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**Conference Paper**

## 5G Fixed Wireless Access for rural broadband

31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022

**Provided in Cooperation with:**

International Telecommunications Society (ITS)

*Suggested Citation:* Laitsou, Eleni; Ioannou, Nikos; Katsianis, Dimitris (2022) : 5G Fixed Wireless Access for rural broadband, 31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022, International Telecommunications Society (ITS), Calgary

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# **Title: “5G Fixed Wireless Access for rural broadband”**

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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 traffic [1], [2], [3]. The advent of 5G is allowing mobile technology to intersect with the demands of fixed line services. With fixed wireless access (FWA), network operators can provide ultra-fast broadband to suburbs and rural areas to support home and business applications where fiber installation and maintenance is very expensive.

In this paper a techno-economic study is performed to assess the feasibility of the deployment of a 5G Standalone fixed wireless access network in a rural area. 24 European countries are taken as case studies. In each of these 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 can be an important tool for decision/policy makers in investment strategies for rural broadband networks and for the European Commission that has launched a targeted public consultation on a proposed revision of the Guidelines on State aid rules for broadband networks, 5g fixed wireless access networks included<sup>1</sup>.

## **Keywords**

5G fixed wireless access network, techno-economic evaluation, TONIC model, rural area, Net Present Value, Internal Rate of Return, Payback year, CAPEX

## **1. Introduction**

Rural Internet users continue to suffer from poor broadband due to the high costs to build wired network infrastructure because of the low density of users, resulting in a digital divide between rural and urban communities. Usually, mobile and fixed access have been provided through different technologies, with mobile services coming from cellular technologies and fixed broadband coming from fixed access technologies. However, a convergence between mobile and home access has started to emerge through cellular fixed wireless access (FWA) technology, making a cost-effective alternative for fixed broadband. The development of 5G networks is the next step in the telecommunications market which is expected to overcome the technological challenges.

However, only a few studies have been carried out concerning the techno-economic evaluation of 5G [4]. This paper presents a techno-economic analysis to assess the feasibility of the development of a 5G Standalone fixed wireless access network in different types of rural areas based on household density. The European countries have been taken as case studies, twenty-four (24) in total, i.e., all the European countries except the UK, Luxembourg, Malta and Cyprus because for these countries there is no accurate data.

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

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.

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<sup>1</sup> [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_21\\_6049](https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6049)

## **2. Literature Review**

There have been many studies in recent years in the area of the fifth-generation 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.

Salah et al. [5] 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.

Lappalainen et al. [6] study the planning of a rural 5G multi-user massive MIMO fixed wireless access system to offer fixed broadband service to homes. Specifically, they aim to determine the user limit, i.e., the maximum number of homes that can simultaneously receive target minimum bit rates (MBRs) on the downlink (DL) and on the uplink (UL) given a set of network resources and a cell radius. They study the impact of group size and show that smaller groups yield larger user limits in a 3.5 GHz band.

Alimi et al. [7] discuss different network requirements of the 5G FWA system. Also, a comprehensive overview of the broadband schemes' technical challenges is presented and they proffer viable solutions for achieving cost-effective and scalable 5G FWA solutions. Moreover, they exploit diversity scheme and present a closed-form expression for the multiple-input, multiple-output scheme in which the path-loss (PL) and beam-forming schemes are considered. Simulation results show significant performance improvement compared with a single-input single-output configuration.

In Neokosmidis et al. [8] a road mapping 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.

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 Fixed Wireless Access network in different types of rural areas that correspond to the rural areas of the 24 European countries could be economically viable.

## **3. Methodology**

In this study, an economic and financial analysis for the deployment of 5G fixed wireless access network in a rural area is performed 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.

An eight-year study period is assumed, from 2023 to 2030, a reasonable period for broadband 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 supports a download speed of 300 Mbps and the Bronze one which supports 100 Mbps.

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

**Table 1 European Countries Household Density**

<b>EU Country</b>	<b>Code</b>	<b>Rural HHs &amp; enterprises</b>	<b>Rural Area Size (km<sup>2</sup>)</b>	<b>HH density</b>
<b>Austria</b>	<b>AT</b>	1,639,784	4,841	339
<b>Belgium</b>	<b>BE</b>	724,035	2,159	335
<b>Bulgaria</b>	<b>BG</b>	889,331	962	924
<b>Croatia</b>	<b>CR</b>	593,033	1,847	321
<b>Czechia</b>	<b>CZ</b>	1,797,534	2,413	745
<b>Denmark</b>	<b>DK</b>	1,243,045	3,065	406
<b>Estonia</b>	<b>EE</b>	288,006	1,546	186
<b>Finland</b>	<b>FI</b>	919,306	10,015	92
<b>France</b>	<b>FR</b>	11,753,633	33,762	348
<b>Germany</b>	<b>DE</b>	8,249,638	18,522	445
<b>Greece</b>	<b>EL</b>	1,157,366	4,715	245
<b>Hungary</b>	<b>HU</b>	1,267,434	2,137	593
<b>Ireland</b>	<b>IE</b>	891,523	4,089	218
<b>Italy</b>	<b>IT</b>	4,648,436	7,376	630
<b>Latvia</b>	<b>LV</b>	294,719	980	301
<b>Lithuania</b>	<b>LT</b>	555,168	406	1,367
<b>Netherlands</b>	<b>NL</b>	812,250	156	5,219
<b>Poland</b>	<b>PL</b>	4,663,458	12,724	367
<b>Portugal</b>	<b>PT</b>	1,247,962	5,730	218
<b>Romania</b>	<b>RO</b>	3,193,054	6,870	465
<b>Slovakia</b>	<b>SK</b>	873,732	1,576	555
<b>Slovenia</b>	<b>SI</b>	391,459	934	419
<b>Spain</b>	<b>ES</b>	2,654,672	4,601	577
<b>Sweden</b>	<b>SE</b>	1,530,182	5,012	305

As case studies, 24 countries are used, all the European countries except the UK, Luxembourg, Malta and Cyprus because for these countries there is no accurate data.

