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Comparative Techno-Economic Evaluation of 5G mobile network deployments in different scale urban areas

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Abstract

Mobile communication technology is moving into the fifth-generation (5G) which is expected to overcome the new challenges that have emerged with the Internet of Things (IoT) and the exponential growth in demand for mobile traffic. Therefore, the Mobile Networks Operators (MNOs) are planning to improve their networks in order to achieve the required standards for capacity, coverage and quality of service.

In this paper, a techno-economic study is performed to assess the feasibility of the deployment of a 5G mobile network in different types of urban areas depending on population density. In each of these different cases, the conditions are studied under which such an investment can be economically viable through increased revenues and reduced costs.

The findings of this study could become an important tool for decision and policymakers in investment strategies for 5G mobile networks.

Keywords

5G mobile network, techno-economic evaluation, TONIC model, urban area, Net Present Value, Internal Rate of Return, Payback period, OPEX, CAPEX

1. Introduction

The world is ready to change with the implementation of fifth-generation technology for telecommunications networks across the world. 5G will bring faster data speeds, low latency communications, and higher bandwidth, which will help improve user experiences both in the consumer and business space, from cloud gaming to telehealth use cases. 5G will act as the catalyst for the fusion of technologies such as Artificial Intelligence, robotics, 3D printing, and the Internet of Things (IoT) [1], [2], [3].

However, only a few studies have been carried out concerning the techno-economic evaluation of 5G. This paper presents a techno-economic analysis to assess the feasibility of the development of a 5Gmobile network in different types of urban areas based on population density. Three different types of urban areas are used.

In each of these three cases, the following financial indicators for the assessment of the investment are evaluated and compared: Net Present Value (NPV), Internal Rate of Return (IRR), Payback period. Furthermore, the costs of the network components are used to calculate investments for each year, Capital Expenditure (CAPEX) and Operative Expenditure (OPEX).

The remainder of this paper is organized as follows. Section 2 presents a literature review of the existing bibliography, while Section 3 describes the methodology. Section 4 presents the results and the related discussion. Finally, Section 5 summarizes the analysis of the findings.

2. Literature Review

There have been many studies in recent years in the area of the fifth-generation mobile communication technology including the main features, the performance, the deployment and the applications of this technology standard. The discussion below follows a chronological order of the relevant studies and focuses on their outcomes.

G. Smail et al. [4] propose a techno-economic analysis and mathematic modeling approach, as well as, a new pricing model to be consistent with the growth of mobile broadband. The results show that 5G is very beneficial, not only because of its lower cost compared with 4G LTE but also due to the increment of average data consumptions offered by 5G mobile technologies and the increasing growth of the number of users.

In Neokosmidis et al. [5] a roadmapping activity identifying the key technological and socio-economic issues is performed, so as to help ensure a smooth transition from the legacy to future 5G networks. Based on the fuzzy Analytical Hierarchy Process (AHP) method, a survey of pairwise comparisons has been conducted within the CHARISMA project by 5G technology and deployment experts, with several critical aspects identified and prioritized. Moreover, I. Neokosmidis et al. [6] determine and prioritize the factors that will affect 5G systems deployment and adoption. The authors also provide a reference model describing the relationships between the involved players, revenue streams and cost drivers as well as several guidelines towards making 5G a commercial success.

Oughton et al. [7] analyze the capacity, coverage and cost of different enhanced Mobile Broadband (eMBB) infrastructure strategies. Both a supply-driven and demand-driven investment analysis is undertaken using a case study of the Netherlands. The key contribution is estimating the traffic threshold delivered per user from integrating 5G spectrum bands on the existing Dutch macrocell network. Based on the inputs of this analysis, they find that 5G spectrum bands provide an average per-user traffic capacity improvement of approximately 40% for the Netherlands in comparison with the existing LTE capacity.

Y. Siriwardhana et al. [8] highlight methodologies to effectively utilize 5G for e-health use cases and its role to enable relevant digital services. They also provide a comprehensive discussion of the implementation issues, possible remedies and future research directions for 5G to alleviate the health challenges related to COVID-19.

Ahokangas et al. [9] identify a set of regulatory challenges for local 5G networks in complex industrial multi-stakeholder ecosystems where the telecommunication and information technology-related regulations meet with vertical-specific regulations, leading to a complex environment in which to operate. As highly country-specific, these regulations can open new business opportunities or significantly slow down or even prevent a market opening to local private 5G networks for vertical-specific use.

