BoR (19) 246

Final public report for BEREC

Study on the determinants of investment in VHCN – a System Dynamics approach:

Volume 1: Technical Report

November 2019

Disclaimer:

Report prepared by:

Decision Analysis Services Ltd

SPC Network Ltd

Strategy Dynamics Ltd

Greenwood Strategic Advisors AG

Authored by:

Stephen Curram (Decision Analysis Services)

David Exelby (Decision Analysis Services)

Richard Cadman (SPC Network Ltd)

Kim Warren (Strategy Dynamics Ltd)

Alan Graham (Greenwood Strategic Advisors AG)

Contents

1 Executive Summary

There is an established political consensus in Europe that Very High Capacity Networks (VHCNs) are required to create the "Gigabit Society"[1] that will drive economic and social growth and the competitive position of the European Union. VHCNs, including Fibre to the Premises (FTTP) and fibre backhaul to mobile base stations to support 5G services, will be needed to meet demand for high speed communications and access to the Internet for video and other data-rich applications.

Recognising this drive for VHCNs, BEREC has sought to better understand the various factors which influence investment in VHCNs, some of which may be susceptible to influence through actions by National Regulatory Authorities (NRAs). Actions might be intended to accelerate, increase or otherwise improve the level of investment in VHCNs, but might unintentionally have the opposite effect for some VHCN providers

BEREC commissioned this study to consider how new tools and approaches can best represent the complexity of VHCN investment within regulated markets and understand how the underlying structures, path dependences and actions of all stakeholders in this system will influence observed behaviours. The new tools and approaches have centred on the application of System Dynamics. The System Dynamics (SD) modelling approach is a good way to capture how various factors might influence investment in VHCNs. It is a well-structured and proven methodology to study dynamic complexity both qualitatively and quantitatively. The system in which VHCN investment takes place is complex, comprising operators, market participants, suppliers and regulators each adopting behaviours and strategies in response to the other. Complexity arises because this market system is:

- Dynamic – change occurs over different timescales. Infrastructure investment may require long pay back periods.
- Tightly coupled – regulators, operators and investors interact strongly with one another.
- Governed by feedback – actions feedback on themselves. This is observed, for example, in investment cycles. System Dynamics is a methodology centred on discovering and analysing such closed loops.
- Non-linear – need to explicitly recognise non-linear responses between cause and effect.
- Counterintuitive – cause and effect are distant in time and space and can demonstrate that policies can cause very different behaviours over the short and long term.

The study requirements laid out a research-based agenda reflecting this systems-based approach. This comprised:

- Creating a comprehensive repository of current published work on investment and role of regulation across European telecom markets.
- Engaging with stakeholders across the market to understand determinants of investment and the decision-making processes for operators, financiers, technology providers and regulators.
- Developing a qualitative System Dynamics model that could capture as a whole system the determinants of investment, their role in corporate decision making and in turn how these decisions play out in operator and market performance.
- Demonstrating how these qualitative models can provide insight into how markets have or will develop in the future and provide guidance for regulators on alternative courses of action available or confirm their existing actions.

[1] As set out in European Commission (2016) *Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society*

- Assessing if and how the qualitative tools and analysis can be taken forward to provide quantitative simulation-based tools. This powerful extension of System Dynamics can be used to substantiate qualitative findings and provides a scenario planning toolset for the NRA community.

The study used a participatory approach to research and build the models and analyses. To complement the literature survey of over 100 published papers, over 30 structured interviews and two workshops were undertaken with NRAs, network operators, technology companies and trade bodies. This has provided the evidence base from which the qualitative models have been developed.

A set of qualitative System Dynamics models was developed that included a Generic Network Business Model. This is a qualitative map of causal relationships that can describe the business system activities and accounts including investment in a VHCN, premises access and uptake of VHCN services. A central element of the model has been to represent the corporate investment decision making processes by the network and retail operators that may seek access to the network. This decision making has been structured around Net Present Value (NPV) assessments of investment. This has proved to be an intuitive and comprehensive framework to capture determinants of investment, each of which will influence one or more of the components of the NPV equation - capital costs, future cashflows and financing conditions. It further enabled the generic model to capture competing investment decisions by operators in terms of upgrading existing legacy networks and building new VHCN assets. The Generic Network Business Model is extensible to create a whole market description where multiple operators may compete.

The study revealed a wide range of determinants of investment that have been captured systemically encompassing capital cost, determinants of the rollout costs (e.g. availability of ducts), infrastructure-based competition (including 5G & wireless), the degree of co-investment, wholesale access conditions, operating costs, retail demand and willingness to pay for higher bandwidths. Many of the drivers within these categories above may be well documented by other studies but adopting the methodology of System Dynamics has demonstrated how these determinants are path dependent and interdependent.