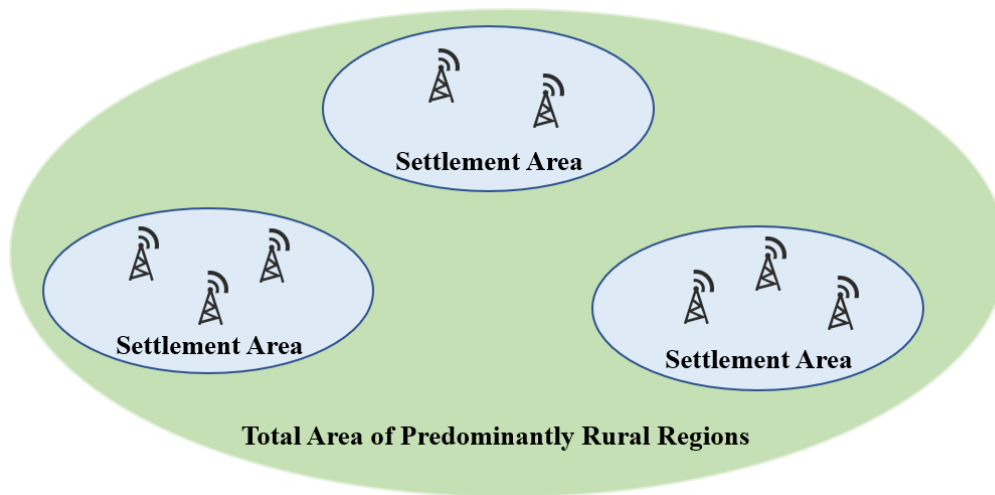
For each country, total rural area size and the number of rural Households and active enterprises were used for the corresponding dimensioning/coverage and demand parameters.

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

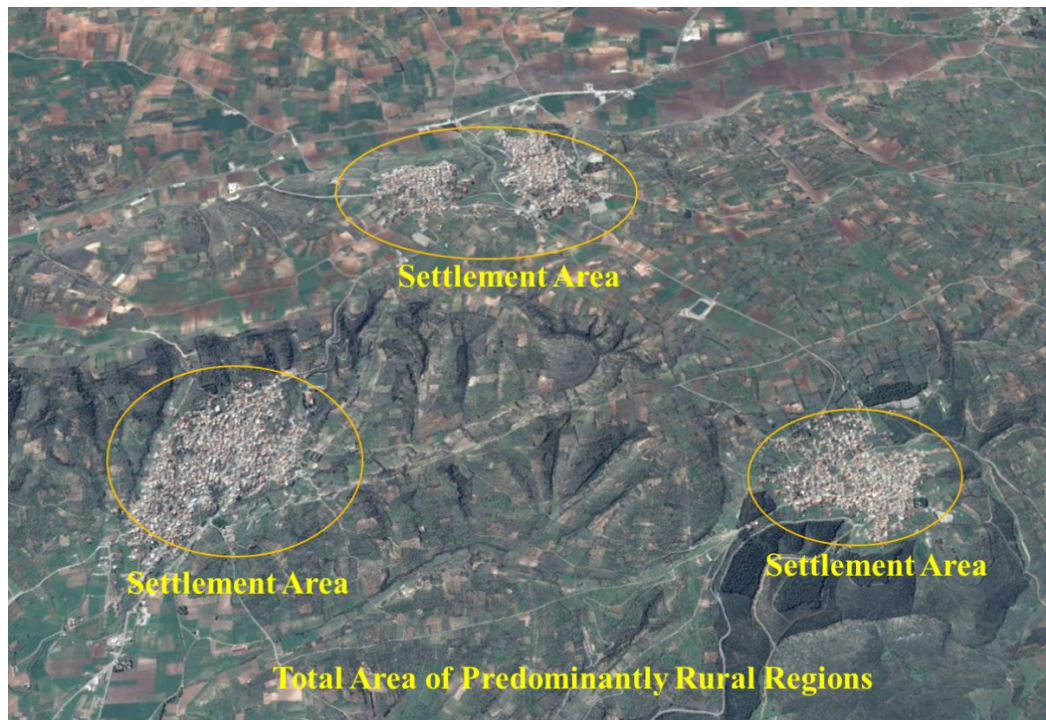
$$\text{Rural\_Area\_Size} = \text{Total\_Area\_of\_Predominantly\_Rural\_Regions} \times \text{Settlement\_Area\_Percentage} \quad (1)$$

where

$$\text{Settlement\_Area\_Percentage} = \text{Settlement\_Area} / \text{Total\_land\_cover} \quad (2)$$