Yu Tang et al. [10] provide a complete survey on 5G technology in the agricultural sector and discuss the need for and role of smart and precision farming; benefits of 5G; applications of 5G in precision farming such as real-time monitoring, virtual consultation and predictive maintenance, data analytics and cloud repositories.

Salah et al. [11] examine the evolution of mobile communication networks starting from the first generation through to the fifth-generation with comparative studies. Subsequently, the main requirements of 5G networks and emerging technologies are highlighted. Furthermore, an overview of several technologies that might be used to achieve the 5G requirements including Massive-MIMO, Millimetre-waves, beamforming, full-duplex, and Small-Cells are explained.

Lehr et al. [12] compare and contrast 5G with earlier generations of cellular and related wireless technologies and examines how the economic forces that have shaped the MNO industry heretofore are changed with 5G. This study highlights the potential for new business models and competition to disrupt the wireless industry in the coming years.

Shorbagy [13] focuses on the analysis of 5G technology and highlights its advantages and disadvantages, which impact the visual appearance and aesthetics of both buildings and the city. This study also explores various solutions to overcome the predicament of the wireless signal coverage and the penetration of buildings. Furthermore, this research aims to define a set of recommendations for the construction industry to take further innovative steps towards achieving advanced building materials that can adopt the 5G technology.

The above-mentioned research reveals important aspects of the 5G technology. This study’s contribution focuses on the techno-economic analysis defining the conditions under which the deployment of a 5G mobile network in different types of urban areas could be economically viable.

3. Methodology

In this study, an economic and financial analysis for the deployment of 5G mobile networks in urban areas is performed in order to describe the revenue and predict costs. The techno-economic methodology is based on a bottom-up analysis of discounted cash flows for network deployment, operation and maintenance cost.

An eight-year study period is assumed, from 2021 to 2028, a reasonable period for mobile network deployments, considering the time it usually takes to reach market maturity. The market penetration of broadband services and the tariffs for these services as well as their market share have to be defined. For the analysis, demand and price forecasts have been incorporated in order to calculate network components needed as well as revenues generated by network services. Two service bundles are offered, the Gold one which offers unlimited data and the Bronze one with limited data plan.

Regarding the forecasting model, the 3-parameter TONIC model is chosen, that well fits the services having diffusion-type characteristics of mobile telecom.

Three different types of urban areas are used:

Small size urban areas: population less than 50,000 inhabitants.

Medium size urban areas: population from 50,000 to 180,000 inhabitants.

Large size dense-urban areas: population over 180,000 inhabitants.

Specifically, in each of the above types of urban areas the case studies with the following demographic characteristics are used:

UrbanS: Population 38,554 inhabitants, Area 9 km^2, Population density 4,284 inhabitants/ km^2

UrbanM: Population 118,707 inhabitants, Area 15 km^2, Population density 7,914 inhabitants/ km^2

UrbanL: Population 315,196 inhabitants, Area 20 km^2, Population density 15,760 inhabitants/ km^2

The results could also be used in a scenario, which includes a synthesis of the above urban-type areas by combining the areas and the possible revenues and cost as well as the NPV results.

The results of this paper were derived using the inCITES TEN web application (https://www.incites.eu/products-and-services-ten-web-app).

In the following sections, the methodology is described more analytically.

3.1. Demand forecasts

The Tonic model, which was developed within the IST-TONIC project, was chosen and provided reasonably accurate fitting over historical data related to high-technology products [14], [15], [16].

The demand model is defined by the following expression:

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

where Y(t) is the demand forecast at time t and M is the saturation level of the penetration, which is estimated a priori. The parameters α, b, and c, are estimated by a stepwise procedure, attempting to value these parameters using nonlinear regression [17].

The diagrams in Appendix A show the predicted number of users in percentage rate (service penetration %), in each of the above types of urban areas. Two on demand curves were calculated, a baseline one referencing cities with medium growth to saturation 5G demand and an optimistic one based on countries with fast growth to saturation 5G demand.

The bronze curve corresponds to the Bronze bundle, the gold curve to the Gold bundle and the mauve one corresponds to the total number of predicted users.

