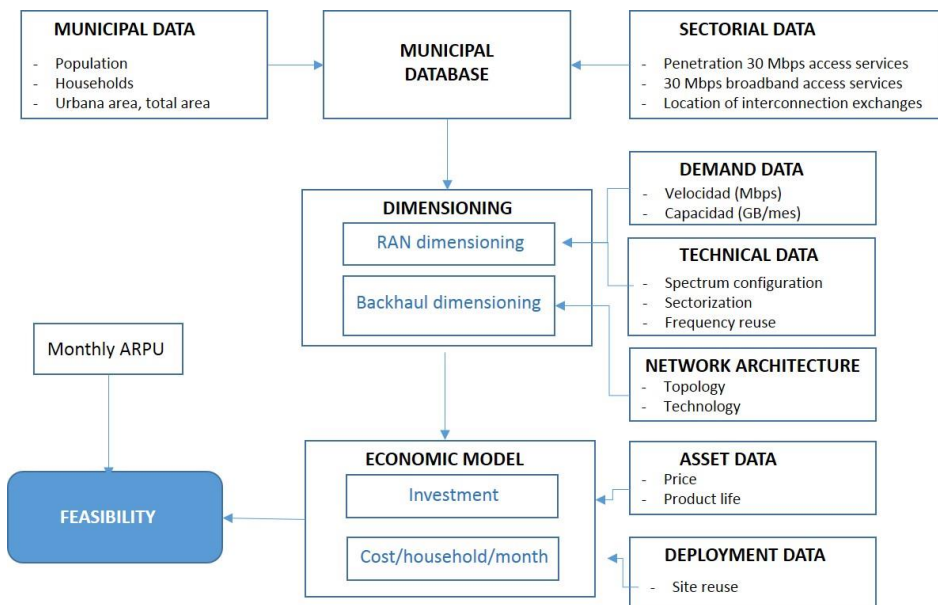


Figure 1. Diagram of the techno-economic model

The techno-economic model estimates the deployments costs – and thus the required investments - for both FTTH and LTE for each municipality, according to different service parameters. The bottom-up approach allow us to present results by regions and size of municipality, identifying so those which present higher risk of digital exclusion for the upcoming years, as it is shown in section 3.2.

Both the dimensioning of the LTE network and the economic model are next described.

### 2.1. Dimensioning of a TD-LTE network

The LTE network is dimensioned according to both coverage and speed constraints, as it is next described. Since the case study refers to fixed wireless access services, the technology chosen for the analysis has been time-duplexing LTE (TD-LTE), since for time multiplexing the standard allows selecting asymmetric schemes for frame distribution between downlink and uplink channels, which is better suited to home traffic patterns.

In the first place, since it is a fixed wireless access service, high values of signal to noise and interference ratio (SINR) can be expected due to higher antenna gains and directivity. Besides that, interference is further reduced by using frequency reuse factors higher than 1, which is typically used for mobile services. Thus, the approach in this work assumes maximum spectral efficiency, which is imposed by the coverage constrain, i.e. the coverage range will be that which allows maximum CQI (*Channel Quality Indicator*)<sup>2</sup>.

On the other hand, the network is dimensioned according to the throughput (speed) required for each user, as in Equation 1.

$$N_{us/eNodeB} = \frac{Thr_{eNodeB} \eta}{Thr_{us}/F}$$

*Equation 1. Dimensioning of the number of users per base station (eNodeB)*

where  $N_{us/eNodeB}$  is the number of user per eNodeB;  $Thr_{us}$  is the required throughput per user;  $\eta$  is the network load at which the network is dimensioned;  $F$  is the oversubscription factor, which refers to statistic multiplexing of users, i.e. 50; and  $Thr_{eNodeB}$  is the throughput of the eNodeB, which in turn can be calculated as in

$$Thr_{sector} = N_{sectors/eNodeB} N_{streams} Thr_{RB} DL_{frames}$$

*Equation 2. Calculation of the throughput of an eNodeB*

where  $N_{sectors/eNodeB}$  is the number of sectors per eNodeB;  $N_{us/eNodeB}$ , the number of streams, depending on the antenna configuration;  $Thr_{RB}$ , the throughput that can be reached as of the amount of available resource blocks, which in turn depend the bandwidth; and finally  $DL_{frames}$  is the proportion of LTE frames devoted to the downlink, according to the assumed configuration of the standard. The calculations for the uplink are equivalent. The assumed values for the dimensioning of the network are summarized in Table 2.

## 2.2. Backhaul dimensioning

Network dimensioning as a whole is carried out following a geometric model with different traffic aggregation levels, in a hierarchy in which the first level are base stations, which are aggregated one to another through links following a star topology and a ratio 4:1. The model uses as many aggregation levels as needed to aggregate all traffic to the next level. The traffic will be finally brought to the interconnection exchange, where it is interconnected to the core network of the operator.

Regarding technological aspects, all aggregation links have been assumed to be either microwave or optical fiber links, depending on the amount of traffic carried in each case. Microwave links are assumed when traffic is below 500 Mbps and optical fiber otherwise. In addition, aggregation links consider a non-linearity factor which represent the presence of obstacles which prevent straight point to point links to be deployed to the interconnection exchange.

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<sup>2</sup> Maximum CQI of LTE standard is 15 and assumes 64 QAM and a coding rate 0,9257

Microwave links range has been assumed to be 13 km, so repeaters will be needed in case longer distances have to be reached.

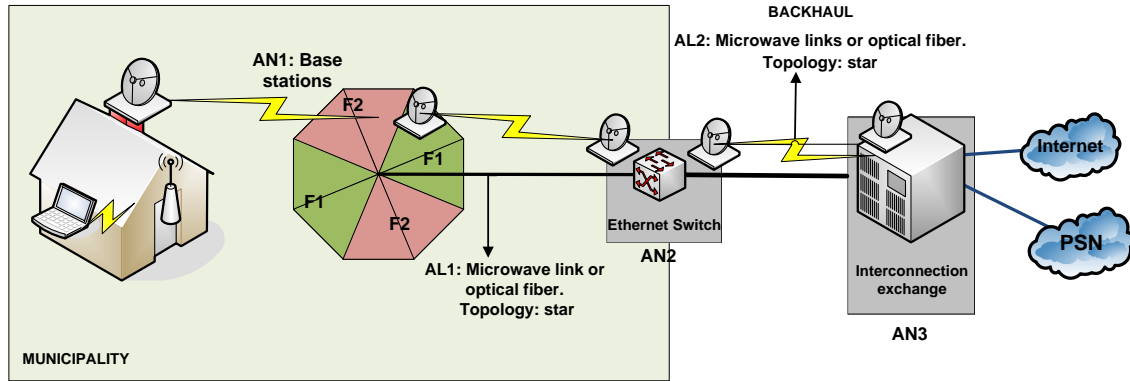


Figure 2. Network architecture assumed

### 2.3. Economic model

The feasibility of the service has been determined comparing the monthly cost per subscribed household to a threshold related to the expected values of average revenue per household (or user, ARPU). To determine the monthly cost per subscriber both capital and operational expenditures of the deployment must be taken into account.