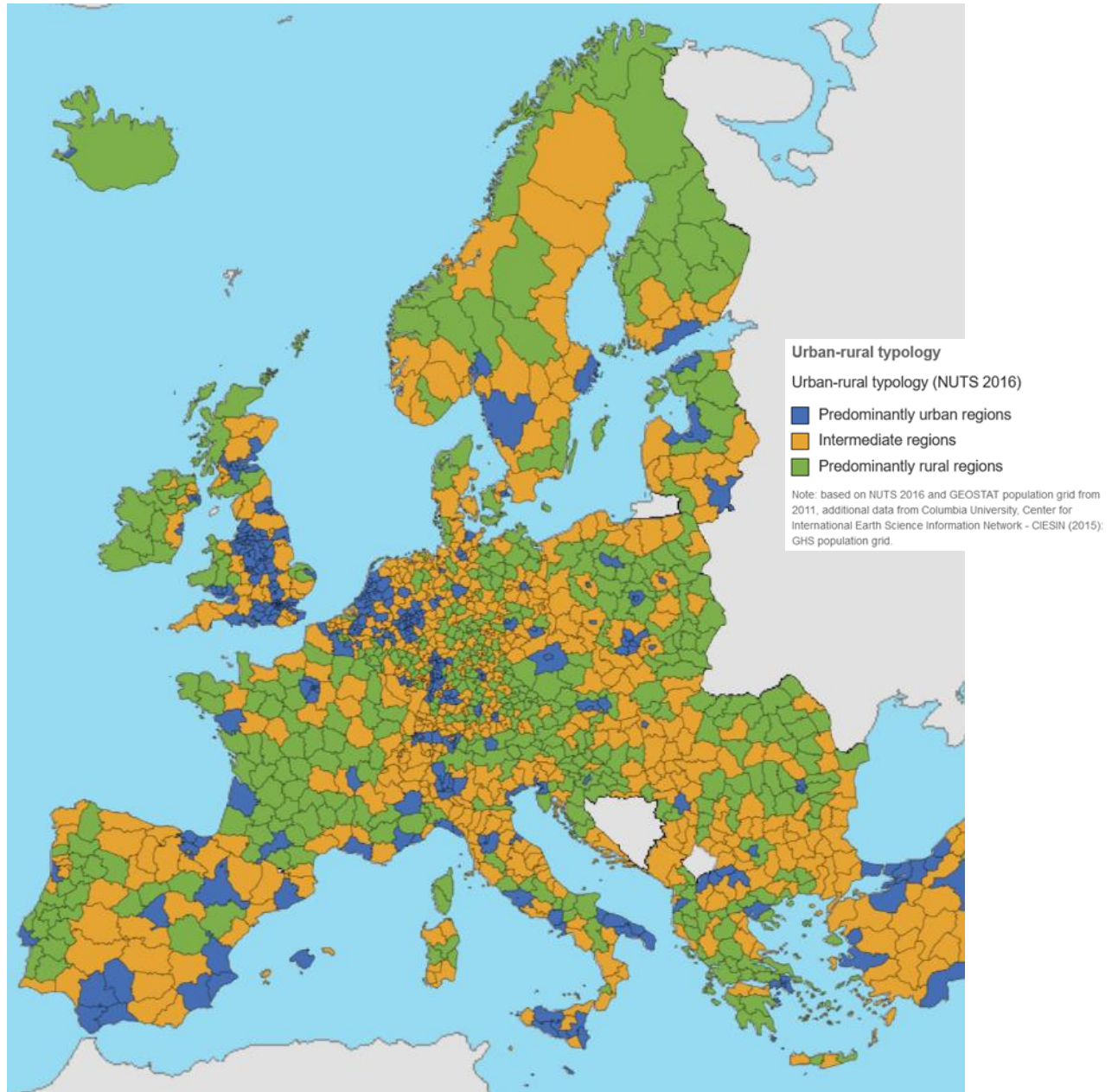
**Figure 1 Total Area of Predominantly Rural Regions**



**Figure 2 Total Area of Predominantly Rural Regions (Geographical mapping)**

The Total\_Area\_of\_Predominantly\_Rural\_Regions is based on EUROSTAT data of predominantly rural regions (based on NUTS 3 regions) (2016) in the following map.





**Figure 3 Urban-rural typology map (NUTS 2016)**

In the following sections, the technoeconomic 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 [9], [10], [11].

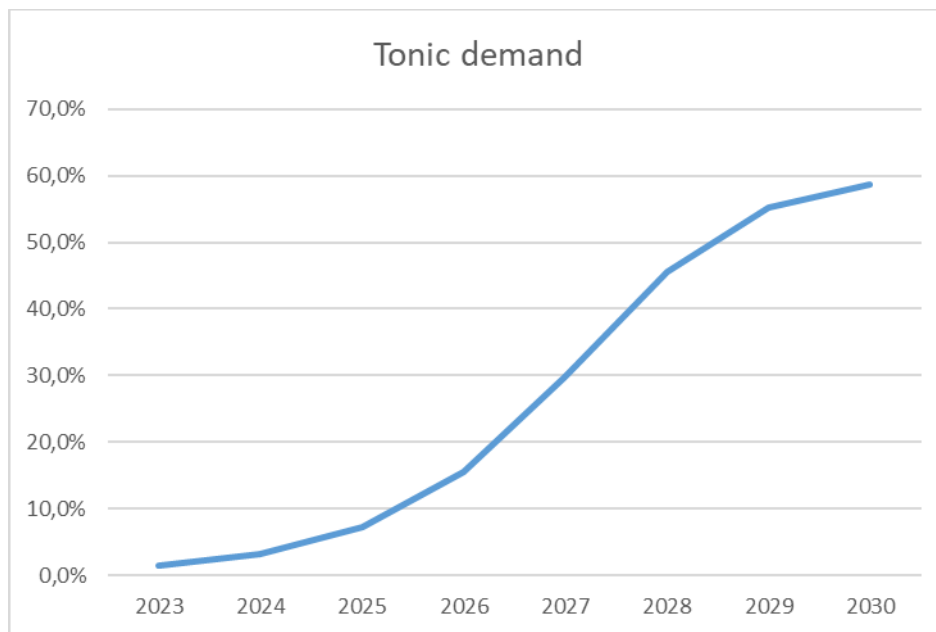
The demand model is defined by the following expression:



$$Y(t) = \frac{M}{(1 + e^{\alpha+b*t})^c} \quad (3)$$

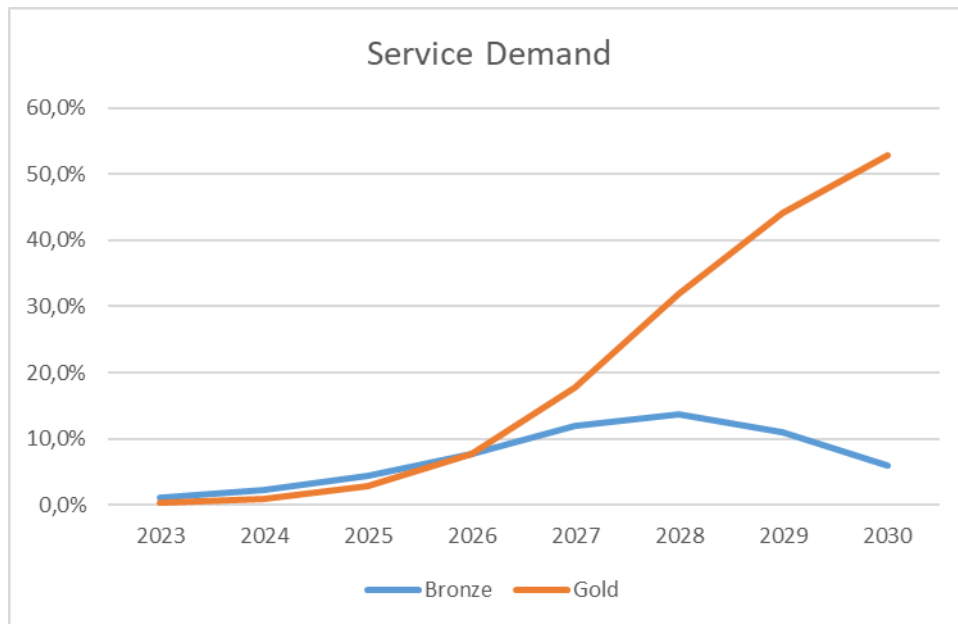
where  $Y(t)$  is the demand forecast at time  $t$  and  $M$  is the saturation level of the penetration, which is estimated a priori. The parameters  $\alpha$ ,  $b$ , and  $c$ , are estimated by a stepwise procedure, attempting to value these parameters using nonlinear regression [12].

