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LTE techno-economic assessment: The case of rural areas in Spain

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ABSTRACT

This paper evaluates whether it is feasible for an LTE operator to deliver a 30 Mbps fixed service in rural areas in Spain and if this is not the case, whether passive network sharing could make it feasible, since this is in fact one of the objectives set out in the Digital Agenda for Europe and a key issue in the national broadband strategy. The research is conducted through a techno-economic assessment in an infrastructure competition scenario. A discounted cash flow method is used to determine the total cost of the deployment for the operator and the minimum average revenue per user (ARPU) which would be required to recover the investment in both approaches: passive network sharing and non-sharing. On the other hand, the three demand scenarios that were considered, depending on the envisaged Spanish broadband penetration by 2020, attempt to calculate what take-up and ARPU are likely in the targeted rural areas. As mobile operators' coverage obligation stipulates covering 90% of the municipalities with less than 5000 inhabitants, extreme rural areas, which correspond to the final 0.7% of the population, are excluded from this assessment. The results indicate that, given the socio-economic characteristics of the assessed area, demand is very sensitive to price and that the existence of other broadband products forces the operator to lower the ARPU. As a result, only very high take-up ratios would make the deployment feasible. The research shows that passive network sharing does not constitute a solution; nevertheless, a single network deployment could solve the unfeasibility problem in rural areas.

1. Introduction

Since the Digital Agenda for Europe (DAE) (European Commission, 2010b) was established, most of the countries involved are searching for the best strategy to achieve it. Despite the DAE objective dates not being mandatory; Spain has made them key issues in the national broadband strategy (Spanish Ministry of Industry, Energy and Tourism, 2013a). In the particular case of Spain, the first step was the 2011 broadband Universal Service Commitment (USC). Since then, the country has been totally covered. The designated operator is Telefónica and it is required to provide a 1 Mbps (average downlink throughput in 24 h) broadband connection with technological neutrality. As regards the *at least 50% of households connected to speeds above 100 Mbps by the 2020* objective, it is assumed that this objective will be achieved through fixed Next

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Generation Access (NGA) networks. The European Commission (2012) reported that in 2012 there was a 40% NGA net coverage amongst all its member States. A recent report from the Spanish Ministry of Industry, Energy and Tourism (2013b) stated that Spain already has a 52% population coverage of more than 100 Mbps broadband with HFC[1] (DOCSIS 3.0 technology) and FTTH technologies. However, there are some uncertainties about how to achieve the objective of *providing coverage of more than 30 Mbps for all citizens*. In the same report it is also stated that there is a 59% population coverage of broadband technologies capable of providing more than 30 Mbps: VDSL, HFC and FTTH. It is important to note that it also mentions the 99% 3 G and 3.5 G population coverage provided by HSPA and HSPA+. This information suggests that wireless networks could be the most cost-efficient solution to achieve the 30 Mbps objective.

The European Commission (2010a), Radio Spectrum Policy Group (2009), and Ofcom (2011), emphasize the importance of the 800 MHz frequency band as the key to the profitable provision of next-generation mobile broadband services in less densely populated areas. This frequency band is harmonized for WiMAX and LTE technologies. Because of LTE's major commercial advantage, which has a direct effect on the price of equipment and devices, and the European operators' commitment to this technology, it is expected that LTE will dominate broadband wireless services as stated in numerous reports (e.g. Arthur D. Little, 2012; GSA, 2013; Norman, 2009).

There is a special concern about the provision of the 30 Mbps broadband service in low population density areas, where the absence of a clear Return on Investment (ROI) makes the deployment of infrastructures through the market forces unlikely. As a solution, governments are encouraging network operators to share investments, at least to share the civil engineering and passive equipment (Passive network sharing[2]) (BEREC-RSPG, 2011). However, there are some experts who believe that this kind of measure is not enough to make the required investments appealing to networks operators by the market forces. Furthermore, they (Cave & Martin, 2010; Falch & Henten, 2010) consider that public initiatives, such as economic incentives, are crucial for its deployment.

The feasibility of the deployment, which is defined as the ability, at least, to recoup the investment at the end of the study period, is highly related to network take-up and, therefore, on service adoption. In scarcely populated areas, adoption tends to be lower than in urban areas, as a result of several barriers. The FCC (2011) states that these barriers are: the cost of broadband, lack of a computing device in the home and low levels – or complete absence – of digital literacy. Information provided by Howick and Whalley (2008) concluded that: “Although broadband is available to 99.9% of households and businesses across the UK, broadband adoption rates are far lower. Internet adoption varies from between 48% and 59% depending on the part of the UK”. Davidson, Santorelli, and Kamber (2012), highlighted that despite the near-universal access to broadband in the United States, less than 70% of households subscribe it. In Spain, the adoption gap depending on the population of the municipalities has been assessed in the most recent regulator's broadband geographical report (CMT, 2013). The penetration rate of fixed broadband lines (the national mean value of 24.3 lines per 100 inhabitants) fell to 17.9 in municipalities with less than 5000 inhabitants and to 12.6 in municipalities with less than 1000 inhabitants.

As a solution to the investment in scarcely populated areas, some Member States have linked population coverage obligations to the 800 MHz spectrum's holders. In Spain, this obligation fell to Telefónica, Vodafone and Orange who acquired 2 × 10 MHz FDD in the 2011 Spanish spectrum auction (Spanish Ministry of Industry, Tourism and Trade, 2011a). They are required to jointly provide 30 Mbps broadband to 90% of the population in rural areas. It is important to note that rural areas refer to the 6809 municipalities with less than 5000 inhabitants, representing 69% of Spanish territory.

A recently published techno-economic assessment (Feijoo & Gomez-Barroso, 2013) has considered that it would take at least 12.6 billion euros (present value) to cover 100% of Spanish households and businesses with next generation networks in 2020. Different technologies (FTTH, VDSL, DOCSIS and LTE) were considered and the most efficient use of the existing network infrastructure per type of municipality was selected. This research also makes a classification depending on the population of each municipality. Although in the LTE scenario very considerable differences with respect to that proposed herein (e.g. carrier bandwidth, antenna configuration and throughput per user[3]) are contemplated, it is very important to bring up two outcomes. The first one is that in rural areas the only feasible NGN deployment is LTE. It also set at 100 inhabitants per square kilometer as the limit in terms of commercial viability. This information has been corroborated by the fact that in the Telecommunications and Ultra-fast Networks Plan (Spanish Ministry of Industry, Energy and Tourism, 2013c) LTE was the only NGN considered to achieve 30 Mbps in rural areas. The second one is the affirmation that the achievement of the objectives set out in the Plan Avanza (Spanish Ministry of Industry, Tourism and Trade, 2011b) and the Digital Agenda for Spain (Spanish Ministry of Industry, Energy and Tourism, 2013a) looks too difficult (especially if there are quality limits that must be ensured). There is a strong belief that if LTE is not the solution to providing 30 Mbps broadband in rural areas, then rural areas may not be covered by any other technology. This is the main motivation of this work.