CAPital EXpenditures(CAPEX) encompass equipment investment and network deployment costs, while Operation al Expenditures include costs derived of its maintenance. Capital expenditures can be obtained aggregating required investment in each asset, which can be annualized according to the product life (PF, *Product Life*) of each of them and taking into account the costs of capital (WACC, *Weight Cost of Capital*), according to Equation 4, where  $i$  represents each assest, while  $N_i$  y  $C_i^{CAPEX}$  denote the number of elements and the cost of each asset  $i$ , respectively.

$$CAPEX_{total} = \sum_i N_i C_i^{capex}$$

Equation 3. Calculation of capital expenditures (CAPEX).

$$CAPEX_{annual} = \sum_i N_i C_i^{CAPEX} \frac{WACC}{1 - (1 + WACC)^{-PF}}$$

Equation 4. Calculation of annualized costs of capital.

On the other hand, OPerationalEXpenditures (OPEX) comprises operation and maintenance costs of the deployed network, which are often expressed as a percentage of the capex of each acquired asset, as well as costs of rented assets and others services.

$$OPEX = \sum_i N_i C_i^{OPEX} + \sum_j M_j C_j^{rent} + \sum_k L_k C_k^{services}$$

Equation 5. Calculation of operational expenditures.

Investments per passed household and subscribed household can be directly obtained dividing CAPEX<sub>total</sub> by the number of households in the service area and by the number of subscribers of the service, respectively. Note thus, that capex per passed household is independent of service penetration or market share, while capex per subscribed household is not.

Finally, as stated above, the methodology adopted evaluates feasibility of the deployment by comparing monthly costs per (subscribed) household to expected revenue per user, which can be devoted to network deployment. Equation 6 shows the calculation of these monthly costs per household, which encompass both investment and maintenance, and where H<sub>S</sub> refers to the number of subscribed households.

$$C_{\text{hogar/mes}} = \frac{(\text{CAPEX}_{\text{annual}} + \text{OPEX})}{12 \cdot H_S}$$

*Equation 6. Calculation for monthly costs per subscribed household.*

The deployment will be considered feasible if monthly ARPU is greater or equal to monthly costs per household, and non-feasible otherwise.

$$\text{If ARPU} \geq \frac{C_{\text{household}}}{\text{month}} \rightarrow \text{Feasible}$$

$$\text{If ARPU} < \frac{C_{\text{household}}}{\text{month}} \rightarrow \text{Non – feasible}$$

*Equation 7. Criteria to determine feasibility of the deployments*

## 2.4. Assumptions

The techno-economic model presented in above allows configuration of many parameters (see Figure 1), which it takes as an input to allow particularization and application to any case study. Thus, the results highly depend on this parameters – on ones more than on others-. Table 2 shows a summary of with many of them<sup>3</sup> and the rest of this section describes in detail how service penetration has been estimated.

### Service penetration estimation

Broadband service penetration is one of the key variables, which directly impacts on the feasibility of the deployments, since monthly cost per subscribed household depends on it (see Equation 6). Thus, the demand of 30 Mbps broadband access services requires a precise prospective estimation, so that realistic results can be derived from the model.

For this calculation, the evolution of standard broadband services in Spain<sup>4</sup> has been considered, since it can be assumed to model good enough national socio-demographic aspects which impact on adoption. This evolution can be characterized by a logistic curve (see Equation 8), also known as ‘S curve’ because it presents different speeds of growth in its trajectory, which allow accurately modeling typical process of technology adoption.

<sup>3</sup> Those which are particular to each municipality has been skipped for practical reasons and for confidentiality of some data.

<sup>4</sup>According to data from *Instituto Nacional de Estadística*.

$$Y_t = a \cdot e^{-b \cdot e^{-c \cdot t}}$$

Equation 8. Logistic curve used to estimate the demand of 30 Mbps broadband Access services

This way, the standard broadband adoption curve in the country under study –in this case Spain– is used to adjust parameters a, b and c. An estimation of the demand of 30 Mbps broadband access services for 2020 can be outlined using the obtained a, b and c parameters and the penetration of 30 Mbps broadband services so far<sup>5</sup>. This methodology provides an average penetration of 57.7% for broadband access services over 30 Mbps for 2020.

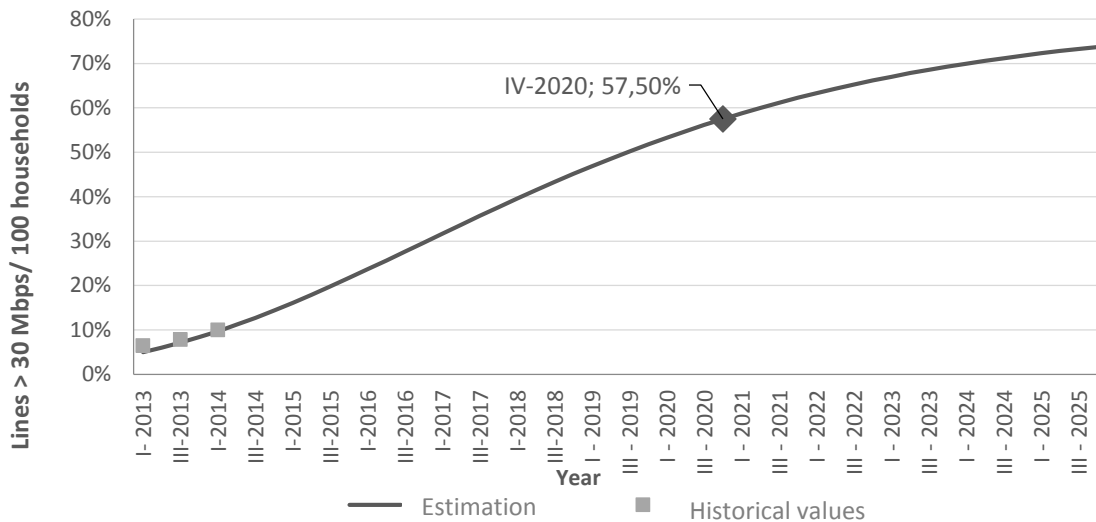


Figure 3. Penetration data (lines/100 households) and logistic curve of the penetration of 30 Mbps broadband access services.

However, given that the analysis is carried out on a municipality basis, this average service penetration must be adjusted for each case depending on the characteristics of each municipality. The Spanish regulator (CNMC) publishes periodic geographic reports from where it can be inferred that one of the variables having a clearer impact on service adoption is the size of the municipality, so the service penetration has been assigned according to this criterion.

Size of municipality	30 Mbps penetration for 2020
Madrid	76,39%
Barcelona	93,25%
From 500.001 to 1.000.000	69,85%
From 100.001 to 500.000	64,32%
From 50.001 to 100.000	58,71%
From 10.001 to 50.000	51,21%
From 5.001 to 10.000	49,00%
From 1.001 to 5.000	40,66%
Less than 1.000	25,05%

Table 1. Penetration of 30 Mbps broadband services for 2020 (lines/100 households).

