

Chiha, Asma; Derveaux, Edward; Verbrugge, Sofie; Colle, Didier

Conference Paper

Balancing the Scales: Exploring Cost-Sharing Models for 5G Networks and OTT Traffic

ITS 33rd European Conference 2025: "Digital innovation and transformation in uncertain times", Edinburgh, UK, 29th June – 1st July 2025

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Chiha, Asma; Derveaux, Edward; Verbrugge, Sofie; Colle, Didier (2025) : Balancing the Scales: Exploring Cost-Sharing Models for 5G Networks and OTT Traffic, ITS 33rd European Conference 2025: "Digital innovation and transformation in uncertain times", Edinburgh, UK, 29th June – 1st July 2025, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/331260>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Balancing the Scales: Exploring Cost-Sharing Models for 5G Networks and OTT Traffic

Asma Chiha^{1,*}, Edward Derveaux, Sofie Verbrugge¹, Didier Colle¹

¹ IDLab, Ghent University-imec, Ghent, Belgium

* Corresponding author, asma.chihaephari@ugent.be

Abstract

The European Commission has initiated a consultation on the future of the telecommunications sector, including the contentious question of whether over-the-top content providers (OTTs) should contribute to the costs of network infrastructure investments. Current cost estimates attributing mobile network expenses to OTT traffic rely predominantly on top-down modeling, a method widely criticized for its oversimplification and lack of transparency. This study contributes to the debate by addressing three key questions. First, it challenges prevailing top-down estimates by applying a bottom-up cost assessment based on total cost of ownership (TCO), incorporating both CAPEX and OPEX. This approach follows a detailed network dimensioning phase, which models the required infrastructure according to key performance indicators (KPIs), user demand, and traffic forecasts. Second, it analyzes the traffic sensitivity of 5G cost categories using this bottom-up model. Third, the framework explores two approaches to allocating 5G deployment costs to OTT traffic: one based on proportional allocation of traffic-sensitive costs according to OTT traffic behavior, and another using an incremental cost model that attributes only the additional costs generated by OTT usage. The analysis draws on case studies from a dense urban region (Brussels-Capital Region) and a rural area (Marche-en-Famenne), yielding a Europe-wide weighted average. Results show that the bottom-up estimates (€0.46–€0.84 per subscriber per Mbps) are significantly lower than current top-down figures (€2.15–€2.30), indicating a substantial overestimation of OTT-related costs in prevailing assessments. Moreover, the assumption that non-traffic-sensitive costs are negligible does not hold in rural contexts. However, incremental costs associated with OTT traffic in urban 5G networks are significant enough to merit careful regulatory consideration.

Keywords: bottom-up cost model, 5G network investments, network cost sharing, OTT traffic, traffic-sensitivity, incremental costs, fair share.

1 Introduction

Global IP traffic on telecommunications networks has experienced remarkable growth, with an estimated compound annual growth rate (CAGR) of 27% between 2018 and 2022 [1]. A significant portion of this traffic is generated by a small group of over-the-top content providers (OTTs). For example, the Body of European Regulators for Electronic Communications (BEREC) reports that 51% of all traffic delivered by France’s main Internet Service Providers (ISPs) can be attributed to just five Content and Application Providers (CAPs) [1]. This continuous surge in data traffic is a major driver behind the expansion and upgrading of network infrastructure. To meet the growing demand, telecom operators invest heavily in upgrading network capacity—investments that are fundamental to supporting an increasingly digital society.

However, the revenue growth of telecommunications operators has not kept pace with the exponential increase in network usage [2]. As a result, many operators fear they will be unable to achieve viable returns on their investments, while CAPs continue to benefit from telecom infrastructure at little direct cost. Given their limited negotiating power with large OTT players, the CEOs of four major European telecom companies have called upon the European Commission to ensure that “all market players benefiting from the digital transformation make a fair and proportionate contribution to the costs of public goods, services, and infrastructures” [3].

In response, on February 23, 2023, the European Commission launched an exploratory consultation on the future of the connectivity sector and its infrastructure. Through a public survey open to organizations, businesses, and citizens, the Commission invited views on whether all players benefiting from the digital ecosystem should contribute fairly to telecom infrastructure investments.

Following the end of the exploratory consultation on May 19, 2023, the European Commission published the results in October 2023, shedding light on the different positions regarding the "fair share" debate. First, telecom operators and certain business associations advocated for a mandatory contribution mechanism, arguing that large traffic generators benefit from the networks without proportionately contributing to their expansion, and that such contributions could help close the €200 billion investment gap needed to meet Europe's 2030 connectivity targets. Second, digital platforms and some research institutions opposed this idea, emphasizing that they already invest heavily in infrastructure, such as data centers and content delivery networks, which reduce the burden on telecom networks, and warning that additional fees could harm consumers and threaten net neutrality. Third, the Commission recognized the complexity of the issue, highlighting the need for a balanced approach that would support network investments without undermining competition or consumer interests. [4].

While the consultation underscored the complexity of the issue and the need for further analysis, the European Commission has not yet reached a definitive decision on implementing a fair share mechanism. Legislative proposals on the matter are still under consideration and are expected to follow only after broader political and institutional alignment. Similar discussions are emerging worldwide. In South Korea, policymakers are considering legislation requiring large digital platforms to contribute to network costs following a surge in traffic caused by the series *Squid Game*. In the United States, there are increasing calls to include Big Tech firms in funding programs like the Universal Service Fund [5].

This debate raises a fundamental question: Why focus on digital platforms for cost-sharing rather than simply increasing prices for end users? Access to digital media has become essential for participation in modern society. Excluding individuals from internet access risks deepening the digital divide—the gap between those who have access to digital services and those who do not. In Europe, 5.4% of children are considered digitally deprived, living in households without a computer or internet access [6]. Such disparities hinder education, social engagement, and future employment opportunities. On a global scale, UNICEF Executive Director Henrietta Fore has emphasized that lack of connectivity isolates young people from economic opportunities [7]. Therefore, maintaining affordable access to connectivity is critical. Raising end-user prices could exacerbate digital exclusion, making it an unsuitable solution. Given this context, this study adopts the perspective that large digital platforms—referred to hereafter as OTTs—should contribute fairly to network investment costs. To support informed policymaking, a clear understanding of the cost structures associated with OTT traffic is necessary. Current estimates largely rely on top-down approaches [8], which are criticized by OTTs for their lack of transparency and accuracy [9].