The aim of this paper is to evaluate whether it is feasible for an LTE operator to deliver the 30 Mbps fixed service in rural areas in Spain and if this is not the case, whether passive network sharing could make it so. The research is carried out

[1] Acronyms: Long Term Evolution (LTE), Hybrid Fiber Coaxial (HFC), Fiber To The Home (FTTH), Very High bit-rate Digital Subscriber Line (VDSL), High-Speed Packet Access (HSPA) and Worldwide Interoperability for Microwave Access (WiMAX).

[2] For the type of network sharing, we use the classification described in Table 1 in Khan, Kellerer, Kozu, and Yabusaki (2011). Regarding passive network sharing, we considered the sharing of civil engineering and passive equipment.

[3] The carrier bandwidth considered for this assessment was 20 MHz. The frequency band was not specified. The antenna configurations were MIMO2 × 2 and MIMO 4 × 4. The downlink throughput considered was from 1 to 5 Mbps, which is not enough to consider it as a solution for the 30 Mbps DAE's proposal.

through a techno-economic assessment in an infrastructure competition scenario. A discounted cash flow method is used to determine the total cost of the deployment for the operator and the minimum average revenue per unit (ARPU) that would be required to recover the investment in both approaches: passive network sharing and non-sharing.

For the assessment, an LTE 2×10 MHz FDD carrier in the 800 MHz frequency band is considered. The cost of this service is expressed by the monthly Average Revenue Per User (ARPU) required for a Net Present Value (NPV) equal to zero at the end of the 10-year study period, starting in 2014[4] (scheduled date in which the 800 MHz frequency band will be released as a consequence of the analog switch-off). Three demand scenarios are given, based on adoption predictions to the proposed broadband service. Three broadband products, differenced by the monthly download limit (datacap), are evaluated. The results are being appraised through a sensitivity analysis. Finally, the feasibility of the deployment will be discussed by the ARPU required in each demand scenario.

Lately, new technologies and techniques promising economic and technical improvements have emerged. Active network sharing can provide management flexibility by reducing the total cost of ownership. Furthermore, several papers (e.g. Ballon, Lehr, & Delaere, 2013) state that the use of cognitive radio in active network sharing will allow the existence of profitable primary and secondary operators on the same spectrum. On the other hand, LTE Advanced's carrier aggregation feature would surely improve the throughput per user that operators can provide.

There is abundant bibliography concerning the data avalanche that will come in short term, and there are different business models to monetize it (Markendahl, Molleryd, Makitalo, & Werding, 2009; Werding, Markendahl, Mäkitalo, & Mölleryd, 2010; Zander, 2013; Mölleryd, Markendahl, Mäkitalo, & Werding, 2010). Offloading proposals have also been made to handle the predicted mobile network's capacity constraint that will come in short term (Grønsund, Grøndalen, & Lähteenoja, 2012; Markendahl, Mölleryd, Beckman, & Mäkitalo, 2011; Popescu, Ghanbari, & Markendahl, 2013). One of the most promising trends in offloading techniques is the use of femtocells. As Grønsund et al. (2012) remark, femtocell backhaul relies on an existing fixed broadband connection or on a transmission link to the Base Station (BS). The downside of the second option is that BS capacity is used. As our assessment is focused on fixed broadband unserved area, the only option is the second one, however it does not constitute a solution to maximize the cell's throughput.

All these technologies and techniques are outside the scope of this assessment for three reasons. The first one, because we are developing a short term analysis with technologies currently present in the market. The second one, because in rural areas mobile networks are not capacity-constrained but coverage-limited. And third, because we are depicting a greenfield deployment.

This paper is structured into 4 sections. Section 2, Theory and calculations, is subdivided into four sections: theoretical model, conceptual model, techno-economic assessment in the Spanish context and base scenario description. It is also supported by Appendices A and B. The theoretical model, describes the network's characteristics and a general overview of the model as well as the theoretical contribution on which the model is based. In the Conceptual model specific inputs and calculations of the geographical classification, radio technical model and techno-economic model are described. Techno-economic assessment in the Spanish context explains the economic and policy elements in which this assessment is developed and the base scenario description provides a detailed explanation of the case assessed. Section 3 is made up of three subsections. In Section 3.1, the cost of deploying a rural LTE nationwide network, the network's related costs and the ARPU required for a network operator are explained both with and without network sharing, are discussed. ARPU required in the three demand scenarios is discussed in Section 3.2, where it is going to be debated whether passive network sharing, as proposed by the Ministry (Spanish Ministry of Industry, Energy and Tourism, 2013a), is enough to solve the problem or if any other kind of measure would be needed. In Section 3.3, Sensitivity analysis, the main inputs will be appraised through a sensitivity analysis to determine which are the most influential on the return on the investment. Finally, the conclusions are presented in Section 4.

2. Theory/calculation

2.1. Theoretical model

The model uses the European Rocket project (Moral, Arambarri, Bravo, Armas, & Vidal, 2010) with a minimum adaptation to LTE.[5] It presents and describes business models and estimations on the costs associated with the deployment, operation and maintenance of an OFDM-based 4 G system. The Rocket model in turn contains many fundamental aspects from the Costa Model (Vergara, Moral, & Pérez, 2010), developed jointly by Telefónica and the *Universidad Politécnica de Madrid* (UPM).

The Rocket model uses a geometric modeling for the network dimensioning, as originally applied in Costa Model (Vergara et al., 2010), which is based on the ICT BREAD project (BREAD project, 2006). The characteristic of this type of modeling is that the coverage area, assumed as square-shaped, is recursively divided into square-shaped subareas for the

[4] On december 30, 2014 it was stated, by a Royal Decree, that the availabity of 800 MHz frecuency band, will be delayed until April 1, 2015. Despite the economic implications of the delay, it doesn't affect the assessment outcomes.

[5] The Rocket model was originally designed for WiMAX in the 2.6 GHz frequency band. The minimum adaptation consisted of changing the frequency band, giving different antenna options (SISO, MIMO 2×2 and MIMO 4×4), as well as considering three different broadband products and LTE equipment prices.

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different aggregation levels that make up the aggregation network (see Fig. 1). As can be seen in Moral, Vidal, Pérez, Agustín, Marina, Høst-Madsen, & Samardzija (2011), the Rocket model is made up of four Aggregation Nodes (AN) linked through microwave or Ethernet Aggregation Links (AL) which are given as a percentage in each geotype. AN1 is the radio access network, were users are uniformly distributed. It is made up of four eNodeB linked by leased Ethernet links in most of the geotypes, except for rural 3 and rural 4 where microwave links are considered (40% and 60% respectively). AN2 and AN3 constitute the transport network and are made up of Ethernet switches and access routers. Eight Ethernet switches make up one AN2 and eight access routers make up an AN3 and they are linked through Ethernet links in a ring topology. Finally, AN3 is linked by ring topology Ethernet lines to the core network elements (AN4).

