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Comparative Techno-Economic Evaluation of 5G Infrastructure Sharing Business Models in European Rural Areas*

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Abstract

The deployment of 5G standalone (5G SA) broadband networks in European rural areas lags behind urban and suburban regions due to high infrastructure costs and the unique characteristics of these areas. However, the advancements in 5G and Beyond-5G (B5G) telecommunication networks have presented new opportunities for cost-effective network deployment through infrastructure sharing. This paper conducts a comprehensive techno-economic study to determine the most cost-effective infrastructure sharing business model for providing affordable broadband in European rural areas, taking into account the specific attributes of each country. By examining real data from EU statistics and considering diverse infrastructure sharing scenarios, the study aims to bridge the research gap regarding the evaluation of 5G infrastructure sharing models on a per-country basis. The study applies a bottom-up model based on Discounted Cash Flow (DCF) analysis, encompassing both Mobile Broadband and Fixed Wireless Access (FWA) use cases. Leveraging the Eurostat database for geographical and demand data, the research utilizes logistic models to forecast demand based on the diffusion characteristics of broadband telecom services. The techno-economic analysis is adjusted for different infrastructure sharing models, including Single Host Network (SHN), Multiple Host Network (MHN) via Passive Sharing and Active Sharing, and Neutral Host Network (NHN). The paper presents total cost results, CAPEX/OPEX outcomes, Net Present Value (NPV), Return on Investment (ROI), and payback periods for each infrastructure sharing model in each country group consisting of European countries with similar density characteristics. Sensitivity and risk analyses are conducted to identify the most influential factors affecting the investment viability for each model and case. Moreover, the study examines the profitability of each scenario, considering the Average Revenue Per User (ARPU) and demand conditions necessary for investment sustainability. The discussion encompasses the reuse of existing infrastructure, network slicing implications, and regulatory policy considerations.

Keywords

techno-economic feasibility, 5G Standalone, rural, infrastructure sharing, network slicing, neutral host, business models

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1 Introduction

The deployment of high-speed broadband networks in rural areas has emerged as a critical engineering challenge in Europe. While urban and suburban regions have made significant progress in adopting 5G technology, rural areas encounter distinct hurdles stemming from low population density and the associated high infrastructure costs. However, recent advancements in 5G and B5G networks offer new possibilities for affordable broadband deployment in rural areas. To leverage these opportunities, it is crucial to explore innovative approaches, such as infrastructure sharing business models, that can reduce costs and accelerate network deployment.

Infrastructure sharing involves the collaborative use of network infrastructure among multiple operators. By sharing both active and passive equipment, operators can significantly lower the total cost of ownership while enhancing network quality. This approach has shown promising results in various deployment scenarios, offering benefits such as reduced costs, improved network coverage, increased capacity, and faster rollout. In the context of 5G broadband deployment in European rural areas, this paper aims to conduct a techno-economic study to determine the most cost-effective infrastructure sharing business model. The study fills a research gap by focusing on evaluating these models on a per-country basis, considering the unique characteristics of each country and utilizing real data from Eurostat [1][2][3][4] and World Bank [5].

This paper presents a techno-economic analysis to assess the feasibility of the development of a 5G Standalone FWA and Mobile Broadband network in different types of rural areas based on household density. The European countries have been taken as case studies, twenty-four (24) in total, i.e., all the European countries except the UK, Luxembourg, Malta and Cyprus because for these countries there is no accurate data available at the time of the study.

The techno-economic analysis in this study is based on a bottom-up model using DCF analysis. The model incorporates both Mobile Broadband and FWA use cases to capture the full potential of 5G SA networks. Demand forecasting models, based on the diffusion characteristics of broadband telecom services, are used to estimate future demand in rural areas. The analysis is adjusted to consider different infrastructure sharing business models, including Single Host Network (SHN), Multiple Host Network (MHN) via Passive Sharing and Active Sharing, and Neutral Host Network (NHN). The expected results of this study include Total Cost (CAPEX+OPEX) results, Net Present Value (NPV), Internal Rate of Return (IRR), Return on Investment (ROI), and payback periods, for each infrastructure sharing model in each country. Sensitivity and risk analyses are conducted to identify the most influential factors impacting the investment viability of each model and case. Additionally, the study will explore the profitability of each scenario, considering the ARPU and demand conditions required for investment sustainability.

The findings of this research can contribute to the ongoing discussions among academia, industry stakeholders, and policymakers regarding network sharing schemes in rural areas. By identifying the most cost-effective infrastructure sharing models for European countries, the study aims to facilitate the discussion about the deployment of affordable broadband in rural areas for narrowing the digital divide. Ultimately, the research aims to provide decision-makers with actionable insights to stimulate private sector investment, enhance connectivity, and foster sustainable economic growth in European rural regions.

The subsequent sections of this paper are organized as follows: Section 2 provides a comprehensive review of the literature on 5G infrastructure sharing models for broadband deployment, with a focus on rural areas, highlighting the existing gaps. Section 3 outlines the methodology employed to develop the 5G Techno-Economic model. Section 4 presents the results obtained from applying the findings of the techno-economic analysis for each infrastructure sharing model (SHN, MHN, and NHN) in different European countries. It includes cash flow results, financial indexes, and sensitivity and risk analysis. Section 5 discusses the implications of the findings. Finally, Section 6 concludes the paper and suggests potential avenues for further research.

2 Literature review

Infrastructure sharing has garnered significant attention in recent years as a cost-effective approach for expanding broadband coverage, particularly in areas with limited population density and high infrastructure costs. Several studies have investigated the advantages and challenges associated with each infrastructure sharing model, shedding light on their potential benefits.

In [6], Smail and Weijia focus on the techno-economic analysis and prediction for the deployment of 5G mobile networks. Their study demonstrates the benefits of 5G in terms of lower costs compared to 4G LTE, increased average data consumption offered by 5G technologies, and the importance of analyzing the Price Elasticity of Volume as a margin of benefit. The authors also highlight the impact of reusing existing sites and the limitations related to capacity and coverage in certain scenarios. Oughton *et al* [7] present a scenario-based assessment of 5G infrastructure strategies in relation to mobile traffic growth. Using an open-source modelling framework, they quantify the uncertainty associated with demand and supply, emphasizing the role of spectrum strategies and small cell deployments. The analysis underscores the importance of adapting business models to address increasing traffic growth and boost revenues by exploiting technological developments such as IoT and Smart Cities.