3.2. Pricing Model

Regarding the pricing, we suggest three different scenarios (Table 1), in which the tariff is fixed during the 8-year period we are considering and there is a difference only depending on the bundle of services selected. The three scenarios are aimed at citizens with different financial status and focuses on satisfying them by adjusting the pricing according to their individual requirements. Specifically, the first scenario (PriceL), suggests that the Gold bundle with more upgraded network services costs 360 euros per year, i.e. 30 euros per month, while the Bronze bundle with less upgraded network services costs 240 euros per year, i.e. 20 euros per month. The second scenario (PriceM), suggests the cost of 360 euros per year for the Bronze bundle and 540 euros per year for the Gold bundle, while the third scenario (PriceH), suggests the cost of 480 euros for the Bronze and the cost of 720 euros per year for the Gold bundle.

Table 1 Annual Tariff – ARPU (€)

Scenarios	Bronze	Gold
1. PriceL	240	360
2. PriceM	360	540
3. PriceH	480	720

3.3. Technoeconomic Indicators

The net present value (NPV) describes today's value of the sum of resultant discounted cash flows (annual investments, running costs, revenues, etc.), or equivalently the volume of money expected over a given period of time. If the NPV is positive, the project is acceptable, and it is a good indication of the profitability of an investment project, taking into account the time value or opportunity cost of money, which is expressed by the discount rate [17], [18].

The internal rate of return (IRR) is the interest rate resulting from an investment and income (resultant net cash flow) that occur over a period of time. If the IRR is greater than the discount rate used for the analysis, the investment is profitable. The IRR gives a good indication of the value achieved with respect to the money invested.

The cash balance (accumulated discounted cash flow) curve generally goes negative in the early part of the investment project because of initial capital expenditures. Once revenues are generated, the cash flow turns positive, and the cash balance curve starts to rise. The lowest point in the cash balance curve gives the maximum amount of funding required for the project. The point in time when the cash balance turns positive represents the PayBack Period (PBP) for the project.

3.4. Model assumptions

For the purposes of this study, the inCITES TEN database of telecommunication network components was used. It is worth mentioning that the weighted average cost of capital (WACC) is set to 10%, a relatively high value, due to the risk profile of the investment of 5G networks. The taxation is set to 20%.

Regarding the dimensioning of the network, it is assumed that there is only one provider that covers the whole area. The number of 5G network components (macro cell, small cell etc.) are set according to the following criteria:

- Geographically
- Antennas capacity
- Number of users/ cell

Moreover, it is considered that during the 8 years, the number of users of the Gold bundle continues to increase, however, those of the Bronze bundle decrease. The following diagram shows the market share of each bundle as a percentage.

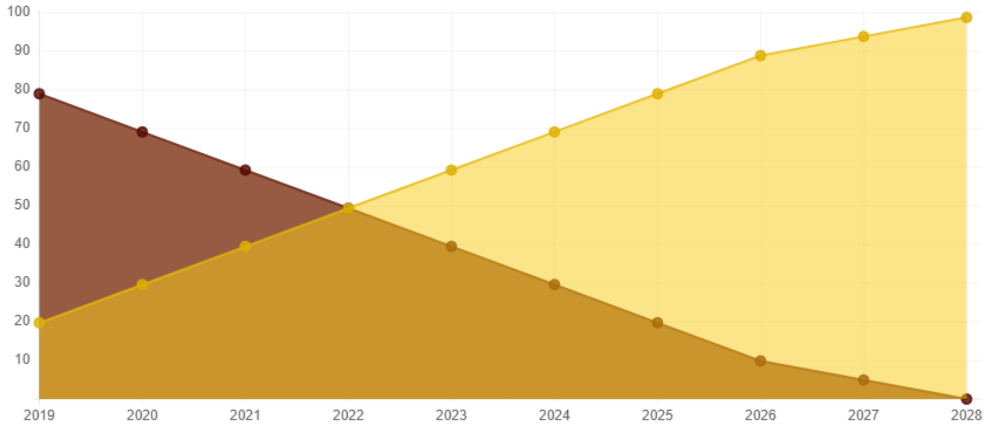

Figure 1 Bundles Market Share

4. Results and discussion

The following tables and figures include a synopsis of the results.

Tables 2-4 summarize the economic results for each one of the three different types of urban areas.

According to **NPV**, it is noticed that for:

UrbanS: no scenario is profitable. NPV is negative in all cases.

