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Network modelling approaches for calculating wholesale NGA prices: A full comparison based on the Greek fixed broadband market[*]

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Abstract

According to the 2013/466/EC Recommendation for setting copper and NGA wholesale access prices where cost orientation is imposed as a remedy, NRAs should adopt a BU LRIC+ costing methodology that estimates the current cost that a hypothetical efficient operator would incur to build a modern efficient NGA network. The starting point of modeling an efficient operator investing in NGA networks is the network modeling approach. In this paper, we compare the most widely adopted network modeling approaches in terms of wholesale FTTH prices. In particular, the modified scorched node approach is compared to the extreme cases of the scorched node and the scorched earth approaches. The comparison between the aforementioned scenarios sheds light on the impact of each approach on the wholesale FTTH prices. The main finding of this paper is that the scorched earth approach leads to a maximum of 10% reduction in the short-term access prices compared to the most inefficient scorched node approach, whereas further extending its optimizations by optimizing the number of central offices, both the short-term and long-term wholesale price reductions are quite significant (more than 20%) regardless of service speeds. Obviously, these findings provide valuable information to both network operators and telecom regulators.

Keywords: FTTH, (Modified) scorched node, scorched earth, wholesale NGA prices

JEL codes: L43, L51, L96

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1. Introduction

During the last decade, the demand for bandwidth has continuously been increasing due to the emergence of new digital applications and services, such as virtual reality and e-health, which require reliable networks in terms of speed, quality and responsiveness. Obviously, the legacy copper networks are incapable of meeting such trends, thus telecom operators are facing the crucial decision of deploying high-speed broadband infrastructures, the so-call Next Generation Access (NGA) networks.

According to the European Commission (EC) Recommendation on promoting competition and enhancing the broadband investment environment (2013/466/EC), *NGA networks means wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks* (European Commission, 2013).

The significance of NGA networks for the economy and the society has been highlighted in the Digital Agenda for Europe which seeks to ensure that, by 2020, (i) all Europeans will have access to much higher internet speeds of above 30 Mbps; and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps" (European Commission, 2010). In addition, the EC envisions a European Gigabit Society since its objective for 2025 is that all European households, rural or urban, will have access to Internet connectivity offering a downlink of at least 100 Mbps, upgradable to Gigabit speed (European Commission, 2016).

Recent empirical studies have tried to quantify the positive impact of investing in broadband infrastructures on the main economic and social indices. In general, the literature concludes that economic growth and employment are positively affected by the availability and the adoption of basic broadband (see the surveys of Briglauer, Frübing, & Vogelsang, 2015, and Abrardi & Cambini, 2019). Given that this positive impact on economic and social outputs is increasing in the broadband speed (Rohman & Bohlin, 2012), it is expected that ultra-fast broadband services delivered via NGA networks will have an even more profound effect on productivity, economic growth and job creation.

However, the main obstacles towards the deployment of such networks are the huge investment cost combined with demand and regulatory uncertainty (Tselekounis & Varoutas, 2013). However, it is admitted that "*the social benefits from investment in digital infrastructures by far exceed the private incentive for investment*" (EC, 2011). On the other hand, it is clearly stated that "*the cost savings in just four sectors of economy (transport, health, electricity and education) would justify the construction of a national fibre-to-the-home (FTTH) network* (OECD, 2009).

These views call for public intervention with the goal of encouraging investments in NGA networks without much distorting the competition level achieved through the regulation of the copper access networks. Although demand-driven and supply-driven subsidization policies work toward this direction, the reference point of this objective is the 2013/466/EC recommendation which describes the main costing methodology guidelines for estimating the wholesale price of accessing NGA networks.

According to the EC Recommendation for setting copper and NGA wholesale access prices where cost orientation is imposed as a remedy, NRAs should adopt a bottom-up long-run incremental costs plus (BU LRIC+) costing methodology that estimates the current cost that a hypothetical efficient operator would incur to build a modern efficient NGA network. The BU LRIC + methodology calculates the current costs on a forward-looking basis (i.e., based on up-to-date technologies, expected demand, etc.), while models the incremental capital and operating costs, as well as adds a mark-up for strict recovery of common costs.

Although the EC Recommendation shapes the main guidelines for calculating the cost of an efficient operator investing in NGA networks, it provides NRAs with sufficient flexibility to implement its proposed costing methodology. Indeed, when modeling an efficient operator, NRAs have to undertake some critical decisions which form the profile of such an operator. This task requires an elaborate analysis because it crucially affects the final results.

The starting point of modeling an efficient operator investing in NGA networks is the network modeling approach. According to the International Telecommunication Union (ITU), this decision is related to the adoption of a “scorched node” or a “scorched earth” approach. In the former case, cost modeling is based on the existing network topology, whereas, in the latter case, the costs are based on an ideal topology.

The scorched earth approach models a completely hypothetical fiber access network where optimally dimensioned equipment would be employed at locations that are ideally selected to complement the overall transmission design. In the scorched node approach, the modelled network topology relies on the nodes of an existent infrastructure, while any efficiency improvement is limited to the utilization of the most efficient hierarchies and transmission technologies that connect these nodes. A middle ground solution, the so-called modified scorched node approach, takes the number of existing nodes as given but allows for location-based optimization in order to alleviate some of the inefficiencies that can potentially accompany a scorched node model.

In this paper, we compare the three network modeling approaches in terms of wholesale NGA prices. For this reason, we model the Greek fixed broadband market by using the public BU-LRIC+ NGA model of the Greek NRA. The implemented modified scorched node approach is compared to: (i) the scorched node approach (based on GIS dimensioning of the existing node locations of the incumbent operator); and (ii) the scorched earth approach (based on the optimal number and location of nodes of an efficient operator). In each scenario, service demand and technology coverage remain the same along with other technical and cost assumptions for the network assets.

The comparison between the aforementioned scenarios indicates that the modeling approach chosen can have an important effect on the investment costs but also on the wholesale access prices on the long run. Therefore, NRAs should consider all the available modeling approaches based on careful evaluation of operators' investment plans and the policy goals on a forward-looking perspective. The efficiencies which can be achieved are heavily based on the geotype and the extend of network optimizations (i.e., merging of COs) or the dependence on legacy copper-based architectures. Consequently, these options can have a long-term cost effect on prices and could offer a competitive advantage to infrastructure owners in the absence of effective price regulation regarding the appropriate choice of modeling approach.