A limitation of the model is the inability to set the distance and the positioning of network elements in a specific place, as a result of the square-shaped dimensioning. The positioning of eNodeBs, according to the model, is based on traffic considerations only. In real networks, however, there are other factors such as coverage, site availability or administrative restrictions which have an influence on the eNodeB locations. Due to the nature of the assessment, which focuses on rural municipalities spread across all Spanish territory, the use of a reduction factor[6] (F) was proposed in order to maintain the relationship between the national deployment and the assessed deployment. This factor was obtained after developing an incremental cost assessment for covering Spain with LTE network (Ovando & Pérez, 2014). After determining the total number of BS required to cover the entire national territory, we extract the adjustment factor to cover municipalities with less than 5000 inhabitants and the coverage limitation resulting from this area's orography. The cell radius resulting from the LTE radio model is multiplied by F, in order to simulate the difficulties of a real deployment. This method has also been applied by Analysys Mason (2010) and Moral et al. (2011).

The general model operation is shown in Fig. 2. The Rocket model uses a Discounted Cash Flow (DCF) method, which is an approach that has been used in several European projects, operators and regulators (e.g. ECOSYS, 2006; Loizillon et al., 2002). It is used in this assessment to determine the economic feasibility of a rural national LTE network. As can be seen in Fig. 2, an initial monthly ARPU is required to calculate the DCF. To provide further clarity, inputs are subdivided into 3 categories[7]: demand inputs (ARPU, market share, service penetration and datacap per user), technical inputs (population density per geotype, network element configuration and total coverage area) and economic and financial information (network element per unit cost assumptions, discount rate study period and business driven expenses). The origin of the geographic and traffic inputs come from the geographic classification, the radio technical model, and will be explained in the conceptual model section. However, the economic and financial parameters come from operator information (CMT, 2012; Telefónica, 2010), consultancy (Analysys Mason, 2010; SVP Advisors, 2011) and industry reports (GSA, 2013; Heavy Reading, 2013), etc. The set of geographic parameters used are shown in Table 1. Moreover, unit costs are listed in Appendix A, where CAPEX and OPEX per asset are specified.

By combining the aforementioned inputs, the Rocket model calculates the results necessary for the DCF analysis such as cash flows, net present values (NPVs), internal rate of return (IRR), and payback period. Excel's goal seeker functions are also used to determine the ARPU needed for an NPV=0 in each case assessed. Special attention is given to this final output that will let us analyze and debate the feasibility of the deployment. More details on the methodology are presented in Moral et al. (2011).

2.2. Conceptual model

2.2.1. Geographical classification

The assessed area consists of 6681 municipalities, which correspond to 69% of the Spanish mainland (INE, 2009). In 2011 the Spanish Ministry of Industry, Tourism and Energy launched the "Plan Avanza new telecommunications infrastructure" (Spanish Ministry of Industry, Tourism and Trade, 2011b), whose main objectives are to provide financial aid (up to €100 million in loans) to operators as an incentive to deploy Next Generation Access Networks (NGAN) which could provide 50 Mbps broadband in rural areas. This program has published a list of municipalities (Spanish Ministry of Industry, Energy and Tourism, 2013d) that already have the required infrastructure. There are also included those where there are plans for its deployment in the next 3 years. The remaining municipalities with less than 5000 inhabitants are the subject of our analysis.

In contrast to other studies (e.g. Coomonte, Feijóo, Ramos, & Gómez-Barroso, 2013; Feijoo & Gomez-Barroso, 2013), where municipalities are directly classified by a proxy, a clustering method (Anderberg, 1973) has been developed. The information used for the geographical classification was gathered from the Spanish Census (INE, 2009), Spanish industry Report (CMT, 2013), broadband reports (ONTSI, 2013) and other sources (La Caixa, 2011). Following the same methodology as Vergara (2011), a k nearest neighbor method was developed using the Statistical SPSS tool. The main variables in this classification were: main household density, percentage of 1 Mbps coverage before 2012 USC, and scattered population ratio. The original ratios are shown in Appendix B. 734 municipalities (open geotype in Appendix B), were excluded from the assessment. Their low population density and orographic features makes them an unfeasible territory for a Radio Access Network (RAN) deployment. Other solutions such as satellite may be considered. There is another important reason for the exclusion of this area: the fact that operators are not required to cover it. The coverage obligation stipulates that they are

[6] F cannot be extrapolated; it is only valid for this assessment.

[7] The classification is not rigid; inputs could be classified in more than one category. However, it was simplified as shown.

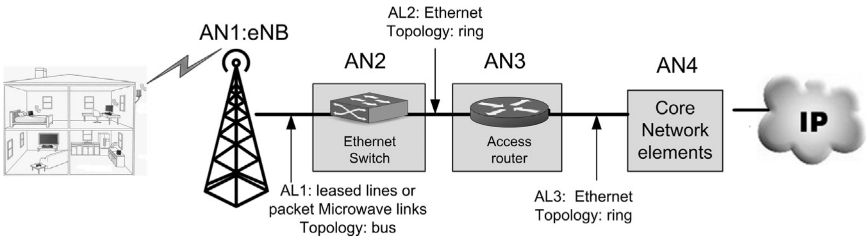

Fig. 1. Basic LTE diagram. Description: LTE network configuration.

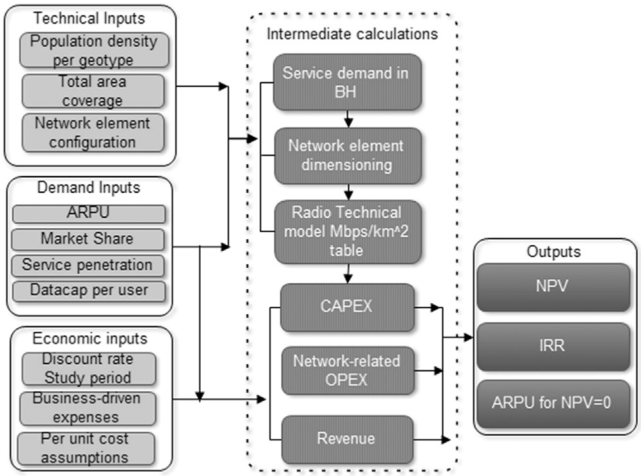

Fig. 2. Rocket model diagram. Description: Rocket techno-economic model follows a Discounted Cash flow method.

Table 1
Geotype Inputs.

Geotype	Area Km^2	Households	Population	Area share (%)	Population share (%)	Traffic share (%)
Suburban	45	60,384	124,632	0.013	2	5.0
Rural	2979	3,018,036	5,216,155	1	92	92.0
Open	310,604	141,208	340,627	99.1	6	3.0
Total	313,627	3,219,628	5,681,414	100	100	100

required to cover 90% of the municipalities with less than 5000 inhabitants. This area represents only 9% of the municipalities covered by this condition. Finally, 6681 were classified into 3 geotypes as can be seen in Table 1.