To contribute to this debate, this study addresses three key research questions:

1. How do the costs in a 5G network derived from a bottom-up cost model compare to current top-down estimates?
2. What are the traffic-sensitive network costs in the 5G last-mile network?
3. What portion of the deployment costs should be allocated to OTT traffic?

To address these questions, we propose in this paper a new cost analysis framework. The remainder of the paper is organized as follows. Section II presents the methodology and framework development. Section III analyzes the sensitivity of 5G network costs to traffic. Section IV applies the developed bottom-up cost model to a case study comparing an urban and rural setting. Section V provides a comparative analysis between the bottom-up results and existing top-down cost estimates. Finally, Section VI concludes the paper with a summary of findings and a discussion of their policy implications.

2 Methodology and developed framework

To address the limitations of top-down cost assessments typically used to estimate OTT-related costs in mobile networks, this paper proposes a comprehensive framework based on a bottom-up modeling approach grounded in the Total Cost of Ownership (TCO) concept. Top-down models often aggregate operator-level expenditures and allocate costs uniformly across all traffic, without accounting for regional differences, traffic sensitivity, or infrastructure-specific variables. In contrast, the bottom-up framework developed in this study builds the cost model from the network layer up, using detailed technical and economic inputs to more accurately reflect real-world deployment conditions.



Figure 1: The 5G cost analysis and allocation model framework

The framework consists of five sequential steps, as presented in Figure 1. It begins with the dimensioning of a 5G network, which determines the required infrastructure (macro cells, small cells, backhaul, and spectrum) needed to meet projected user demand and performance targets in a given geographic area. This step uses population density, data usage forecasts, and active user assumptions to model network needs over a defined planning horizon.

Second, the model estimates the Total Cost of Ownership (TCO), incorporating both capital expenditures (CAPEX) and operational expenditures (OPEX), including energy use, maintenance, site rental, and spectrum licensing. These costs are normalized per Mbps and per subscriber to facilitate comparison between different contexts and estimation models.

Third, each cost component is classified according to its sensitivity to traffic. Costs directly driven by traffic—such as small cell deployment, energy consumption linked to active load, and backhaul capacity—are identified as traffic-sensitive. In contrast, baseline infrastructure such as macro cell coverage and spectrum fees are treated as fixed or non-traffic-sensitive. This classification is essential to isolate the cost drivers that are directly influenced by OTT-induced demand.

Fourth, the framework applies two cost allocation models to estimate the share of 5G network costs attributable to OTTs:

- The proportional allocation model, which assigns a share of traffic-sensitive costs to OTTs based on their estimated share of busy-hour traffic (e.g., 50% of total load);
- The incremental cost model, which calculates the additional cost of scaling the network to handle OTT traffic, based on a counterfactual network designed to serve only non-OTT demand.

Fifth, to ensure regional representativeness and comparability with Europe-wide top-down estimates, the model is applied to two Belgian case studies: the Brussels-Capital Region, representing a dense urban environment with high traffic demand, and Marche-en-Famenne, a rural area with sparse population and different cost dynamics. These contrasting settings enable the analysis of how geography and demand patterns influence network costs and OTT cost attribution.

The results from both case studies are then combined into a weighted average, based on national population distribution, to generate a cost estimate reflective of a broader European context. This average is compared against publicly available top-down estimates to assess methodological discrepancies and their implications for ongoing debates about fair cost-sharing between telecom operators and OTT platforms.

2.1 Network dimensioning and cost modelling

The TCO cost model proposed hereunder relies on the work done in [2] and in the 5G Blueprint report [10]. The model works in two stages as presented in Figure 2. First, the network is dimensioned, and secondly, the cost model provides the total cost of ownership (TCO) using unitary cost data.

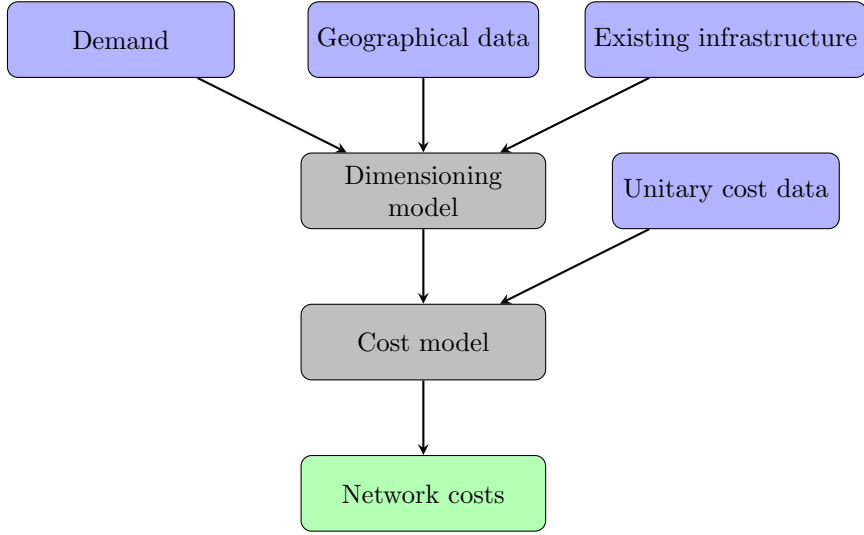


Figure 2: Structure of the bottom-up model

The dimensioning of the 5G mobile network involves calculating the necessary infrastructure to support projected data demand in a given area, taking into account several key inputs, such as:

- Geographical characteristics of the area (urban or rural)
- Population density and the percentage of active subscribers
- Data rate assumptions (e.g., 50 Mbps per user)
- Existing network capacity

This dimensioning process determines the Bill of Material (BOM), specifically the number of macro cells and small cells required, taking into account the available 4G/5G capacity and the need for additional small cells to handle excess demand, together with additional equipment.

The number of macro cells and small cells is determined based on the area that needs to be covered, the existing capacity and the additional capacity needed. The macro cells are then meant to provide a basic coverage of the area and small cells are added for additional capacity.

$$N_{MC} = \text{ceil}\left(\frac{A}{\text{Coverage}_{MC}}\right) \quad (1)$$

$$\text{Coverage}_{MC} = \frac{3\sqrt{3}}{2}R^2 \quad (2)$$

$$N_{SC} = \text{ceil}\left(\frac{\text{Cap}_{total} - \text{Cap}_{available}}{\text{Cap}_{SC}}\right) \quad (3)$$

$$\text{Cap}_{total} = \rho \cdot \%sub. \cdot \%sim. users \cdot data rate \quad (4)$$

N_{MC} is the number of macro cells needed to provide basic coverage of the area A . The coverage of one macro cell, Coverage_{MC} , is approximated by the area of a hexagon. R is the radius of a macro cell. The number of small cells, N_{SC} , is determined based on the total capacity needed Cap_{total} , the existing capacity from 4G and 5G macro cells, $\text{Cap}_{available}$ and the capacity per small cell, Cap_{SC} . The number of small cells is then derived from the extra capacity needed on top of the available capacity. The total capacity is driven by population density, ρ , the percentage of subscribers, $\%sub.$, the percentage of simultaneous users, $\%sim. users$, and the demanded data rate.