Wisely *et al* [8] conduct a techno-economic analysis of 5G enhanced mobile broadband scenarios in dense urban areas. Their study models different density networks at various frequency bands and evaluates deployment options in terms of capacity, headline rate, and cost. The analysis highlights the feasibility of achieving high headline rates with certain technology options but also emphasizes the significant cost increase compared to LTE networks. In [9], Yaghoubi *et al* present a comprehensive techno-economic framework for estimating the total cost of ownership (TCO) and analyzing the business viability of 5G transport networks. Their study focuses on the backhaul segment and compares microwave and fiber technologies. The framework considers both capital expenditure and operational expenditure aspects. Gedel and Nwulu [10] present a techno-economic analysis of infrastructure sharing for 5G deployment, specifically investigating suitable passive infrastructure for 5G technology in Ghana and Africa. The study proposes a mathematical model to calculate costs, total cost of investment (TCI), TCO, and NPV. Their experiments and sensitivity analysis provide insights into variables affecting TCO/TCI, NPV, and ROI. The findings provide insights into the most economical passive infrastructure architecture for implementing 5G technology in Ghana and Africa. Research by Kumar *et al* [11] with the goal to minimize the digital divide, explores the techno-economic feasibility of using network slicing with 5G NHN infrastructure sharing model in the rural areas of India. The study underscores the considerable potential of deploying 5G NHN with network slicing as a means to substantially decrease the overall capital investment necessary for provisioning 5G services in rural areas.

Additionally, in [12] the authors explore the various infrastructure sharing models, including SHN, MHN via Passive Sharing and Active Sharing, and NHN. Their findings indicate the efficacy of a rural 5G NHN strategy in reducing the total cost by 10-50% when compared to other sharing strategies. Moreover, their analysis reveals that, in comparison to a baseline strategy with No Sharing, rural 5G sharing strategies yield a net present value that can generate between 30-90% higher profits. The outcomes of this research underscore the potential economic advantages of implementing an NHN approach in rural areas, demonstrating the feasibility of utilizing this infrastructure sharing model to enhance cost-efficiency and financial returns. Moreover, the Business Models (BMs) for 5G sliced systems play a crucial role in infrastructure sharing. A study by Borcoci *et al* [13] provides a comprehensive overview and comparative analysis of various business models (BMs) specifically tailored for 5G sliced systems, and also defines the BM for a novel EU research project.

Despite the extensive research on infrastructure sharing models, the literature lacks a comprehensive analysis of these models on a per-country basis, specifically focusing on the rural areas of European countries. This study aims to address this research gap by performing a techno-economic analysis that incorporates real data from EU statistics and considers the unique characteristics of each country. By filling this gap, the study intends to provide decision-makers, policymakers, and industry stakeholders with valuable insights for formulating investment strategies and policies tailored to the specific requirements of European rural areas.

The analysis performed in our work is based on 5G SA as described in [14], and the model used is a based on an extended version of [15] where both Mobile Broadband along with Fixed Wireless Access (FWA) use cases are taken into account.

In summary, the literature review demonstrates the growing interest in infrastructure sharing as a cost-effective approach for broadband deployment. It highlights the need for accurate techno-economic analysis, regulatory support, and technological advancements such as network slicing to maximize the benefits of infrastructure sharing models. The gaps identified in the literature underscore the importance of this study in evaluating infrastructure sharing business models in European rural areas, contributing to the ongoing discussions within the research community and informing practical solutions for bridging the digital divide.

3 Methodology

In this study, an economic and financial analysis is conducted to assess the feasibility of deploying a 5G Mobile Broadband and FWA network in a rural area. The objective is to evaluate the revenue potential and predict the associated costs. The techno-economic methodology employed utilizes a bottom-up approach, specifically employing a DCF analysis to evaluate the financial aspects of network deployment, operation, and maintenance.

The study assumes an eight-year study period spanning from 2023 to 2033, which is a reasonable timeframe for broadband network deployments, considering the typical duration required to achieve market maturity. Key factors that need to be defined include the market penetration of services, the corresponding tariffs for these services, and the market share of the network operator. These parameters play a crucial role in determining the financial viability of the network deployment. To facilitate the analysis, demand and price forecasts are incorporated into the evaluation. These forecasts are crucial in calculating the network components required for the deployment and estimating the revenues generated by the network services. For the purpose of forecasting, the TONIC model is selected. The TONIC model [17],[18],[19] is well-suited for capturing the diffusion-type characteristics of broadband telecom services. The study considers two service offerings: the FWA service, which supports a download speed of 1Gbps, and the Mobile Broadband service, which offers a download speed of at least 100Mbps. These service offerings aim to cater to the varying needs and preferences of potential customers.

As part of the case studies conducted in this research, a total of 24 countries were analyzed, encompassing all European countries except for the United Kingdom, Luxembourg, Malta, and Cyprus. These four countries were excluded from the analysis due to the unavailability of accurate data necessary for the study. For each of the included countries, specific parameters related to rural areas were utilized to determine the appropriate dimensioning and coverage requirements, as well as to estimate the demand for broadband services. The parameters considered included the total size of the rural area and rural population [5] as well as the number of rural households [1] and active enterprises [2] within each country. These variables were crucial in assessing the scope and scale of the deployment, as well as in estimating the level of demand for broadband services in rural areas.

Two distinct types of area sizes are considered for network dimensioning in this study. The first type is known as the Rural Settlement Area [3], which encompasses residential rural regions where significant capacity requirements are anticipated for both Fixed Wireless Access (FWA) and Mobile services (**Fig. 1**). The Rural Settlement Area is characterized by the need to cater to substantial data demands from residential users. The second type is referred to as the Non-Residential Rural Area, which encompasses non-residential land in rural areas. In this type of area, the primary focus is on providing mobile services and ensuring adequate coverage rather than addressing high capacity requirements.

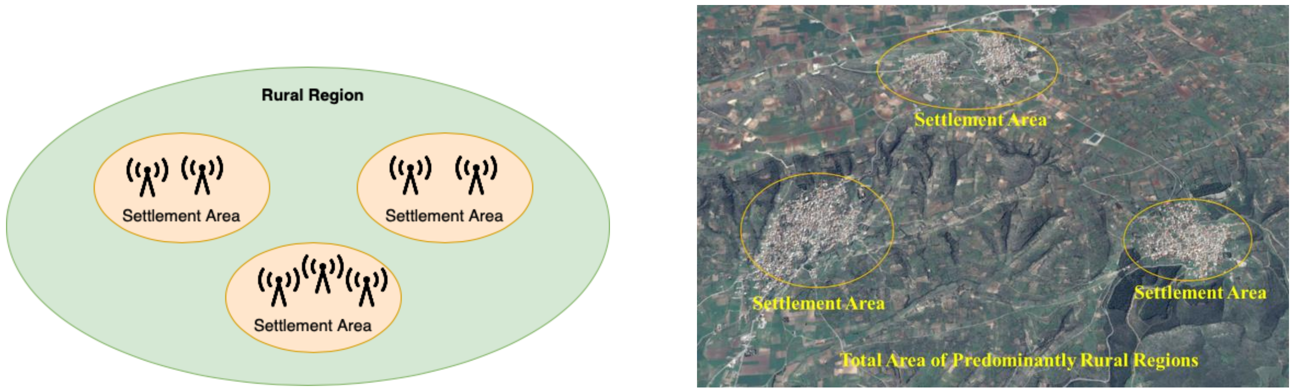

Fig. 1. Total Area of Predominantly Rural Regions (Geographical mapping).