2.2.2. Radio technical model

The Radio Technical Model is based on the Ofcom Technical Models (Ofcom, 2009b, 2011). This is a macrocellular approach that starts with a link budget, followed by the cell area calculation, while setting basic QoS parameters; and finishes with a traffic table (Mbps per Km^2). The traffic table is constructed as can be seen in paragraphs A13.390-A13.394 from the Ofcom HSPA traffic model (Ofcom, 2009a). This modeling has also been used in LTE traffic modeling (Frias & Perez, 2012). The main technical inputs are from different technical sources such as: (3GPP (2012); Dahlman, Parkvall, & Skold, 2011; ETSI, 2012; Holma & Toskala, 2009). The objective of the link budget is to determine the cell characteristics to provide a 30 Mbps throughput with an LTE FDD in the 800 MHz frequency band, the average number of users per cell and the cell radius. The multi-user gain is described in Holma and Toskala (2009) and is comparable as in Schwarz et al. (2012). The main inputs are described in Table 2.

It is important to highlight that the ability to achieve 30 Mbps depends on different parameters such as bandwidth, number of simultaneous users, and channel conditions. The highest peak rate with the considered bandwidth is 42 Mbps (Agustí et al., 2010). Nokia stated that in October 2011, Telia was providing an average downlink throughput of 21 Mbps per user in a Stockholm suburb through the LTE 2 × 10@800 MHz carrier (Nokia Siemens Networks, 2012). In our model we are

Table 2
Technical inputs.

Parameter	
Downlink mean throughput per user	30 Mbps
Frequency band	800 MHz
Carrier bandwidth	10 MHz FDD
Antenna technique	SISO
Cellular layout	120° sectorial antenna
Propagation model	Okumura-Hata
BS power	46 dBm
Outdoor antenna gain plus cable losses	9.5 dBi
Bs Antenna gain	15 dBi
Thermal noise	– 104 dBm
Interference margin	1 dB
Control channel overhead	0.8 dB
Cell area formula	$0.95r^2F$
Simultaneous user	1.46
Radius reduction factor (*F*)	Suburban 0.13, rural(1–3) 0.26 and rural4 0.20
Proportion of daily data traffic in busy-hour (BH)	20%
Uplink to downlink busy-hour (BH) data traffic ratio	10%

setting the QoS parameters, reducing the cell area and using outdoor directive antennas[8] (included in the customer premise equipment) in order to increase the received signal quality and thus provide 30 Mbps. The number of simultaneous users per BS and the cell radius (r in Eq. (1)) is compared with the geographic and demographic characteristics obtained from the geographic analysis in order to assure the user throughput. If the desired traffic/km^2 is greater than the BS capacity/km^2, there is a reduction in the cell radius as shown in Eq. (1). Moreover, throughput on the edge is considered in the model by reserving resource blocks to provide at least 24 Mbps.

$$r = \sqrt{\left(\frac{BS\ \text{Capacity/km}^2}{\text{traffic} \times 9(\sqrt{3}/8)}\right)} \tag{1}$$

2.3. Techno-economic assessment in the Spanish context

The techno-economic model has been implemented to determine whether it is feasible for an LTE operator to deliver a 30 Mbps fixed service (the DAE's objective) in rural areas in Spain, assuming an infrastructure competition scenario; and if this is not the case, whether passive network sharing could make it feasible. It has been found necessary to put this assessment in the telecommunications sector context regarding investments, roll-out announcements and commitments.

From 2005 to 2010 the three biggest mobile operators have invested over €500 million annually: Vodafone €758 million, Telefónica €679 million, and Orange €583 million (CMT, 2012). In 2011 the spectrum auction and the comparative hearing of 310 MHz in 800 MHz, 900 MHz, 1800 MHz and 2.6 GHz frequency bands took place, in which all operators invested close to €2 billion. It is important to note that the 800 MHz frequency band has not been released at the present moment; however LTE is already being deployed and providing 4 G mobile services in Spain's main cities at 1800 and 2600 frequency bands.

As previously mentioned, since 2012, Telefónica, Vodafone and Orange are required to pay the cost of the 1 Mbps Universal Service and to provide 30 Mbps broadband jointly to 90% of the population in rural areas by the end of 2020. As the universal broadband service is being provided by mobile operators, most of rural areas are being served through 3.5 G mobile networks, since 99% of the population is covered by this technology.

The telecommunication sector in Spain is facing a consolidation process. Recently Vodafone, the second largest mobile operator, has purchased Ono, the biggest cable (DOCSIS 3) operator in Spain. Both operators, Telefónica and Vodafone, can currently reach over 7 million households through fiber technologies. Only a few months after this acquisition, Orange launched a takeover bid over Jazztel, an important national xDSL and fiber provider. With the merger, Orange acquired 1.5 million broadband clients, and remaining the third network operator in number of subscribers. It has become very common to stimulate the demand though offering bundling services, at the same price as ADSL few years ago.

It is not the goal of this paper to determine the most cost effective technology in each geotype assessed. This analysis has already been developed in Ovando and Pérez (2014),[9] where it was stated that LTE is the most cost-effective technology, representing savings from 66% (Rural2) to 89% (Rural3) compared to a VDSL deployment. However, as in Spain price discrimination on a geographical basis[10] is not allowed, it has found important to extend the incremental access cost of an LTE deployment from 40% to 100% of the Spanish population which is shown in Fig. 3, where the area assessed is detailed.

[8] Directive Antennas were considered instead of MIMO Systems due to the fact that the key feature of MIMO is the ability to turn multipath propagation into a benefit for the user (Gesbert, Shafi, Shiu, Smith, & Naguib, 2003), and multipath propagation is not a characteristic of rural areas.

[9] The *F* factor was not used in the incremental analysis, as it was an entire country assessment.

[10] Operators in Spain are required to set the same price of a broadband product in the entire national territory; however they can decide where to supply the service.

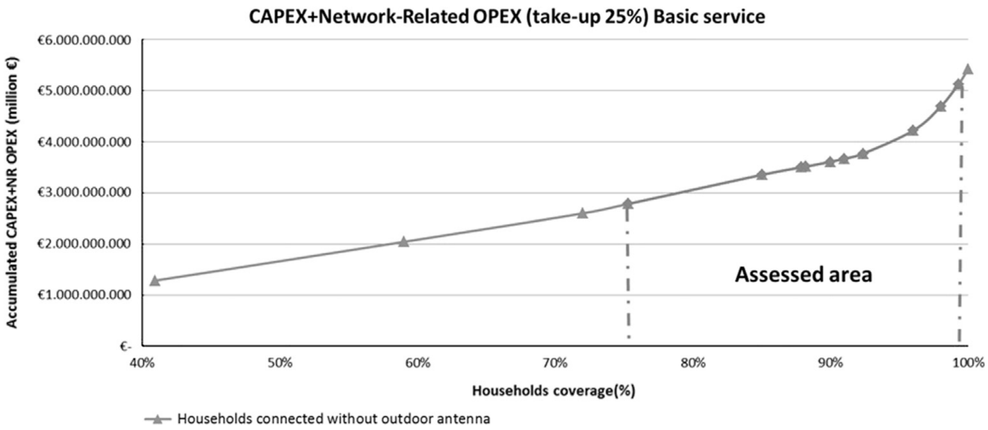

Fig. 3. Incremental LTE roll-out access cost. Access cost CAPEX and Network-Related OPEX for the basic service. The area assessed is remarked.