Once the network is dimensioned, the costs can be determined. The costs are split up per network part and are discussed hereunder. The metric used to compare costs in this study is TCO. The

TCO over N years is then:

$$TCO = CAPEX + \sum_{t=1}^N OPEX_t + C_{spectrum} \quad (5)$$

RAN

The RAN CAPEX, $CAPEX_{5G-RAN}$, is split up into the CAPEX to upgrade existing cell sites to 5G macro sites, $CAPEX_{RAN-upgrade}$ and the CAPEX to deploy new cell sites, $CAPEX_{RAN}$. C_{MC} and C_{SC} represent the cost of a macro cell, respectively small cell. $C_{installation}$ is the installation cost and is estimated at 15% of hardware costs, $C_{Hardware}$. $dist_{MC-agg}$ is the distance from the macro cell to the aggregation point, and C_{fibre} is the fibre per unit length cost. $N_{sites-upgrade}$ is the number of cell sites upgraded to a 5G macro cell site and $C_{site-upgrade}$ is the related cost.

$$CAPEX_{5G-RAN} = CAPEX_{RAN} + CAPEX_{RAN-upgrade} \quad (6)$$

$$CAPEX_{RAN} = N_{MC} \cdot (C_{MC} + dist_{MC-agg} \cdot C_{fibre}) \quad (7)$$

$$+ N_{SC} \cdot C_{SC} + C_{installation}$$

$$CAPEX_{RAN-upgrade} = N_{sites-upgrade} \cdot C_{site-upgrade} \quad (8)$$

$$C_{installation} = 15\% \cdot C_{Hardware} \quad (9)$$

If site sharing occurs between mobile network operators (MNOs), the cost per cell site increases by 20% per extra operator [11]. The same holds for the cell's energy consumption. The OPEX is divided into three categories: energy consumption (C_{energy}), cell site rental (C_{rent}) and maintenance ($C_{maintenance}$).

$$OPEX_{RAN} = C_{energy} + C_{maintenance} + C_{rent} \quad (10)$$

$$C_{energy} = N_{SC} \cdot C_{en,SC} + N_{MC} \cdot C_{en,MC} \quad (11)$$

$$C_{rent} = N_{SC} \cdot C_{rent,SC} + N_{MC} \cdot C_{rent,MC} \quad (12)$$

$$C_{maintenance} = 7\% \cdot CAPEX \quad (13)$$

$C_{en,MC}$ is the yearly energy cost of a macro cell and $C_{en,SC}$ of a small cell. $C_{rent,SC}$ is the rent of a small cell and $C_{rent,MC}$ is the rent of a macro cell.

Backhaul

To calculate backhaul costs, the CAPEX related to the backhaul of a macro cell and small cell, $CAPEX_{MC,bh}$ and $CAPEX_{SC,bh}$, is used. The same holds for OPEX.

$$CAPEX_{bh} = N_{MC} \cdot CAPEX_{MC,bh} + N_{SC} \cdot CAPEX_{SC,bh} \quad (14)$$

$$OPEX_{bh} = N_{MC} \cdot OPEX_{MC,bh} + N_{SC} \cdot OPEX_{SC,bh} \quad (15)$$

The OPEX of the backhaul network comprises the maintenance cost. The energy cost is neglected because, on the one hand, the backhaul connection is assumed a fibre connection with hence limited energy costs and on the other hand the cost of upgrading the backhaul network can be seen as a necessary step in the roll-out of 5G regardless of traffic. Equivalent to RAN maintenance costs, the backhaul maintenance cost is estimated at 7% of CAPEX.

Core network

Core network costs can be estimated as 10% of RAN and backhaul CAPEX [12].

Spectrum costs

The amount of spectrum license fees an MNO pays, $C_{spectrum}$, consists of two parts. First, there is a one-off fee and secondly, there is a yearly contribution fee. These prices are publicly available [13]. To come up with annual spectrum costs across all operators, $C_{spectrum,annual}$, the unique fees paid for spectrum bands, $C_{i,unique}$, are added and divided by their respective periods, T_i . The rights on the 700 MHz and the 1400 MHz bands are valid for 20 years. The rights on the 3600 MHz band are valid for 25 years. Secondly, the annual fees $C_{i,annual}$, are multiplied by the MHz in the acquired bands, MHz_i . Duplex bands are counted double. They are then added to the annualized unique fees.

$$C_{spectrum,annual} = \sum_{i=1}^N \frac{C_{i,unique}}{T_i} + \sum_{i=1}^N C_{i,annual} \cdot MHz_i \quad (16)$$

2.2 5G Traffic-Sensitive Costs

Based on the bottom-up model, the costs that are influenced by traffic are identified. From Equation 3 it is apparent that the number of small cells is driven by the data demand. Cell splitting and the installation of small cells are inherently driven by data demand. The number of small cells is also the cost driver of all small cell-related costs. Hence, the small cell equipment, installation, energy consumption, maintenance and site rent are considered traffic-sensitive. Small cell backhaul costs are also driven by the number of small cells and hence are traffic-sensitive too. From [2], it can also be seen that the number of small cells determines the amount of hardware and sites and thus influences the small cell maintenance cost.

The number of macro cells on the other hand is driven by the area to cover. Complete coverage of an area is necessary regardless of traffic requirements. Consequently, the number of macro cells cannot be considered traffic-sensitive. Equivalently, the costs related to the number of macro cells are also not traffic-sensitive. However, as [14] shows, the electricity consumption has a baseline part and an incremental part. So the macro cell energy cost is partly traffic-sensitive. No other macro cell costs are traffic-sensitive.

Note that no conclusion is reached on the traffic sensitivity of the core network. In the bottom-up model presented in Subsection 2.1 the core network cost is estimated as a percentage of other costs. Hence, any conclusion holding for those network parts is immediately imposed on the core network too. Therefore, it is judged not useful to classify the core network as traffic-sensitive or not.