The following diagram shows the predicted number of users in percentage rate (service penetration %). The network penetration is expected to reach 58,6% of the population in 2030.



**Figure 4 Predicted number of users (service penetration %)**

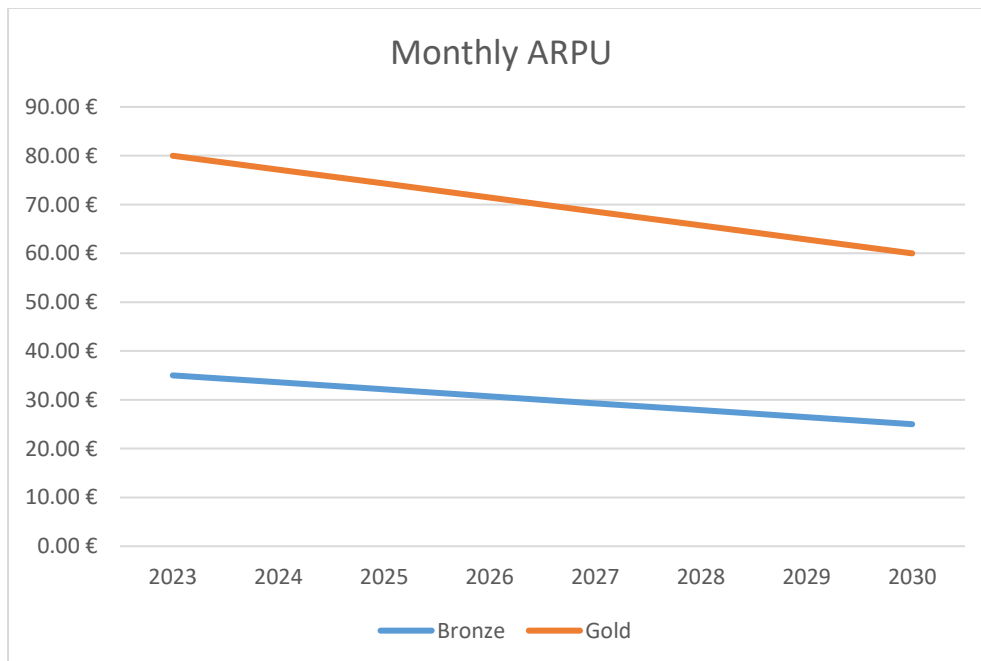
Moreover, it is considered that during the 8 years, the number of users of the Gold bundle continues to increase, however, those of the Bronze bundle decrease. The following diagram shows the two on-demand curves that correspond to the two bundles as a percentage of the predicted number of users, the blue curve corresponds to the Bronze bundle, the orange curve to the Gold bundle.



**Figure 5 Bundles service penetration**

### 3.2. Pricing Model

Regarding the pricing, we suggest two different scenarios in which the tariff follows a linear evolution of monthly Average Revenue Per User (ARPU) during the 8-year period depending on the bundle of services selected. Specifically, the Gold bundle costs 80€ per month in 2023 and gradually decreases to 60€ in 2030. The Bronze bundle costs 35€ monthly in 2023 and gradually decreases to 25€ in 2030.



**Figure 6 Bundles monthly ARPU linear evolution**

### **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 [12],[13].

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.

Furthermore, the costs of the network components are used to calculate investments for each year, Capital Expenditure (CAPEX).

### **3.4. Model assumptions**

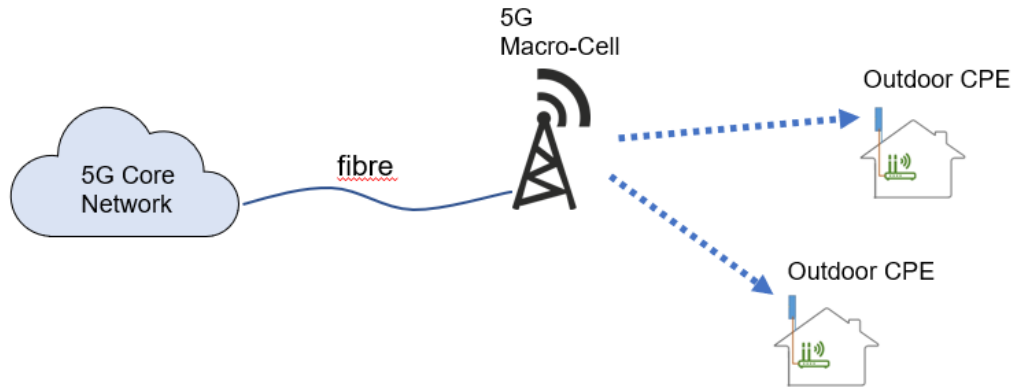
For the purposes of this study, the weighted average cost of capital (WACC) is set to 5%. The taxation is set to 20%.

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:

- ✓ FWA Macro cells are 6-sector with a range of about 1km
- ✓ The existing Macro sites are upgradable at a percentage rate of 80%
- ✓ The existing Macro sites which are connected to fiber cover a percentage of 70%
- ✓ The Customer Premises Equipments (CPEs) are outdoor antennas

It is worth mentioning that the percentage of Existing Macro sites connected to fiber is one of the most important parameters for the viability of the investment.

