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A 6G Techno-Economic Framework for evaluating the feasibility of the proposed technology enablers and business models*

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Abstract

The last years have witnessed a surge in research papers focusing on the visions, enabling technologies, use cases, business models, and applications of 6G Wireless Communications Networks. While the technological advancements have garnered significant attention, the technoeconomic feasibility of these proposed solutions remains unanswered. Due to the performance improvements over 5G and the necessary network densification, the implementation of a new 6G network is anticipated to incur significant infrastructure expenses. However, these expenditures can be reduced with careful planning and a smooth transition from 5G to 6G. It is crucial to study this transition and the interplay between parameters such as anticipated technologies, applications, services, business models, and policies to ensure the affordability of 6G systems. This research aims to provide a first, comprehensive technoeconomic framework capable of evaluating proposed technologies, use cases, and business models for the evolution of 6G wireless communications, in comparison to 5G deployments. The framework seeks to address fundamental questions such as the cost-effectiveness of adopting specific technologies in the deployment phase and the feasibility of proposed business models in terms of revenue generation and demand assumptions. Such knowledge is invaluable to researchers, engineers, regulators, and other industry actors as it enables quantification and assessment of different 6G deployments and investments. Additionally, it paves the way for an open, cross-industry dialogue on the economic prospects of 6G within a clear framework. Assessing various technology combinations prior to the standardization of 6G offers a significant advantage in terms of globally economical, high-capacity, and low-latency road mapping for broadband access. By developing a technoeconomic framework that considers both technical and economic aspects, this research contributes to the understanding and planning of 6G networks. The framework aids in the evaluation and selection of technologies and business models that align with cost-effective deployment strategies. Ultimately, it enables stakeholders to make informed decisions regarding the future development and deployment of 6G wireless communication networks.

Keywords

6G mobile communication, Business models, Techno-economic analysis, 5G mobile communication, Technology enablers, Feasibility

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1 Introduction

The evolution of wireless communication technologies over the years has revolutionized the way our society operates and interacts. By providing seamless connectivity between its actors (i.e., individuals, groups, and organizations) wireless communications have transformed foundational sectors of its economic, production and social models: Healthcare, transportation, education, manufacturing, and entertainment. Given the significance of their role, as the sixth generation (6G) of wireless networks approaches, there is an increasing need to establish comprehensive frameworks that cover not only the technical elements but also the economic issues connected with the deployment and operation of these advanced networks. This study proposes a novel 6G Techno-Economic Framework (TEF) that incorporates technology improvements, cost analyses, and market dynamics, comparatively to 5G deployments, to promote informed decision-making for stakeholders participating in the 6G ecosystem.

Building upon the successes and lessons learned from the current 5G technology, 6G is envisioned to provide unprecedented data rates, ultra-low latency, and ubiquitous connectivity. However, the path towards realizing the full potential of 6G networks is riddled with complex challenges, including the deployment of massive numbers of small cells, spectrum allocation, energy efficiency, and monetization strategies. Addressing these challenges necessitates a holistic approach that considers both the technical capabilities and economic viability of the network.

While existing studies have investigated various aspects of 6G technology or possible economic models in isolation, there remains a critical knowledge gap in terms of a unified framework that explicitly considers the techno-economic aspects of 6G networks. This research aims to bridge this gap by presenting a comprehensive and integrated 6G Techno-Economic Framework that considers the interplay between technological advancements, investment costs, revenue models, and market dynamics regarding three main use case groups, consisting of six use cases in total, as they have been identified in the relevant literature.

The significance of this research lies in its potential to guide policymakers, network operators, and other stakeholders in making informed decisions related to 6G infrastructure investments, spectrum management and service pricing. The proposed framework facilitates a comprehensive evaluation of the costs, benefits, and potential risks associated with the deployment and operation of 6G networks, serving six specific, state-of-the-art use cases. The results of the framework are expressed as factors in comparison with the latest (ongoing) deployment of 5G Networks. More specifically, the results consist of the quantitative evaluation for the 6G scenarios that have been defined, accompanied with guidelines and specific viability metrics, such as the 6G Average Revenue Per User (ARPU), which is evaluated comparatively to the corresponding 5G metrics. Also, depending on the inputs, the model can either assess the feasibility of the proposed technology scheme or define a target of innovation or unit cost target per proposed technology, for the scenario to be feasible. Based on the proposed technology scope, the network and its innovation target are split into four categories: Coverage & Antennas, Backhaul, Spectrum and MECs. Additionally, this research contributes to the existing body of knowledge by providing a systematic and rigorous quantitative approach to techno-economic analysis in the context of 6G.

The subsequent sections of this paper are organized as follows: Section 2 provides a comprehensive review of the literature on 6G technology and economic modeling, highlighting the existing gaps. Section 3 outlines the methodology employed to develop the 6G Techno-Economic Framework. Section 4 presents the results obtained from applying the framework to a hypothetical scenario. Section 5 discusses the implications of the findings and highlights the limitations of the proposed framework. Finally, Section 6 concludes the paper and suggests potential avenues for further research.

By integrating technological advancements with economic considerations, the 6G TEF presented in this study aims to facilitate the successful deployment and sustainable operation of 6G networks. With the potential to revolutionize various industries and drive economic growth, it is crucial to adopt a comprehensive approach that balances technological advancements with economic feasibility in the development of 6G networks.

2 Literature review

The literature on 6G networks encompasses a broad spectrum of analysis, covering multiple key areas. In order to provide clarity on the state-of-the-art for each thematic section, the bibliography related to this work can be categorized into five central axes.

The **first axis**, representing the earliest stage in the literature, focuses on the visions of 6G networks, exploring their capabilities and the underlying technologies. Noteworthy is the work of [1], which describes 6G as a convergence of 5G mobile networks and Internet of Things technologies, leveraging artificial intelligence for optimization and automation. This vision highlights the potential of 6G to enable a wide range of applications, including advanced communication services, immersive experiences, and intelligent automation.

The **second axis** constitutes the largest portion of the relevant literature, addressing the scenarios and use cases supported by 6G networks. These works present candidate enabling technologies [3][4][8][9][10], identify various challenges, and include collaborative efforts between industry and academia [7]. According to [8], the main use cases can be categorized into three groups: Experience Sharing, Remote Control, and Connecting Everything. Examples within these categories include Augmented Reality/Virtual Reality (AR/VR), Holographic Communications, eHealth, Industry 4.0 & Robotics, Unmanned Mobility, Pervasive Connectivity, and enhanced models of Smart Cities. Dominant enabling technologies identified include THz Communications, Visible Light Communications (VLC), Reconfigurable Intelligent Surfaces (RIS), new Coding and Modulation technologies, Distributed Multiple-Input Multiple-Output (D-MIMO), Integrated Sensing and Communications (ISAC) [10]. Additionally, integration with AI, IoT, and Blockchain [3] is seen as essential for realizing the full potential of 6G networks in supporting diverse use cases.

The **third axis** focuses on translating the aforementioned use cases into quantified Key Performance Indicators (KPIs). Although fewer in number compared to the second axis (with some works overlapping), these studies hold significant importance as they allow for the technical and financial assessment of network capabilities. Highlighted indicators include Data Rate, Latency, Traffic & Connection Density, Mobility Support, Spectrum Efficiency, Positioning Accuracy, Spectrum Support, Reliability, and Network Efficiency [3][4][8][10]. Furthermore, [10] provides a comprehensive technical feasibility study for each KPI, addressing the challenges and potential solutions to achieve the desired performance levels.