UrbanM: only one scenario is profitable, with Demand: Fast and Tariff: PriceH

UrbanL: all the scenarios are profitable except one with Demand: Medium and Tariff: PriceL

According to **IRR**, it is obvious that for:

UrbanS: Only the last scenario is profitable, with Demand: Fast and Tariff: PriceH

UrbanM: Three scenarios are profitable. Two of them with Demand: Fast

UrbanL: All the scenarios are profitable

According to the **Payback Period**, it is noticed that for:

UrbanS: Only one scenario has a payback period of less than 8 years and more specifically 6.10 years

UrbanM: Three scenarios have a payback period of less than 8 years

UrbanL: All the scenarios have a payback period of less than 8 years

Moreover, checking all the three financial indicators for the assessment of the investment, it is observed that:

UrbanS: no scenario comply the profitability criteria

UrbanM: only one scenario is profitable with Demand: Fast and Tariff: PriceH

UrbanL: the majority of scenarios comply with the profitability criteria. There is one exception scenario, with Demand: Medium and Tariff: PriceL

Table 2 Economic results for a small size urban area

		UrbanS		
Demand	**Annual Tariff-ARPU**	**NPV (€)**	**IRR**	**PBP**
Medium	PriceL	-28,709,061	-37.46%	Infinity
Fast	PriceL	-22,796,842	-26.40%	Infinity
Medium	PriceM	-21,453,663	-14.43%	Infinity
Fast	PriceM	-13,109,255	-2.97%	Infinity
Medium	PriceH	-14,413,897	-2.13%	Infinity
Fast	PriceH	-3,719,902	10.46%	6.10 years

Table 3 Economic results for a medium size urban area

			UrbanM	
Demand	**Annual Tariff-ARPU**	**NPV (€)**	**IRR**	**PBP**
Medium	PriceL	-49,919,043	-20.33%	Infinity
Fast	PriceL	-32,791,262	-8.28%	Infinity
Medium	PriceM	-28,195,248	-0.89%	Infinity
Fast	PriceM	-3,758,988	12.81%	5.85 years
Medium	PriceH	-7,001,937	11.23%	6.22 years
Fast	PriceH	25,148,250	26.83%	4.50 years

Table 4 Economic results for a large size dense-urban area

			UrbanL	
Demand	**Annual Tariff-ARPU**	**NPV (€)**	**IRR**	**PBP**
Medium	PriceL	-2,015,743	14.07%	6.03 years
Fast	PriceL	30,101,479	28.07%	4.56 years
Medium	PriceM	53,255,131	33.23%	4.52 years
Fast	PriceM	105,928,928	51.67%	3.10 years
Medium	PriceH	108,429,292	47.19%	3.81 years
Fast	PriceH	181,546,554	69.60%	2.60 years

CAPEX comes from the network migrating elements, which is usually considered as the fixed investment cost.

It is noticed that the total CAPEX cost of UrbanL is significantly higher than the costs of the other types of urban areas, but CAPEX per capita for UrbanL is less than half of the CAPEX of capita for UrbanS.

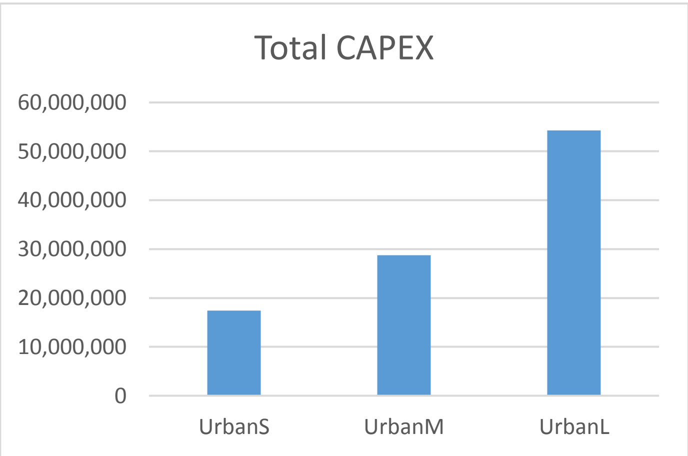

Figure 2 Total CAPEX (€)