<sup>5</sup>According to data provided by the regulator (CNMC)



Using the same beans of size of municipality than the CNMC and foreseeing that current imbalance between municipalities of different sizes will remain in 30 Mbps access networks, a service penetration has been assigned to each municipality according to its size, as in Table 1.

Sector data	
30 Mbps service coverage	Depend on municipality
30 Mbps service penetration	Depend on municipality
Distance to Exchange centers	Depend on municipality
Financial data	
WACC	10%
ARPU for LTE	20 €
ARPU for FTTH	30 €
Demand data	
Throughput per household	30 Mbps
Monthly download volume per household	30 GB
Busy hour daily traffic	15%
Technical data	
Cell load ( $\eta$ )	85%
N streams	1
DL frames	6/9
Sectorization	4
Frequency reuse factor	2
Spectrum	40 MHz in 3,5 GHz
Network architecture	
Topology	Star
Technology	Microwave links or optical fiber
Deployment data	
Base station site reuse	50%
Microwave links site reuse	80%

Table 2. Summary of the data use for the case study.

### 3. Results

#### 3.1. Distribution of households

Results of the feasibility analysis are next presented regarding two different criteria: firstly, by size of municipality, which constitutes one of the variables influencing the deployment costs most, and also by regions<sup>6</sup>, which allow appreciating the impact of other kind of factors. Therefore, it is important to know beforehand how households are in general distributed for the case under study—here the Spanish case – and particularly the distribution of the households not covered by any 30 Mbps access network, as of size of municipality and region.

Figure 4 and Figure 5 show general household distribution and the distribution of households out of the 30 Mbps coverage footprint by size of municipality, respectively; while Figure 6 and Figure 7 show the equivalent for the different Spanish regions. We can appreciate that most households not covered by any 30 Mbps network belong to municipalities whose size is within the segment of population between 5.000 and 10.000 inhabitants: around 2.5 million households (out of 18.1 million).

<sup>6</sup>Comunidades Autónomas

It should be noted that population distribution differ notably from region to region. As an example, while *Castilla y León* is characterized by numerous municipalities of small size, *Galicia* count on municipalities of much bigger size, but whose population is distributed in a high number of population entities. The techno-economic models developed use the municipality as working unit, so they do not distinguish between population entities because there is no data at this level. This methodology might underestimate deployment cost in some region, as *Galicia*, with numerous population entities and a very particular orography.

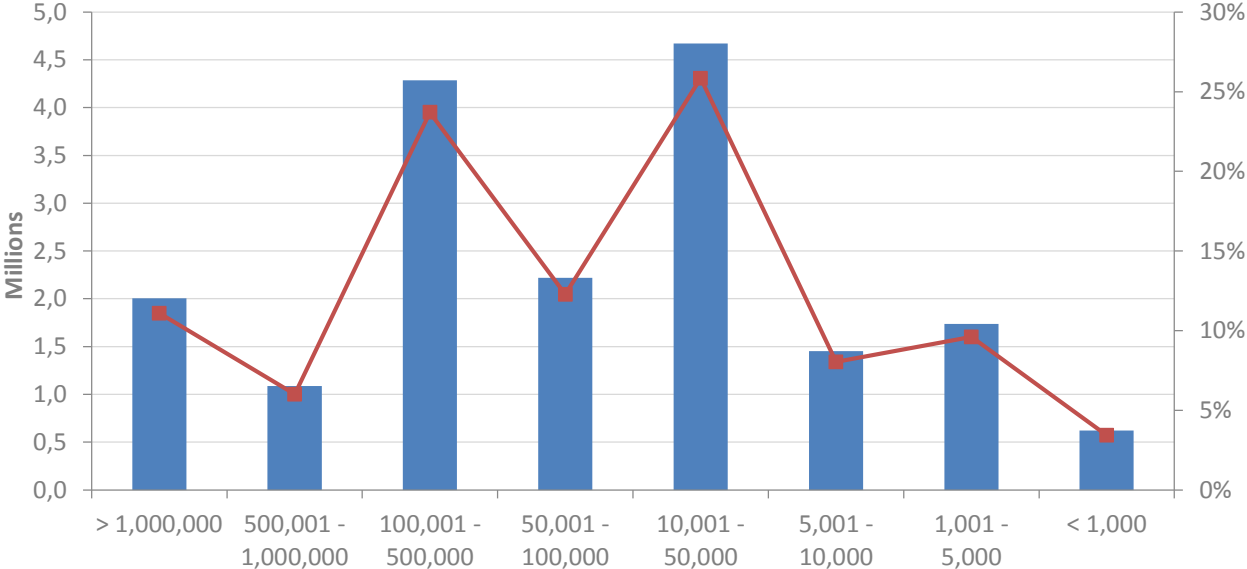


Figure 4. Distribution of Spanish households by size of the municipality (absolute values and in percentage)

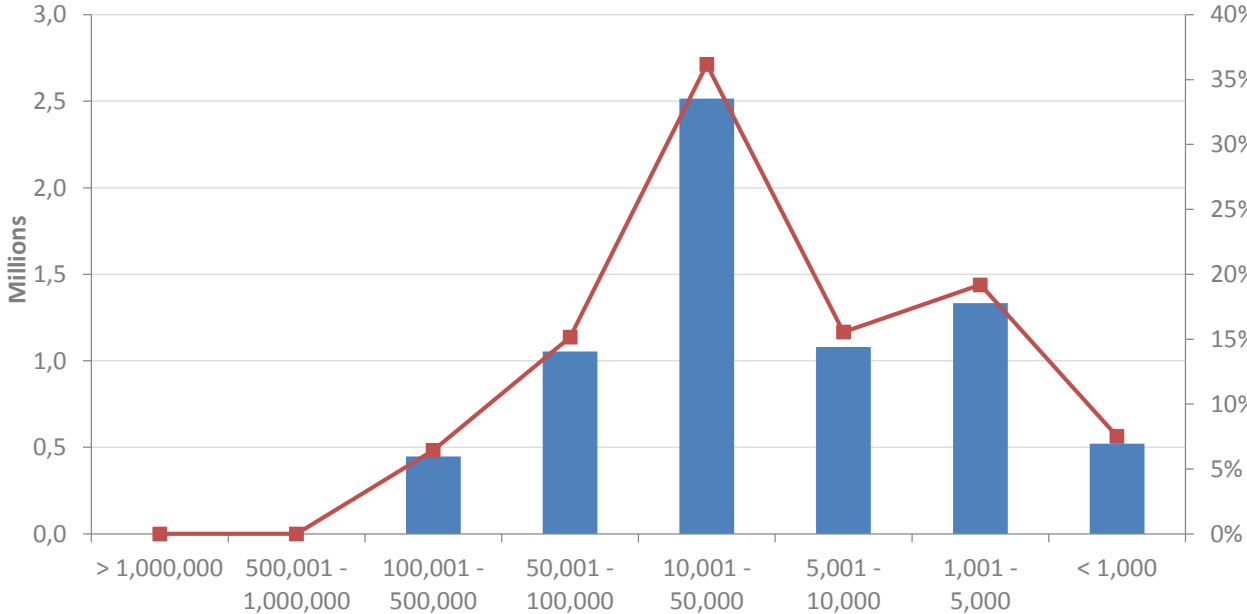


Figure 5. Distribution of out of 30 Mbps services coverage by size of the municipality (absolute values and in percentage)

On the other hand, regions that concentrate the highest number of households are *Andalucía*, *Cataluña* and *Comunidad de Madrid*. *Andalucía* and *Cataluña* are precisely also the regions with a

higher number of households without coverage of any 30 Mbps access network, with 23% and 16.5% of all the households non covered in Spain, respectively.