The **fourth axis** delves into the Business Models and value creation paradigm of 6G networks [2][9][11]. These works primarily focus on categorizing the business models of 5G and beyond, emphasizing the creation of intellectual property value within mobile communications across various levels of system architecture [2]. Additionally, efforts have been made to describe the implications for transforming business models [9]. The advent of 6G networks is expected to bring about significant shifts in business models, as the integration of various industries and technologies enables new opportunities for revenue generation and value creation. Moreover, the approach of considering 6G as a General Purpose Technology (GPT) is of significant interest [11]. As a GPT, 6G is seen as a pervasive technology that has the potential for continuous technical improvements and enables innovative complementarities across a wide range of industrial sectors. This perspective underscores the transformative nature of 6G and its potential to reshape various aspects of the economy and society.

Finally, the **fifth axis**, which aligns with the present work, pertains to the Techno-Economic analysis of 6G networks. Notably, the literature in this area is scarce. One relevant effort is [5], which discusses emerging trends from the 5G techno-economic literature and provides five key recommendations for the design and standardization of next-generation 6G wireless technologies. These recommendations include clarifying Quality of Service (QoS) assumptions, utilizing meaningful financial metrics to reflect increased network virtualization, quantifying uncertainties in the 6G model through sensitivity analysis, openly sharing 6G model data and code, and promoting greater collaboration between economists and engineers. This highlights the need for comprehensive techno-economic analysis to assess the feasibility and viability of 6G networks from both technical and financial perspectives.

Thus, to the best of our knowledge, this work represents the first contribution to present a 6G TEF for evaluating specific 6G use cases, employing a comparative approach to 5G design and deployment costs. By considering the visions, use cases, enabling technologies, and business models of 6G networks, along with their corresponding technical and financial indicators, the proposed TEF aims to provide a comprehensive framework for evaluating the techno-economic feasibility of 6G deployments. This framework will be invaluable for researchers, engineers, regulators, and industry stakeholders in making informed decisions and investments in the development and deployment of 6G networks.

3 Methodology

In this section, we present the methodology employed to assess the viability of 6G use cases within the 6G TEF. The proposed methodology aims to provide a systematic approach for evaluating and quantifying the potential profitability and feasibility of those use cases, but it can be used for a wide range of technologies, use cases, business models and their combinations. The Figure presented below illustrates the key steps involved in the methodology, which will be comprehensively analyzed in the subsequent sections.

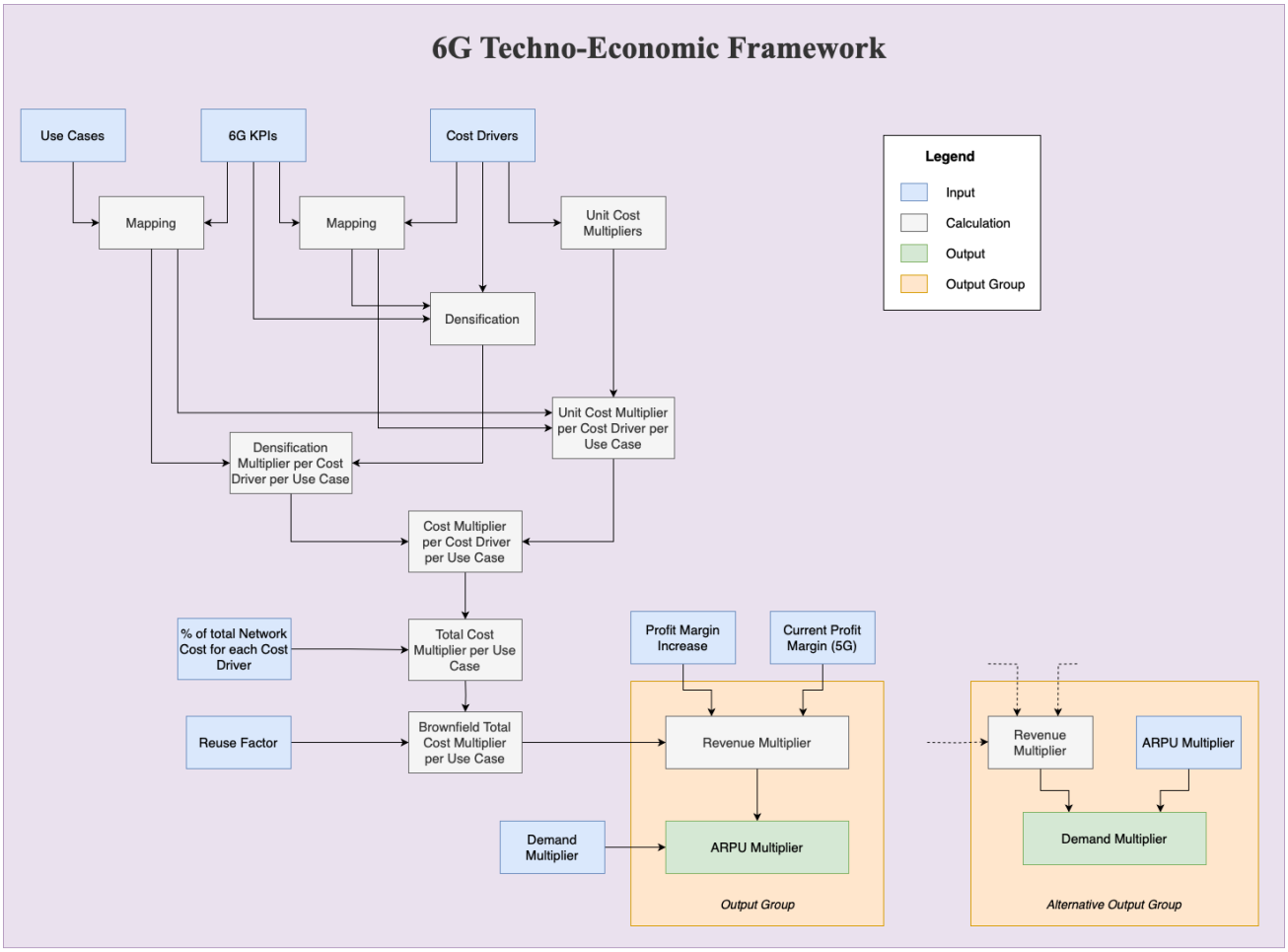


Fig. 1. The proposed 6G TEF methodology.

1. Use Case Identification

The first step in our methodology is to identify the use cases that will be assessed within the TEF. Through a thorough analysis of industry trends and the literature review, the use cases of [8] for evaluation in the context of 6G networks have been adopted: AR & VR, Holographic Telepresence, Advanced Health Services, Industry 4.0 & Robotics, Unmanned Mobility, and Pervasive Connectivity & Smart Cities.

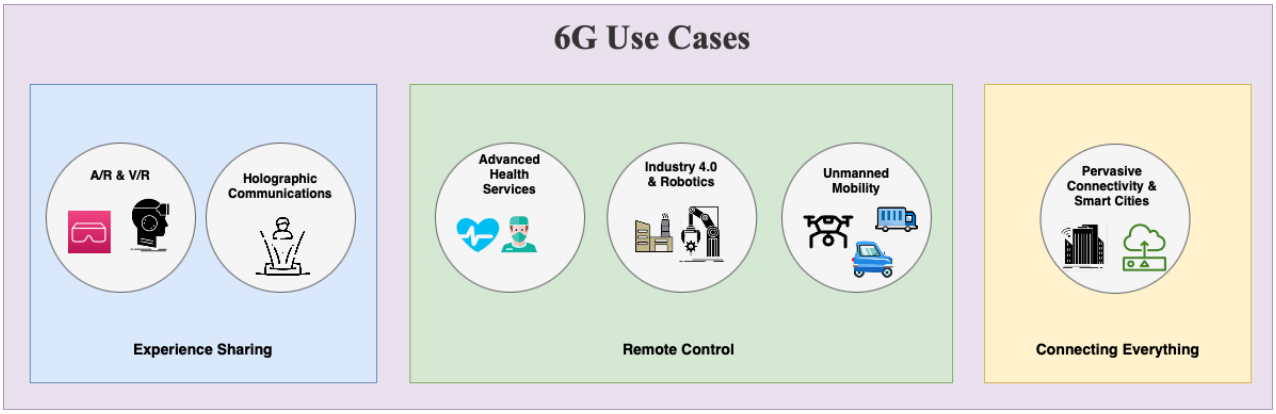


Fig. 2. The Use Cases evaluated by 6G TEF as suggested by literature.