From spectrum license auctions, it is apparent that the MNO with the largest market share buys in total a broader spectrum band than other providers and hence also pays the most [15, 16]. Therefore, there seems to be a correlation between spectrum costs and traffic carried by an MNO. This is also confirmed by [9]. The author mentions that to meet traffic growth among other factors more spectrum is required.

A reason that may lead people to judge spectrum costs as non-traffic-sensitive is the fact that this investment in spectrum licenses can be seen as an upfront and sunk cost. Whether an operator carries more or less data afterwards, does not affect the price he paid anymore. In short, there seems to be a relation to the sum spent at the auction, but afterwards, it does not change anymore if the MNO loses or gains market share. It can be seen as a sunk cost. However, this also holds for any investment made. Nonetheless, the upfront investment would not have been made if not for traffic growth. For these reasons, the spectrum costs are considered traffic sensitive.

Table 1: Traffic-sensitivity of the last mile 5G network costs

	Macro cell	Small cell	Backhaul
Equipment and installation	No	Yes	Yes (for small cells)
Energy consumption	Partly	Yes	/
Maintenance	No	Yes	Yes (for small cells)
Site rental	No	Yes	/
Spectrum costs	Yes		

Table 1 gives an overview of the traffic-sensitive costs in the 5G last mile network. In [8], all mobile network costs are considered traffic-sensitive. This bottom-up analysis reveals however that this does not hold. In particular macro cell costs (except for incremental energy consumption) and macro cell backhaul costs cannot be considered traffic-sensitive.

From the case studies in Section 3 it is clear that the assumption that non-traffic-sensitive costs are negligible only holds for urban areas. Outside of urban areas, this certainly does not hold and a more fine-grained analysis is appropriate.

2.3 Cost allocation metrics and proposed models

Cost allocation metrics are now proposed for the costs classified as traffic-sensitive in Subsection 2.2. Since these costs are, by definition, dependent on traffic levels, traffic behavior naturally serves as the logical basis for allocation. As presented in [8], all traffic-sensitive costs are allocated to OTTs according to their share of busy-hour traffic relative to total traffic, reflecting the fact that networks are dimensioned to handle peak bandwidth demands.

As illustrated in Equation 3, the number of small cells is driven by the traffic requirements. Hence, the amount of small cell equipment and the installation costs of all this equipment are also driven by traffic requirements. In that optic, splitting the costs based on bandwidth during busy hours

seems a reasonable proposition.

Maintenance is dependent on the amount of hardware and hence also the number of small cell sites that have to be installed. Since this is dictated by peak data requirements, busy hour bandwidth also provides a reasonable allocation key. A similar reasoning holds for small cell site rental.

Another major cost category is energy consumption. Based on Equation 11 one might judge that energy costs are also best reflected by busy hour bandwidth. However, as mentioned in [14], cell sites have an incremental and a baseline energy consumption. Using C-RAN technology idle equipment can be turned off [17]. Thus, baseline power consumption can be avoided and energy costs are not entirely dependent on busy hour bandwidth. Hence, for this cost category, overall data usage is a more appropriate allocation metric.

MNOs need to buy enough spectrum licenses to meet their customers' demand at all times. In other words, even during peak hours, enough spectrum should be available to satisfy the required data rates. Hence, peak data usage provides a logical allocation key for spectrum costs. To allocate costs to OTT traffic, we propose two cost allocation models:

The first is the **proportional allocation model**, which assigns a share of traffic-sensitive costs to OTTs based on their estimated share of busy-hour traffic (e.g., 50% of total load). Consistent with the reasoning in Section 2.2, only the last-mile network segment is considered. Using the developed bottom-up cost model, we identified the relevant cost categories and assessed their traffic sensitivity in Section 2.2. For each traffic-sensitive category, cost drivers are identified and qualitatively analyzed.

The second model is **the incremental cost model**. Figure 3 provides a schematic overview of this approach, inspired by the standard definition of incremental costs—that is, the additional cost required to provide an increased quantity of output. Based on the bottom-up cost model described in Section 2.1, the total cost of a network dimensioned to handle 100% of the required capacity is calculated. Then, a second hypothetical network is modeled to carry only non-OTT traffic. The variable X% in Figure 3 represents the share of total traffic not attributed to any of the OTTs under consideration. The incremental cost is defined as the cost required to upgrade the X% capacity network to full 100% capacity. Under this model, MNOs are responsible for the costs of the base (non-OTT) network, while OTTs pay for the incremental costs associated with their traffic.

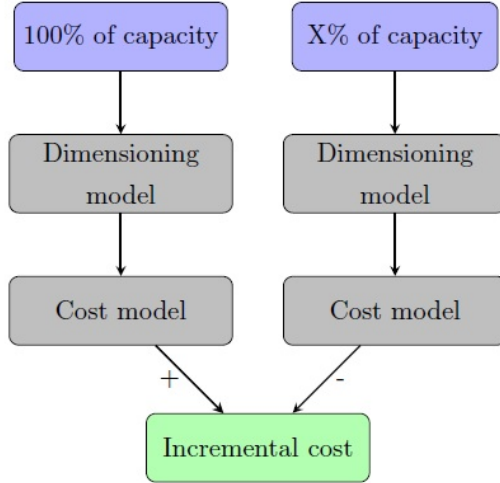


Figure 3: The incremental cost model relies on two distinct network dimensioning scenarios: one for full capacity, which includes both non-OTT and OTT traffic, and another for non-OTT traffic only. The incremental cost is then derived as the additional investment required to upgrade the network from the non-OTT baseline to full capacity.

Table 2: Proposed cost allocation metrics for traffic-sensitive 5G network costs

	Small cell	Small cell backhaul	Macro cell
Equipment and installation	Peak usage	Peak usage	/
Energy consumption	Usage	/	Usage
Maintenance	Peak usage	Peak usage	/
Site rental	Peak usage	/	/
Spectrum costs	Peak usage		

Table 1 gives an overview of the proposed cost allocation metrics for the traffic-sensitive costs in a 5G network. In [8], all mobile network costs were allocated using busy hour bandwidth. This makes sense for most cost categories. However, for energy consumption, which is not an insignificant category, overall data usage provides a better allocation metric.