2. Implementation

An important methodological step that precedes the actual implementation of a technoeconomic model is the establishment of the principles and assumptions that characterize the network modeled. These principles answer foundational questions and provide guidelines that a crucial role every step of the way. The design, development of the model as well as its results, are all affected by those principles which are relative to general methodological decisions but also suggestions posed by the EC recommendation. The issues discussed in the methodological principles are bound to arise during the development of a technoeconomic model and as a result it is prudent to address them sooner rather than later. Establishing a solid methodological framework allows for an accurate description of the elusive hypothetic operator.

One of the first questions arising deals with the network's design and the degree to which it should be based on topologies of preexisting networks. If the modelled network utilizes legacy topology, it is said to be following the scorched node approach. Practically that would mean that central office and cabinet locations remain as is while the infrastructure is upgraded. A case can be made that preexisting networks can suffer from inefficiencies and that a new network should completely abandon previously used network deployments following the scorched earth approach. Both ways have their own advantages and disadvantages as scorched node can prove more suitable for deployments that rely heavily on infrastructure reuse while scorched earth can be the optimal solution when entirely new technologies are being introduced alleviating the reliance to legacy infrastructure. Another frequently used approach by European NRAs is that of the modified scorched node that combines some characteristics from both sides, based on existent network nodes but at the same time adopting the necessary optimizations to diminish inefficiencies. There is no consensus on the approach that should be used as best practice in NGA BU-LRIC+ models. However, according to the most recent BEREC (2019) report, the scorched node approach is most frequently used in practice (by 4 NRAs) followed by the modified scorched node (3 NRAs) and the scorched earth (1 NRA) approaches.

But to actually design an operator, the geographic coverage of its network needs to be decided. A discussion that might look easy to overcome but encompasses question marks related to what constitutes an efficient operator. Such an operator might not be keen on providing services in regions that are not profitable and then follows the identification of those regions. These decisions might be in contrast with the EC recommendation that considers the goals of the Digital Agenda 2020 as part of a suitable BU model. With a baseline goal of 30 Mbps access for all, implementing an operator that is maybe more efficient but does not provide adequate coverage would not be in line with the EC's suggestions. A way to untangle the subject is to exclude all subsidized regions from the implementation and consider all else as economically viable. A logical assumption and route as subsidies are mostly utilized for the deployment in locations where private operators show no intention of providing services while incorporating subsidized locations in a cost model would skew the results by including costly regions that are not part of a paid cost that should be recovered by the operators.

Regarding the Greek investment landscape, a unique multi-phase bidding process was adopted by the NRA, aiming to support fast NGA deployment. Operators were able to assume deployment responsibilities via regional bidding, selecting COs and underlying cabinets from the incumbent's legacy network. The first phase allows bidding only to the incumbent granting first mover advantage alongside an obligation to cover 80% of existing cabinets. The COs not selected by the incumbent become available to the other operators in the second phase with 50% coverage obligation. In the third phase, every operator can select from the remaining COs committing to a 30% coverage. This process helped accelerate the investment plans of the operators especially regarding the goal of creating a national network able to provide nationwide services.

The network that is developed can be described by its width as well as its scope, i.e., the part that is implemented on an architectural level. The services that are being modeled play a crucial role in understanding which parts of the infrastructure are being included in the calculations. In the case of this document, access services are being discussed and as a result only the necessary components that are utilized to provide the respective services are being modelled. More specifically that would mean the implementation of every component of the network that is located between the Layer 2 Aggregation point and the end user. That would include the central offices (COs) that house the L2A infrastructure as well as lower hierarchy COs, cabinets, equipment used by the end user and all infrastructure that is used to connect COs and end-users (e.g., trenches, ducts, manholes, MSANs, OLTs, fiber cables etc.).

To produce results, a cost model utilizes the expected demand for the services implemented and calculates the singular cost that each consumer would need to pay. So, another crucial detail is the achieved accuracy of the demand forecasts. Overestimation can lead to lower prices but impede cost recovery for operators, an undesirable after effect that would negatively affect the market as a whole. On the other hand, underestimation of the demand would lead to higher prices something that impacts not only consumers but once again the telecom market as wholesale providers can make more out of less essentially creating the environment for potential competition weakening. Understandably, there lies great difficulty in accurately predicting demand for new services and therefore state of the art algorithms for demand forecasting should be employed to lessen the chances of costly miscalculations. Additionally, as no local infrastructure-based competition is observed in the case discussed, a single wholesale provider is modelled simplifying demand and network calculation while also excluding the possibility of overlapping investments, consistent with the allocation process described previously.

In the previous two paragraphs the importance of clearly defining the services to be modeled is underlined. Firstly, to know which segments of the network should be included in the model implementation and secondly to conduct specific demand forecasts which will drive the cost allocation, i.e., the process of assigning the respective costs that the wholesale operator incurs to be able to provide each service. In this paper, only monthly recurring costs are being considered while one-off costs related to the services such as connection fees are not included and in particular for wholesale local access services.

The costing methodology utilized is the bottom-up long run incremental plus (BU-LRIC+) as is suggested by the EC recommendation, calculating the current cost, based on modern technologies and expected demand, that an efficient operator would incur supposing it was developing a brand-new NGA network able to provide identified services. The total capital and operational expenditures incurred to deploy such a network along with an added common costs increment constitute the total cost for the hypothetical operator. Each service is driving the cost for parts of the total cost and subsequently cost allocation takes place to establish each service's cost. Relative to the LRIC+ methodology is the study period selected that is impactful mostly regarding cost recovery and the identification of accurate prices for the assets that are being utilized by the model. The start of the study period should also be relevant to the decision-making rationale followed by the NRA but is not a choice that includes controversy.

Even though an NGA network is being modeled, according to the EC recommendation the BU model used for the costing should be able to do so for entirely copper based services as well and two approaches to accomplish that are proposed by the EC. The first is to replace optical elements with efficiently priced copper elements in the developed NGA model essentially allowing to create a two-for-one model able to implement both optical and copper solutions. The second solution proposed is to design two simultaneous overlaying networks, both NGA and copper that share to an extent the same civil infrastructure. Ideally the two approaches would be equivalent but the availability of data on legacy networks and the accuracy of forecasts on the diffusion of NGA services can potentially pose great difficulties. Regardless of approach, the degree to which infrastructure is reused by the NGA deployment is a deciding cost factor that relates closely to the greater question posed in this document and the suitability of the scorched earth perspective.

To allocate costs with the desired degree of accuracy the evaluation of the utilized assets needs to be properly conducted. Newly deployed and reusable assets are the two categories that take part in this evaluation. For those newly deployed the full cost is incurred and its modern equivalent asset when replacements are taking place during the study period. Those assets that are reusable should be evaluated, per recommendation, employing the indexation method to calculate current costs for the Regulatory Asset Base corresponding to the reusable legacy assets. The most important part of the discussion on reusable assets is not their evaluation, which can be done in a straightforward manner, but rather the effort to establish what constitutes a reusable asset and how big a part of the legacy copper network can be reused for the purposes of the NGA deployment.