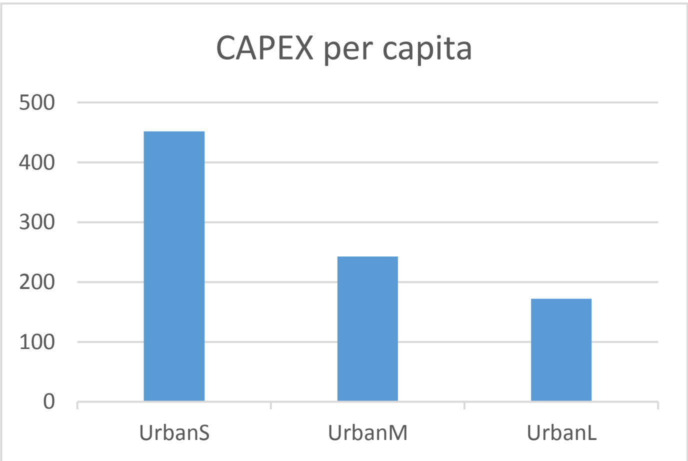

Figure 3 CAPEX per capita (€)

OPEX is the cost that comes after the deployment of dimensioned networks related to management and maintenance.

It is noticed that there are small differences in operational costs between medium and fast Tonic demand model. In total OPEX, there is a big difference between UrbanS and UrbanM, while for the OPEX per capita, there is a big difference between UrbanM and UrbanL.

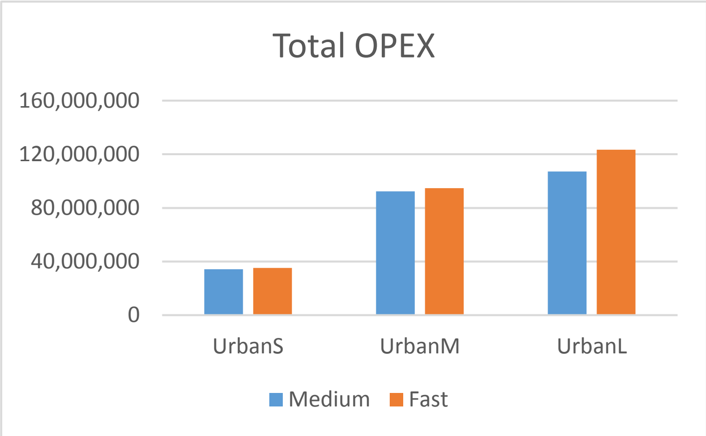

Figure 4 Total OPEX (€)

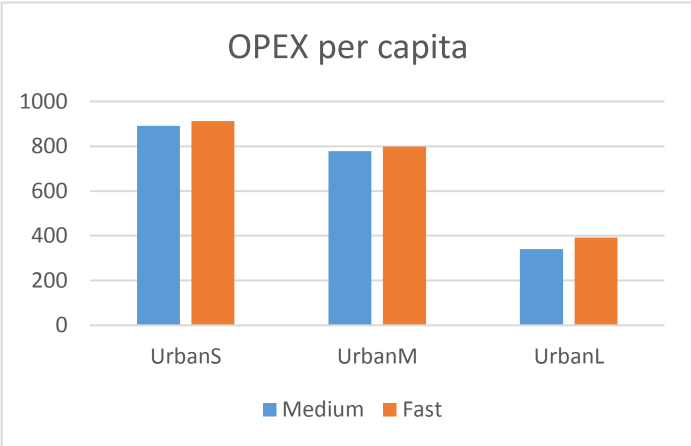

Figure 5 OPEX per capita (€)

5. Conclusions

The development of 5G networks is the next step in the telecommunications market which is expected to overcome the technological challenges. The results of this study help operators to identify the differences, advantages and disadvantages that arise during the implementation of 5G networks in urban areas with different population densities.

The Net Present Value, the Internal Rate of Return and the payback period have been estimated as well as the investment (CAPEX) and the operational (OPEX) costs for each one of the three different types of urban areas.

The results derived in this study are:

1. The development of a 5G network in a **Large size dense-urban area** is profitable and could become economically viable, even with a low pricing cost of the offered services by the Network Operator with the prerequisite of fast demand growth.
2. The 5G deployment in a **Medium size urban area** needs medium investment costs per capita, but high operational costs. It could be profitable only with a high pricing cost of the offered services by the Network Operator in conjunction with fast demand growth.

3. The creation of a 5G network in a **Small size urban area** requires high investment and operational costs and could not be profitable with the pricing and demand scenarios that have been assumed in this study.