3 Application of the TCO cost model: Case study

To provide grounded and geographically representative cost estimates, the bottom-up cost model developed in this study is applied to two contrasting regions in Belgium: the Brussels-Capital Region (urban) and Marche-en-Famenne (rural). These case studies enable a detailed comparison of network costs across environments with differing population densities, infrastructure demands, and deployment challenges. This regional approach also supports the construction of a weighted average for Europe-wide cost estimates. Additionally, the current top-down estimates provide an average figure for OTT-related costs across Europe—covering a broad mix of urban, suburban, and rural areas—comparing them solely to results from a single region (e.g., urban) would be misleading. Therefore, incorporating both urban and rural case studies allows for a more balanced and fair comparison, yielding a population-weighted average that better reflects the European context.

3.1 TCO cost results

In the urban and rural areas under consideration, hypothetical 5G networks are dimensioned to meet projected user demand. Using unit cost data, deployment costs are subsequently calculated for both regions. The bottom-up modeling approach used for this purpose is described in Subsection 2.1. Consistent with [12], the network is dimensioned to deliver a data rate of 50 Mbps per user. For existing 4G infrastructure, a capacity of 1 Gbps/km² is assumed, as referenced in [18].

In rural areas, where this estimate would be overly optimistic, a more conservative baseline network capacity of 20 Mbps is adopted, following [19]. With regard to site infrastructure, it is assumed that all three Mobile Network Operators (MNOs) operating in Belgium share 50% of the sites operated by the smallest among them Telenet. For simplicity, this model assumes that site sharing always involves all three MNOs jointly, and never occurs bilaterally.

[20] mentions that 38.9 % of the EU population lived in an urban area, 35.9 % in a suburban area and 25.2 % in a rural area. No case study on a suburban area was performed. Hence, half of the suburban population is attributed to the urban case and the other half to the rural case. Table 3 shows the inputs necessary for the dimensioning model and Table 4 shows the inputs used in the cost model.

The results of the bottom-up cost model are summarized in Table 5. To ensure meaningful comparisons between the urban and rural cases, cost per subscriber is used as the baseline metric. However, since the network may be dimensioned for different data rates in different contexts, direct cost comparisons may be misleading. To normalize this, the cost per subscriber per Mbps is adopted, allowing for a more fair cross-scenario evaluation.

In the rural case, it is important to note that Universal Service Obligations (USOs) may influence network deployment decisions. Although such obligations can impact cost structures, Belgium currently does not designate a Universal Service Provider (USP) for geographical coverage [21]. This is not uniformly true across Europe, where USOs still play a regulatory role in some countries [22].

Table 3: Input parameters in the dimensioning model

Parameter	Value	Source
Area (A) of Brussels	162.4 km ²	[23]
Area (A) of Marche-en-Famenne	121.4 km ²	[24]
Population density in Brussels	7 527 inhabitants/km ²	[23]
Population density in Marche-en-Famenne	145 inhabitants/km ²	[23]
R _{macro cell}	2 km	[2]
% subscribers	77%	[25]
% simultaneous users	2%	[26]
Data rate 5G	50 Mbps	[12]
Available capacity in Brussels	162.4 Gbps	[18]
Available capacity in Marche-en-Famenne	5.42 Gbps	[18]
Small cell capacity	120 Mbps	[27]
Macro cell capacity	207.5 Mbps	[27]
Number of MNOs	3	[28]
Mobile market share Proximus	43%	[28]
Mobile market share Orange	33%	[28]
Mobile market share Telenet	24%	[28]

Table 4: Input parameters of the network cost model

Parameter	Value	Source
Cost macrocell (equipment, installation)	€200 000 - 300 000	Confidential
Cost small cell (excluding installation)	€4 000 - 7 000	Confidential
Cost site upgrade	€45 000 - 60 000	Confidential
$dist_{MC-agg}$ in Brussels	1 km	[12]
$dist_{MC-agg}$ in Marche-en-Famenne	8 km	[12]
Cost fiber	€6 000 - 9 000	Confidential
Annual cost spectrum in Brussels	€5 149 487	[13]
Annual cost spectrum in Marche-en-Famenne	€74 155.40	[13]
Yearly energy cost macro cell	€4 000	[27]
Yearly energy cost small cell	€1 000 - 3 000	Confidential
Rent macro cell site	€10 000 - 15 000	Confidential
Rent small cell site	€300	[29]
Backhaul cost macro cell (CAPEX)	€15 000 - 30 000	Confidential
Backhaul cost small cell (CAPEX)	€5 000 - 10 000	Confidential
Cost of capital	5%	[10]
Annual decrease CAPEX cost	3%	[10]
Investment horizon	5 years	Assumption

To derive an estimate that reflects the Europe-wide 5G deployment cost, a weighted average of the urban and rural case studies is calculated. This step ensures consistency when comparing bottom-up results with existing top-down estimates, which typically reflect continent-wide averages. According to [20], in 2021 the population distribution across the EU was approximately 38.9% urban, 35.9% suburban, and 25.2% rural. Since no suburban case study was conducted in this analysis, the suburban population is equally divided between the urban and rural cases—a reasonable approximation for weighting purposes. This yields a composite estimate that better represents the diverse deployment contexts across Europe.

Table 5: Results bottom-up model

	Brussels	Marche-en-Famenne
TCO_{annual}	€42 976 758	€1 142 653
TCO_{annual}/sub	€45.66	€84.30
$TCO_{annual}/sub/Mbps$	€0.91	€1.69
EU TCO_{annual}/sub		€62.33
EU $TCO_{annual}/sub/Mbps$		€1.25

Before proceeding to the next step—allocating costs to OTTs based on traffic sensitivity—it is essential to first analyze the results of the cost model. Figure 4 presents the breakdown of network costs by component for both the urban and rural case studies.

It is immediately evident that the relative importance of each cost category differs significantly between the two regions. In urban areas, small cells are the primary cost driver, largely due to higher population density and greater data demand. The extensive deployment of small cells also increases the complexity and scale of the backhaul network, making backhaul a relatively larger share of total costs in these environments.

In contrast, rural areas exhibit markedly different cost dynamics. The lower population density and reduced traffic demand can typically be met using macro cells alone, without the need for additional small cells. As a result, macro cells represent the dominant cost component in rural deployments.