The evaluation of the network's assets is followed methodologically by the way they are depreciated. Several depreciation methods can be used by a technoeconomic model with varied levels of complexity. A commonly used depreciation method for NGA networks in the EU is the Flat Annuity. Its main advantage is the inclusion of the weighted average cost of capital (WACC) in the calculations leading to complete recovery of costs. In the case where asset costs fluctuate in time, a more suitable method is the Tilted Flat Annuity that also considers asset price changes helping the model being truthful to price changes that influence the market that network providers are active in. The Economic Depreciation method can also be considered as it incorporates price dynamics created from demand changes, but is also delicate in that regard as demand fluctuations are hard to be accurately predicted.

The impact that WACC has on a model's results is well known among technoeconomic circles, thus its value is also subject to discussion as well as the parameters to be used for its calculation. The cost of debt, the cost of equity, the organization's total debt and the shareholder's equity should express the realities of the economy that surrounds the operator that is being modelled to be able to model a precise cost model.

In this paper, the case of deploying a single hypothetical nationwide FTTH network in Greece is modeled considering all mentioned methodological questions posed in the previous paragraphs. The model follows a modified scorched node approach mirroring the investing realities as expressed by the operators during the allocation process that the NRA adopted. The modified part comes mostly in the form of hierarchical optimizations and efficient trenching. All areas apart from those subsidized are modelled, a perspective consistent with the suggestions coming from the EC and the DAE 2020. Network modeling does not include core services but all parts that fall between the layer 2 aggregation point and the end user up to the building entry point (BEP) and the Floor Box, while the copper services are modeled by replacing the optical elements in the NGA model to create a copper network able to be used for copper costing purposes. However, FTTC service costing is not included in the current study which focuses mainly on FTTH network rollout and service pricing. Traditional LRIC+ methodology is employed assigning common costs and business overheads following the equi-proportionate mark-up methodology (EPMU).

To reach these conclusions and allow the development of a model capable of encompassing all these aspects, a thorough examination of modeling principles needs to be first conducted. Possible rigidity and lack of understanding of the issues discussed would most possibly bring forward great barriers that would impede a model's capacity for accurate costing especially considering the fact that a model that is set to decide on pricing can heavily impact the market for years to come.

3. Network modeling approach

In this section, the methodology of the three network approaches employed will be discussed. The most important differences and key points that enhance the use of each approach will be highlighted. In addition, the main implementation techniques used to extract the network dimensioning results will be discussed as well as the most important technical parameters that affect each approach.

Taking into account that total trenching length is one of the most important factors of total costs we focus mainly on reducing the trenching needed as well the number of FTTH cabinets. In the case of scorched earth approach, the total length of trenches is calculated by using a Spanning Tree algorithm in order to connect each building to the nearest central offices in terms of road/cable distance. The number of FTTH cabinets is calculated using the number of available fibers in each cabinet, the number of buildings and their respective average size in terms of households in each area. The number of central offices and their locations remains the same in the default scorched earth scenario. However, further extensions to this scenario are discussed in the results section of this paper. The scorched earth attempts to eliminate most of the inefficiencies of existing network design in order to model an efficient operator when new FTTB/FTTH networks are being deployed without any limitations posed by the regulatory framework. In the following figure, an example of trenching and the number of cabinets is given for a specific dense urban area in Greece.

Figure 1. Scorched earth sample of trenching (blue lines) and FTTH cabinets (red points) in dense urban area in Greece

Contrary to scorched earth, in the scorched node approach (Figure 2. Scorched node sample of trenching (green lines) and preexisting FTTH cabinets (red points) in dense urban area in Greece) the number and the historical locations of the existing cabinets and central offices are being used. Each cabinet is connected to its respective central office according to historical data regardless of road distance between the cabinet and other central offices. Then, each building is connected to the nearest cabinet using a Spanning Tree algorithm. The scorched node approach is usually implemented to calculate the cost of current networks when regulatory constraints (specific areas of deployment based on the historical location of nodes) and/or technical constraints (reusing the existing copper segment) are binding.

Figure 2. Scorched node sample of trenching (green lines) and preexisting FTTH cabinets (red points) in dense urban area in Greece

In the case of the modified scorched node, a location-based optimization is employed for the cabinet of each central office. The relocation is based on the geometric model used in Greek NRA's model where the total area size, the size of the populated area, the number of buildings and the number of cabinets are maintained but reshaped based on rectangle shaped road network (Figure 3) and optimal positions of the cabinets in the center of uniformly dense areas in order to reduce the trenching length. Although this modeling approach is based on GIS data as well as trenching samples, it is a hypothetical approach and is used in an effort to estimate the trenching and cabling requirements when optimizing only the location of the cabinets.

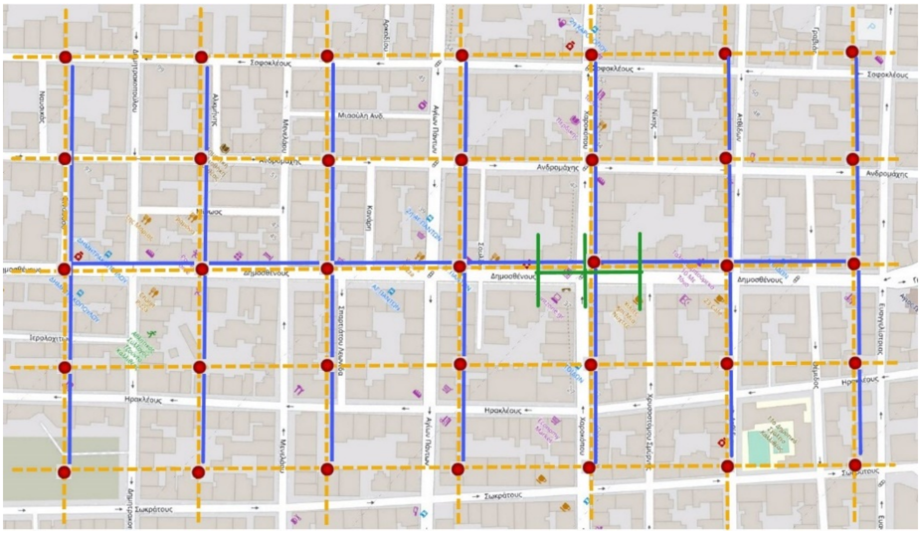

Figure 3. Modified scorched node example of trenching (blue and green lines) and preexisting FTTH cabinets (red points) in dense urban area reshaped based geometric modeling (yellow lines)

As already stated, the deployment of a single hypothetical nationwide FTTH network in Greece is modeled including all the areas of Greece regardless of subsidization scheme and the current investment plans expressed by the operators. All the other technical, economic and demand assumptions and modeling principles used in the Greek NGA model and discussed in the previous section, remain the same in all the scenarios assessed in this study. For the GIS data, the available road network and buildings data of the OpenStreetMaps were used along with data on buildings size and households of each area according to the Hellenic Statistical Authority (ELSTAT) database.