2.4. Base scenario description

For the assessment, the aforementioned geographic characteristics (Table 1), radio model parameters (Table 2) and techno-economic inputs (Table 3) have been considered. The current assessment does not take into account the existence of a core network in the assessed area, since a greenfield scenario is reflected. Three broadband products, differenced by the monthly download limit (Basic 10 GB, Silver 20 GB and Gold 30 GB), but maintaining the other technical characteristics, have been considered in both network scenarios: non-sharing and passive (civil engineering and passive equipment) network sharing. The set of different services that (such as mobile broadband) could be provided by the same network was not considered. The cost of the user equipment (Integrated outdoor CPE-fixed antenna) and its installation are included in the assessment, as fixed broadband service is intended to be provided.

The spectrum purchased by the operators, Telefónica, Vodafone and Orange, in the latest auction (Spanish Ministry of Industry, Tourism and Trade, 2011a), has been reflected: 2×10 MHz FDD in the 800 MHz Frequency band each. The assessment focuses on the deployment cost of any of the aforementioned operators. The deployment will start in 2014 (scheduled date in which the 800 MHz frequency band will be released as a consequence of the analog switch-off) and the study period will finish in 2024. The universal coverage is supposed to be completed by 2020, in accordance with the 800 MHz spectrum holders' coverage obligation. It is modeled using an *S* curve as in Moral et al. (2011). In all the cases considered, the NPV has been fixed at zero at the end of the 10 years study period, to determine the cost of the service provision. The Rocket model determines the monthly ARPU required to achieve the aforementioned condition. A typical value of 45% of total expenses corresponding to network-related OPEX and the rest (55%) corresponding to business-driven expenses has been assumed (Markendahl et al., 2009; Moral et al., 2011). License acquisition spectrum costs and core network elements are proportional to the customers in rural areas.

Two cases have been studied: the total cost of the deployment and an assessment of the demand scenarios. To determine the cost of the deployment for the three broadband products, first (Section 3.1), take-up has been fixed at 25%. Then, minimum ARPU for the provision of the three broadband products is calculated by changing network take-up.

For the second case (Section 3.2), three demand scenarios were considered depending on the envisaged Spanish broadband penetration by 2020. From the OECD broadband portal (OECD, 2013) the latest 10 triannual broadband penetration per 100 inhabitant reports from France, Germany, Italy, United Kingdom and Spain (EU5) were extracted. Then they were modeled in Matlab, using the Levenberg-Marquardt algorithm, to extract the Gompertz[11] coefficients $y(t) = ae^{be^{ct}}$ as can be seen in Table 4. The coefficient "*a*" indicates the maximum penetration in terms of broadband per 100 inhabitants. Coefficients "*b*" and "*c*" determine the displacement and growth rate, according to the scenarios' previsions and "*e*" is the error for the algorithm approximation.

In 2012 the broadband penetration was 24.6 per 100 inhabitants, which means a 58% broadband penetration, while the fixed line penetration (100%) was 42.8 per 100 inhabitants. The low demand scenario implies that the Spain will maintain the current broadband trend. This means that broadband policies to encourage broadband adoption would not have succeeded. Medium demand, Spain will follow the EU5 average current trend, implying that broadband policies have had a positive impact on the adoption of the service, but have not met the objective. Finally, high demand implies that Spain will achieve 100% broadband penetration.

[11] The Gompertz model has been successfully used to model broadband adoption in previous academic research as in Crandall, Jackson and Singer (2003), Dippon (2012) and Kovács, Mogensen, Christensen, and Jarvela (2011).

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Table 3
Techno-economic inputs.

Parameters	
Broadband products	
Basic	10 GB/month
Silver	20 GB/month
Gold	30 GB/month
WACC	13%
Service penetration in 2020	Suburban 100% Rural 95% Open 70%
Promotion cost per new costumer	5€
BS that can be co-ubicated	80%
Yearly growth rate of download datacap	1%
BH per month	60
Annual price trend per broadband subscriber	−4%
Final take-up	25%
Study period	10 years, starting in 2014
Market Share	100% 1 operator

Table 4
Demand scenarios assumptions.

Demand scenario	**Penetration**	**National penetration equation**
Low demand	Spain current trend	$a=33.47$, $b=-1.12$, $c=-1.31$, $e=5.77\times10^{-17}$
Medium demand	Mean EU5 current trend	$a=40.84$, $b=-1.86$, $c=-1.31$, $e=1.22\times10^{-26}$
High demand	BB penetration=fixed line penetration	$a=42.77$, $b=-1.69$, $c=-1.13$, $e=6.77\times10^{-17}$

Finally, to estimate the VHBB penetration in rural areas, a factor of 2.4 developed by Altran Business Consulting (2013) [12] between total broadband penetration in Spain and Very High broadband (VHBB) penetration was used. A time shift, in accordance with the service availability, has also been applied. We are assuming that in rural areas the VHBB will be LTE. As can be seen in Fig. 4, the predicted broadband adoption varies from 17% to 30%.

3. Main results and discussion

3.1. *The cost of deploying a rural LTE nationwide network*

In Fig. 5, a 10 year accumulated CAPEX and CAPEX+OPEX in both network scenarios are compared. Because of the geometric approach of the model, the cost of the roll-out varies when take-up increases, as a consequence of the backhaul required to cover the demand. However, the cost of the network is maintained from a 25% take-up to any lower value, representing the minimum investment required to supply the service. The total CAPEX varies from €755 to €916.87 million from basic to gold service. The average CAPEX per home connected (including the CPE cost) in the assessed area is €860, €954 and €1045 in the non-sharing scenario and €779, €854 and €928 in the sharing scenario for the basic, silver and gold service respectively. As monthly download limit increases, savings increase in the sharing scenario: it increases from 9.5% for the basic service to 11.2% for gold service. The sum of CAPEX and OPEX in varies from €2760 million (basic service) to €3641 million. In contrast with the CAPEX, CAPEX and OPEX sharing savings tend to decrease from 19% for the basic service to 18.1% for the gold service.

It is important to highlight that these costs are per network in the assessed area, meaning that if there are three operators they will have to invest around €3000 million for the basic service in the non-sharing scenario and €2500 million each in the sharing scenario. Moreover, the adoption will also be split between the three operators. However, it is important to note that the economic impact of network externalities and the improvement in the quality of the LTE mobile service (derived from a nationwide coverage), as well as cross-subsidization between urban and rural areas, have been excluded from the analysis.