The Rural Settlement Area is estimated with the use of the following equations:

$$Rural\_Settlement\_Area\_Size = Total\_Area\_of\_Predominantly\_Rural\_Regions\ x\ Settlement\_Area\_Percentage \quad (1)$$

where

$$Settlement\_Area\_Percentage = Settlement\_Area \,/\, Total\_land_{cover} \quad (2)$$

The Non-Residential Rural Area is calculated as

$$NonResidential\_Rural\_Area\_Size = Total\_Area\_of\_Predominantly\_Rural\_Regions - Rural\_Settlement\_Area\_Size \quad (3)$$

The *Total_Area_of_Predominantly_Rural_Regions* is based on EUROSTAT data of predominantly rural regions (based on NUTS 3 regions) [4] shown in the following map (**Fig. 2**).

Finally, the main geotype inputs of the model for each country are presented in **Table *1***.

Table 1. European Countries Rural Characteristics.

EU Country	Total Rural Area (km^2)	Rural Settlement Area (km^2)	Rural Population	Rural Households & Enterprises	Rural Population Density (pop/km^2)	Rural Settlement Population Density (pop/km^2)
Austria	62,182	4,841	3,672,325	1,639,784	44	759
Belgium	9,956	2,159	218,295	724,035	8	102
Bulgaria	24,302	962	1,648,939	889,331	15	1714
Croatia	35,233	1,847	1,642,337	593,033	30	890
Czechia	28,269	2,413	2,709,018	1,797,534	35	1123
Denmark	21,598	3,065	688,752	1,243,045	17	225
Estonia	35,791	1,546	407,066	288,006	9	264
Finland	251,171	10,015	798,128	919,306	3	80
France	327,760	33,762	12,708,476	11,753,633	24	377
Germany	136,344	18,522	18,682,511	8,249,638	53	1009
Greece	81,389	4,715	2,124,201	1,157,366	17	451
Hungary	25,049	2,137	2,694,980	1,267,434	29	1262
Ireland	60,877	4,089	1,816,369	891,523	26	445
Italy	76,067	7,376	16,937,284	4,648,436	57	2297
Latvia	25,651	980	595,103	294,719	10	608
Lithuania	8,656	406	889,294	555,168	14	2190
Netherlands	741	156	1,302,355	812,250	35	8369
Poland	164,903	12,724	15,070,539	4,663,458	49	1185
Portugal	71,990	5,730	3,422,889	1,247,962	39	598
Romania	158,691	6,870	8,732,240	3,193,054	37	1272
Slovakia	22,465	1,576	2,515,539	873,732	52	1597
Slovenia	14,650	934	939,634	391,459	47	1007
Spain	85,124	4,601	8,982,440	2,654,672	19	1953
Sweden	99,686	5,012	1,225,108	1,530,182	3	245

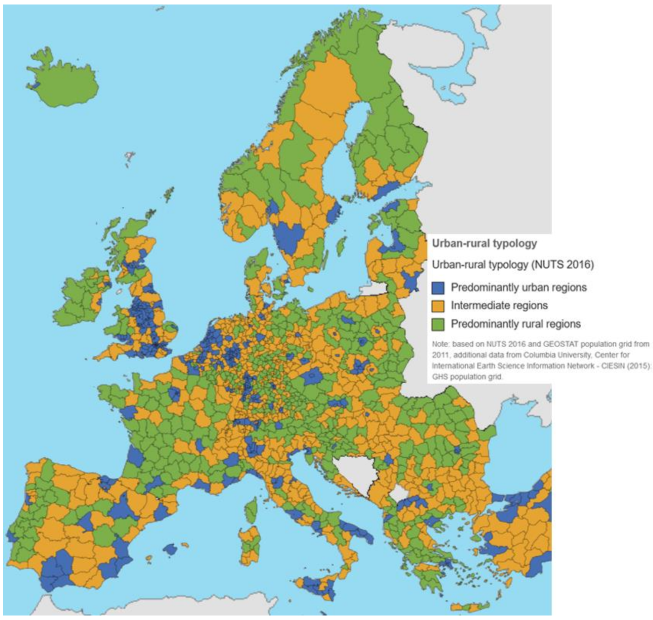

Fig. 2. Urban-Rural Topology Map (NUTS 2016).

3.1 Demand Forecasts

The Tonic model, developed as part of the IST-TONIC project, was selected for its ability to accurately fit historical data related to high-technology products [17],[18],[19]. The demand model utilized in this study, for each of the countries separately, is represented by the following equation:

$$Y(t) = \frac{M}{(1 + e^{\alpha + b*t})^c}$$

where Y(t) represents the forecasted demand at time t, while M denotes the saturation level of penetration, which is estimated a priori. The parameters α, b, and c are estimated through a stepwise procedure, employing nonlinear regression techniques [20] to determine their values.

The diagram below (**Fig. 3**) illustrates the projected percentage rate of users (service penetration %). According to the analysis, it is anticipated that network penetration for FWA service will reach 58.6% of HHs and enterprises covered by the year 2033 (low demand scenario) and 80% of population (high demand scenario) for Mobile services.

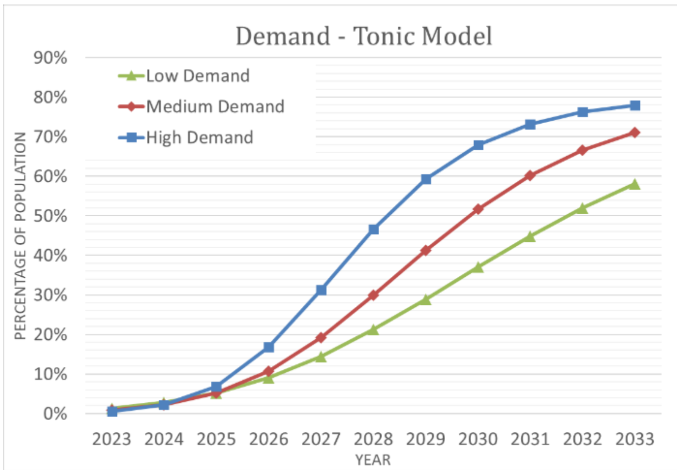

Fig. 3. Predicted Service Penetration (%).