4. Results

The results of the technoeconomic model presented in this section will focus mainly on the total and per line cost of the FTTH network as well as the cost of providing wholesale access to FTTH services delivered to the Layer 2 aggregation points of the core network. These costs vary for each scenario and are mainly driven by the different results of the dimensioning model for each scenario, such as the number of FTTH cabinets (or flexibility points) and the total length of trenches required.

The financial and technical parameters of the public model have been kept constant in all three scenarios, treated as exogenous factors that are not directly related to the modeling of the network. As a result, WACC, Business Overheads and unit costs remain the same in all scenarios without any changes in the values of the public model. In addition, no changes have been made to the adoption forecasts of NGA services, the demand by service speed and the corresponding data traffic profile per subscriber provided by the Greek NRA. Modifying the design of the NGA network from an FTTC-FTTH hybrid network to a purely FTTH network for universal coverage is expected to cause changes to parameters such as WACC, Overheads and the demand for NGA services. However, any changes to these parameters are outside of the scope of this study and are not expected to affect its key conclusions.

As it has been already stated above, the main differences in the dimensioning of the three scenarios under study concern the number of cabinets and the resulting total trenching in the access network. The corresponding results of the dimensioning are shown in Figure 4. It is observed that there is a reduction of 38% in the number of cabinets in the scorched earth approach compared to the scorched node and modified scorched node. The number of cabinets in the modified scorched node does not change because only the location of the cabinets is optimized.

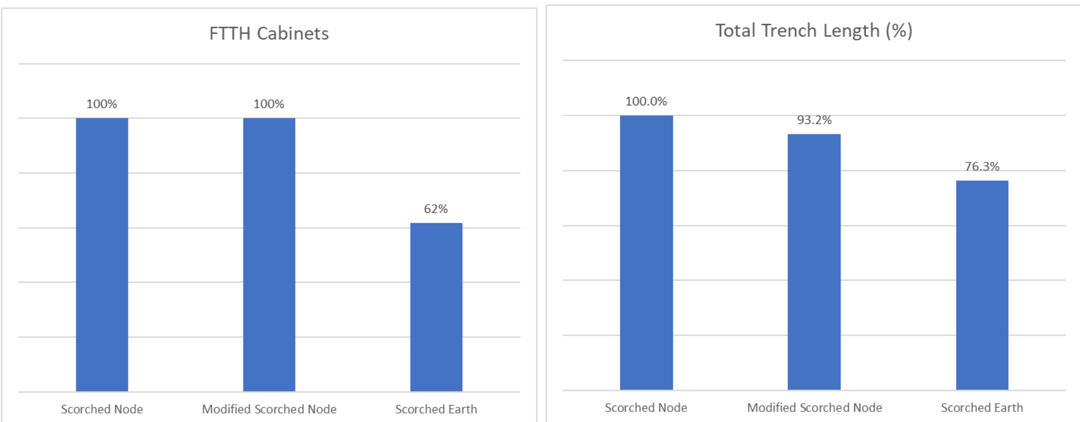

Figure 4. Comparison between the three modeling approaches in terms of total number of cabinets and total trench length results of dimensioning.

Regarding the corresponding total trenching, there is a reduction of the required trenching length by about 7% in the case of the modified scorched node compared to the scorched node, which is due to the optimization of the cabinets' position. Furthermore, the reduction in trenching length when using the scorched earth approach is significantly greater and is about 24%. This demonstrates the significant optimization of the design of the access network in the absence of restrictions, such as the use of the preexisting cable concentration points (cabinets).

By examining the trenching length for each geotype separately (Figure 5), it is evident that the scorched earth approach achieves higher efficiency in the resulting trenching length in more densely populated areas like urban and dense urban areas. However, scorched earth's results show only a 7% reduction of trenching length in rural areas. This shows that the inefficiency of networks designed based on copper technologies, as in the case of Greece, is much greater in densely populated areas where these is a limit to the number of copper pairs aggregated in each cabinet resulting to a much higher number of needed cabinets and the corresponding trenching required.

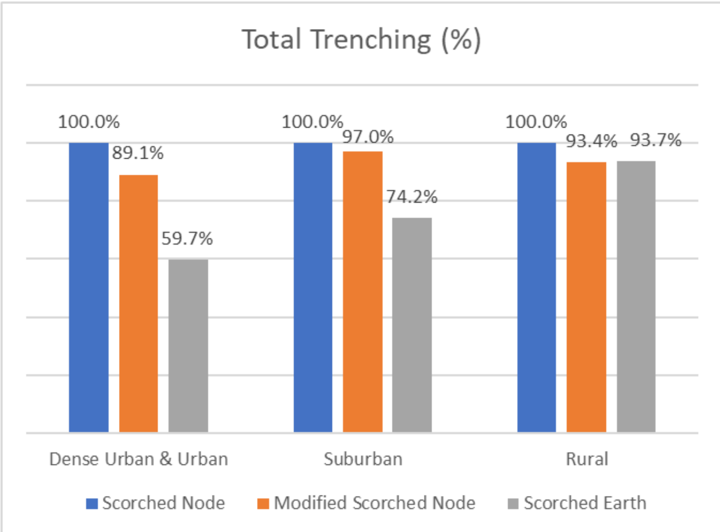

Figure 5. Comparison between the modeling approaches for the total trenching length for each geotype.

Concerning the cost implications of these dimensioning results, the costs presented in Figure 6 consist of the cumulative 10-year CAPEX and OPEX of the total modeled network for each approach. The duration of 10 years (2019-2028) is the modeling duration chosen by the Greek NRA. It is obvious that the scorched earth approach leads to a much greater reduction in the total CAPEX as well as the OPEX during the 10-year period of the model. These savings are about 16.5% of total CAPEX and 7.5% of total OPEX compared to scorched node. In the case of modified scorched node, the corresponding cost reduction is limited to about 4% of CAPEX and 1.5% of OPEX. It should be noted that the savings in OPEX are lower than the reduction of CAPEX for all scenarios, as the optimizations caused by modified scorched node and scorched node mainly affects the passive equipment and infrastructure of the access network.