Fig. 6 shows more clearly where the saving is found. In the sharing scenario there is a significant reduction in the cost of sites, which is reflected in the accumulated CAPEX. Moreover, the most significant reduction is in the accumulated OPEX, where the rental fee is shared by the three operators. It can be seen that three most relevant network-related costs in CAPEX

[12] The Altran Bussiness Consulting (2013) reduction factor based on broadband predictions (EIU 2013; Heavy Reading, 2013; Morgan Stanley, 2013; Telefónica, 2010).

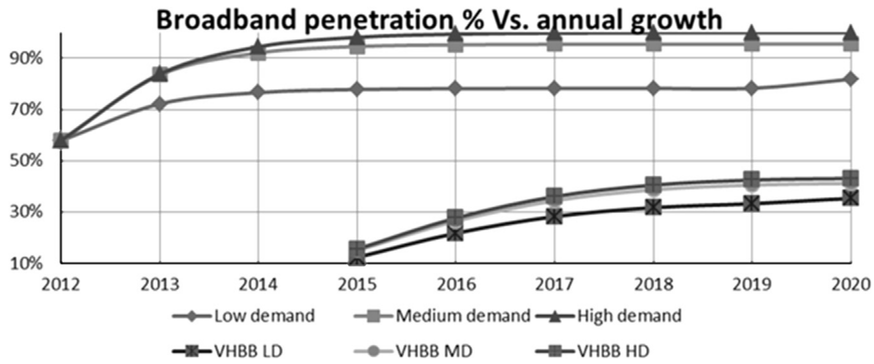

Fig. 4. Broadband predictions. Description: National household broadband penetration scenarios and Very High broadband (LTE in the assessed area) penetration scenarios.

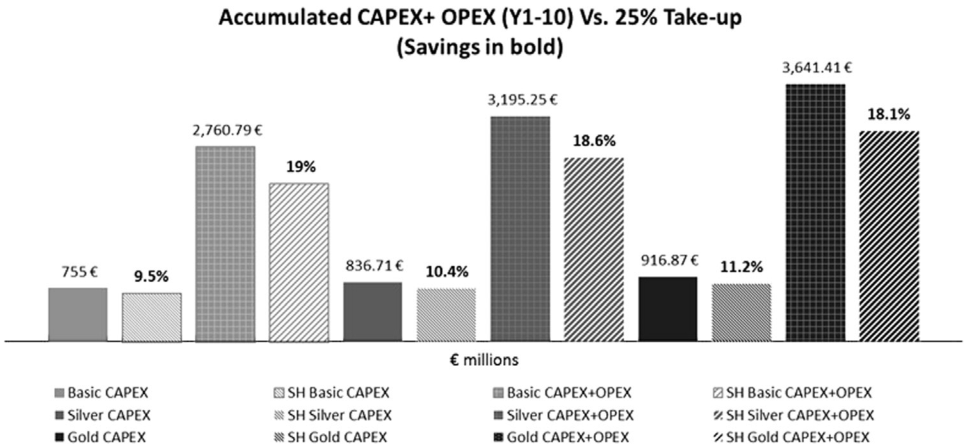

Fig. 5. Cost of the deployment. Description: 10 years accumulated CAPEX and CAPEX and OPEX of the three broadband products, considering 25% take-up. Savings with passive network sharing are shown in bold.

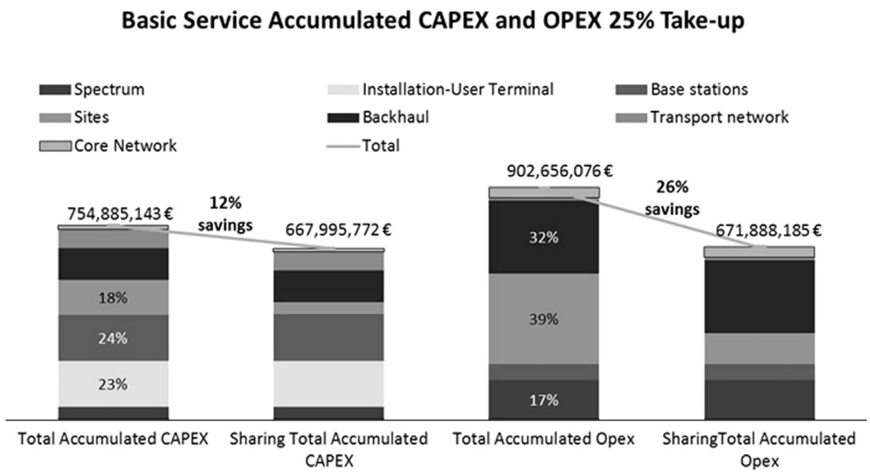

Fig. 6. Networks costs distribution. Description: Basic service accumulated CAPEX and network-related OPEX per asset category (see Appendix A). Savings with passive network sharing are shown in bold.

are the BS, 24% (27% sharing), user terminal (integrated outdoor CPE and fixed antenna and installation), 23% (26% sharing) and sites, 18% (only 7% sharing). On the other hand, in OPEX, the cost of the site rental plays an important role, 39% (17% sharing), as well as the backhaul (leased lines, tower rental, etc.), 32% (43% sharing). Spectrum costs, such as spectrum fees, also represent 17% (and 33% sharing). There is an overall cost reduction of 12% in the total accumulated CAPEX and 26% in the network related OPEX for the basic service.

Although the required investments are in line with operators' annual investments, they are related to the ability to recoup it. As this ability is directly related to the network take-up, and, of course, service adoption, there are serious concerns about network feasibility in rural areas.

3.1.1. ARPU required in both network scenarios

Monthly ARPU is calculated after a 10-year study period using the aforementioned DCF method, considering the annual price trend (see Table 3). Figs. 7 and 8 show the ARPU required to provide the three broadband products for an NPV=0. Network take-up is in the abscissa axis. It is important to highlight that NPV being equal to zero means that the cost of the investment is equal to revenues at the end of the study period. The ARPU reflected here is exclusively for the assessed area and it does not take into account cross subsidization. It is important to mention that the CPE cost and its installation has been included in the ARPU calculation. If, instead of using an outdoor antenna CPE, the user uses, for instance, a dongle, there would be a reduction in ARPU. However, the quality of the signal will be reduced, and as consequence the throughput will also be reduced.

The sharing network scenario represents ARPU savings from 40% to 37% in the three broadband products offered. Considering a network take-up of 25% (877,483 home connected) the basic service will require an ARPU of more than €69.9 (€66.50 without CPE) in the non-sharing scenario of more than €41.13 (€38.15 without CPE) in the sharing scenario.