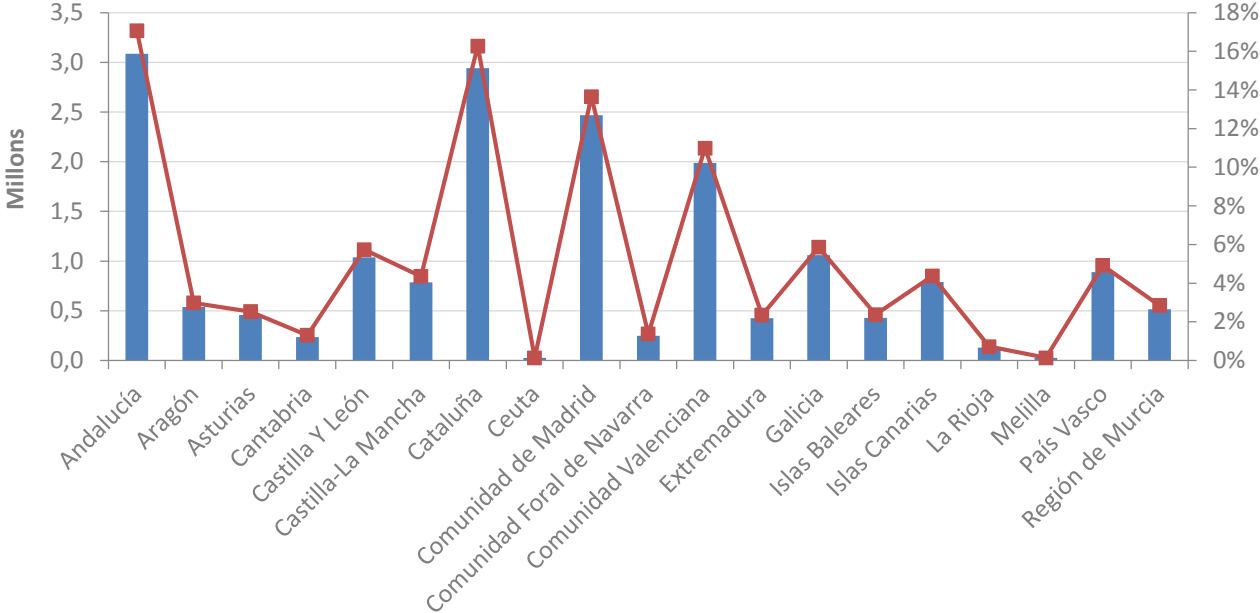


Figure 6. Distribution of Spanish households by regions (absolute values and in percentage).

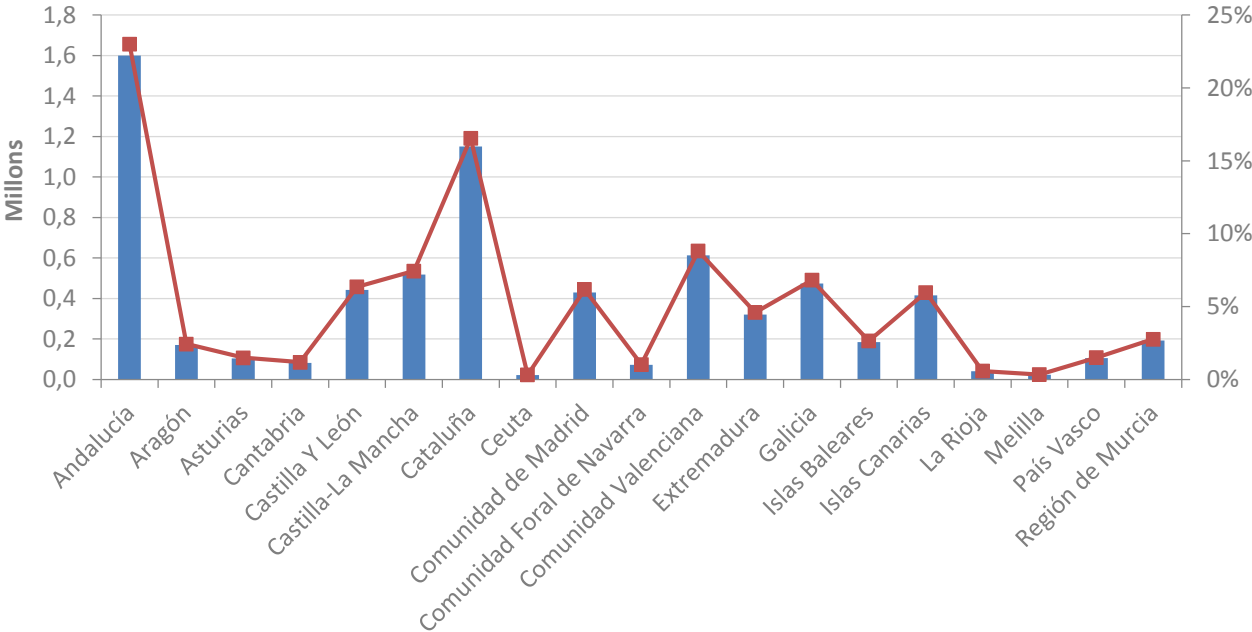


Figure 7. Distribution of out of 30 Mbps services coverage by region (absolute values and in percentage).

3.2. Contribution of the LTE network to close the broadband gap

For the results presented next we have considered FTTH will be the technology deployed when feasible, because of its ability to provide more and better services, while LTE will be the

technology chosen where it results feasible but FTTH does not. Otherwise, the deployment will be considered non-feasible.

### Results by size of municipality

Figure 8 show monthly costs per subscribed household for FTTH and LTE deployments averaged by size of the municipality for the case of Spain<sup>7</sup>. LTE turns to be the most economical alternative in every case, though, as noted above, the performances of each technology are not fully comparable.. Note, nonetheless, that where FTTH is not feasible, LTE plays a crucial role, especially in municipalities below 10,000 inhabitants. Indeed, the average monthly cost per household turn from 144€ to 19.5 € in municipalities between 1,000 and 5,000 inhabitants.