Each use case represents a distinct application domain with unique requirements and potential benefits.

2. Key Performance Indicators (KPIs) Determination

For each identified use case, we define a set of relevant KPIs that will serve as quantitative metrics for assessing their performance and economic viability. **Table *1*** illustrates the KPIs derived from the existing literature. These KPIs include parameters such as data rate, latency, traffic & connection density, mobility support, reliability, spectrum and network efficiency. Different authors present varying values for the KPIs, albeit with close proximity.

Table 1. An overview of the suggested 6G KPIs by existing literature.

KPI	[3]	[4]	[8]	[10]
Data Rate	100Gbps-1Tbps	1Tbps	1Tbps	10-100Gbps
Latency	0.1ms	1ms	0.1ms	0.1ms
Traffic Density	100-10,000 Tbps/m^2	-	-	0.1-10 Gbps/ km^3
Connection Density	0.1 billion connections/km^2	-	0.01 billion connections/km^2	0.01-0.1 billion connections/km^3
Mobility	>1000km/h	1000km/h	1000km/h	>1000km/h
Reliability	> 99.99999	-	> 99.99999	> 99.99999
Spectrum Efficiency	200-300bps/Hz	100bps/Hz	-	-
Network Efficiency	200bits/J	-	-	-

Given the absence of standardized benchmarks for 6G performance, our aim is to ensure that the developed TEF accommodates a comprehensive spectrum of conservative and optimistic approaches. It is essential to operate within the frameworks defined by the supported Use Cases while considering a broad range of possibilities, thereby accounting for different perspectives on the network's performance. Therefore, instead of fixed KPI parameter values, probability distributions for each of the KPI parameters have been used, to reflect the uncertainty involved. These distributions will be used for risk analysis of the results. The probability distributions are defined as (uniform/beta/triangular) distributions using the minimum, maximum and expected/likeliest values for each parameter.

Furthermore, given the comparative nature of our approach with 5G networks, the KPI ranges used are not expressed in absolute values, but rather as factors relative to the performance of 5G, in order to define the probability distribution. These factors are outlined in **Table *2***.

Table 2. KPI Factor ranges compared to 5G performance.

Factor	**Expected**	**Minimum**	**Maximum**
Data Rate	30	10	100
Latency	10	9.99	10.01
Traffic Density	30	10	100
Connection Density	100	99.99	100.01
Mobility	2	1.99	2.01
Reliability	10	9.99	10.01
Spectrum Efficiency	2.5	2	3
Network Efficiency	2	1.99	2.01

Undoubtedly, it should be acknowledged that different Use Cases have varying performance requirements. For instance, Advanced Health Services necessitate ultra-low latency to accommodate real-time tactile feedback, whereas other Use Cases like Industry 4.0 & Robotics prioritize higher Connection Density compared to 5G. However, certain performance aspects such as Spectrum and Network Efficiency are common considerations across all 6G networks. The comprehensive mapping of these Use Cases with their respective KPIs is presented in **Table *3***.

Table 3. Mapping of Use Cases with their respective KPIs.

Use Case	**KPIs**							
	Data Rate	**Latency**	**Traffic Density**	**Connection Density**	**Mobility**	**Reliability**	**Spectrum Efficiency**	**Network Efficiency**
AR & VR	X	X	-	-	-	-	X	X
Holographic Telepresence	X	-	-	-	-	-	X	X
Advanced Health Services	X	X	-	-	-	X	X	X
Industry 4.0 & Robotics	-	X	-	X	X	X	X	X
Unmanned Mobility	-	X	-	-	X	X	X	X
Pervasive Connectivity & Smart Cities	-	X	X	X	X	-	X	X

By selecting appropriate KPIs, we ensure that the evaluation captures the essential characteristics and performance requirements of each use case. In the case of Holographic Telepresence, we assume that there is no physical interaction (e.g., haptic feedback) with the holographic presentation. In such scenario the mapping of Holographic Telepresence would be the same with AR & VR Use Case.

3. Cost Drivers Analysis

In order to evaluate the economic feasibility of the selected use cases, we conduct a detailed analysis of the cost drivers associated with the set of the KPIs. This involves identifying the key factors that contribute to the overall cost, such as the Coverage & Antennas, Backhaul, Spectrum and Multi-access Edge Computing units (MECs) or future equivalent assets that are needed to support the aforementioned KPIs (**Table *4***). By understanding the cost drivers specific to each use case, we gain insights into the potential cost-saving opportunities and challenges.

Table 4. Cost Drivers Analysis and Mapping.

KPIs	Coverage & Antennas	Backhaul	Spectrum	MECs
Data Rate	X	X	X	-
Latency	-	X	-	X
Traffic Density	X	X	X	-
Connection Density	X	X	-	-
Mobility	X	-	-	X
Reliability	X	X	X	-
Spectrum Efficiency	-	-	X	-
Network Efficiency	X	X	-	X

4. Cost Drivers Densification

In this phase, we calculate the multipliers of each cost driver compared to existing 5G networks. The multiplication results from each KPI and its associated Cost Driver, with the aim of meeting the desired performance levels for each use case.

The densification factor of Network Efficiency (0.95) represents cost reduction (by 5%) due to less power consumption and is calculated as

$$\boldsymbol{DensificationFactor_{NetworkEfficiency}} = \mathbf{1} - \frac{\boldsymbol{PercentageOfNetworkCost_{power}}}{\boldsymbol{Factor_{NetworkEfficiency}}}$$

where $Factor_{NetworkEfficiency}$ is the expected value of Network Efficiency (2) and $PercentageOfNetworkCost_{power}$ is the network energy consumption as a percentage of the network cost, set at 10%. Additionally, the densification factor of Spectrum Efficiency (0.4), which results in less spectrum needed, is calculated as

$$\boldsymbol{DensificationFactor_{SpectrumEfficiency}} = \frac{\mathbf{1}}{\boldsymbol{Factor_{SpectrumEfficiency}}}$$

where $Factor_{SpectrumEfficiency}$ is the value of Spectrum Efficiency factor (2.5).

Table 5. Cost Drivers Densification.

KPIs	Coverage & Antennas	Backhaul	Spectrum	MECs
Data Rate	1	$\sqrt{\ }$	1	0
Latency	0	$\sqrt{\ }$	0	30
Traffic Density	1	$\sqrt{\ }$	1	0
Connection Density	1	$\sqrt{\ }$	0	0
Mobility	1	$\sqrt{\ }$	0	30
Reliability	1	$\sqrt{\ }$	1	1
Spectrum Efficiency	0	0	0.4	0
Network Efficiency	0.95	0.95	0	0.95

The densification factor of backhaul is assumed to be approximately the square root ($\sqrt{\ }$) of the respective factor (**Table *5***). This is based on the assumption that as the area or cell density doubles, the necessary fiber backhauling increases by a factor close to the square root of 2. This can be seen in the case of geometric modeling of fiber trenches when the number of nodes in a given area doubles.