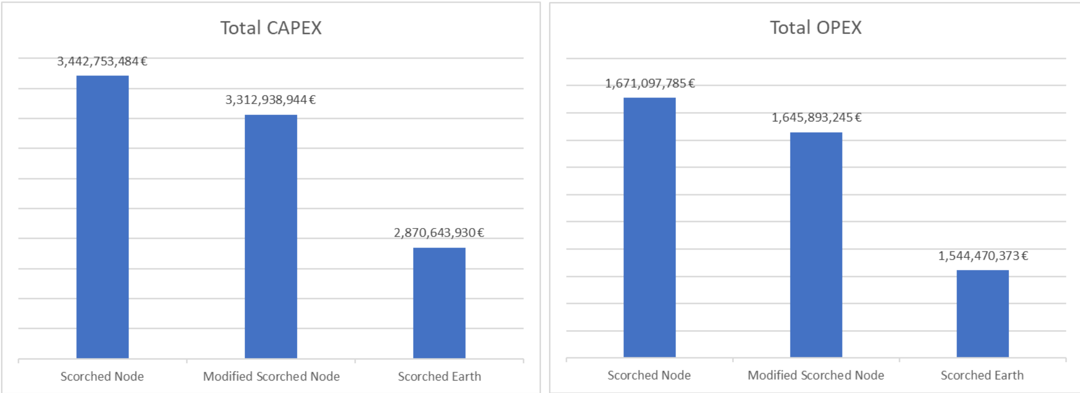

Figure 6. Cumulative 10-year CAPEX and OPEX results for the three modeling approaches.

The results of CAPEX per line and total Cost per line presented in Figure 7 are analogous to the total CAPEX and total network cost (CAPEX plus OPEX). Therefore, the use of the modified scorched node results to about 4% reduction of CAPEX per line and a 3% reduction of total cost per line compared to scorched node, while scorched earth shows a 16.5% and 13.5% reduction respectively.

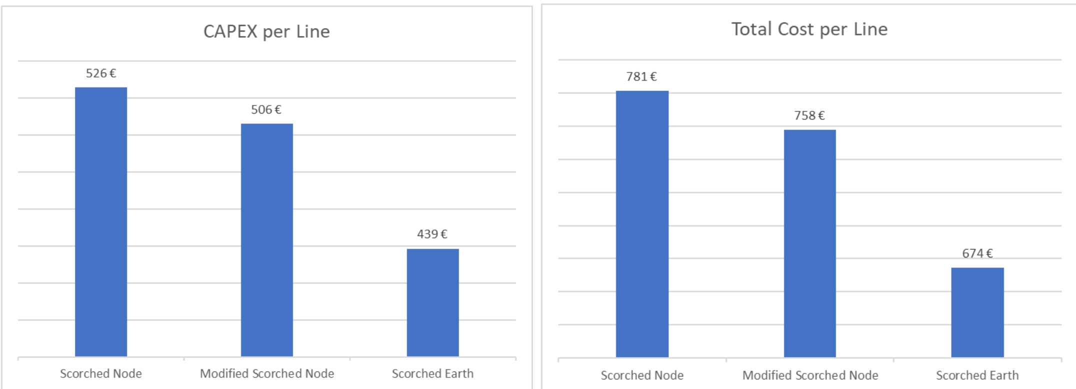

Figure 7. CAPEX and total cost per line for each of the three modeling approaches.

In Figure 8 and Figure 9 we compare the monthly wholesale cost of FTTH services between the three approaches in euros and percentage values based on the Greek NRA model results for year 2020. These services include access speeds of 100Mbps, 500Mbps and 1Gbps over FTTH infrastructure. From the costs presented it can be deducted that the cost reduction in each approach translates into to a greater decrease in monthly wholesale access prices the lower the access speed. This is due to the fact that the cost per line at higher speeds is more affected by the active equipment of the network as opposed to the lower speeds. Therefore, since the changes in active equipment are minimal in each scenario, the cost savings due to the reduction of passive equipment and infrastructure result in a significantly lower reduction in the monthly cost of the higher speed FTTH services. It is worth mentioning that the aforementioned active equipment is located in the central offices and near the delivery points of the wholesale access.

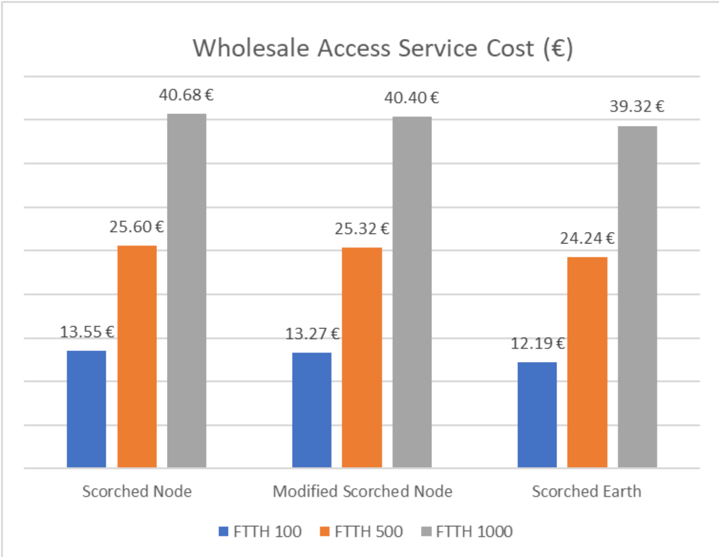

Figure 8. Wholesale access prices for FTTH services of 100Mbps, 500Mbps and 1Gbps speeds for each approach.

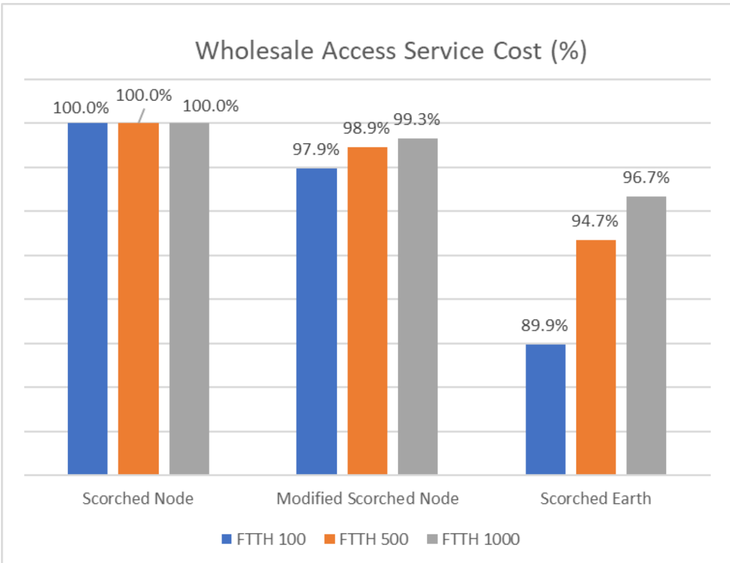

Figure 9. Comparison between the three approaches in terms of wholesale access prices for FTTH services of 100Mbps, 500Mbps and 1Gbps speeds.