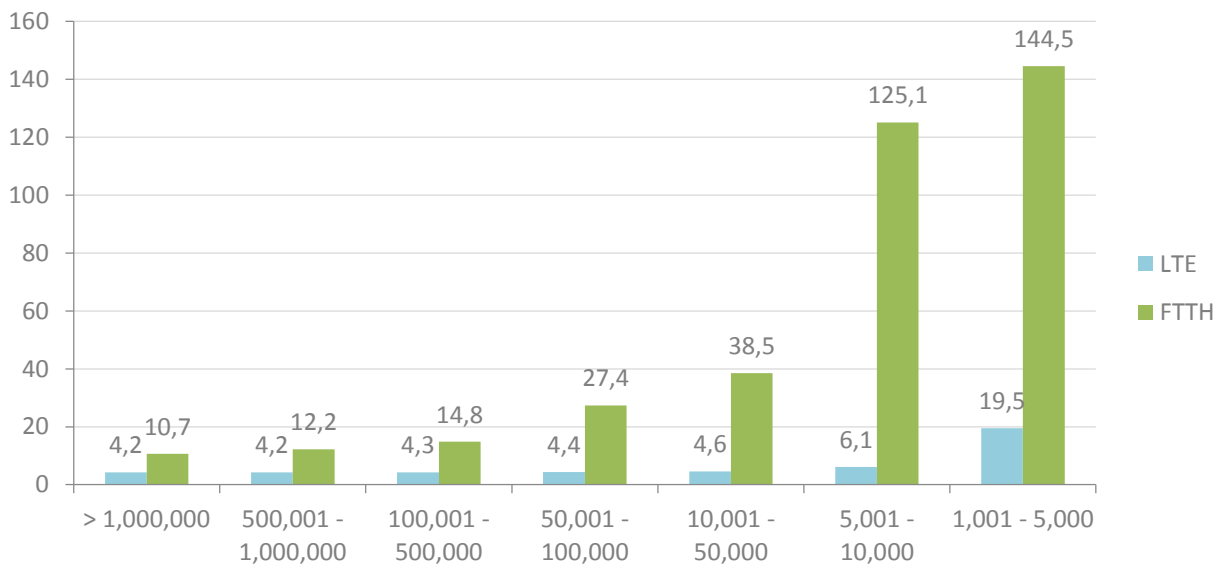


Figure 8. Cost/household/month for LTE and FTTH according to size of the municipality

	Cost/HH/month FTTH	Cost/H/month LTE	Capex FTTH	Capex LTE
> 1.000.000	10,7 €	4,2 €	508,7 €	159,5 €
500.001 - 1.000.000	12,2 €	4,2 €	641,8 €	160,8 €
100.001 - 500.000	14,8 €	4,3 €	882,1 €	165,9 €
50.001 - 100.000	27,4 €	4,4 €	2.034,9 €	167,8 €
10.001 - 50.000	38,5 €	4,6 €	3.045,5 €	175,4 €
5.001 - 10.000	125,1 €	6,1 €	11.052,1 €	237,5 €
1.001 - 5.000	144,5 €	19,5 €	12.841,4 €	736,5 €
< 1.000	854,1 €	489,6 €	78.113,4 €	18.528,7 €

Table 3. Detailed comparison on cost/household/month and investment for LTE and FTTH according to size of municipality.

With regard to required investments for the provision of services, we can observe that LTE allow reducing it in one order of magnitude, as shown in Figure 9.

<sup>7</sup> Municipalities under 1,000 inhabitants are not shown in the graphic, since their costs are very high and otherwise the differences among the rest of the cases would not have been noticed.

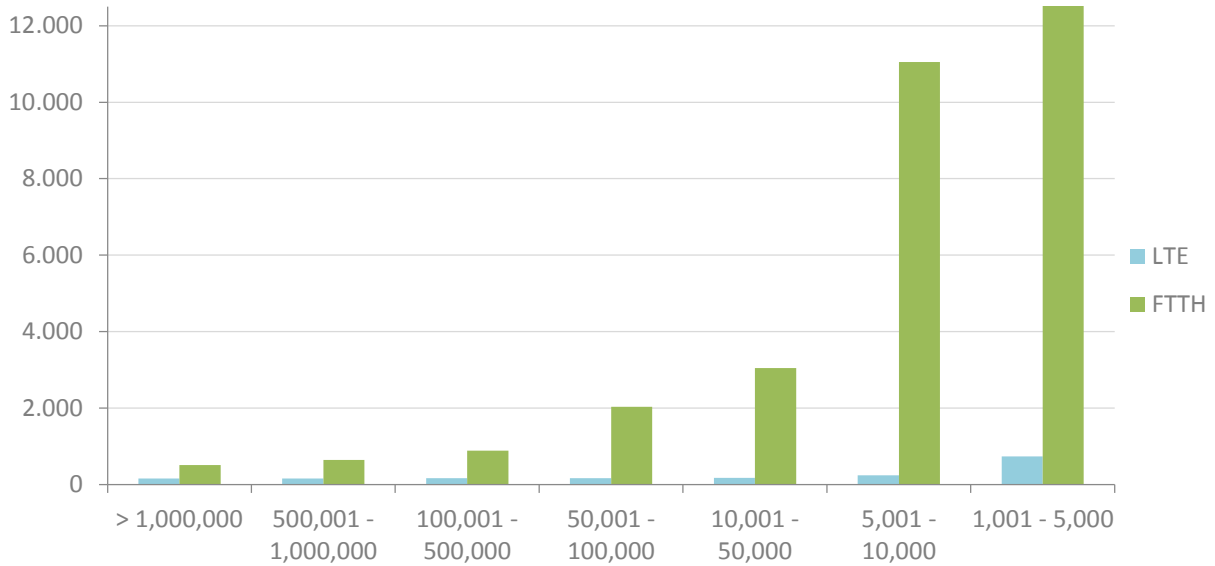


Figure 9. Required investment per subscribed household with technologies FTTH and LTE according to size of municipality.

Figure 10 shows the current coverage of 30 Mbps access networks and the prospective results of the study carried out for the footprint of FTTH and a TD-LTE network for 2020. As it can be observed, FTTH coverage will still increase, since it results feasible for many households in municipalities in the range from 10,000 to 100,000 inhabitants. In addition, the proposed TD-LTE network starts being important for the municipalities under 50,000 inhabitants and especially from 1,000 to 10,000. For municipalities under 1,000 inhabitants, which are currently out of the coverage footprint of 30 Mbps access networks, neither FTTH nor LTE result feasible.