For the purposes of this study, the inCITES TEN web application was used with the addition of upgrade modules (<https://www.incites.eu/products-and-services-ten-web-app>) .



**Figure 7 5G FWA network architecture**

#### 4. Results and discussion

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

Table 2 summarizes the economic results for each of the 24 European countries.

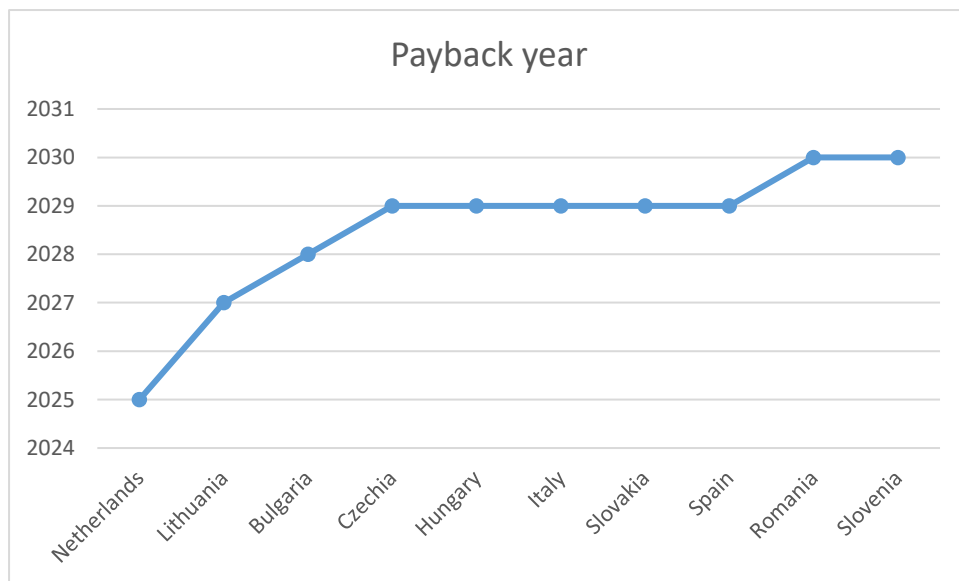
**Table 2 .European countries technoeconomic indicators**

Countries	Payback year	IRR (%)	NPV (€)	CAPEX per Household
<b>Austria</b>	> 2030	-7.54	-358,387,671	473
<b>Belgium</b>	> 2030	-6.63	-146,886,762	477
<b>Bulgaria</b>	2028	25.30	177,391,258	216
<b>Croatia</b>	> 2030	-7.52	-132,634,818	496
<b>Czechia</b>	2029	17.68	254,118,643	251
<b>Denmark</b>	> 2030	-1.24	-121,964,557	406
<b>Estonia</b>	> 2030	-23.98	-199,516,680	806
<b>Finland</b>	> 2030	-	2,058,058,425	1567
<b>France</b>	> 2030	-22.25	5,643,915,971	462
<b>Germany</b>	> 2030	-5.76	1,369,760,049	376
<b>Greece</b>	> 2030	-17.37	-535,772,874	628
<b>Hungary</b>	2029	10.71	91,710,077	299
<b>Ireland</b>	> 2030	-20.78	-505,822,835	698
<b>Italy</b>	2029	10.31	306,869,530	285
<b>Latvia</b>	> 2030	-8.97	-76,175,011	525
<b>Lithuania</b>	2027	39.51	150,233,752	167
<b>Netherlands</b>	2025	109.72	296,991,616	103

<b>Poland</b>	> 2030	-9.24	1,123,713,669	442
<b>Portugal</b>	> 2030	-22.00	-741,220,284	699
<b>Romania</b>	2030	1.04	-185,959,270	363
<b>Slovakia</b>	2029	8.92	44,946,973	315
<b>Slovenia</b>	2030	0.75	-25,578,892	396
<b>Spain</b>	2029	8.77	129,802,374	305
<b>Sweden</b>	> 2030	-10.77	-445,182,474	518

#### 4.1. Payback Year

The following diagram shows the Payback year for 10 of the 24 countries which have values less or equal to 2030. We notice that the Netherlands has the earliest Payback year i.e., 2025, Lithuania and Bulgaria follow with values 2027 and 2028 respectively. The same Payback year, i.e., 2029 have five countries, Czechia, Hungary, Italy, Slovakia and Spain. Romania and Slovenia follow with Payback year 2030.



**Figure 8 European countries Payback Year**

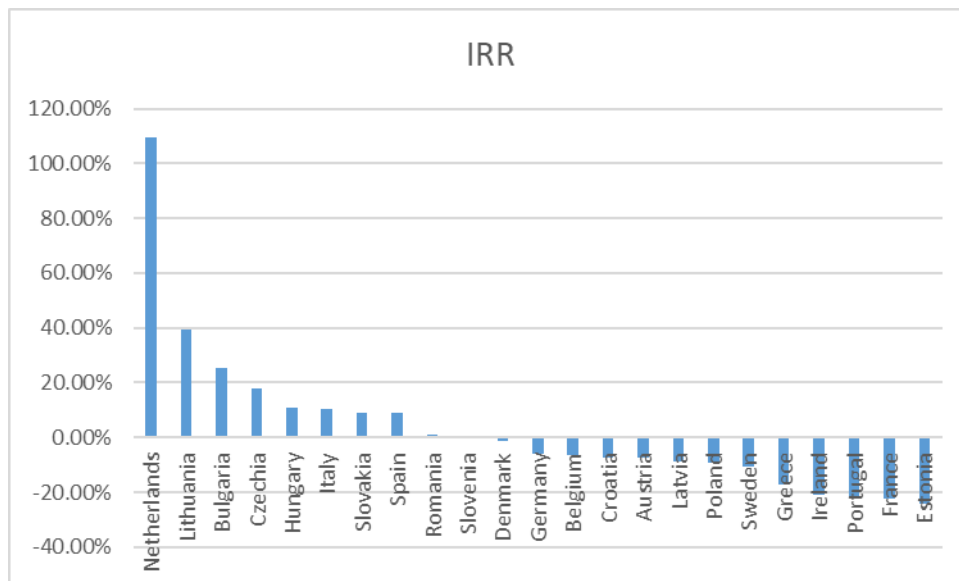
Table 3 shows the order of the European countries according to the Household (HH) density from the highest value to the lowest. The same values are also depicted in the diagram of Figure 12. We notice that the countries with the highest household densities have the earliest Payback year.