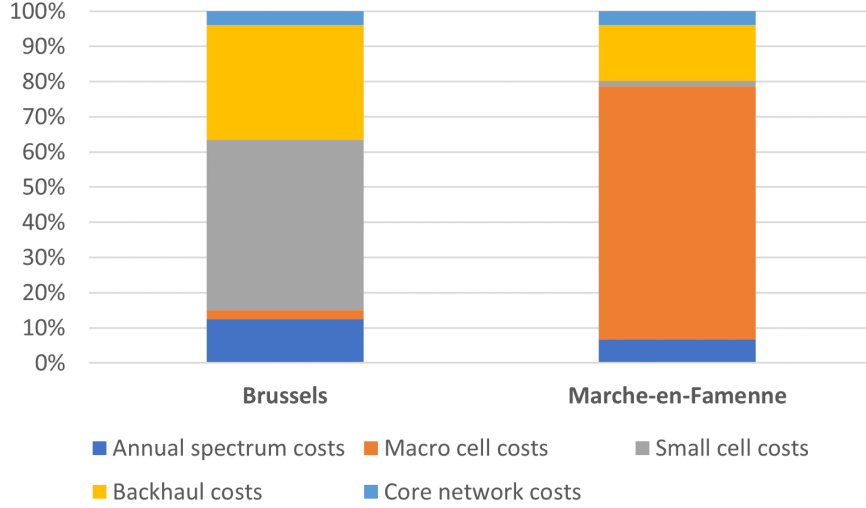


Figure 4: Cost breakdown per network part

3.2 Sensitivity analysis

To assess the impact of uncertainty inherent in any modeling exercise, a sensitivity analysis is conducted in this subsection. A selection of parameters—either subject to high variability or expected to significantly influence the Total Cost of Ownership—is systematically varied within a range of -50% to $+50\%$ of their nominal values.

For the Brussels-Capital Region, the results are visualized in Figure 5. The parameters examined include data demand, macro cell radius, small cell site rental cost, electricity prices, small cell equipment and installation costs, backhaul installation and equipment for small cells, and the degree of site sharing for both small and macro cells.

A similar analysis is performed for Marche-en-Famenne, with results shown in Figure 6. The parameters analyzed in the rural context include data demand, macro cell radius, macro cell site rental cost, electricity prices, macro cell equipment and installation costs, backhaul installation and equipment for macro cells, and the level of infrastructure sharing between operators.

In the urban area of Brussels, data demand has the most significant impact on the total cost. This is because higher data demand directly increases the required number of small cells, which, according to Figure 4, already constitutes the largest cost category. In contrast, in rural areas, macro cells dominate the cost structure, making the macro cell radius (R) the most influential parameter in that context.

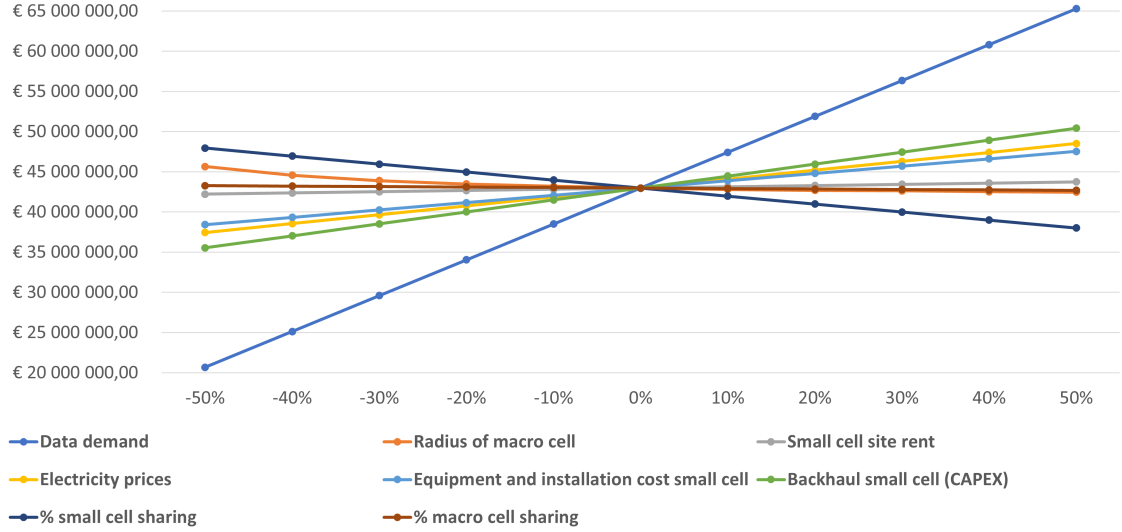


Figure 5: Sensitivity analysis on parameters for the Brussels-Capital Region

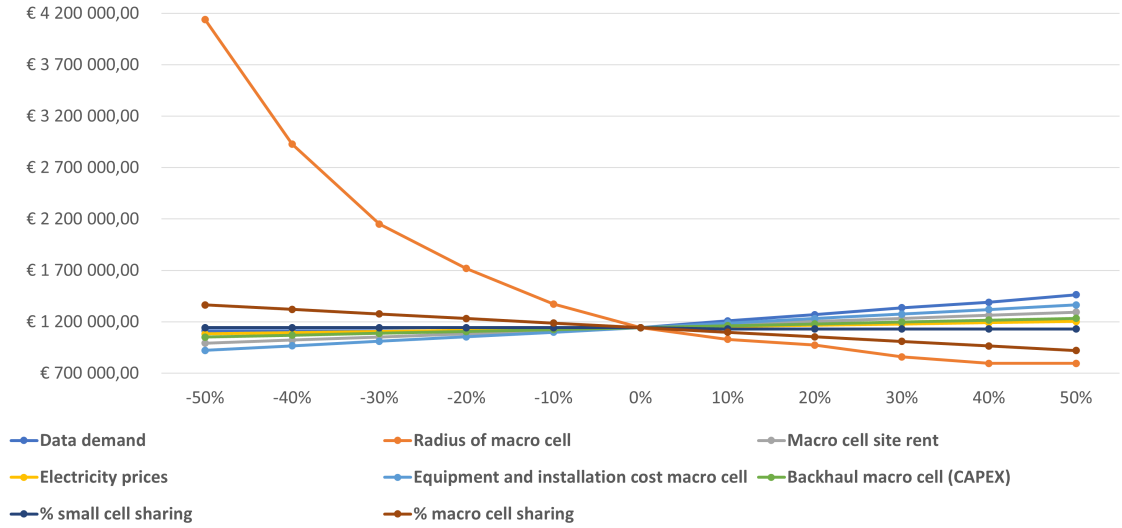


Figure 6: Sensitivity analysis on parameters for Marche-en-Famenne

3.3 Bottom-up (TCO) cost estimate vs. top-down estimate

The current top-down estimate of [8] yields an annual cost per subscriber related to OTT-traffic on European mobile networks of €43 - €46. This top-down estimate is based on the financial information of OTTs and is necessarily based on legacy networks (4G). Notice that 5G networks and legacy networks are built for different requirements. Hence a comparison based on the cost per subscriber per Mbps is more fair, 50 Mbps is assumed for 5G and 20 Mbps for 4G [12], [18]. The cost per subscriber related to OTT traffic is calculated using Equation 17.

$$\frac{TCO_{annual} \cdot \% \text{ busy hour bandwidth of OTTs}}{\text{subscribers}} \quad (17)$$

A busy hour bandwidth attributable to OTT traffic of 50% is assumed. The results are then given in Table 6.