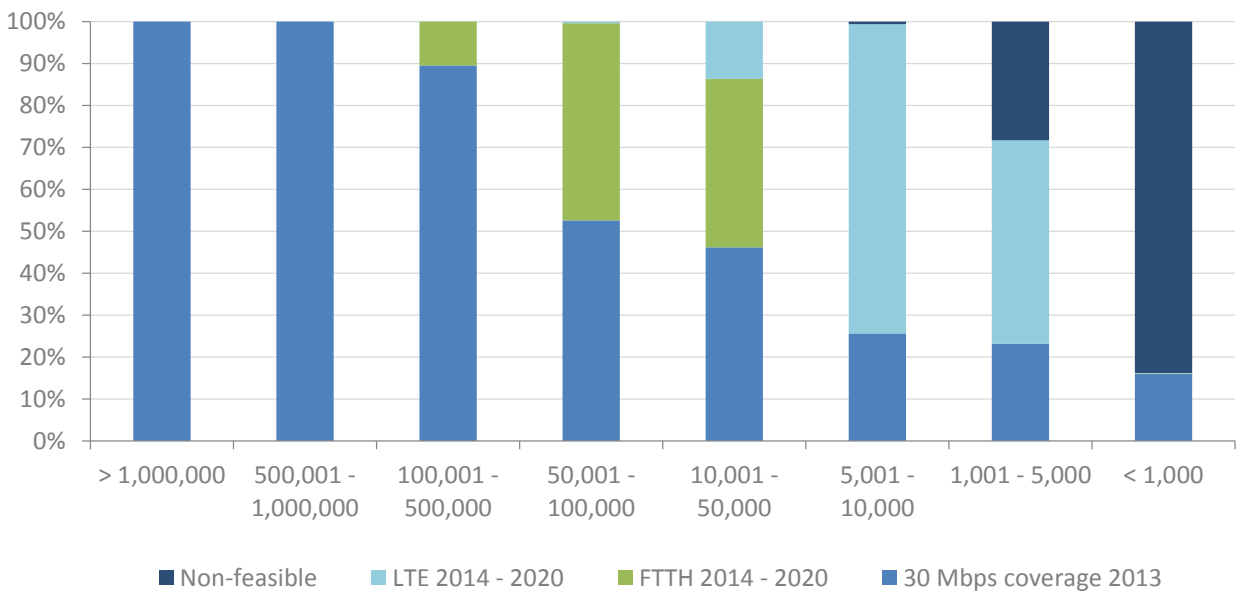


Figure 10. Current coverage of 30 Mbps, and prospective coverage of LTE and FTTH technologies for 2020 in percentage of households.

Regarding non-feasible municipalities, Figure 11 show average the distribution of cost as of size of the municipality. Generally, the smallest size of a municipality, the further from interconnection

exchange it is, so backhaul costs are proportionally higher since, more and more microwave links (of fiber kilometers) are needed.

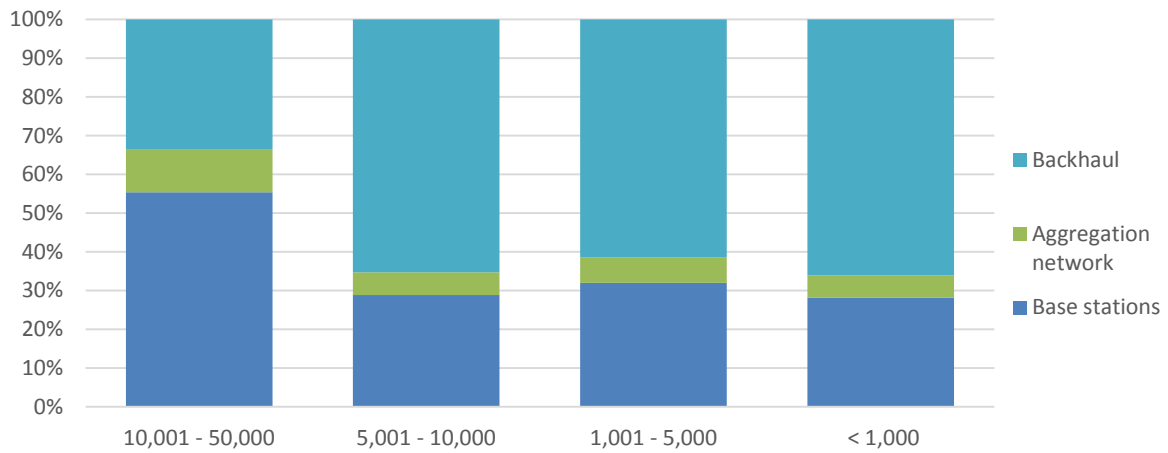


Figure 11. Distribution of cost in the cases of non-feasible municipalities.

### Results by regions

On the other hand,

Figure 12 show on the map of Spain the municipalities for which FTTH and LTE result feasible. As expected, the area on the map of FTTH is much smaller, since it belong to the cities and towns, while the area of LTE is much bigger because it corresponds to the municipal area of more rural places.

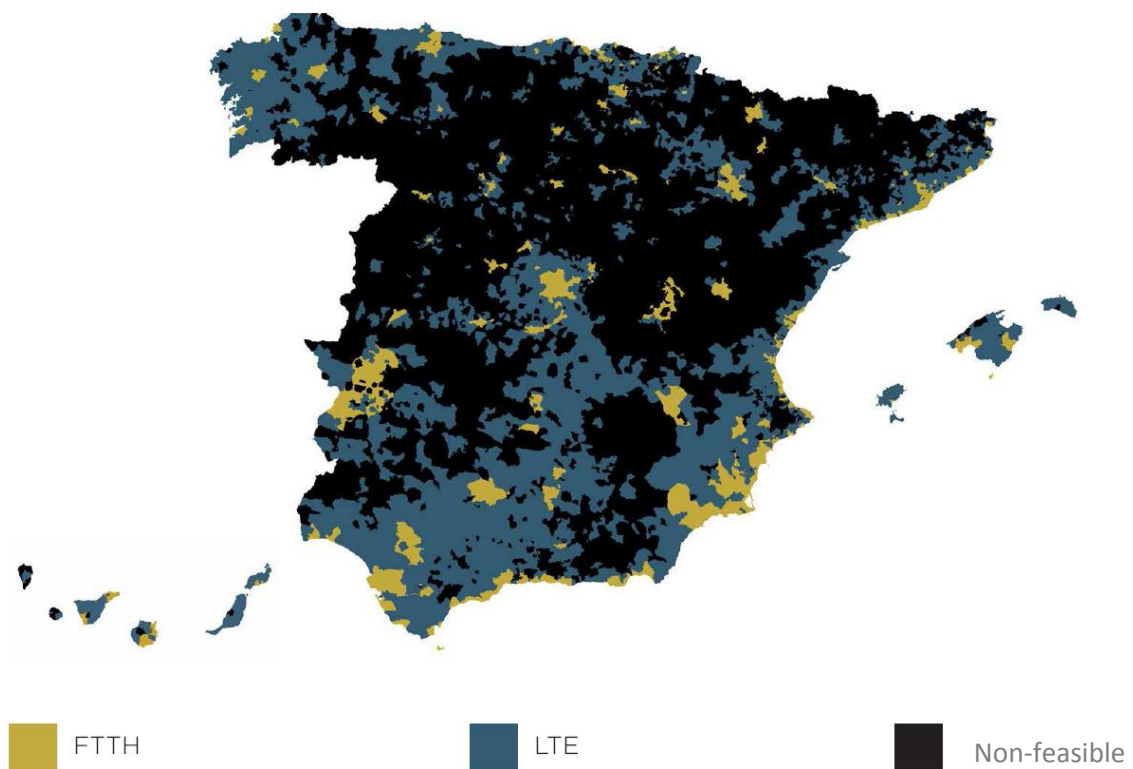


Figure 12. Municipalities where FTTH and LTE would be deployed on the map, according to the prospective analysis for 2020.