**Table 3 European countries order according to HH density**

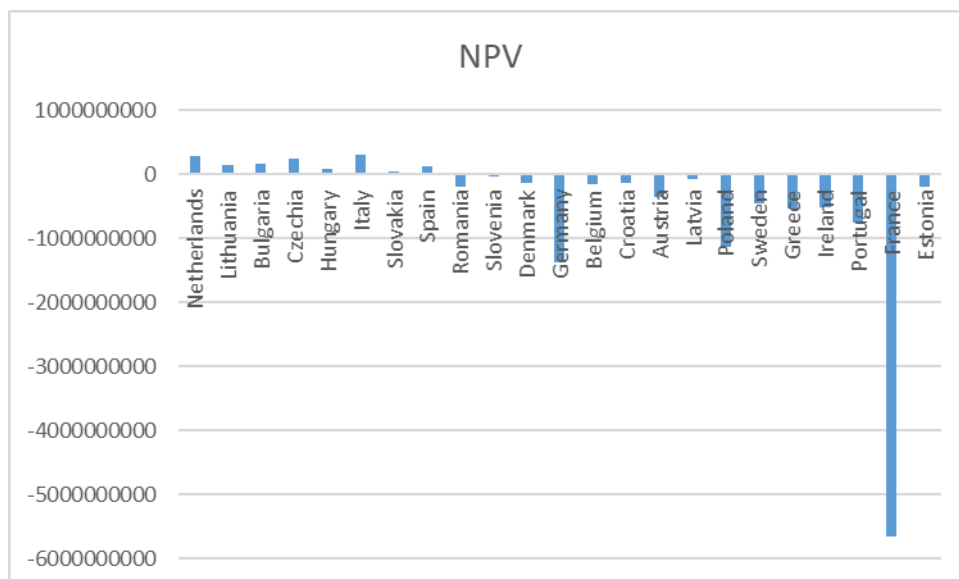
<b>EU Country</b>	<b>HH density</b>
<b>Netherlands</b>	5219.228
<b>Lithuania</b>	1366.995
<b>Bulgaria</b>	924.2083
<b>Czechia</b>	745.0826
<b>Italy</b>	630.1928
<b>Hungary</b>	593.0988
<b>Spain</b>	576.9625
<b>Slovakia</b>	554.5565
Romania	464.8115
Germany	445.4047
Slovenia	419.2797
Denmark	405.5307
Poland	366.518
France	348.1304
Austria	338.7325
Belgium	335.3087
Croatia	321.1652
Sweden	305.2837
Latvia	300.6748
Greece	245.4727
Ireland	218.0395
Portugal	217.7974
Estonia	186.3195
Finland	91.78979

#### **4.2. NPV - IRR**

The following diagrams show the IRR and NPV values for the 24 countries. It is noticed that the best values are obtained for the following countries: the Netherlands, Lithuania, Bulgaria, Czechia, Hungary, Italy, Slovakia and Spain.



**Figure 9 European countries IRR**



**Figure 10 European countries NPV**

If we compare the results with Table 3, we notice that the countries which have NPV positive and IRR greater than the discount rate are the countries with the highest values of Household density.



### 4.3. CAPEX per Household

The following diagrams show the CAPEX per Household and the Household density for each European country in an alphabetical order.