3.2. ARPU required in the three demand scenarios

Assuming that LTE will be the VHBB deployed in rural areas, three demand scenarios, as previously mentioned, have been constructed. A low demand scenario implies that service adoption will be between 12% and 36%, medium demand

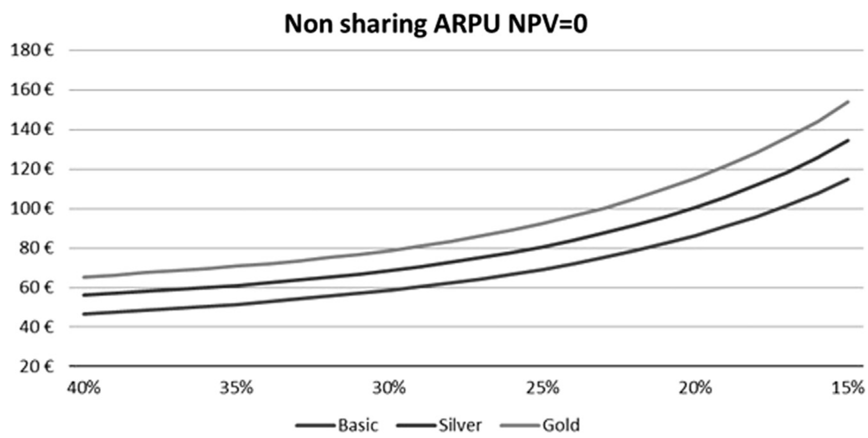

Fig. 7. ARPU required vs. Take-up non sharing scenario. Description: Three broadband products ARPU required for the return of the investment in the assessed area.

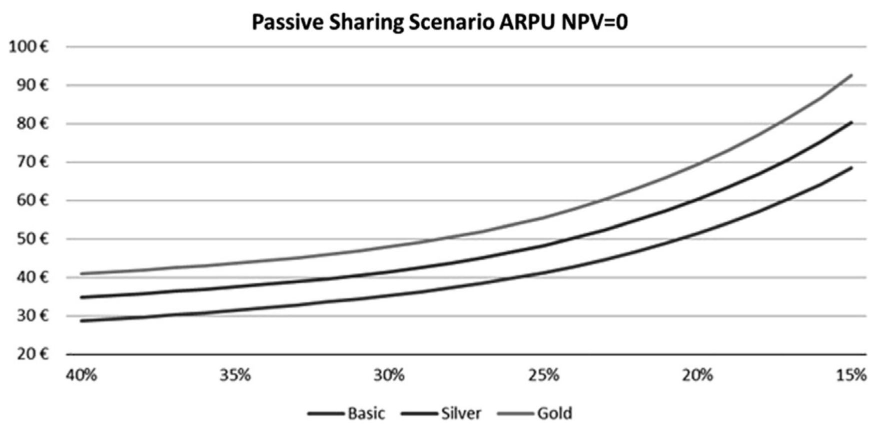

Fig. 8. ARPU required vs. Take-up sharing scenario. Description: Three broadband products ARPU required for the return of the investment in the passive network sharing scenario in the assessed area.

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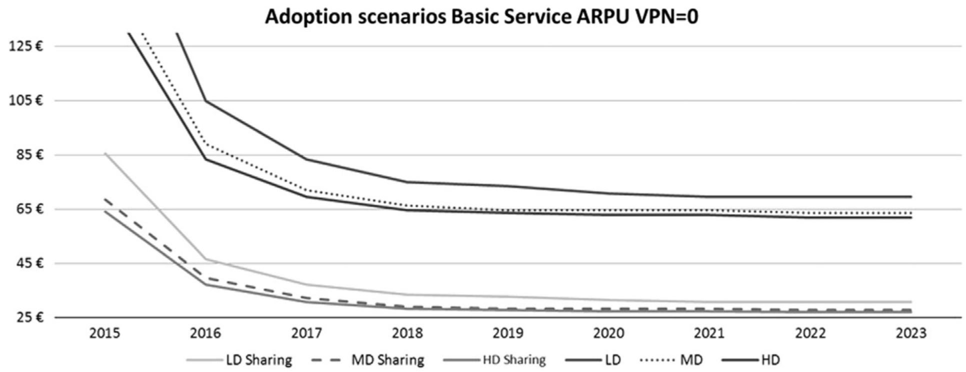

Fig. 9. ARPU required for the demand scenarios considered. Description: Basic service ARPU required for the return of the investment given the three broadband scenario predictions in both network scenarios considered, to provide 30 Mbps fixed broadband in the assessed area.

between 15% and 42% and high demand 16% and 44%. In Fig. 9 the three demand scenarios in both network approaches are shown. In all cases, the network adoption is below 45%. The cost of the user terminal is included together with its installation. For the basic service, at the end of the study period, the ARPU (NPV=0) required varies from €50.48 to €43.41 in the non-sharing scenario and from €30.80 to €27 in the sharing scenario. The amounts expressed here are per network considering that service adoption is the same as the network's take-up. However, it must be considered that the adoption will be split between the number of existing networks.

Despite the availability of a broadband universal service (1 Mbps) with a regulated price (€29.99 per month, plus an installation fee of €66) only 66.7% of households adopted broadband in Spain in 2012 (ONTSI, 2013). The FCC (FCC, 2011) explained the existence of 3 barriers to broadband adoption, which are: the cost of broadband, lack of a computing device in the home and low levels – or complete absence – of digital literacy. Thus, it is important to note that only 73.9% of Spanish households have a PC.

The National Statistical Institute has recently published a survey on the reasons for not adopting the internet (INE, 2013). 66% of respondents said that they do not need it and 30% the lack of digital literacy. The third reason was the very high internet prices.[13] The typical socio-demographic characteristics of Spanish municipalities with less than 5000 inhabitants are: low and middle low income households and an average age of more than 50 years old.

As it was noted that the population is highly sensitive to the cost of the service, it is necessary to compare the proposed service with other broadband products present on the market. In a recent report (Van Dijk Management Consultants, 2014) it was stated that Spain has one of the most expensive broadband prices in the European Union. In the 12–30 Mbps and 10 GB download limit, equal to our basic service category, the prices varies from €38.73 to €56.83, and the price of the average offer is €54.45 (broadband access and fixed line), Telefónica being the only nationwide provider through VDSL technology. If the fixed line is excluded, the monthly fee of this broadband service is €42.23. Fig. 9 clearly shows that the LTE broadband service in the non-sharing scenario cannot compete with the HSPA+ broadband service offered in densely populated areas such as Madrid either. HSPA+ with a datacap of 10 GB (similar to the basic service proposed in this assessment) is provided for between €40 (Telefónica) to €35 (Yoigo) per month. Only the sharing scenario of the basic service can compete with the price established in USC. However, the adoption is distributed according to each operator's market share, reducing take-up and increasing the ARPU required.

Despite it appearing unlikely to achieve high take-up rates in rural areas, the fact that fixed and mobile broadband and TV services, could be provided in the same network has not been considered. In fact, offering bundling services has become a common practice to stimulate demand, and it has become a successful measure. If that is the case, network take-up would increase and the ARPU required would decrease. As an optimistic example, it can be assumed that, if 10% of the high demand scenario subscribers also subscribed to a mobile service, network take-up would be 48% and the ARPU required would be €40.77 in the non-sharing scenario, nearly equal to Telefónica's HSPA+ service. Nevertheless, given the current demographic and socio-economic characteristics it seems unlikely that the required take-up rates to compete with HSPA+ service in a network infrastructure scenario would not be achieved.