It is evident that the state and policymakers should motivate operators to invest in all types of urban areas in order to avoid the differentiation in the offer of network services and the creation of citizens of two categories.

The results of this study aim to contribute to the debate over network evolution scenarios among academia, industry, regulators, policymakers and governments.

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Appendix A (Service Penetration %)

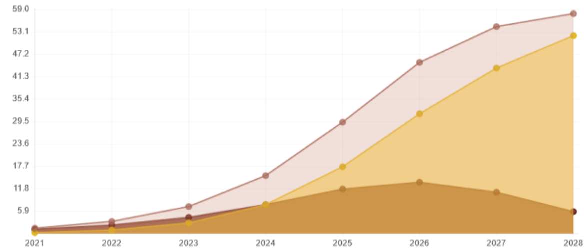

Figure 6 UrbanS, Medium demand

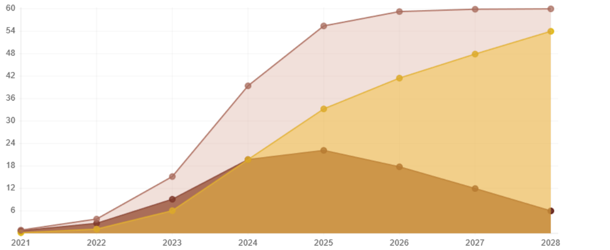

Figure 7 UrbanS, High demand

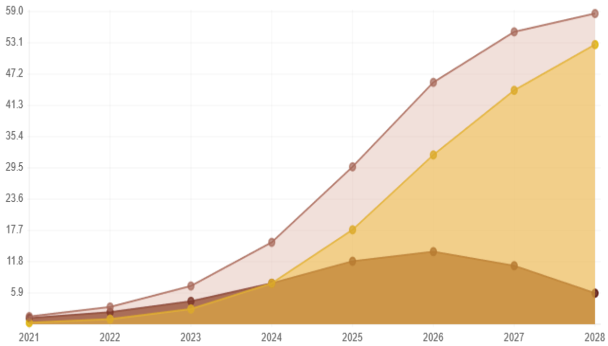

Figure 10 UrbanM, Medium demand

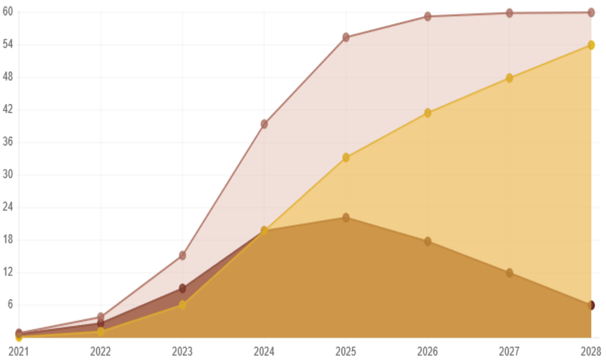

Figure 8 UrbanM, High demand

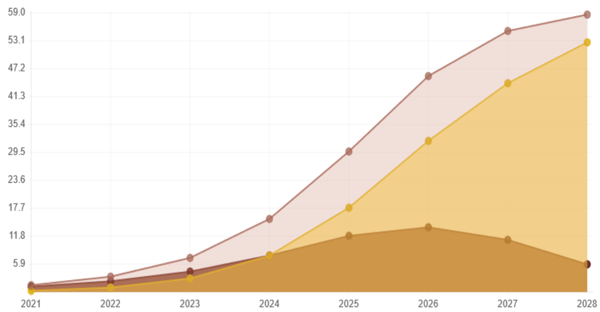

Figure 11 UrbanL, Medium demand

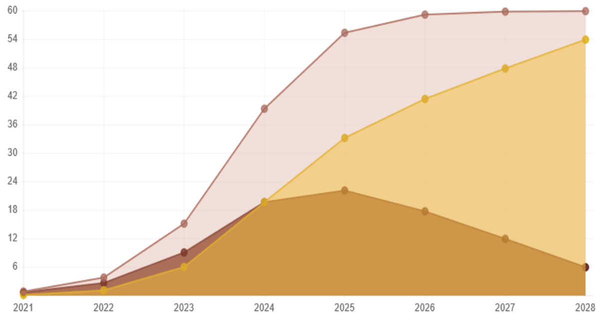

Figure 9 UrbanL, High demand