Most areas of *Castilla y León* and *Aragón*, regions with a lot of surface scarcely populated, result non-feasible. Here we can also see some correlation between orography and feasibility, since areas in the Pyrenees or *Sierra Nevada* result also non-feasible.

Figure 13 show current coverage of 30 Mbps, and prospective coverage of LTE and FTTH technologies for 2020 in percentage of households by each region. The highest increase in coverage of 30 Mbps access networks are for the regions of *Andalucía*, *Extremadura*, *Castilla-La Mancha* and *Cataluña*, all of them with a lot of population in mid-size rural municipalities. Regarding the proposed TD-LTE network, in all of the previous cases it increases the FTTH footprint, but its contribution is especially relevant in the regions of Galicia and Islas Baleares.

The cases of the autonomous towns of Ceuta and Melilla are very significant. Both show population density, distance to the interconnection exchange, etc. so as to be feasible to deploy a FTTH network. Yet, their 30 Mbps coverage footprint is still very limited. This is probably due to other factors, such as their connection to core networks, due to their situation in North Africa.

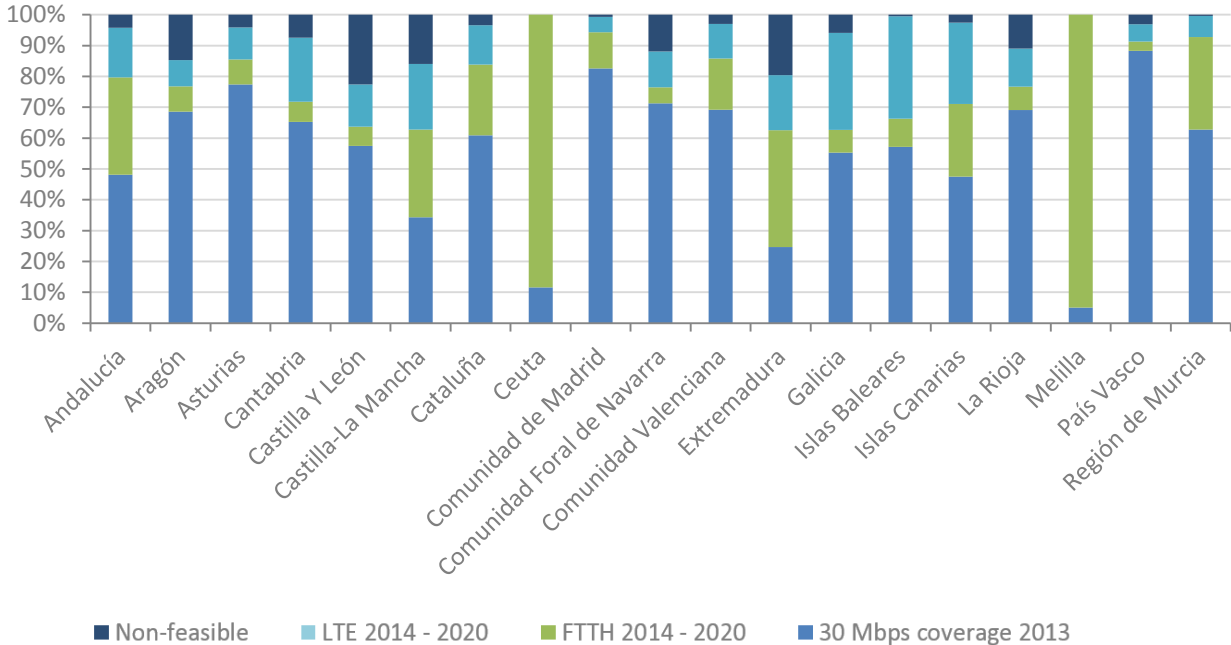


Figure 13. Current coverage of 30 Mbps, and prospective coverage of LTE and FTTH technologies for 2020 in percentage of households.

Overall results

Table 4 shows a summary of results of the feasibility study as of size of municipality, which should be interpreted considering the distribution of Spanish households not covered by any access network of at least 30 Mbps, as presented in section 3.1.

Size of municipality	Prospective 30 Mbps coverage for 2020						
	FTTH		LTE		Other	Non-feasible	
	% HH	Capex	% HH	Capex	% HH	% HH	Capex
> 1.000.000	100,0%	- €	0,0%	- €	0,0%	0,0%	- €
500.000 - 1.000.000	100,0%	- €	0,0%	- €	0,0%	0,0%	- €
100.001 - 500.000	100,0%	341.476.949 €	0,0%	- €	0,0%	0,0%	- €
50.001 - 100.000	98,7%	727.925.505 €	0,4%	875.425 €	1,0%	0,0%	- €
10.001 - 50.000	80,9%	1.846.515.760 €	13,7%	59.427.910 €	5,4%	0,0%	- €
5.001 - 10.000	0,0%	- €	73,8%	146.036.296 €	25,7%	0,6%	4.375.523 €
1.001 - 5.000	0,0%	- €	48,4%	147.117.828 €	23,2%	28,4%	269.599.568 €
< 1.000	0,1%	209.069 €	0,1%	86.343 €	15,9%	83,9%	1.191,2 M€
<b>TOTAL</b>	<b>73,8%</b>	<b>2.916,127 M€</b>	<b>14,2%</b>	<b>353,543 M€</b>	<b>6,4%</b>	<b>5,6%</b>	<b>1.465,18 M€</b>
			<b>94,4 %</b>				<b>5,6%</b>

Table 4. Estimation of 30 Mbps coverage for 2020 in Spain by technologies. Summary of results.

For each technology, it shows for every segment of size of municipality the proportion of feasible households that would be covered by each technology and the required investment to cover these households. The column 'non-feasible' shows the percentage of non-feasible households in each case and the required to cover them with LTE<sup>8</sup>.

According to the analysis carried out, around 74% of households would be covered with FTTH, requiring investment close to 3 billion €. That coverage footprint could be extended to additional 14% households with a TD-LTE network, requiring additional investment of 353 million €. Coverage extension to the left 5.6% with LTE would cost additional 1.5 billion €.