Due to the lack of population and without considering any regulatory incentives (e.g. cross subsidization) in the area assessed, take-up ratios of more than 50% per network in the basic service will be required to compete with the current HSPA+ monthly fee offered in densely populated cities. Moreover, more than 75% of take-up per network will be required and to compete with the U.S. The only way to reach Telefonica's HSPA+ monthly fee is if network costs are equal to the sharing network's cost.

From the above, it may be concluded that that passive network sharing, by itself, cannot certainly guarantee the viability of three LTE network deployments in the assessed area. On the other hand, a reduction in the number of networks could

[13] What the respondents consider high prices will not be discussed, but the fact that the perception of high prices is one of the main barriers to service adoption.

Table 5
Sensitivity Analysis.

Input type	Input	Initial value	IRR (%)	NPV (%)
Demand	ARPU	€70	50	48
Demand	Take-up	25%	39	42
Technical	Rural area coverage	95%	0	0
Economic	Site lease expense	€13,762	3	5
Economic	Rural deployment year	6	1	2
Demand	Daily traffic in BH	20%	1	0
Technical	Suburban area coverage	100%	0	0
Demand	Datacap (monthly download limit)	10 GB	0	0
Technical	BS that can be co-ubicated	80%	2	0
Economic	Backhaul-tower lease	€28,639	0	2
Demand	Yearly data cap growth	1%	1	1
Economic	License acquisition 800 €/MHz/POP	€0.46	2	0
Economic	Suburban deployment year	4	0	0
Economic	WACC	13%	0	0
Economic	Leased lines backhaul	€4347.07	1	0

allow matching VDSL and HSPA+ prices. Furthermore, a single network deployment, by concentrating the demand, would allow the provision of 30 Mbps fixed broadband service at prices approaching those of universal service.

3.3. Sensitivity analysis

Finally, in order to simulate the uncertainties in the telecoms market a sensitivity and risk analysis has been incorporated. Like other techno-economic models (Katsianis et al., 2001; Križanović, Grgić, & Žagar, 2010; Kyriakidou, Katsianis, Orfanos, Chipouras, & Varoutas, 2011), the Crystal Ball TM software was used to determine which inputs or factors have a major impact on the final results on the IRR and NPV.

To this end, base scenario, non-network sharing, inputs (described in Table 5) have been subject to a ±10% variation in a Gaussian distribution. It is important to highlight that, because of the NPV=0 network assumption, IRR is always below WACC. The number of iterations considered for this analysis was 1000.

In accordance with the input classification exposed in Fig. 2, this sensitivity analysis has confirmed that the most sensitive inputs were demand related, influencing 91% on both IRR and NPV. Furthermore, economic inputs only impact 7% and 9% on IRR and NPV, respectively, while technical inputs have an incipient impact of 2% on IRR. In particular, ARPU (1st) and take-up (2nd) play the largest role; Site lease expense and rural area coverage, 3rd and 4th following far behind the impact on IRR. Technical parameters do not have a significant impact on NPV and IRR compared to the aforementioned variables. Changing traffic parameters in order to reduce or increase cell radius have almost no impact at all. Neither does the use of MIMO techniques in a suburban geotype.[14] It does not imply that these variables do not represent savings, but that the variation should be greater than 10% to impact on NPV and IRR and that the deployment is highly dependent on take-up and ARPU. Another deployment input, rural deployment year has a 1% impact on both IRR and NPV. On the other hand; an increase in the suburban geotype deployment year has no impact. These outcomes were expected as the study period is 10 years in a Greenfield scenario, and variations in deployment year are during that period. The variables that have more influence on IRR and NPV are shown in Table 5.

This information confirms that network feasibility is highly dependent on the network's take-up, and, therefore, on service adoption and the fact that the efforts of both operators and governments should focus on stimulating the demand. Moreover, network sharing savings (site lease expense and backhaul tower lease) impacts on IRR and NPV to a lesser extent.

4. Conclusions

This paper evaluates whether it is feasible for an LTE operator to deliver a 30 Mbps fixed service in rural areas in Spain and if this is not the case, whether passive network sharing could make it feasible, since this is, in fact, one of the objectives set out in the Digital Agenda for Europe and a key issue in the national broadband strategy. The assessment covers from 75.3% to 99.3% of the Spanish population, while the extreme rural areas containing the last 0.7% is excluded.

The investments required for providing a 30 Mbps fixed service to households in rural areas varies from €755 to €916.87 million from basic to gold service. Cost savings associated with site cost reduction can range from between 9.5% and 11.2%. Nevertheless, passive network sharing savings have a greater impact on the OPEX. It was noted that sharing the site lease expenses represents a 26% reduction in network-related OPEX for the basic service. Since the investment required is less than the mobile operators' previous annual investments for the national territory, it can be concluded that they can afford it.

[14] For additional information about the economic implications of MIMO techniques in more densely populated geotypes, see the incremental assessment portrayed by Ovando and Pérez (2014).

However, the return on the investment is largely dependent on network take-up, as shown in the sensitivity analysis. It was also found that technical parameters (traffic dimensioning, cell radius, MIMO techniques in Suburban area) and variations in the deployment year in a rural geotype do not have a significant impact on NPV and IRR compared to the take-up and ARPU. It has been noticed that greater than 10% variations are required to impact on both aforementioned outputs.

As the existence of other broadband products, such as 3 G and 3.5 G broadband, forces the operator to lower the ARPU, very high take-up rates would be required, more than 50%, to provide the service at a price comparable to that currently offered by operators in large cities in Spain. Despite considering the possibility of providing other services on the same network and very optimistic demand scenarios, given the demographic and socio-economic characteristics of the assessed area and without considering any regulatory incentives (e.g. cross subsidization) in the assessed area, it appears unlikely that take-up rates that would make the service appealing and the cost comparable to other broadband services are achievable. Finally, the research concludes that passive network sharing, despite being an effective tool in cost reduction, is not enough to solve the problem of unfeasibility in rural areas in Spain.

However a single network deployment in which service competition should be encouraged could make it possible to offer broadband services at prices as competitive as those currently offered in densely populated cities in Spain. Furthermore, if the demand is stimulated with the appropriate measures, take-up in rural areas could make IRR an appealing investment opportunity for operators.

Despite the market situation, demographic and orographic characteristics, technical inputs (e.g. base stations availability, frequency band availability, etc.), and economic inputs are specific for the Spain rural areas, the results of this assessment might be applicable to others big European countries, with similar characteristics.

Governments, in general, are facing the challenge of bringing about greater flexibility regarding spectrum policy. The (near) future data avalanche and the decrease in revenues, are propitiating the emergence of new sharing models. Passive network sharing is a first step, but governments should also pay attention to the evolution of new technologies and techniques that promise economic and technical improvements, such as, active network sharing, cognitive radio in active network sharing and offloading proposals.

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Appendix. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.telpol.2014.11.004.

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