3.2 Pricing Model

The pricing of the two services plays an important role in determining the economic viability of the network deployment. In our analysis, we propose setting the FWA service price at 2 times higher than the Mobile Broadband service price. This pricing strategy takes into account the enhanced capabilities and higher bandwidth provided by the FWA service, justifying a higher price point. By appropriately pricing the FWA service, sufficient revenue can be generated along with Mobile services which mainly cover the investment costs and operational expenses associated with the deployment of the 5G network in rural areas.

Another important pricing consideration is the Wholesale Tariff for the NHN. The NHN enables multiple operators to share the network infrastructure, promoting cost-efficiency and reducing duplication of resources. To facilitate the adoption of the NHN model and encourage operator participation, it is crucial to establish a competitive Wholesale Tariff. In our analysis, we propose setting the price for each slice of the network so that the wholesale ARPU is 65% of the retail ARPU. This tariff structure allows the NHN infrastructure operator to generate revenue while providing attractive pricing conditions for the slice tenants. The Wholesale Tariff, set at an optimal level, ensures that the NHN model remains economically viable and fosters fair competition among operators given that the current profit margin of operators is close to 35% [21].

3.3 Infrastructure Sharing Business Models

The current study examines five distinct Infrastructure Sharing business models, namely No Sharing (NS), Passive Site Sharing (PSS), Passive Backhaul Sharing (PBS), Active Sharing – MORAN (Multi-Operator Radio Access Network), and Neutral Host Network (NHN) with a single infrastructure operator. **Fig. 4** illustrates the characteristics of each strategy, with A, B and C being the three MNOs. This classification is similar to GSMAs [22] but MOCN (Multi-Operator Radio Access Network) is not examined in this study due to its close similarity to the NHN.

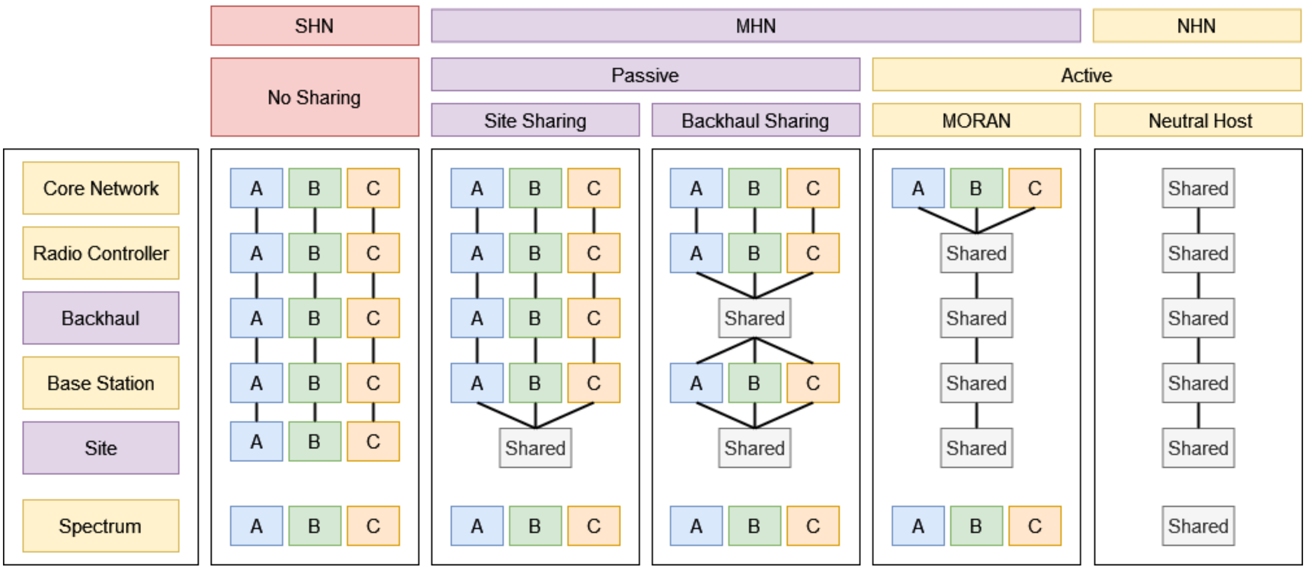

Fig. 4. 5G SA Infrastructure Sharing Business Models.

In the NS approach, each MNO maintains complete control over their network and associated equipment and therefore represents the Single Host Network (SHN) model. In the Multiple Host Network (MHN) model types, both PSS and PBS strategies fall under the umbrella of "Passive Sharing," with the former involving site sharing between MNOs and the latter encompassing the sharing of backhaul resources and sites. The MORAN strategy represents a deeper level of sharing, which is called Active Sharing, encompassing common network elements and resources from Radio Controllers to Sites. Finally, the NHN strategy facilitates end-to-end network sharing, including spectrum, among multiple slice tenants.

3.4 Technoeconomic Model Assumptions

The key assumptions and input parameters of the techno-economic model utilized in this study are outlined in **Table *2***. The analysis is based on an initial investment and deployment year of 2023, followed by an operation and investment study period spanning from 2024 to 2033, totaling 10 years. In terms of the network's technical characteristics, the deployment scenario considered is 5G SA. This deployment variant enables the delivery of innovative services, including low-latency services and network slicing, which are crucial for the NHN business model.

Table 2. Main parameters of the Techno-economic Model.