Table 6: Annual costs related to OTT traffic

	Brussels	Marche-en-Famenne
Top-down/sub	€43–€46	
Top-down/sub/Mbps	€2.15–€2.30	
Bottom-up/sub	€ 22.83	€ 42,15
Bottom-up/sub/Mbps	€ 0.46	€ 0.84
EU bottom-up/sub	€31.17	
EU bottom-up/sub/Mbps	€0.62	

The OTT traffic costs from the bottom-up model are considerably lower for the urban area than for the rural area. Note that the bottom-up estimate for Europe is lower than the top-down estimate both when compared per subscriber and per subscriber per Mbps, respectively 28% and 71% lower than the top-down estimate. The existing top-down estimate of [8] hence seems exaggerated.

3.4 Allocating costs to OTT traffic

Two models for allocating costs to OTT traffic are considered in Section 2.3. This subsection first discusses the traffic-sensitive cost model, followed by the incremental cost model. As explained in Section 2.2, no definitive conclusion was drawn regarding the traffic-sensitivity of core network costs. Therefore, the traffic-sensitive cost allocation model presents a range: the lower bound excludes core network costs, while the upper bound includes them.

Due to the lack of detailed traffic data, a constant OTT traffic share of 50% is assumed, effectively splitting traffic-sensitive costs evenly. Table 7 presents the portion of traffic-sensitive costs attributed to OTT traffic. Unlike Table 6, non-traffic-sensitive costs are excluded here.

Table 7: Traffic-sensitive costs related to OTT traffic

	Brussels	Marche-en-Famenne
OTT cost/sub	€21.22 – €22.13	€5.85 – €7.49
EU OTT cost/sub	€14.59 – €15.81	
EU OTT cost/sub/Mbps	€0.29 – €0.32	

The costs attributed to OTT traffic using the traffic-sensitive cost model are much higher in the urban area than in the rural area even though the cost per subscriber is higher in rural areas, cf. Table 5. the traffic-sensitive costs are much less important in rural areas, cf. Figure 4. Excluding non-traffic-sensitive costs has a significant impact on the costs attributed to OTT traffic. As a result, the estimate for Europe including only traffic-sensitive costs is ca. 50% of that including all costs from Table 6. These results are hence certainly below the top-down estimate of [8], specifically 87% lower. However, note that the traffic-sensitive costs can certainly not be ignored.

Secondly, costs are divided using the incremental cost model. The incremental cost model gives the cost to update a network built only for non-OTT traffic to a network fulfilling the demand for all traffic. Again a 50% split between OTT and non-OTT traffic is assumed. Table 8 shows the results of the incremental cost model and the incremental cost estimate by [8], notice that the total cost is the sum of the standalone and the incremental costs.

Table 8: Incremental costs

	Brussels	Marche-en-Famenne
Total cost	€45.66	€84.30
Incr. cost/sub	€23.70	€2.24
Standalone cost/sub	€21.96	€82.06
EU incr. cost/sub	€14.44	
EU incr. cost/sub/Mbps	€0.29	
Incr. cost/sub [8]	€20 – €33	
Incr. cost/sub/Mbps [8]	€1 – €1.65	

A clear difference between the urban and rural areas can be observed. Further, note that the

incremental cost in Brussels is higher than the standalone cost. This is explained due to the fact that the player bearing the standalone cost benefits from the existing capacity and hence has to install less new capacity.

Across Europe, the bottom-up estimate of incremental costs is lower than the top-down incremental cost estimate by [8] both when compared per subscriber and per subscriber per Mbps. The top-down estimate is hence exaggerated. However, claims made by [1] and [9] that incremental costs for mobile networks are low, do not hold up either for 5G networks. Only in rural areas, this assumption is valid.

4 Conclusion

This study investigates traffic-related cost implications in 5G networks in the context of the European Commission’s consultation on the future of the telecommunications sector. The debate over whether over-the-top content providers (OTTs) should contribute financially to network infrastructure is increasingly central to European digital policy. While estimates of OTT-related costs in Europe already exist, they are widely criticized for relying on top-down methodologies that lack granularity, fail to differentiate between network components, and often rest on questionable assumptions about cost drivers and traffic behavior.

To contribute constructively to this debate, in this we developed and applied a comprehensive bottom-up cost modeling framework for 5G networks, addressing three core research questions: how bottom-up cost estimates compare to existing top-down figures; which network components in the last-mile 5G architecture are traffic-sensitive; and how OTT-related traffic costs can be allocated in a fair and technically robust manner. The model incorporates two case studies—one in the urban Brussels-Capital Region and the other in the rural area of Marche-en-Famenne—capturing the distinct network dynamics and deployment challenges across geographic contexts. These are then combined into a population-weighted average to provide a representative, Europe-wide estimate that is directly comparable to existing top-down models.

The results reveal a substantial gap between the two approaches. When expressed as annual total cost of ownership (TCO) per subscriber per Mbps, the bottom-up estimates are, on average, 71% lower than current top-down figures. This indicates that the latter significantly overstate the financial burden associated with OTT traffic, likely due to their failure to disaggregate cost categories and account for actual traffic sensitivity. By contrast, the bottom-up model isolates cost elements that are truly influenced by traffic—such as small cell deployments, energy consumption under peak load, and spectrum requirements—while excluding fixed or coverage-driven infrastructure like macro cell sites and associated backhaul, which are not materially affected by OTT usage. This refined classification challenges both ends of the spectrum in the current debate: those who consider all costs as traffic-sensitive, and those who dismiss the possibility of OTT impact altogether.

The study further examines two cost allocation models. The first attributes traffic-sensitive costs proportionally to OTTs based on their share of busy-hour traffic, while the second adopts an incremental cost approach that calculates the additional infrastructure required to support OTT demand. Both models demonstrate that only a part of total 5G deployment costs can be reasonably linked to OTT traffic. In fact, when using the incremental model, the OTT-related share is up to 87% lower than that suggested by prevailing top-down estimates. These results strongly advocate for evidence-based, traffic-aware frameworks in any cost-sharing mechanism under regulatory consideration.