Although the above savings on monthly access costs are not significant for the year 2020 in the case of high-speed services, by evaluating the evolution of cost savings in the long-run (Figure 10 and Figure 11), the picture is noticeably different. In the case of scorched earth, the savings in monthly costs even for the highest speeds increase significantly as the cost of active equipment decreases over time and subscribers move to higher speeds which causes sharing the cost of active equipment among a greater number of subscribers. As a result, this lessens the impact of active equipment on monthly prices and increases the impact of passive infrastructure on the monthly cost due to its much longer lifetime and therefore long-term impact on costs.

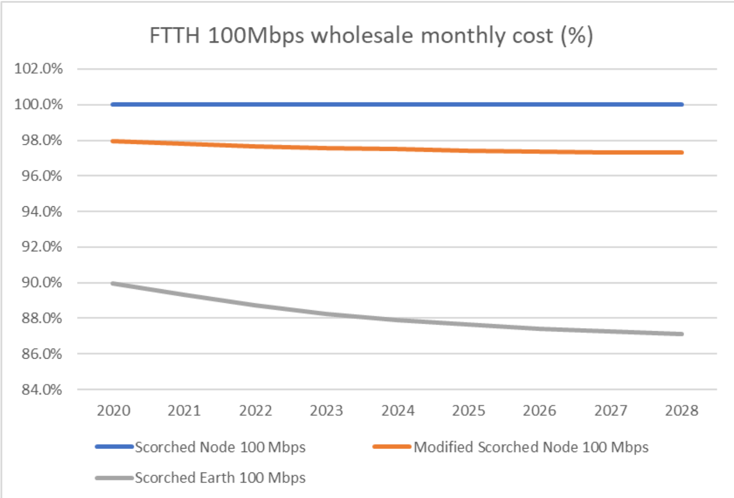

Figure 10. Evolution of wholesale access prices for FTTH 100Mbps for each modeling approach compared to scorched node price values.

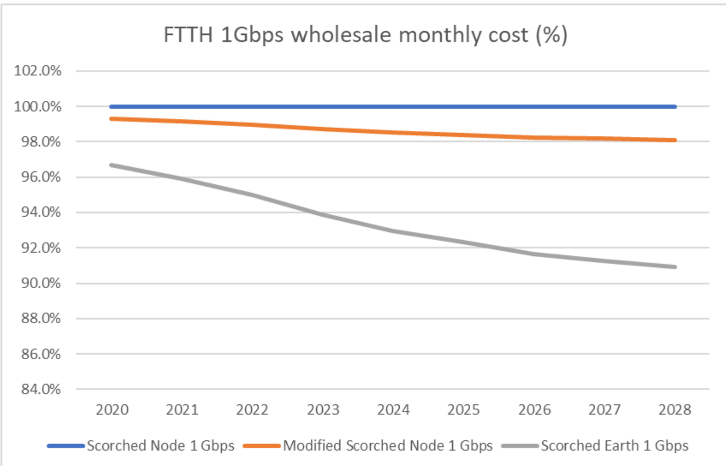

Figure 11. Evolution of wholesale access prices for FTTH 1Gbps for each modeling approach compared to scorched node price values.

4.1 Extensions to scorched earth approach

While the scorched earth approach clearly shows the most promising results in terms of cost savings, it can be argued that other costs saving parameters like reuse of existing available trenches do not apply in this case. It is acknowledged that this view is reasonable given that the reduced number of cabinets and the fact that their respective locations do not match the existing cabinets. It should be noted that in the Greek model the reuse of trenches concerns only the feeder section, that is the section between cabinets and the central office (CO). Additionally, assuming that a provider is implementing a network based purely on FTTH architecture without being constrained by any inefficiencies of the existing infrastructure, it is expected that the optimizations should include both the number of cabinets in the access network and the number of COs in the core network. Therefore, these two cases should be included in the results in order to draw comprehensive conclusions about the impact of each approach on roll out costs and service costs.

In the case of scorched earth without reuse of existing infrastructure, the 20% reuse of existing feeder segment trenches assumed in the public model is reduced to 0%. When considering the possible optimizations on the number of COs we assumed a merging of the existing COs as a more realistic approach for an operator while also taking into account the limitations of fiber cable distance for the GPON technology (less than 20 km). In our case we consider a 12 km maximum fiber cable distance between the OLT located in the CO and the buildings which results to about 60% reduction on the number of existing COs included in the model. In Figure 12, by including in the results the CAPEX and total cost per line of the scorched earth without reuse and the respective values of scorched earth with optimization of COs number, it can be deducted that no reuse of the feeder causes an increase of the costs of scorched earth but it is not significant (about 1.5% and 1%) mostly due to the already highly reduced length of the feeder segment and the reduced number of cabinets in the scorched earth approach.

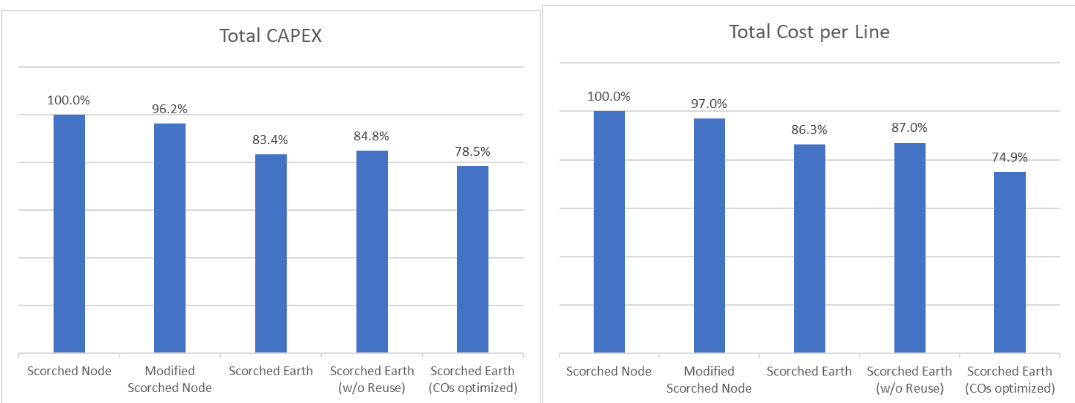

Figure 12. Cumulative 10-year CAPEX and total cost per line for all modeling approaches.