Parameter	Type	Value	Unit
Number of MNOs	Market	3	
Network Coverage	Market	100	%
Market share	Market	33	%
5G FWA take-up (in 2033)	Market	58.6	%
5G Mobile take-up (in 2033)	Market	80	%
Annual Churn Rate	Market	2	%
Initial Investment Year	Economic	2023	Year
Investment Duration	Economic	10	years
Default Retail Mobile monthly ARPU	Economic	15	€
Default Retail Fixed monthly ARPU	Economic	2	x Mobile ARPU
Wholesale ARPU (for NHN)	Economic	65	% of retail ARPU
Annual Tariff Degression	Economic	2	%
Taxes	Economic	20	%
WACC (Discount Rate)	Economic	10	%
Average OPEX annual increase	Economic	2.5	%
Spectrum	Technical	700MHz (10MHz BW) 3.6GHz (100MHz BW) 30GHz (400MHz BW)	
Macro Cell range	Technical	1 - 3	kilometers
Small Cell range	Technical	< 100	meters
Sectors	Technical	3	
FWA service capacity	Technical	1	Gbps
Mobile service capacity	Technical	> 100	Mbps
Sites per MEC	Technical	30	
Spectrum	CAPEX	0.03	€ per MHz/population
Macro Cell New Site	CAPEX	122,800	€
Macro Cell Existing Site	CAPEX	91,800	€
Small Cell New Site	CAPEX	42,800	€
MEC	CAPEX	147,000	€
Fiber Backhaul	CAPEX	15,000	€ per kilometer
FWA CPE	CAPEX	150	€ per household
Macro Cell New Site	OPEX	3,200	€
Macro Cell Existing Site	OPEX	2,200	€
Small Cell New Site	OPEX	1,800	€
MEC	OPEX	4,500	€

Regarding spectrum allocation, the 700MHz band is primarily allocated for non-residential rural areas to ensure extensive coverage. In contrast, the 3.6GHz and 30GHz bands are allocated in settlement rural areas, where capacity requirements play a significant role. In non-residential rural areas, it is assumed that existing Macrocell Towers can be fully reused, resulting in a 100% reuse rate. However, no reuse is considered for Macrocell and SmallCell deployments in settlement areas. Additionally, for the provision of Fixed Wireless Access (FWA) services, Macrocells are designed to have a maximum range of 1 km. Each household within the coverage area is equipped with Customer Premises Equipment (CPEs) and outdoor antennas (**Fig. 5**).

Furthermore, the analysis assumes full reuse of the existing 5G Core network due to prior investments in urban areas. Only incremental upgrades specific to the 5G SA core network for rural areas are considered, with associated costs taken into account. Finally, it is worth noting that each operator has a market share of about 33% assuming 3 mobile operators and infrastructure owners in these areas except for NHN where only infrastructure owner is considered with 33% of retail market share and 100% of wholesale market share. Finally, an annual churn rate of 2% is used in every demand forecast scenario.

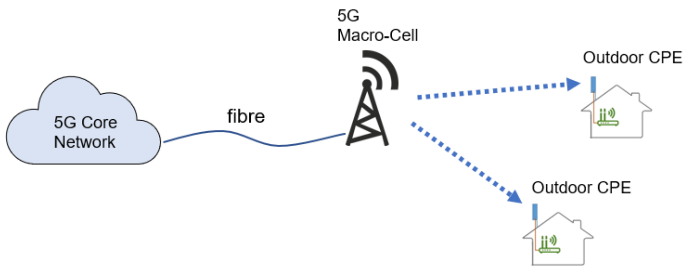

Fig. 5. 5G FWA deployment

3.5 Country Groups

In order to facilitate analysis and comparison, the results obtained for each individual country have been grouped into five distinct country groups (**Fig. 3**). The grouping of countries was determined based on two key factors: Rural Population Density and Rural Settlement Population Density. By clustering countries with similar characteristics in terms of these density metrics, we aimed to create meaningful country groups that would enable a comprehensive examination of the techno-economic feasibility of deploying 5G broadband networks in rural areas.

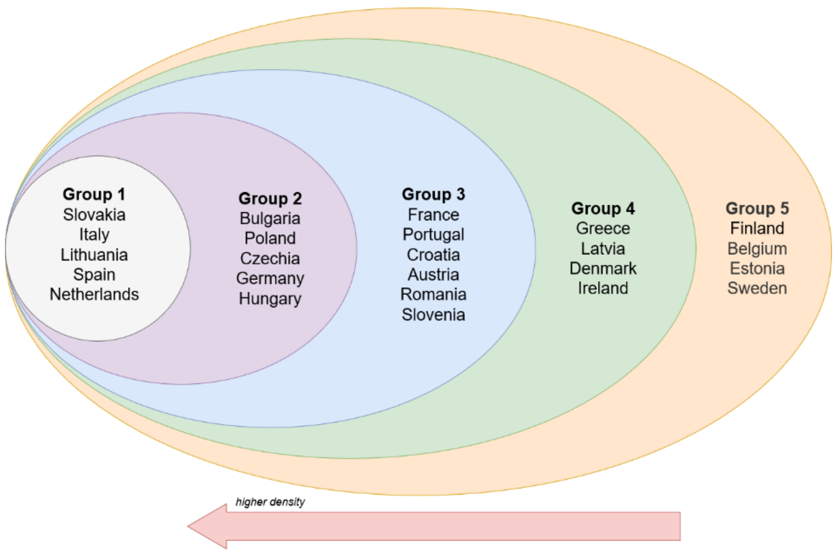

Fig. 6. Country Grouping based on Rural Population Density and Rural Settlement Population Density.

This approach allows for a more systematic evaluation and identification of patterns or trends within each group, enhancing the overall understanding of the impact of population density on the cost-effectiveness and viability of broadband deployment strategies.

4 Results

Using the country grouping described in the methodology section, the following figures include a synopsis of the results.

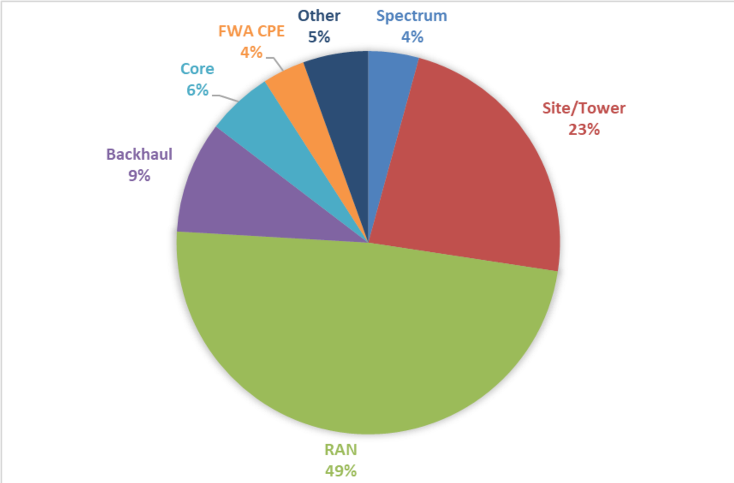

Fig. 7. Cost of each network component with respect to the total network cost.