The densification factor of backhaul is equal to 30 which is assumed to be the number of sites per MEC in a fully developed 5G Stand Alone (SA) network. Due to the low maturity of the MEC technologies and their high respective cost, the current deployments of MECs are located in central or regional data centers tenths to hundreds of kilometers away from the access (**Fig. 3**). However, we expect that as the technology matures the 5G MECs will be deployed in the Aggregated Edge of the network a few tenths of kilometers form the access and then to the far or deep edge, only a few kilometers away from the access, with every MEC processing traffic from 20 to 40 5G sites. In the case of 6G, we assume one small MEC per site, so the respective densification factor should be equal to a number between 20 and 40.

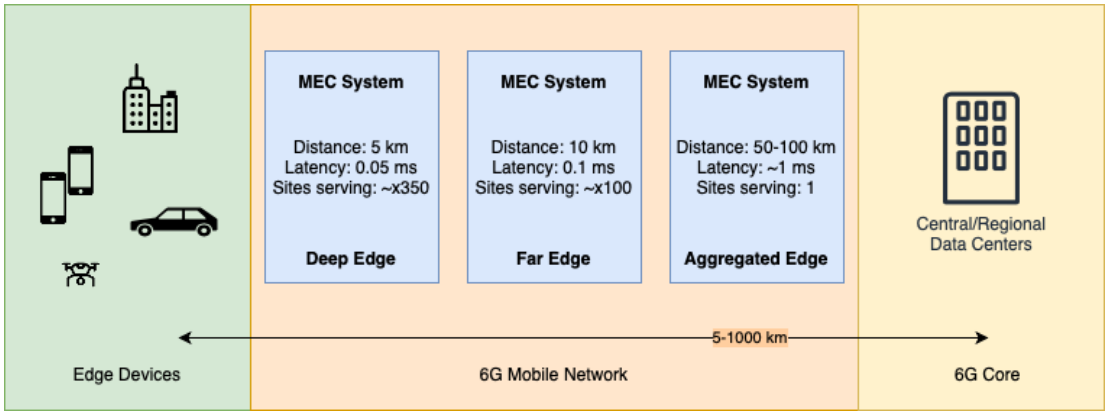


Fig. 3. MEC System deployment topology in a 6G network.

Therefore, the final densification multiplier for each cost driver per use case is given by the equation

$$\boldsymbol{Densification_{CostDriver}} = \boldsymbol{max}\{\boldsymbol{Densification_{CostDriver\ per\ KPI}} * \boldsymbol{MappingMatrix_{CostDriver\ to\ KPIs}} * \boldsymbol{MappingMatrix_{UseCases\ to\ KPIs}} * \boldsymbol{Factors_{KPIs}}\}$$

Where $Densification_{CostDriver\ per\ KPI}$ is **Table 5**, $MappingMatrix_{CostDriver\ to\ KPIs}$ is **Table 4**, $MappingMatrix_{UseCases\ to\ KPIs}$ is **Table 3** and $Factors_{KPIs}$ are the factors calculated by the distributions in **Table 2**.

5. Cost Drivers Unit Cost

Building upon the densification analysis, we determine the unit costs associated with each cost driver (**Table 6.**).

Table 6. Cost Drivers Unit Cost.

KPIs	Expected	Minimum	Maximum
Coverage & Antennas	10%	5%	20%
Backhaul	20%	15%	30%
Spectrum	5%	1%	10%
MECs	5%	3%	10%

We assume that the cost of antennas and sites per unit will be greatly reduced to the range selected due to the wide deployment of small cells with a range of a few tenths of meters with the very small size equipment compared to the current 5G cell equipment. Respectively, in the case of MECs the cost reductions due to new technologies like Artificial Intelligence (AI) and Machine Learning (ML) which will be significant for the cost of edge computing.

For backhauling, we expect that the fiber infrastructure will be used, and will depend on the cost of FTTH services which is a function of future FTTH coverage and demand. According to FTTH Council Europe [12] the FTTH/B coverage in Europe reached 62.2% (219 million homes passed) in September 2022 while penetration is around 31% (108 million subscribers). Therefore, it can be expected that by the time of 6G deployment FTTH coverage and demand will reach almost 100% which will reduce the cost per line to less that 1/3 of today's service cost.

The cost of Spectrum per MHz will be several times (tenths of times) less that the current cost due to the migration to higher frequency bands.

The unit cost multiplier for each cost driver per use case is given by the equation

$$\boldsymbol{UnitCost_{CostDriver}} = \boldsymbol{max}\{\boldsymbol{UnitCost_{CostDriver}} * \boldsymbol{MappingMatrix_{CostDriver\ to\ KPIs}} * \boldsymbol{MappingMatrix_{UseCases\ to\ KPIs}} * \boldsymbol{Factors_{KPIs}}\}$$

where $UnitCost_{CostDriver\ per\ KPI}$ are the values generated by the ranges of **Table 6.**

The final cost multiplier for each cost driver per use case if given by the equation

$$\boldsymbol{Cost_{CostDriver}} = \boldsymbol{Densification_{CostDriver}} * \boldsymbol{UnitCost_{CostDriver}}$$

6. Percentage of Total Network Cost for Each Cost Driver

To provide a comprehensive economic assessment, we use the percentage contribution of each cost driver to the total network (**Table *7***). This analysis helps in identifying the key cost drivers that have a significant impact on the overall network expenditure. By understanding the distribution of costs across different components, stakeholders can prioritize cost optimization strategies and allocate resources efficiently.

Table 7. Percentage of Total Network Cost for Each Cost Driver.

KPIs	Expected	Minimum	Maximum
Coverage & Antennas	69%	60%	75%
Backhaul	17%	15%	35%
Spectrum	2%	0.1%	10%
MECs	12%	10%	20%

The above ranges are based on MTR (mobile Termination Rates) cost models of various European NRAs (National Regulatory Authorities) for 2G, 3G and 4G network with the percentage of MECs being an assumption based on Core and controller percentages.

$$\boldsymbol{TotalCost_{UseCase} = W_{Antennas} * Cost_{Antennas} + W_{Backhaul} * Cost_{Backhaul} + W_{MECs} * Cost_{MECs} + W_{Spectrum} * Cost_{Spectrum}}$$

where $\boldsymbol{W_i}$ are the cost Weights (percentages of network cost) per Cost Driver generated by the distributions in **Table *7***.

7. Reuse Factor (Brownfield Scenario)

A reuse factor is applied to each cost driver based on the anticipated maturity of the existing infrastructure at the time of deployment. In scenarios where a complete fiber-to-the-home (FTTH) infrastructure already exists, we consider the reuse factor as a crucial factor in cost assessment. It is expected that in most probably operators will invest in areas in which most of the fiber infrastructure will be owned or readily available. By reusing the existing infrastructure, the network operator can benefit from lower entry barriers and reduced deployment costs.

Table 8. Reuse Factor in Brownfield Scenario.

KPIs	Expected	Minimum	Maximum
Coverage & Antennas	0%	0%	0 %
Backhaul	70%	50%	90%
Spectrum	0%	0 %	0%
MECs	0%	0%	0%

We consider no reuse for MECs, sites and radio equipment due to the introduction of the new technologies and the heavy densification of the network required. We also assume that the frequency bands allocated to 6G will not be already used by the 5G network.