However, that is not the case for the scorched earth with optimization of COs where it is evident that significant cost savings can be achieved, amounting to 5% of CAPEX reduction and almost 11.5% of total cost when compared to the default scorched earth scenario. These cost savings are mainly driven by the greatly reduced OPEX due to the merging of OPEX sensitive infrastructure and active equipment of the COs. This reduction of OPEX is also evident by the sharp decline in monthly wholesale costs presented in Figure 13, where the scorched earth with optimization of COs shows around 20% reduced service costs when compared to the scorched node regardless of service speeds.

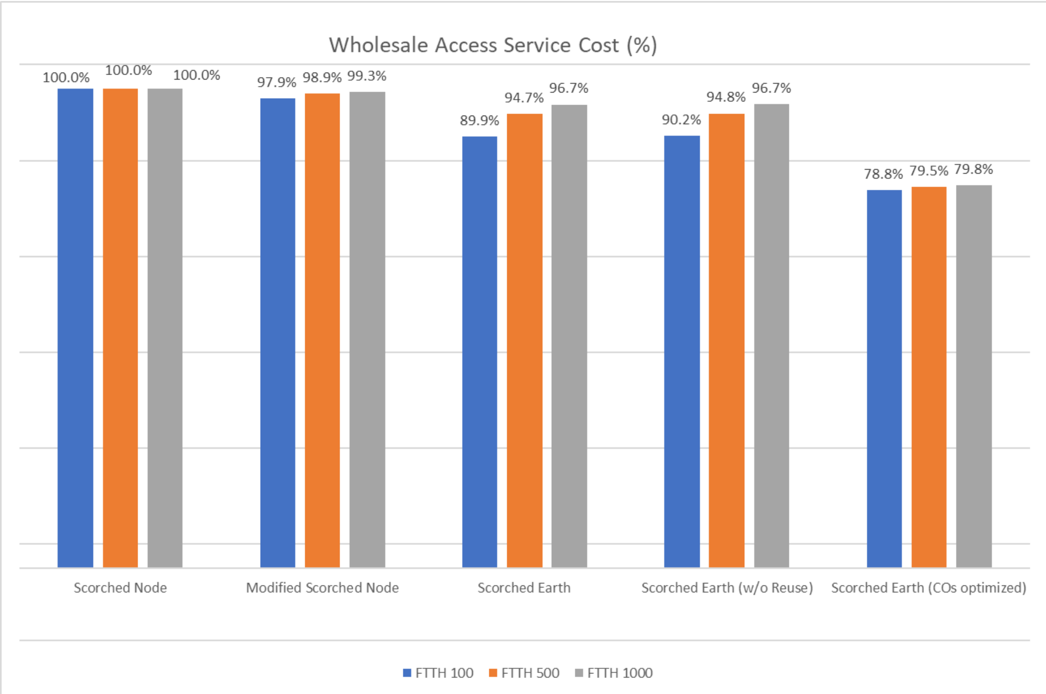

Figure 13. Comparison between all the modeling approaches in terms of wholesale access prices for FTTH services of 100Mbps, 500Mbps and 1Gbps speeds.

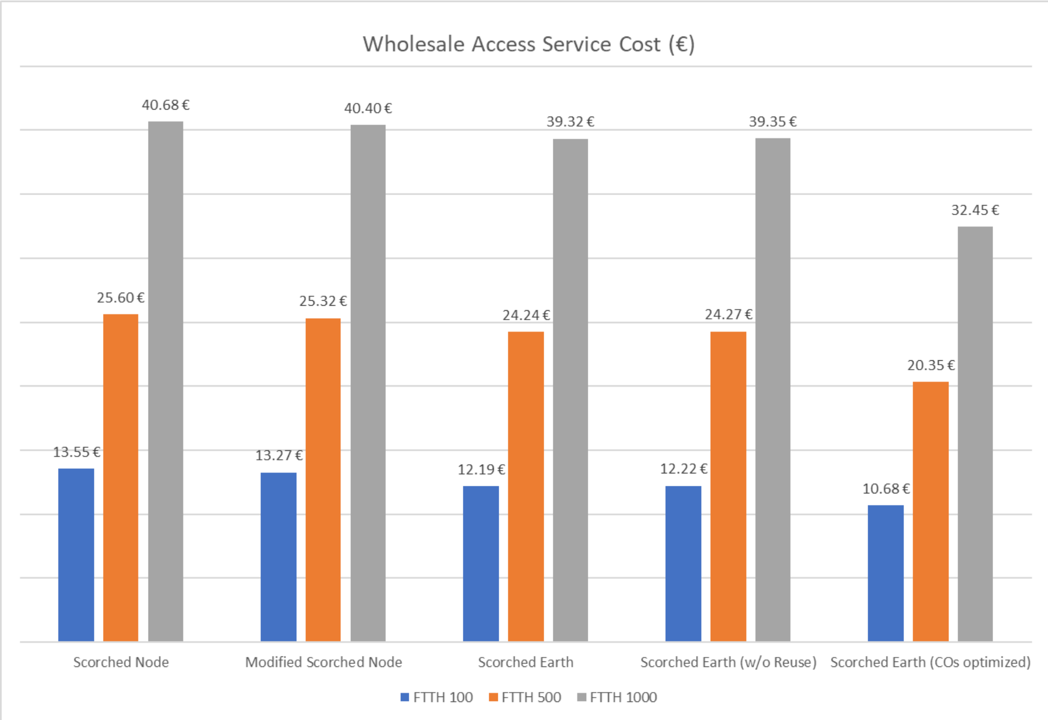

Figure 14. Wholesale access prices for FTTH services of 100Mbps, 500Mbps and 1Gbps speeds for all approaches.

5. Regulatory implications

As it was expected, the scorched earth approach produces the lowest results in terms of actual trenches and derives the lowest cost as well. The scorched earth approach is based on a completely new and optimized network without any inefficiencies of the existing incumbent operator's network. All trenching paths and cabinet locations are selected based on the current household density allowing for greater efficiency of network design when considering that household locations are mirroring the current status of the cities in regard to urban activities, business development etc.

Furthermore, the most critical effect is the decommissioning of copper local exchanges due to technological transformation to fiber infrastructure. In some of the European countries during the next 5-10 years Local Exchanges are expected to be closed while collocation and fiber unbundling will take place in fewer locations. Other Licensed Operators (OLOs) should be informed beforehand about the closing of the Local Exchanges (5 years earlier in Greece). The benefits will be instant for the consumers since the cost of FTTH services could drop by 20% based on the analysis presented. The role of the NRA is to control these prices without leaving space for price squeezing by the incumbent side. The lower the prices the more difficult it is to adjust a fair profit in terms of percentage.