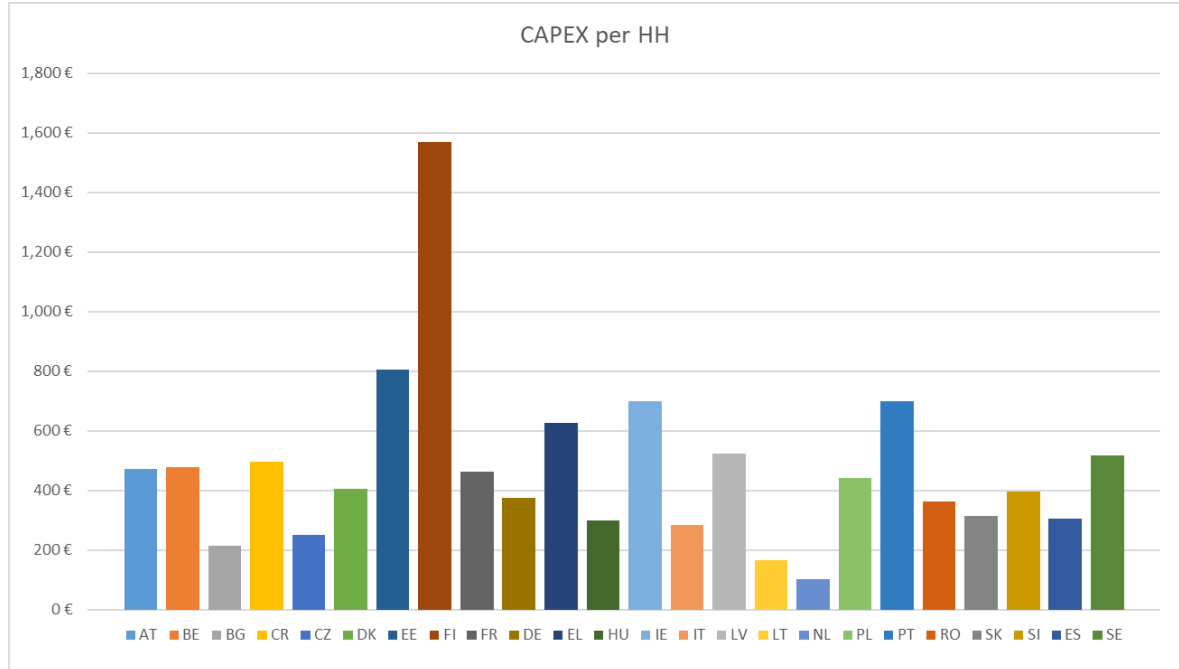


Figure 11 CAPEX per Household

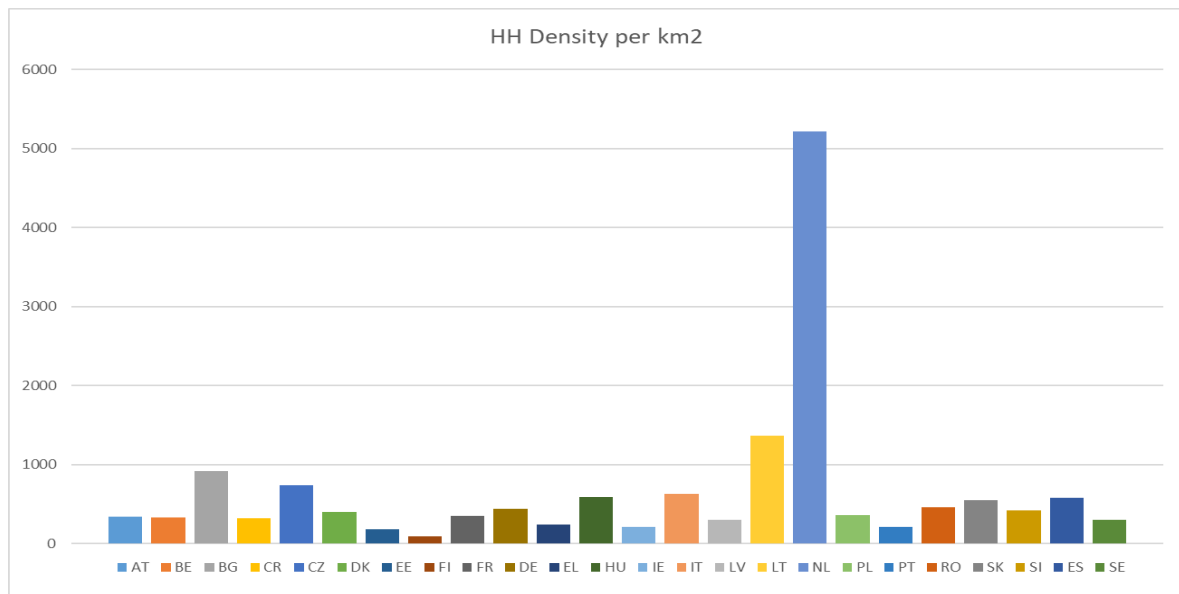


Figure 12 European countries Household density (per km<sup>2</sup>)

It is noticed that the European countries with higher values of Household density have the smallest values of CAPEX per Household and vice versa.

It is obvious from the obtained results that the European Commission has to adjust the subsidization policy and support to a greater extent the European countries which have low Household densities in the rural areas. Otherwise, there will be differentiation in the offer of network services and the creation of European citizens of two categories.

The results (Cash Balances) obtained during this study are included analytically in Appendix A.

## **5. Conclusions**

The world is ready to change with the introduction of the fifth generation of technologies for telecommunications networks around the world. 5G and especially the standalone solution is ready and will result in faster data speed, low latency telecommunications and higher bandwidth, which will help improve the experience of consumers and commercial users, from cloud games to telehealth use cases. 5G will act as a catalyst for the integration of technologies such as artificial intelligence, robotics, 3D printing and the Internet of Things.

The results of this study help operators to identify the differences, advantages and disadvantages that arise during the implementation of 5G Standalone Fixed Wireless Access networks in rural areas with different household densities.

The Net Present Value, the Internal Rate of Return and the Payback year have been estimated as well as the investment (CAPEX) costs for each of the 24 European countries.

The results derived in this study are:

1. The countries with the highest household densities have the earliest Payback year.
2. The countries which have NPV positive and IRR greater than the discount rate are the countries with the highest values of Household density.
3. The countries with higher values of Household density have the smallest values of CAPEX per Household and vice versa.
4. The European Commission has to adjust the subsidization policy and support to a greater extent the European countries with low Household densities in the rural areas.

The results aim to contribute to the debate over network evolution scenarios among academia, industry, regulators, policy makers, governments.

## **ACKNOWLEDGMENTS**

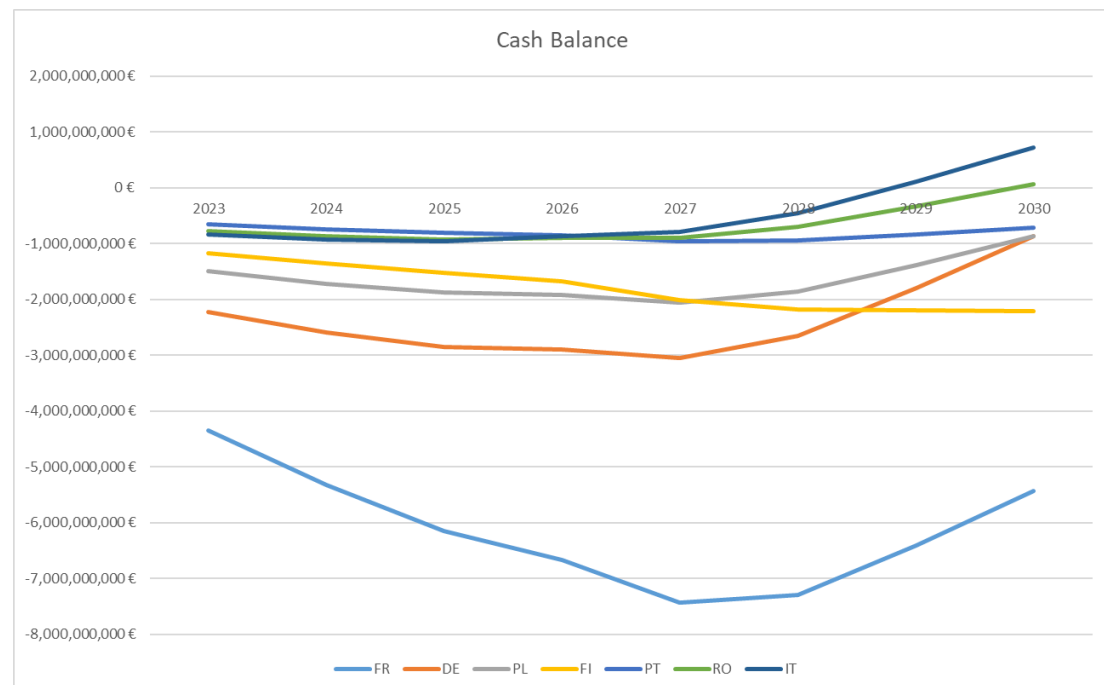
The work described in this article has been funded by the Special Account for Research Grants of the National and Kapodistrian University of Athens (N.K.U.A.).