In the brownfield scenario the total cost multiplier of each use case is calculated as

$$TotalCost_{UseCase} = R_{Antennas} * W_{Antennas} * Cost_{Antennas} + R_{Backhaul} * W_{Backhaul} * Cost_{Backhaul} + R_{MECs} * W_{MECs} * Cost_{MECs} + R_{Spectrum} * W_{Spectrum} * Cost_{Spectrum}$$

where R_i are the reuse factors per Cost Driver generated in the ranges in **Table *8***.

8. Expected Demand

The expected demand for each use case plays a crucial role in the methodology and hence accurate forecasts and industry insights should be used [13]. As in the previous steps, subscriber growth for each use case is expressed as a multiplier of 5G subscribers (**Table *9***).

Table 9. Expected demand as a multiplier to 5G Subscribers per Use Case.

Use Case	**Expected**	**Minimum**	**Maximum**
AR & VR	70%	30%	90%
Holographic Telepresence	50%	20%	70%
Advanced Health Services	25%	10%	40%
Industry 4.0 & Robotics	20.0	20.0	200.0
Unmanned Mobility	1.0	0.5	3.0
Pervasive Connectivity & Smart Cities	50.0	20.0	100.0

In the case of Unmanned Mobility which includes mostly vehicles and UAVs we assume that the likeliest value would be close to one subscription/unmanned machine per 5G subscriber. In the case of Industry 4.0, the expected number is multiplier of subscriptions when compared to the number of personnel who are 5G subscribers. Similarly, the expected value of Pervasive Connectivity case refers to the number of IoT and other devices and machines in a Smart City when compared to the number of people living in the city and are 5G subscribers. AR & VR, Holographic Telepresence and Advanced Health Services refer to the total population who are subscribers of 5G services.

9. Increase of Profit Margin

Furthermore, another important step in the process entails determining the desired enhancement in the profit margin of the 6G Network operator, set at 20% higher than 5G profit margin. This input parameter is incorporated into the TEF to facilitate a comprehensive assessment of the network's financial viability and potential profitability of each use case.

Given the Total Cost Multiplier estimated per Use Case and the current profit margin of a Telecom Operator we can calculate the necessary Revenue Multiplier per use case by using

$$Margin_{6G} = 1 - Cost_{6G}/Revenues_{6G}$$

$$(1 + MarginIncrease_{6G}) * Margin_{5G} = 1 - \frac{CostMultiplier_{6G} * Cost_{5G}}{RevenueMultiplier_{6G} * Revenues_{5G}}$$

$$\boldsymbol{RevenueMultiplier_{6G} = CostMultiplier_{6G} * \frac{1 - Margin_{5G}}{1 - (1 + MarginIncrease_{6G}) * Margin_{5G}}}$$

where $\boldsymbol{CostMultiplier_{6G}}$ is the $\boldsymbol{TotalCost_{UseCase}}$, $\boldsymbol{MarginIncrease_{6G}}$ is set to 20% and $\boldsymbol{Margin_{5G}}$ is the current profit margin of telecom operators set to 35% based on data from Statista [14]. Therefore, the target profit margin is set to 42%. The necessary revenue per Use Case given the total cost multiplier per Use Case and the profit margin targets is calculated as

$$\boldsymbol{Revenue_{UseCase} = TotalCost_{UseCase} * \frac{1 - Margin_{5G}}{1 - (1 + MarginIncrease_{6G}) * Margin_{5G}}}$$

10. Average Revenue Per User

The ARPU multiplier refers to the increase of ARPU of each 6G Use Case when compared to the ARPU of the respective 5G subscribers when taking into account the description and assumptions of the aforementioned Demand multipliers. According to TEF, the ARPU multiplier per Use Case can be calculated given the Demand assumptions made in **Table *9*** and the resulting necessary revenue.

$$\boldsymbol{ARPU_{UseCase} = \frac{Revenue_{UseCase}}{Demand_{UseCAse}}}$$

However, if the willingness to pay could be estimated, ARPU can be given also as input to the TEF either to make estimations of the necessary Demand per Use Case. Finally, given the Demand and ARPU assumptions, estimations can be made about the necessary unit cost reductions and innovation in order to start the 6G investments and network rollout.

11. Risk Analysis

As already mentioned, the uncertainty of the assumptions in terms of the final KPIs, unit costs, network cost allocation, backhaul reuse, demand and ARPU multipliers (when given as input) are modeled as probability distributions which are given as inputs to the risk analysis model, generating a probability distribution of the results after the execution of Monte Carlo simulation of 10,000 iterations.

4 Results

The results obtained from the analysis provide valuable insights into the performance and economic aspects of the proposed 6G TEF. Using the expected input parameter values, the 6G TEF model produces the results showcased in **Table 10** and **Table 11**.

Table 10. Total Cost Multiplier results for expected/mean values of parameters

Use Case	Greenfield	Brownfield
AR & VR	3.9	3.7
Holographic Telepresence	2.2	2.0
Advanced Health Services	3.9	3.7
Industry 4.0 & Robotics	8.6	8.4
Unmanned Mobility	2.5	2.4
Pervasive Connectivity & Smart Cities	8.6	8.4

The evaluation of cost reduction in the Brownfield scenario, arising from the utilization of pre-existing fiber infrastructure for backhauling, ranges from 2.6% to 5.7% of the overall cost compared to the Greenfield scenario. Considering the likelihood of Brownfield deployment being the predominant investment choice, the subsequent results pertaining to revenue and ARPU are founded on this scenario.

Table 11. Revenue and ARPU Multiplier results for Brownfield scenario

Use Case	Revenue	ARPU
AR & VR	4.19	5.99
Holographic Telepresence	2.28	4.55
Advanced Health Services	4.19	16.77
Industry 4.0 & Robotics	9.38	0.47
Unmanned Mobility	2.69	2.69
Pervasive Connectivity & Smart Cities	9.38	0.19

As per the definition of the Demand multiplier, the corresponding ARPU multiplier signifies the increment in service pricing for each 5G subscriber, ensuring the profitability of the specific Use Case in accordance with the desired profit margin. It is important to note, however, that the calculated 6G ARPU derived from the ARPU multiplier is applied to human subscribers in the Use Cases of AR&VR, Holographic Telepresence, and Advanced Health Services. Conversely, in the cases of Industry 4.0, Unmanned Mobility, and Pervasive Connectivity, the ARPU multiplier translates to revenue generated from machines or vehicles connected to the 6G network.

The outcomes of the 6G TEF undergo evaluation via a risk analysis, as previously discussed, utilizing the probability distribution of the model's input parameters. The obtained results pertain to the probability values of the total cost multiplier and the ARPU multiplier for each Use Case, with a confidence level set at 90% (**Fig. 4** and **Fig. 5**).