The graphical representation in **Fig. 7** illustrates the distribution of costs within the 5G SA network infrastructure. The analysis reveals that RAN (Radio Access Network), i.e. radio equipment and controllers, accounts for the largest portion, comprising approximately 49% of the total network costs. The Site/Tower infrastructure constitutes approximately 23% of the costs, highlighting its significant contribution to the overall expenditure. Spectrum acquisition and management represent around 4% of the total costs, while Backhaul infrastructure contributes approximately 9% to the network expenses. The Core network components, including its associated functionalities and operations, constitute approximately 6% of the total costs. Additionally, the costs associated with FWA Customer Premises Equipment (FWA CPE) represent around 4% of the overall expenditure. Additionally, other miscellaneous costs e.g., General and Administrative costs (G&A), account for approximately 5% of the total network cost. Finally, OPEX ranges from 27% to 39% of the total service cost while annualized CAPEX is between 73% and 61%.

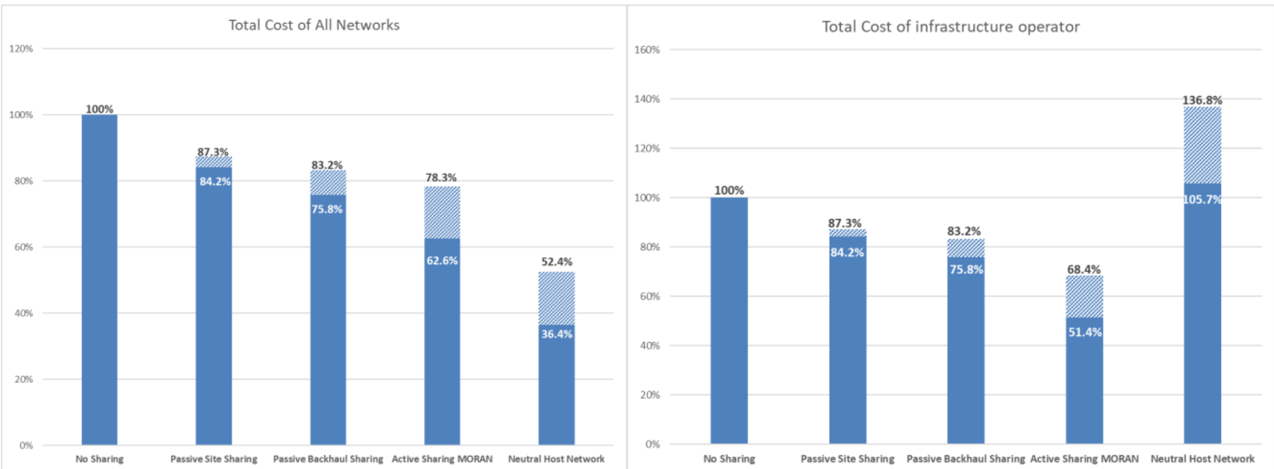

Fig. 8. Total cost of all networks and total cost of the infrastructure operator for each infrastructure sharing business model.

The analysis begins by considering the NS scenario, where the total cost of all networks is set at 100%. Building upon this baseline, our analysis reveals that as infrastructure sharing models progress towards deeper levels of sharing, the total cost of all networks demonstrates a consistent decrease (**Fig. 8**). In the context of different country groups, the adoption of the PSS business model results in total costs ranging from 84.2% to 87.3% compared to the NS scenario. Similarly, the utilization of the PBS business model yields total costs ranging from 75.8% to 83.2%. The MORAN business model shows a further decrease, with total costs spanning from 62.8% to 78.3%. Finally, the NHN business model emerges as the most cost-efficient, with total costs ranging from 36.4% to 52.4% for the respective country groups.

Likewise, the total cost incurred by the infrastructure operators in the NS scenario is established at 100%. Within different country groups, the implementation of the PSS business model produces total costs ranging from 84.2% to 87.3%. Similarly, the adoption of the PBS business model results in total costs spanning from 75.8% to 83.2%. Notably, the MORAN business model exhibits a further reduction in total costs, ranging from 51.4% to 68.4%. However, it is important to note that the NHN business model deviates from this trend, as it leads to an increase in total costs, ranging from 105.7% to 136.8%. This can be attributed to the fact that under the NHN model, the single infrastructure investor is responsible for providing network coverage with sufficient network capacity to the entire subscriber base, thereby experiencing additional expenses due to higher network densification and network management.

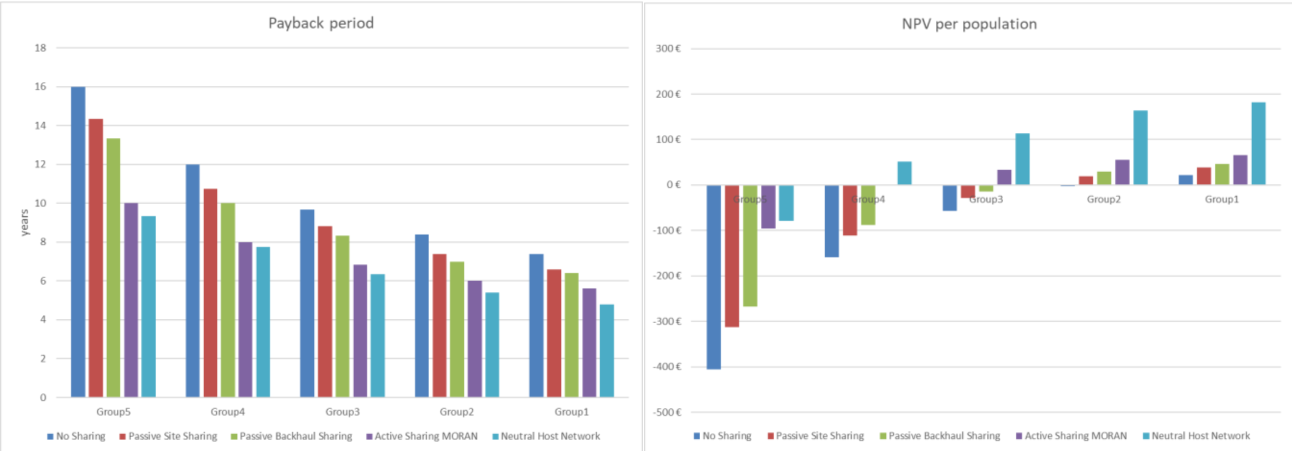

Fig. 9. Payback period and NPV per rural population for each country group and infrastructure sharing business model.