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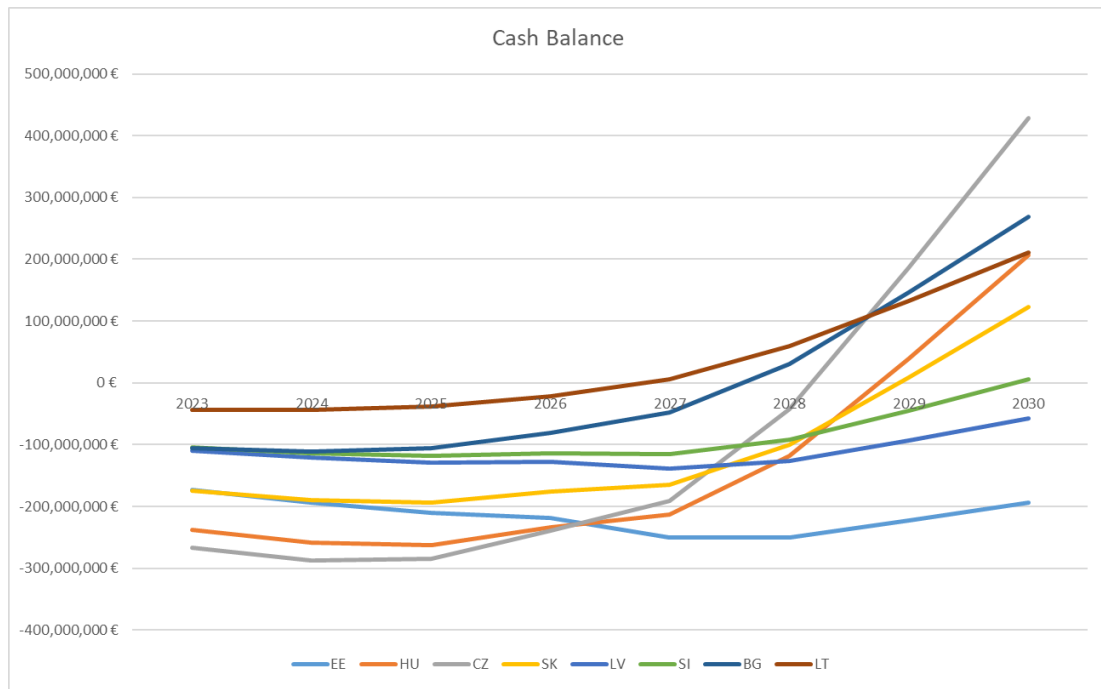
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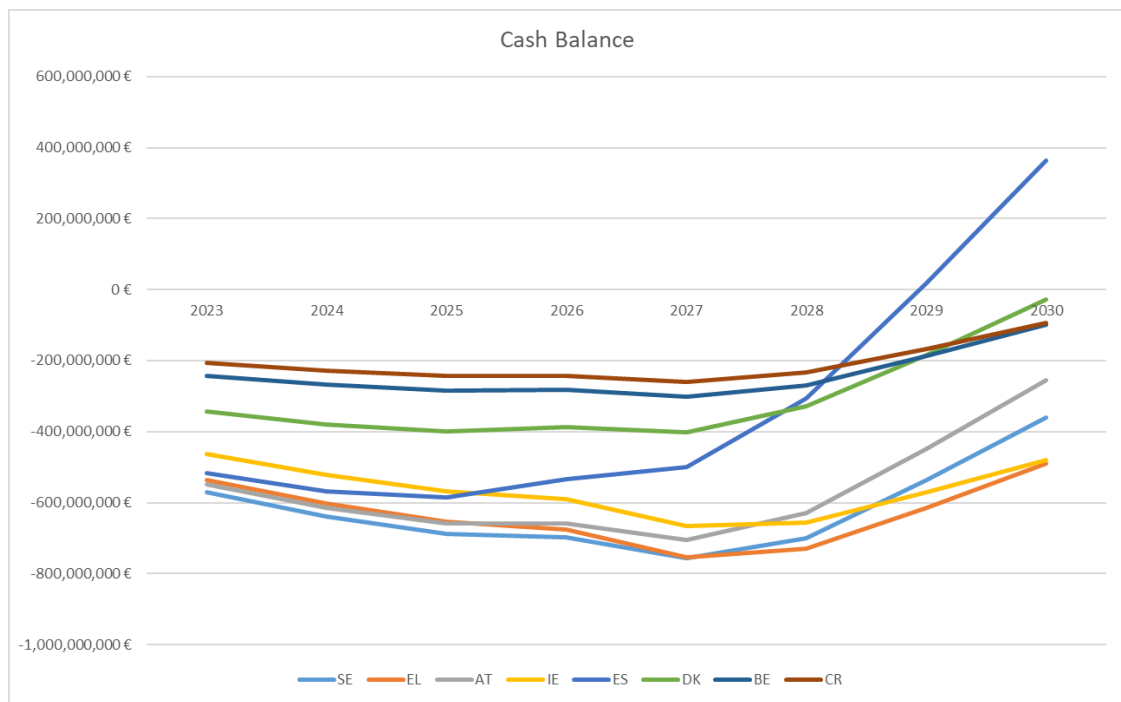
## Appendix A



**Figure 13 Cash Balances (France, Germany, Poland, Finland, Portugal, Romania, Italy)**



**Figure 14 Cash Balances (Estonia, Hungary, Czechia, Slovakia, Latvia, Slovenia, Bulgaria, Lithuania)**



**Figure 15 Cash Balances (Sweden, Greece, Austria, Ireland, Spain, Denmark, Belgium, Croatia)**