From the above analysis and the results presented in the previous section we can draw significant policy implications that reply to the most challenging questions raised by NRAs when setting cost-oriented wholesale NGA prices.

Which are the implications of the results for investment decisions and policy actions?

The results show significant cost savings and wholesale price reduction both short-term for lower speeds but also long-term for all FTTH services regardless of speed. Therefore, scorched earth design should be considered mainly in areas where there is no pre-existing optical access infrastructure or the operators are not bound by the existing copper network (FTTC) or in the case of black NGA areas with more than one FTTH infrastructure available.

Which is the main conclusion concerning the regulation of the FTTH market?

FTTH deployment plans should be given higher priority over FTTC in densely populated areas especially in cases when the availability of reusable infrastructure is not high enough to replace the long-term cost savings of an efficiently designed FTTH network. Therefore, allocating resources to FTTH rollouts in white rural areas while encouraging FTTC in urban areas can result in a misallocation of available resources and inefficiencies in future FTTH network designs. That is also considering the general economic environment and operators' capacity for investment as there is potentially a smaller need in initial capital expenditure in the case of copper reliant NGA networks. In such a case, scorched node FTTC networks can prove a more suitable solution that can be upgraded in future deployment cycles offering an upgrade path to FTTH services.

What does this mean regarding the objectives of the EC Recommendation?

Reducing the number of central offices of networks based on FTTx should be encouraged and NRAs should take into account any plans for a possible future reduction in the number of COs. The technological advancements that fiber infrastructure provides should be exploited and the ability to create effective long-distance links while lessening the number of COs can have positive economic impact on the network's design.

Can we draw a global conclusion, or the results apply only to Greek market?

It can be deducted that countries with high urbanization where most of the population is concentrated in densely populated areas, such as urban and dense urban areas with extensive legacy copper infrastructure, are more likely to benefit from an FTTH network deployment based on scorched earth approach than reusing the existing copper infrastructure and adopting its design inefficiencies. The goal is to strike the right balance between reuse and new deployments as well as understanding the limitations that copper-based networks could pass on to future NGA networks. The existence of new technologies that can sustain the usability of copper cables, for example G.fast, provides a different route to the discussion that should also be examined.

Does our analysis help NRAs meet their objectives?

The findings show that even though short-term pricing reduction may seem insignificant, NRAs should consider alternative approaches such as scorched earth due to the long-term cost reductions incurred by operators in the case of FTTH rollout. However, using FTTC as stepping ground to FTTH rollout can increase possible preexisting inefficiencies in the design of future FTTH network resulting in higher service costs.

Is there any strategic effect that firms may use to manipulate the access price?

The reduction on the number of central offices which can occur in a transition from copper-based legacy networks to new NGA networks based on FTTx technologies can greatly reduce the operational costs of an operator resulting in subsequent reduced service costs. If these changes are not taken into account by the NRAs when implementing long-term policies, it can result in higher wholesale prices undermining competition in the telecom markets especially in the cases where the strategic decisions regarding the majority of infrastructure design are concentrated in one incumbent operator.

6. Conclusions

In this paper, we compared three network modeling approaches, namely the scorched node, the modified scorched node and the scorched earth, in terms of wholesale NGA prices, as well as total investment costs by using the public BU-LRIC+ NGA model of the Greek NRA.

The results derived from this comparison are expected to provide valuable information to network operators and telecom regulators. On the one hand, operators will be able to assess the impact of their deployment plans on cost efficiency and cost-oriented access prices. Additionally, regulators will be provided with a useful guideline on how to foster competition and give operators the right signals to enter the era of superfast broadband and fiber connectivity.

Since all approaches should be comparable, service demand and technology coverage remained the same, along with other technical and cost assumptions. Most importantly, all scenarios modeled a nationwide FTTH network for universal coverage.

According to the results, there is a significant reduction of total trenching length (between 25% and 40%) in the case of the scorched earth especially in densely populated areas, i.e., urban and dense urban areas, which in turn causes substantial cost savings in total investment costs and cost per household. On the other hand, the impact of modeling approach to the wholesale access prices is limited to about 10% which apply mostly to the lower service speeds (less than 200Mbps) in the short-term. Nevertheless, on the long-run, these savings are translated to price reductions for all service speeds due to depreciation of active equipment cost and the higher dependence of the final service cost on the cost of passive infrastructure (trenches, cables, cabinets, etc) which is characterized by its longer lifetime.

By extending the optimizations of the scorched earth approach to the number of central offices, both the short-term and long-term wholesale price reductions are quite significant (more than 20%) regardless of service speeds due to the sharp decline in OPEX and maintenance costs of central office infrastructure and active equipment. Contrary to the initial expectations, the impact of the reuse of existing trenches was minimal because of the highly reduced trenching length and number of cabinets in the case of scorched earth.

The findings highlight the importance of the modeling approaches to service costs which should be taken into account by the NRAs when formulating long-term policies in the telecom sector regarding the NGA investments and regulation. The efficiencies which can be achieved are heavily based on the geotype and the extend of network optimizations (i.e., merging of COs) or the dependence on legacy copper-based architectures, can have a long-term cost effect on prices and could offer a competitive advantage to infrastructure owners in the absence of effective price regulation regarding the appropriate choice of modeling approach. Consequently, NRAs should consider all the available modeling approaches based on an elaborate evaluation of operators' investment plans and the policy goals on a forward-looking perspective.

The methodological analysis presented underlines the more important aspects of network modelling that influence all stages of development as well as the final results. A foundational decision regarding network deployments is whether existent infrastructure should be relied upon a technological stepping stone. There is a balancing act between reusing and building new, but in an ideal environment brand new seems to be more efficient as it considers the evolution of the populated areas serviced in ways that a legacy network cannot, achieving greater efficiency while being more future proof. The economic aspects that precede a reuse-or-new decision should also be considered since the potential to utilize a substantial part of the legacy infrastructure could potentially provide cost savings. But the ability to reuse legacy infrastructure is volatile on a case to case basis and relies heavily on specific characteristics thus making it less possible to evaluate as a scenario applicable to all cases. Therefore, further work should be elaborated to evaluate the benefit of reusing existing infrastructure against the inherited inefficiencies of the copper-based architecture and the long-term implications of choosing FTTC as an upgrade step instead of FTTH rollout close to scorched earth approach.

Finally, even though the main economic and market parameters of the model like the WACC, overheads and demand of NGA services were kept the same, it is expected that these parameters will be affected by the investment decisions and policy derived when taking into account the differences of the modelling approaches. Thus, further research is needed to assess the role of these parameters, the correlation between them and the modelling approach as well as the total implications for the wholesale access pricing of NGA services.

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