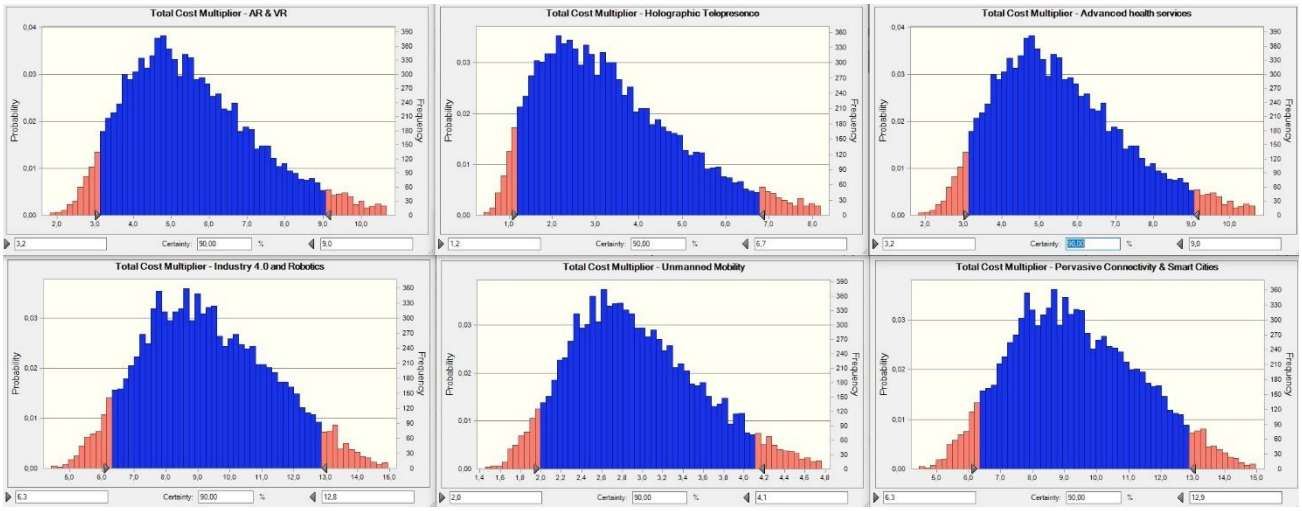


Fig. 4. Risk analysis for Total Cost Multiplier results

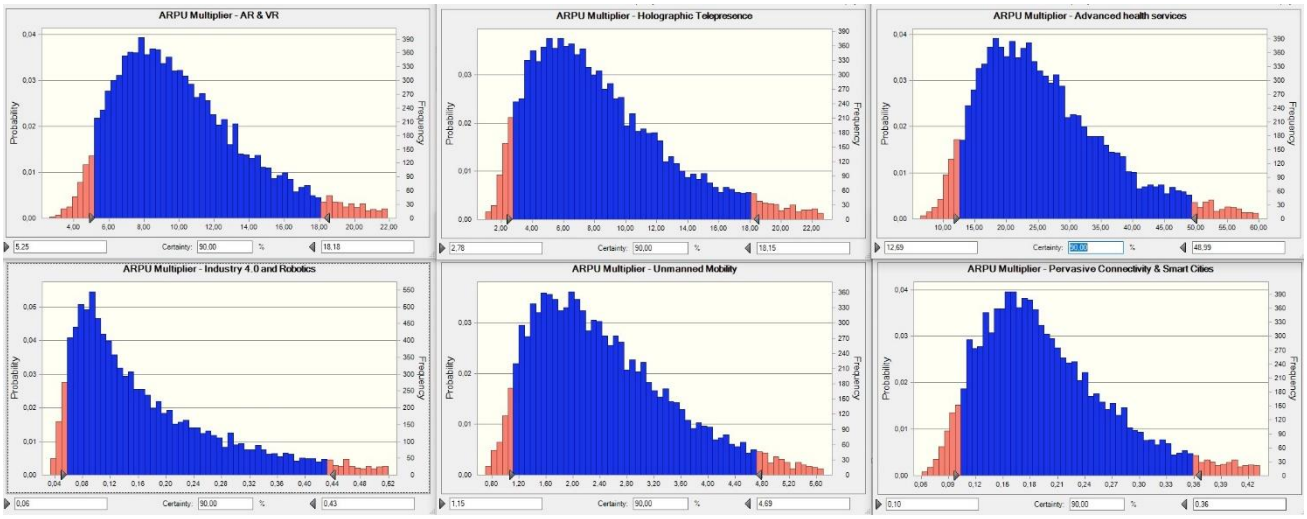
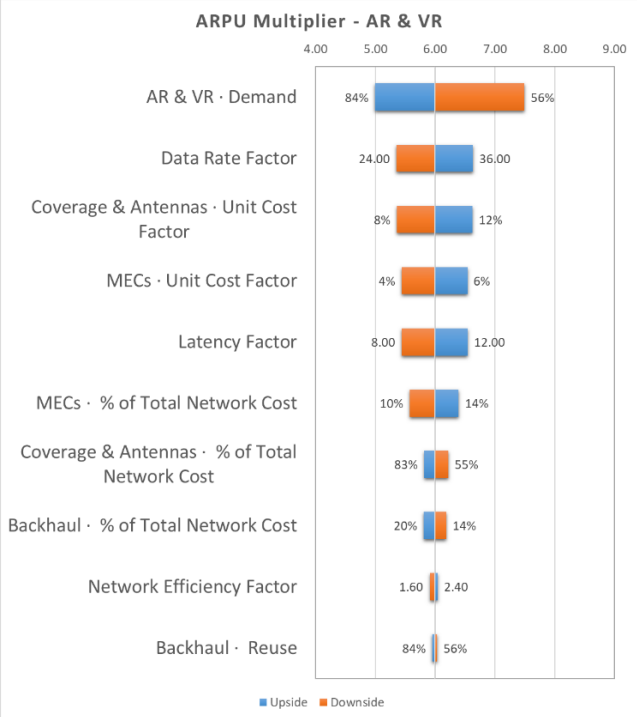
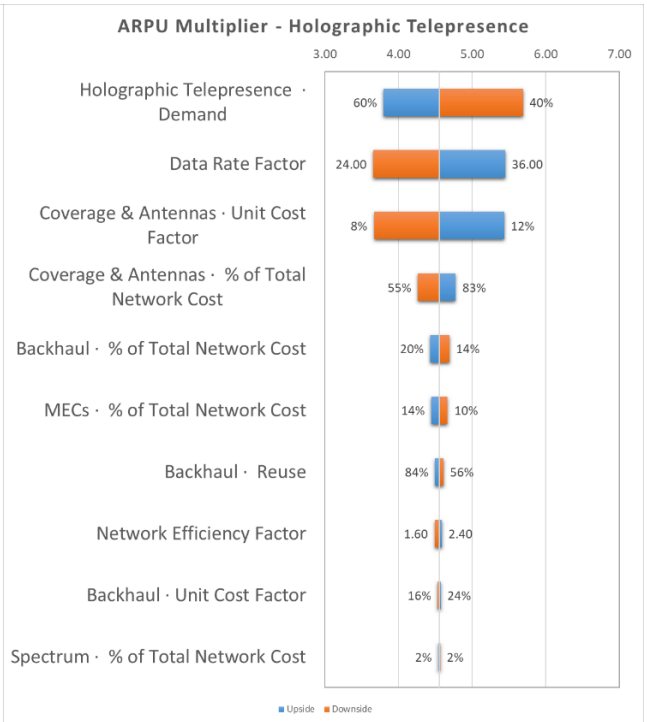
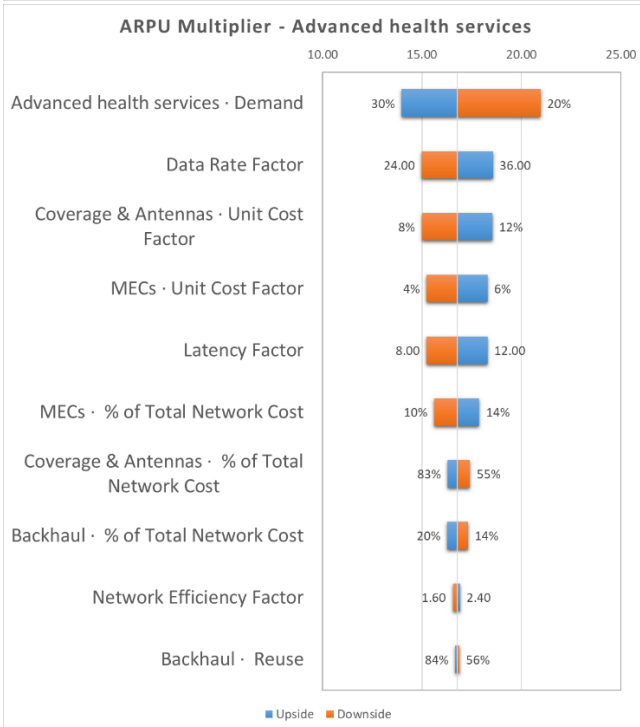