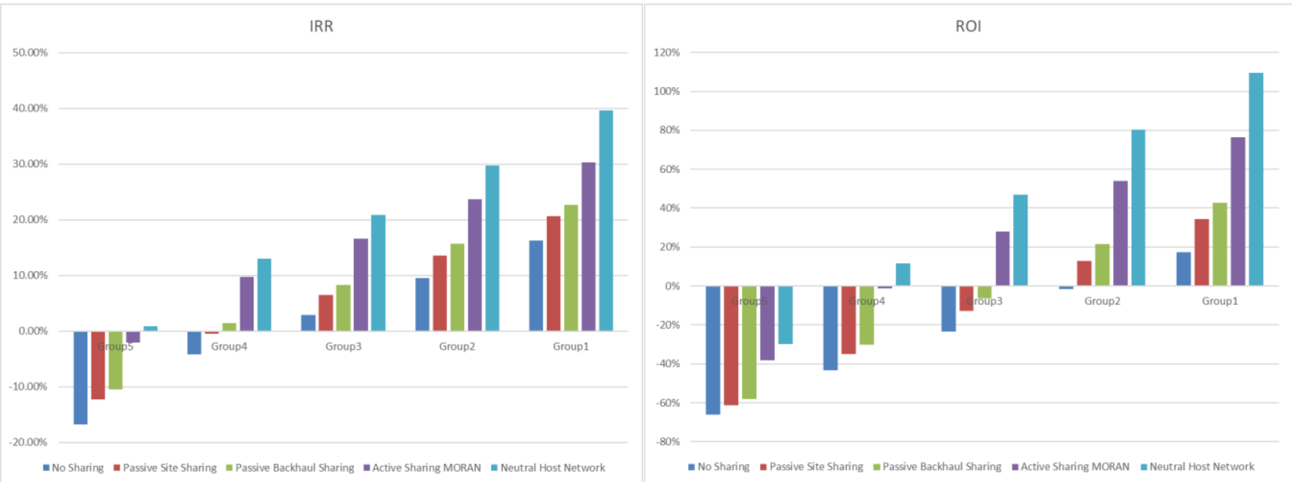

Fig. 10. IRR and ROI indexes for each country group and infrastructure sharing business model.

Fig. 9 and **Fig. 10** present a comprehensive analysis of the Payback period, NPV per rural population, IRR, ROI for each country group and infrastructure sharing business model. The results provide valuable insights into the financial performance and viability of different approaches in deploying 5G SA networks in rural areas. Firstly, the charts highlight that both the NS scenario, the PSS and the PBS models in Group 5 exhibit payback periods longer than the 10-year study period. This suggests that these combinations may require a longer time to recover the initial investment compared to the other infrastructure sharing models and country groups. Secondly, the analysis reveals that country groups characterized by higher population density tend to perform better across all indices. These dense country groups demonstrate shorter payback periods, higher NPV per rural population, higher IRR, and higher ROI. This indicates that the potential return on investment and financial viability of deploying 5G networks in rural areas are generally more favorable in countries with higher rural population density. Furthermore, the charts illustrate a consistent trend where deeper levels of infrastructure sharing lead to improved performance for each country group. As the level of sharing increases, the payback periods decrease, the NPV per rural population increases, the IRR improves, and the ROI becomes more attractive. This underscores the potential benefits and cost-effectiveness of adopting infrastructure sharing models which involve greater collaboration and resource pooling among network operators.

Additionally, the minimum monthly ARPU required in order to achieve an NPV of zero was calculated as an average for each country group (**Fig. 11**). It is worth noting that the NHN ARPU is many cases less than half the ARPU of the NS scenario, following the trend of cost reduction in the total cost of all networks in the area.

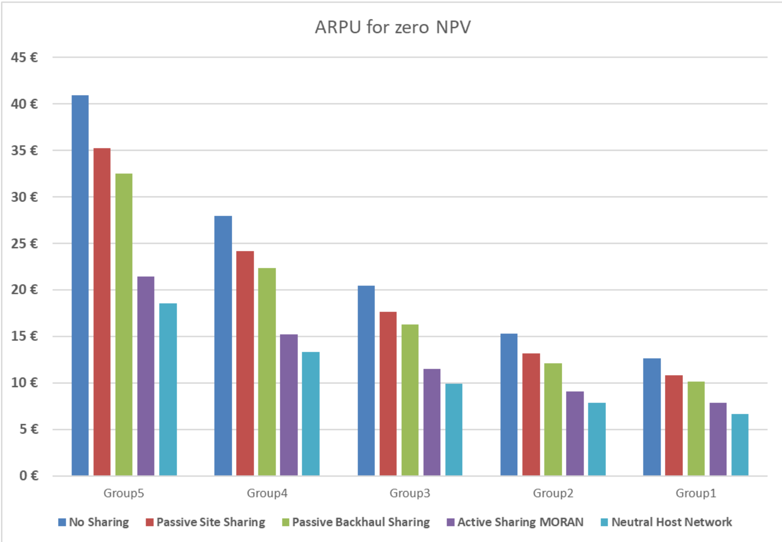

Fig. 11. Necessary minimum ARPU for NPV = 0.

A sensitivity analysis of the model has been carried out in order to rank the most important input parameters according to their impact on the IRR results (**Fig. 12**). Currently the 10 most important parameters are shown for the NS and the NHN scenario which includes wholesale services through slicing. As expected, ARPU is the most important parameter for the final results along with the expected demand levels (service take-up). Furthermore, the costs of Macrocell, Spectrum and Backhaul are of high importance in all cases. However, it is important to note that market share is a crucial parameter in all scenarios except for NHN in which the dominance of a single infrastructure operator in the wholesale market makes the wholesale tariff (price of network slice) one of the key decision factors for the profitability of the investment.