While the current paper focuses primarily on the development and application of the model itself, future work will extend this framework to position it within the broader context of recent regulatory and technological developments in the telecom domain.

References

- [1] “BEREC preliminary assessment of the underlying assumptions of payments from large CAPs to ISPs,” Tech. Rep. [Online]. Available: <https://www.berec.europa.eu/en/document-categories/berec/opinions/berec-preliminary-assessment-of-the-underlying-assumptions-of-payments-from-large-caps-to-isps>
- [2] H. Frank, R. S. Tessinari, Y. Zhang, Z. Gao, C. C. Meixner, S. Yan, and D. Simeonidou, “Resource analysis and cost modeling for end-to-end 5g mobile networks,” in *Optical Network Design and Modeling*, ser. Lecture Notes in Computer Science, A. Tzanakaki, M. Varvari-gos, R. Muñoz, R. Nejabati, N. Yoshikane, M. Anastasopoulos, and J. Marquez-Barja, Eds. Springer International Publishing, pp. 492–503.
- [3] Letter: Europe’s telecoms market risks falling behind rivals. [Online]. Available: <https://www.ft.com/content/68f989f5-96e6-440e-90f4-2a11840d9c99>
- [4] R. May, “FSF comments – report on the future of the universal service fund,” publisher: FSF: Free State Foundation. [Online]. Available: <https://policycommons.net/artifacts/2254838/fsf-comments/3013535/>
- [5] D. Lyons, “Reforming the universal service fund for the digital age.” [Online]. Available: <https://papers.ssrn.com/abstract=2321881>
- [6] Digital inequalities in europe are underpinned by divides in children’s access, interest and confidence. [Online]. Available: <https://blogs.lse.ac.uk/medialse/2022/07/14/digital-inequalities-in-europe-are-underpinned-by-divides-in-childrens-access-interest-and-confidence/>
- [7] A ‘digital canyon’: 1.3 billion school-aged children can’t log on to internet at home | UN news. [Online]. Available: <https://news.un.org/en/story/2020/12/1078872>
- [8] Estimating OTT traffic-related costs on european telecommunications networks. [Online]. Available: <https://www.telefonica.com/es/wp-content/uploads/sites/4/2023/02/Estimating-OTT-Traffic-related-costs-on-European-Telecommunications-Networks.pdf>
- [9] B. Williamson, “An internet traffic tax would harm europe’s digital transformation.” [Online]. Available: <http://www.commmcham.com/pubs/2022/7/7/an-internet-traffic-tax-would-harm-europes-digital-transform-2.html>
- [10] G. B. Consortium, “5g blueprint, techno-economic analysis.”
- [11] C. Bouras, P. Ntarzanos, and A. Papazois, “Cost modeling for SDN/NFV based mobile 5g networks,” in *2016 8th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, pp. 56–61, ISSN: 2157-023X.
- [12] E. J. Oughton and Z. Frias, “The cost, coverage and rollout implications of 5g infrastructure in britain,” vol. 42, no. 8, pp. 636–652. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0308596117302781>
- [13] 5g regulation and law in belgium | CMS expert guides. [Online]. Available: <https://cms.law/en/int/expert-guides/cms-expert-guide-to-5g-regulation-and-law/belgium>
- [14] Y. Zou, Q. Wang, Y. Chi, J. Wang, C. Lei, N. Zhou, and Q. Xia, “Electric load profile of 5g base station in distribution systems based on data flow analysis,” vol. 13, no. 3, pp. 2452–2466, conference Name: IEEE Transactions on Smart Grid.
- [15] Radio spectrum auction ultimately yields more than 1.4 billion euro | BIPT. [Online]. Available: <https://www.bipt.be/consumers/publication/radio-spectrum-auction-ultimately-yields-more-than-1.4-billion-euro>
- [16] The benefits of 5g network sharing in urban areas. [Online]. Available: <https://cms.law/en/int/publication/cms-network-sharing-4-point-5/5g-network-sharing-in-densely-populated-areas>

- [17] V. W. S. Wong, R. Schober, D. W. K. Ng, and L.-C. Wang, *Key Technologies for 5G Wireless Systems*. Cambridge University Press, google-Books-ID: HdAoDwAAQBAJ.
- [18] A. Simmons. What's the difference between 4g LTE and 5g? [Online]. Available: <https://dgtlinfra.com/explaining-the-key-differences-between-4g-and-5g/>
- [19] M. Jackson. Countries ranked by 4g download speed at different times of day. [Online]. Available: <https://www.ispreview.co.uk/index.php/2019/02/countries-ranked-by-4g-download-speed-at-different-times-of-day.html>
- [20] Urban-rural europe - introduction - statistics explained. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural_Europe_-_introduction
- [21] The universal service | BIPT. [Online]. Available: <https://www.bipt.be/operators/the-universal-service>
- [22] "BEREC update survey on the implementation and application of the universal service provisions – a synthesis of the results."
- [23] Stad brussel | IBSA. [Online]. Available: <https://bisa.brussels/cijfers/kerncijfers-per-gemeente/stad-brussel>
- [24] Gemeente van la roche-en-ardenne in de regio waals gewest. [Online]. Available: <https://www.commune-gemeente.be/nl/commune-la-roche-en-ardenne.html>
- [25] Payment gateway belgium. [Online]. Available: <https://apexx.global/country-report/belgium>
- [26] E. J. Oughton, Z. Frias, S. van der Gaast, and R. van der Berg, "Assessing the capacity, coverage and cost of 5g infrastructure strategies: Analysis of the netherlands," vol. 37, pp. 50–69. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S073658531830830X>
- [27] D. Wisely, N. Wang, and R. Tafazolli, "Capacity and costs for 5g networks in dense urban areas," vol. 12, no. 19, pp. 2502–2510, eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1049/iet-com.2018.5505>. [Online]. Available: <https://onlinelibrary.wiley.com/doi/abs/10.1049/iet-com.2018.5505>
- [28] Situatie van de elektronische communicatiesector 2021: presentatie | BIPT. [Online]. Available: <https://www.bipt.be/operators/publicatie/situatie-van-de-elektronische-communicatiesector-2021-presentatie>
- [29] What are small cell lease rates and what should i ask for? [Online]. Available: <https://www.towergenius.com/small-cell-lease-rates/>