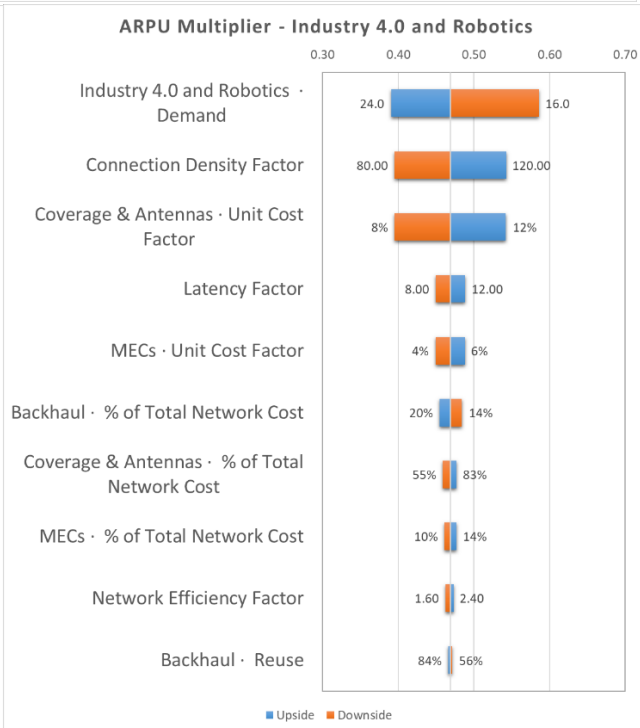
Fig. 5. Risk analysis for ARPU Multiplier results

Sensitivity analysis has been carried out in order to rank a number of selected uncertainty assumption variables according to their impact on the ARPU results (**Fig. 6**). Currently the 10 most important parameters are shown per Use Case. As expected, demand is the most important parameter for the final results followed by the cost of Radio Equipment and Sites and the cost of MECs in some cases. Furthermore, the Data Rate factor or/and the Latency factor, which are the KPI targets set for the future 6G networks are of high importance depending on the Use Case along with the Connection Density factor in Industry 4.0 and Smart Cities use cases.


ARPU Multiplier - AR & VR
4.00
5.00
6.00
7.00
8.00
9.00
AR & VR · Demand
84%
56%
Data Rate Factor
24.00
36.00
Coverage & Antennas · Unit Cost Factor
8%
12%
MECs · Unit Cost Factor
4%
6%
Latency Factor
8.00
12.00
MECs · % of Total Network Cost
10%
14%
Coverage & Antennas · % of Total Network Cost
83%
55%
Backhaul · % of Total Network Cost
20%
14%
Network Efficiency Factor
1.60
2.40
Backhaul · Reuse
84%
56%
Upside
Downside


ARPU Multiplier - Holographic Telepresence
3.00
4.00
5.00
6.00
7.00
Holographic Telepresence · Demand
60%
40%
Data Rate Factor
24.00
36.00
Coverage & Antennas · Unit Cost Factor
8%
12%
Coverage & Antennas · % of Total Network Cost
55%
83%
Backhaul · % of Total Network Cost
20%
14%
MECs · % of Total Network Cost
14%
10%
Backhaul · Reuse
84%
56%
Network Efficiency Factor
1.60
2.40
Backhaul · Unit Cost Factor
16%
24%
Spectrum · % of Total Network Cost
2%
2%
Upside
Downside


ARPU Multiplier - Advanced health services
10.00
15.00
20.00
25.00
Advanced health services · Demand
30%
20%
Data Rate Factor
24.00
36.00
Coverage & Antennas · Unit Cost Factor
8%
12%
MECs · Unit Cost Factor
4%
6%
Latency Factor
8.00
12.00
MECs · % of Total Network Cost
10%
14%
Coverage & Antennas · % of Total Network Cost
83%
55%
Backhaul · % of Total Network Cost
20%
14%
Network Efficiency Factor
1.60
2.40
Backhaul · Reuse
84%
56%
Upside
Downside


ARPU Multiplier - Industry 4.0 and Robotics
0.30
0.40
0.50
0.60
0.70
Industry 4.0 and Robotics · Demand
24.0
16.0
Connection Density Factor
80.00
120.00
Coverage & Antennas · Unit Cost Factor
8%
12%
Latency Factor
8.00
12.00
MECs · Unit Cost Factor
4%
6%
Backhaul · % of Total Network Cost
20%
14%
Coverage & Antennas · % of Total Network Cost
55%
83%
MECs · % of Total Network Cost
10%
14%
Network Efficiency Factor
1.60
2.40
Backhaul · Reuse
84%
56%
Upside
Downside

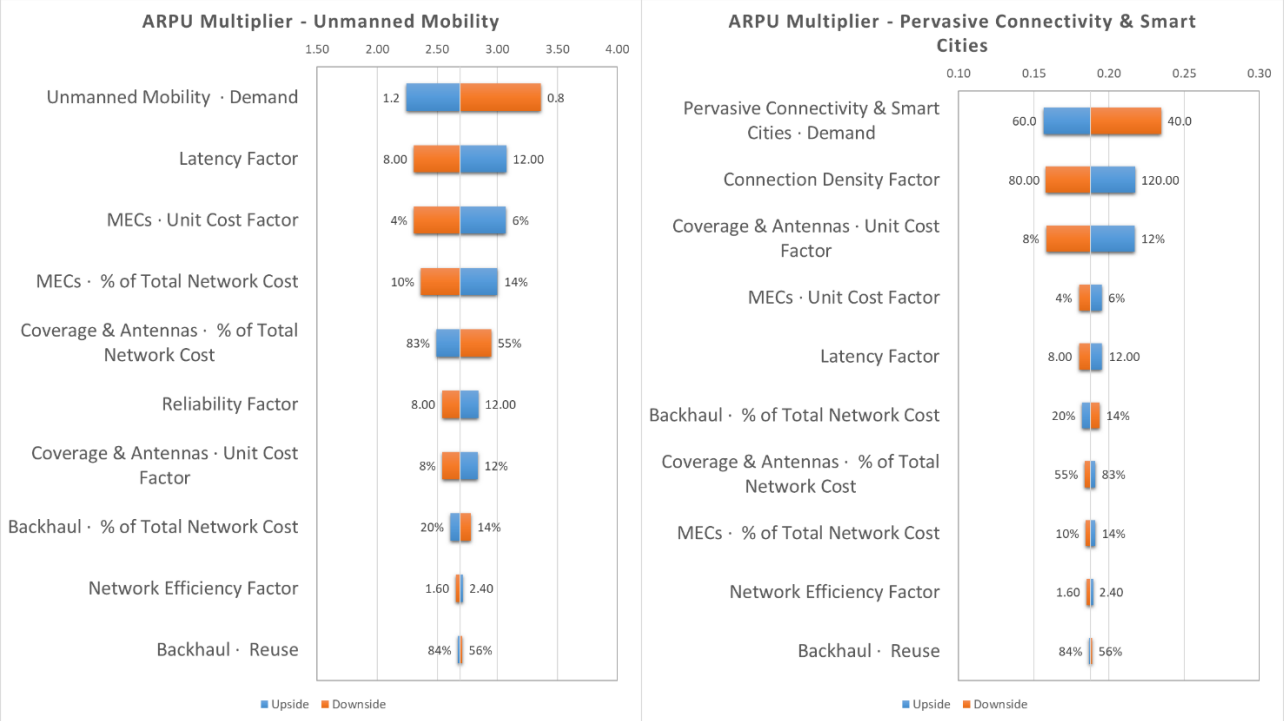


Fig. 6. Sensitivity analysis for ARPU Multiplier results

5 Discussion

The discussion section aims to delve into the implications and potential of 6G wireless communication networks based on the findings of this study. Four key topics are explored, including the identification of promising use cases, the need for innovation, cost considerations, and the importance of infrastructure development.