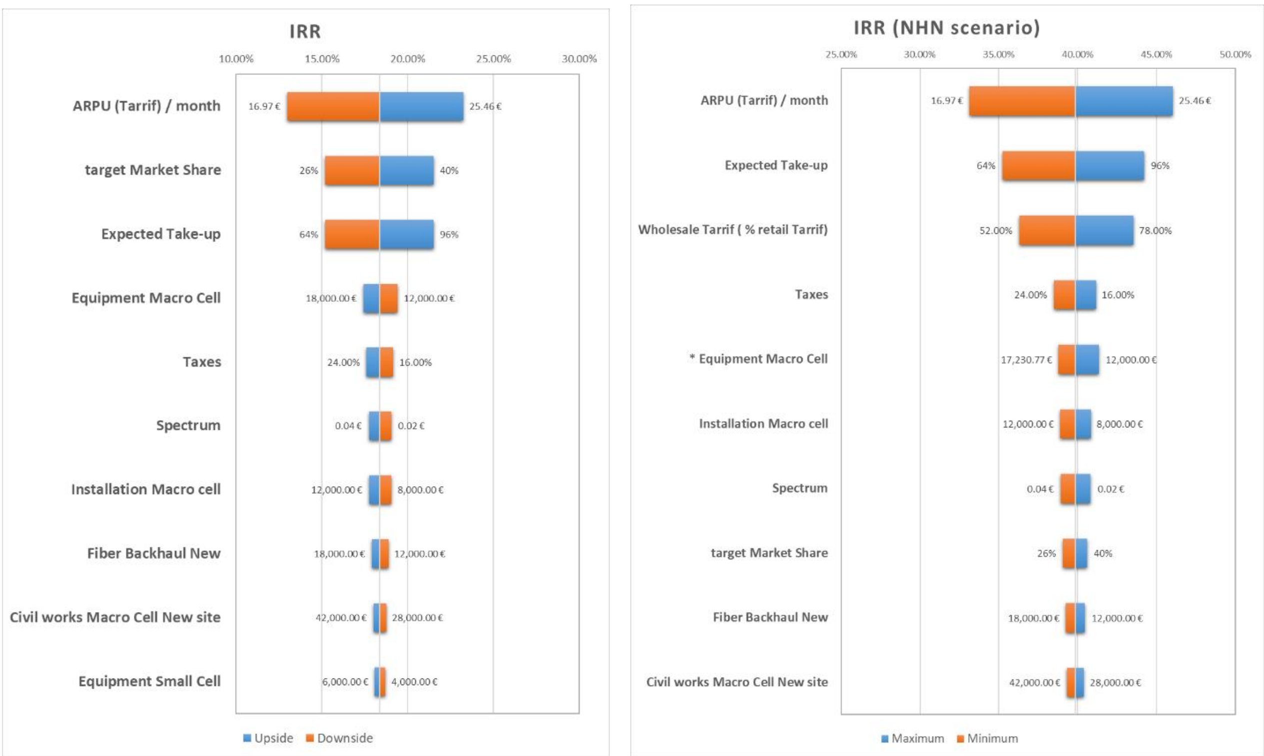

Fig. 12. Sensitivity analysis in the No Sharing (left) and NHN scenario (right).

5 Discussion

The aim of this study was to perform a techno-economic analysis to determine the most cost-effective infrastructure sharing business models for providing affordable broadband in European rural areas. By analyzing the results obtained from our analysis, we can now delve into their implications and discuss their significance. Our findings revealed that the deployment of 5G broadband networks in rural areas can be economically viable by leveraging infrastructure sharing business models (MHN). Specifically, the network slicing and Neutral Host Network models emerged as promising approaches to reduce costs and accelerate network deployment. These models offer opportunities for cost-sharing among mobile operators, thereby addressing the high infrastructure costs associated with rural areas' unique characteristics.

More specifically, the following key topics emerged from our analysis:

1. The deployment of 5G SA networks in rural areas offers the potential to not only meet mobile broadband requirements but also competently address the fixed broadband needs outlined by the European gigabit society. Through the utilization of FWA technology, these networks can provide high-speed internet access to rural communities, bridging the digital divide. Additionally, the introduction of 5G SA enables the provision of new services such as IoT, Industry 4.0, and Unmanned Mobility, which can significantly contribute to the economic development of rural areas. Furthermore, 5G SA is a prerequisite for NHN business model as it allows the use of slicing for network sharing.

2. The viability of investments in 5G SA networks varies across countries and is influenced by multiple factors. One crucial consideration is the density of residential areas, as they require higher capacity to meet the demands of FWA services. Simultaneously, the overall density of rural areas, including non-residential regions, affects the coverage requirements. The interplay between capacity and coverage influences the financial outcomes of investments, such as the NPV, IRR and ROI, which need to be carefully evaluated to determine the feasibility of network deployment in each country.

3. Our analysis indicates that as infrastructure sharing models involve deeper levels of sharing, the total cost of all providers and networks decreases. However, it is essential to address potential challenges related to reduced competition that may arise when infrastructure ownership becomes concentrated in fewer hands. Particularly, in the

case of NHN models, where wholesale monopolies may emerge, careful consideration and potential regulation of network slicing pricing are necessary to ensure fair market conditions and encourage healthy competition among service providers.

4. From the perspective of rollout providers, the overall cost of deploying NHN models tends to increase since they are required to provide network coverage for the entire subscriber base. However, providers benefit from exclusive access to wholesale revenues, derived from offering network services through slicing arrangements. The viability of investments in NHN models is highly dependent on critical factors such as the ARPU for wholesale services. Therefore, careful assessment of these parameters on a case-by-case basis is crucial, taking into account the specific characteristics and demands of each country, to determine the optimal wholesale pricing for network slicing and ensure the profitability of investments.

5. While NHN models emerge as the most cost-effective option, it is important to carefully consider the impact on competition and the potential monopolistic conditions that may arise from concentrated infrastructure ownership [23], [24]. Our findings suggest that alternative sharing schemes have demonstrated sufficient economic viability in certain countries. Therefore, the deployment of NHN networks should be considered mostly in cases where other sharing models are not economically feasible. Balancing the need for cost-effective broadband solutions with maintaining healthy competition is crucial to promote fair market conditions and drive sustainable development in rural areas.

6 Conclusions

This study focuses on evaluating the feasibility of deploying 5G infrastructure and employing various infrastructure sharing business models to provide high-capacity broadband services in rural areas of Europe. The aim is to identify the most cost-effective sharing model for delivering affordable mobile and fixed broadband services. To assess the cost-effectiveness of different sharing models, a per-country evaluation of 5G infrastructure sharing was conducted. The analysis utilized a bottom-up network modeling and costing approach, employing DCF analysis. The infrastructure sharing models considered in the evaluation were NS, PSS, PBS, MORAN, and NHN.

The findings reveal that the Neutral Host Network model consistently emerges as the most cost-efficient business model for delivering high-capacity broadband services in all examined cases. However, in sparsely populated rural areas of certain countries, the No Sharing and Passive Sharing models do not yield profitability during the study period, despite assuming a high enough price (ARPU). The viability of the investment is strongly influenced by the rural population density of each country, particularly when considering the size of the settlement areas. Active sharing (MORAN) and NHN are

In terms of regulatory policy, this study also highlights that low service penetration and high investment costs significantly diminish the profitability of infrastructure-based competition scenarios, leading to market failure. To ensure the profitability of investments in the No Sharing scenario, a considerably higher ARPU, more than double compared to NHN, is required. Therefore, it is important to carefully define the necessary conditions for NHN deployment on a case-by-case basis and implement appropriate regulations to address the monopolistic conditions associated with it. Additionally, the wholesale price, specifically the cost of network slicing, plays a crucial role in the investment's profitability for the NHN model.

Further studies should consider variations in willingness to pay, demand patterns, and differences in nominal unit costs and deployment costs among countries. Finally, the level of wholesale price of network slicing should be estimated in a per country basis. This would provide a more comprehensive understanding of the factors influencing the economic viability of network investments in rural areas.

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