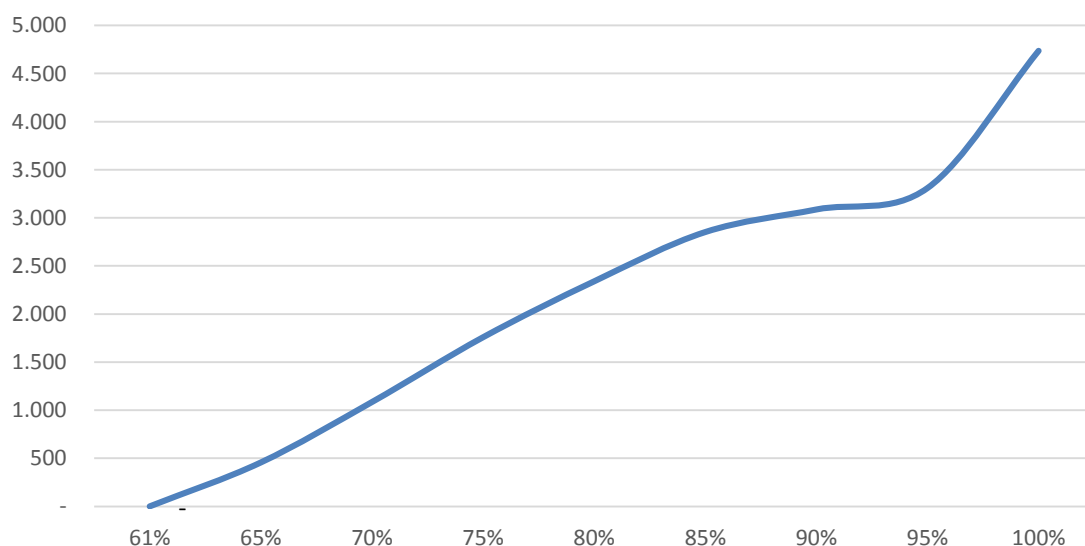


Figure 14. Accumulated investment required according to overall household coverage combining FTTH and LTE

<sup>8</sup> Because it is always the least expensive option



From the rest 12% households –those non-feasible for FTTH nor for TD-LTE- 6.4% are already covered by other technologies which have not been considered in this analysis, as HFC. This would allow reaching 94.4% 30 Mbps coverage for 2020, being only 5.6% households in Spain non-feasible for any technology. In addition, as it can be observed from Figure 14, required investment grows exponentially to cover the last 5% with LTE.

However, these results depend on the thresholds chosen to determine when the deployment is feasible. Because of that, it is needed to assess the sensitivity of the results to the value chosen for the ARPU, what it shown in Figure 15, where x-axis shows the threshold for LTE feasibility and the one for FTTH has been assumed to be 1.5 times that of LTE.

We can appreciate how the proportion of non-feasible households decreases rapidly as the threshold (ARPU) increases. However, it is soon need to increase the ARPU in a big amount so as to slightly decrease the proportion of non-feasible households, what means that the coverage footprint estimated is relatively insensitive to the ARPU considered.

Indeed, for the ARPU initially considered (20 € for LTE 30 € for FTTH), the proportion of non-feasible households is 5.6%. Duplication of the ARPU would only decrease this percentage down to 3.5%. In contrast, investments would increase exponentially, as shown in Figure 14.

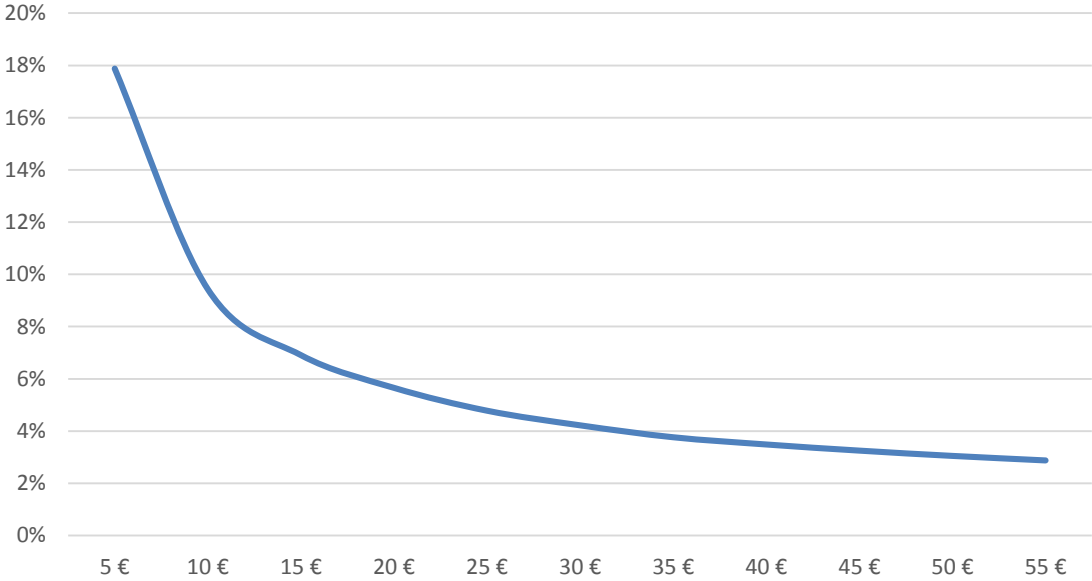


Figure 15. Percentage of non-feasible households as of the average revenue per user considered to be devoted to the deployment and considering the mix of FTTH and LTE technologies.

#### 4. Conclusions

This paper has presented a prospective techno-economic analysis of the deployment of a fixed wireless access network based on TD-LTE for the provision of broadband services of at least 30 Mbps in rural areas for 2020. A feasibility study has been carried out for both LTE and FTTH services, from which the coverage footprint of each technology has been estimated, assuming that when both FTTH and LTE networks are economically feasible, FTTH will be deployed.

The results have been particularized for the case of Spain, where current coverage of 30 Mbps services is around 60%. Based on our analysis, FTTH networks could reach up to 74% households for 2020 and the proposed TD-LTE network could expand this coverage up to 94.4%.

The extension of services to 100% households could be achieved through different options. Firstly, in the authors' view the substitutive character of mobile services with regard to fixed services should be considered regarding short- and mid-term performance required by most widely used services. In fact, the coverage obligations linked to the 800 MHz spectrum award in most European countries and the current coverage of HSPA networks will play an important role in bridging the broadband digital divide. Particularly, in Spain the licensees of 800 MHz spectrum must jointly cover 90% of the population of population entities sized under 5.000 inhabitants with access networks of at least 30 Mbps, which will lead to 98% coverage of 30 Mbps broadband access services nationwide.

Secondly, satellite technologies, which rely on universal coverage by definition, will always be available to provide broadband access to most remote places, where no terrestrial infrastructure can have economic sense. New generation multiple-beam satellites in Ka band have considerably increased satellite performance with regard to broadband Internet access, so it is expected that at the end of the present decade satellite will be able to provide speed access well over 30 Mbps.

Finally, there some other issues that were not considered in this paper, but should be taken into account. They are related to administrative questions of the deployment and others to competition regulation, which also plays a critical role. The Spanish regulation of markets 4 and 5 have both boosted investments and provoked commercial agreements between operators to share infrastructures. The authors would advise regulation to be maintained in this direction, allowing operators to share part of their infrastructure, especially where otherwise the deployments would not be feasible.

In conclusion, guaranteeing access to wide bandwidth spectrum, promoting infrastructure sharing (passive) where the feasibility of investment so require and boosting the demand of services, would allow LTE access networks virtually close the digital divide in the provision of 30 Mbps broadband services.

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