1. Promising Use Cases

Within the assessed 6G TEF, certain use cases have emerged as particularly promising in terms of their profit margin, taking into account their market demand and revenue potential. Among these use cases, Pervasive Connectivity & Smart Cities and Industry 4.0 & Robotics demonstrate strong viability for 6G deployment, with a necessary minimum ARPU multiplier of 0.19 and 0.47 respectively. It is noteworthy that these use cases have already been recognized and qualified by actors involved in 5G deployment. In addition to these use cases, Unmanned Mobility and Holographic Communications also show potential for 6G applications. Although their revenue factor may be marginally higher compared to their total cost multiplier, the immersive experiences and real-time interaction they offer, combined with careful planning and strategic implementation, could make them attractive to various industries and sectors.

However, AR/VR applications pose specific challenges in terms of infrastructure requirements. Their need for ultra-low latency can significantly raise infrastructure costs, which may not be fully offset by the expected market demand. Thus, careful cost-benefit analysis and infrastructure optimization strategies are necessary to ensure the economic feasibility of this use case. The health sector also presents unique challenges and opportunities within the 6G ecosystem due to the high ARPU multiplier requirements. The successful integration of advanced health services into the 6G network may require additional considerations, such as insurance coverage or government subsidies. This emerging area of healthcare in the context of 6G has the potential to create new business opportunities for insurance companies while simultaneously improving access to advanced healthcare solutions for the people.

Business Models should consist of carefully selected portfolios of Use Cases their respective technologies while focusing on these areas and Use Cases which can be the most profitable or have the least risky results in terms of ARPU in the TEF while taking into account the willingness to pay in each case.

2. Innovation as a Prerequisite

Innovation is a cornerstone in the long-term viability of 6G networks. While technological advancements are essential, it is equally important to explore innovative approaches to monetize and capture value from the identified use cases. This requires reimagining the traditional business models and embracing new paradigms, that allow the stakeholders to maximize the economic potential of their networks and drive their widespread adoption.

Innovative business models require the alignment of interests of different stakeholders, including network operators, service providers, content creators, and end-users. These models define the value proposition, revenue streams, and cost structures that underpin the deployment and operation of 6G networks. Emerging business models, such as revenue-sharing agreements, subscription-based services, or platform ecosystems, should be considered and examined per use case, in order to realize the full potential of 6G networks.

Finally, to perform a quantitative evaluation of the profitability of the proposed business models, it is necessary to conduct estimations of demand and willingness to pay for each Use Case included in the business model. Additionally, the expected contribution of each Use Case to the overall profitability of the business model should be assigned appropriate weightage.

3. Cost Reduction through Innovation

Cost reduction is a pivotal aspect in the successful deployment and operation of 6G networks. As the complexity and scale of these networks increase, exploring innovative approaches becomes crucial to address the associated expenses. By embracing innovative solutions in deployment techniques, manufacturing processes, and network technologies, stakeholders can effectively reduce costs and make 6G networks more economically viable and accessible to a broader range of users. Regarding deployment techniques, innovative approaches can streamline the deployment process and optimize resource utilization. For instance, leveraging advanced automation in tower installation, fiber optic cable laying, and infrastructure development can lead to significant cost savings. Additionally, exploring new materials and efficient design methodologies can result in more affordable and sustainable network infrastructure.

Innovations in manufacturing processes also play a vital role in cost reduction. By adopting advanced manufacturing technologies, stakeholders can realize cost efficiencies in the production of network equipment, components, and devices. This enables faster prototyping, customization, and scalability while minimizing material waste and reducing production costs.

Furthermore, innovations in network technologies themselves can contribute to cost reduction. By leveraging advancements in AI/ML, Internet of Things (IoT) and Blockchain technologies, stakeholders can achieve greater scalability and cost efficiency in network management and operation, especially for Edge Computing (MECs) cost reductions. These technologies enable the decoupling of hardware and software, and thus by exploiting the appropriate business models, the decoupling of cost from growth.

4. Importance of FTTH Coverage

With the increase of data-intensive applications and the growth of user demands, high-speed and reliable fiber connections are essential for backhauling the generated traffic by 6G access networks. Therefore, prioritizing the deployment and expansion of FTTH infrastructure emerges as a strategic imperative to ensure the necessary backhaul capacity, support the envisioned use cases, and deliver the needed user experience in the 6G era. Having a well-established FTTH infrastructure lowers the costs of 6G deployment and hence the entry barrier for the aspiring stakeholders.

When a complete FTTH infrastructure exists, network operators can leverage and reuse the existing fiber connectivity, significantly reducing the costs and complexities associated with deploying new network infrastructure from scratch. This reuse of infrastructure offers a cost-effective and efficient approach, allowing operators to focus their resources on enhancing the Radio Access section of the network and delivering innovative services rather than investing heavily in new

infrastructure development. As a result, a comprehensive FTTH coverage not only enables faster and more cost-effective network deployment but also fosters healthy competition among operators, driving innovation and service differentiation in the 6G ecosystem.

6 Conclusions

In this paper, we have presented the first techno-economic framework for assessing the viability and profitability of 6G networks and associated use cases. Through a systematic methodology, we have analyzed key factors including KPIs, cost drivers and Use Cases correlated to business models to provide insights into the economic feasibility of deploying 6G networks, such as the Total Costs and the minimum ARPU needed.

Our findings indicate that certain use cases, such as Pervasive Connectivity & Smart Cities and Industry 4.0 & Robotics, demonstrate strong potential for 6G deployment, with promising revenue opportunities and market demand. Furthermore, our study highlights the critical importance of FTTH coverage for the seamless deployment and integration of 6G networks. A robust FTTH infrastructure ensures the necessary backhaul capacity in order to support data-intensive applications and deliver the needed user experience. In terms of profitability, our analysis reveals the need for innovative business models consisting of portfolios of Use Cases with carefully adjusted/weighted contributions that also align with the interests of various stakeholders. The unit cost reduction assumed is also highly correlated to the innovation of new technology enablers and the corresponding production methods.

The proposed 6G TEF is a novel contribution, invaluable to the relevant stakeholders as it enables quantification and assessment of different 6G deployments and investments. The replicability of this simple methodology paves the way for an open, cross-industry dialogue on the economic prospects of 6G within a clear framework. However, further work is needed to narrow down the uncertainty intervals that arise from the lack of specific, per use case, demand forecasts and the lack of a standardized 6G architecture. Thus, the evolving landscape of use cases introduce uncertainties that may impact the accuracy of our predictions. Additionally, the estimations and assumptions made in our analysis are based on available data and may require further refinement as the 6G ecosystem continues to evolve.

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