The resulting models and evidence base have been used in several ways to develop systems-based narratives of exemplar VHCN market evolution. Spain, Sweden and Ireland were used to demonstrate how very different determinants have driven VHCN penetration.

A number of key messages for regulators, industry and governments has emerged from the study.

- **There is a difference between drivers of investment and determinants of investment** - the study identified a universal set of drivers. However, determinants of investment are contextual, path dependent, contingent on the conditions within a geography and will differ between operators.
- **There is no universal strategy that will work for all countries -** Path dependencies and national/regional conditions can significantly affect the strength of the drivers of investment and the impact of policies on investment rates. However, lessons from markets can be applied to other markets as these markets evolve and the lessons may become relevant.
- **Conditions are not static –** markets evolve, and conditions change which impact revenue potential, capital cost and risk.
- **Regulatory and national policies should consider the impact across the range of operator business model**s – the study identified a wide range of operator business models that have been able to tune NPV business cases to meet particular market segment conditions. Regulators need to consider how their national/sub-national actions will impact each of these operator business models across regions of the country.
- The model and analysis have demonstrated how **deployment costs and cashflows are intrinsically linked.** The NPV models can be used to understand how the costs of deployment effectively set a scale of revenue generation needed to reach sufficient positive NPV that will initiate investment

activity. This also informs insight on the likelihood that a market will support infrastructure competition and possible overbuild. Applying the same regulations in two different countries or regions may have very different impacts on investment, competition and prices.
- **Business risk profiles affect the cost of finance –** the study has identified that incumbent, retail operators and wholesale-only operators each have very different business models. This has attracted a broader range of sources of capital being attracted to the sector with different financing conditions attached.
- **Competition does drive investment –** An incumbent has largely depreciated capital assets making up its copper network, if it has not been revalued, and can enjoy profits on its subscriber cash flows. The introduction of retail competition that has occurred in most markets for copper-based services has reduced the incumbent's market share, but this is partially offset by being able to realise wholesale access charges (subject to regulated pricing). Alternate operators focusing on access seeking can develop business cases with low capital needs and 'aggressive' subscriber acquisition. They may later invest in own infrastructure, if investment costs per household are low (e.g. where ducts are available). In the case where infrastructure competition arises, the incumbent is likely to lose further retail revenue and erosion of wholesale cashflows. Coupled with cable's advantageous incremental upgrade strategies, and/or investments from communities or utilities, this can force a switch in the incumbent to react with its own investment in order not to lose market share.

The whole systems modelling has proven to be an innovative approach to understanding determinants of investment. Creating a **single** model and framework to compare markets, regions and network operators has provided a robust way to consider if insights from one market are relevant in others.

The modelling has demonstrated that markets at very different stages of VHCN penetration and path dependence can still share the same challenges within their VHCN ecosystems. This has been demonstrated for Spain and Portugal where very high coverage and penetration can still mask the challenge for rural areas with high VHCN build costs – a problem shared by many other countries. Nevertheless, the significant savings in operational costs of a fibre-only network is a factor that in some countries might eventually lead to a swift deployment in rural areas.

The systems modelling approach has been a very different starting point for considering VHCN investment determinants – the study team started with a corporate finance framework and the causal modelling process extended this to identify where and how regulation would impact. This contrasts with much of the academic literature that uses the regulatory frameworks as the starting point for analysis and modelling. The systems approach has created a model where regulatory levers have multiple touchpoints in corporate investment decision making. Another advantage of describing corporate business models is to reveal and describe the diversity of the network operators from the largest national operators through new entrant start-ups and municipalities and local communities.

The models and the supporting analysis have been qualitative, and this is aligned to the study requirements. Qualitative analysis does have a limitation in the degree of validity that can be attached and in generating forward looking estimates for the industry standard metrics to measure VHCN investment and take up. The qualitative approach is valuable at the very earliest stages of NRAs undertaking market reviews and considering candidate regulatory actions.

There is opportunity to extend and deepen the models and the analysis. Two areas for further work have been identified building on the current work. These are:

- Further analyses with the **qualitative models** incorporating data driven evidence on key metrics. This strengthens the narrative based arguments and the analyses could include a comprehensive coverage of the BEREC member states, specific study of regulatory impacts such as the Broadband Cost Reduction Directive or deep dive comparison of different network operator business models.

- Development of a **quantitative model** to further substantiate the findings from the qualitative modelling. The quantitative model would not be as detailed as the complete qualitative models presented in this report. Rather they are at an aggregated and simplified level representing the core NPV components of capital costs, cashflows and financing conditions within a market. Data on operator subscriber coverage and penetration, along with build cost estimates, revenues and costs will be required as well as sector level trends in demand. The resulting calibrated model would be used to generate alternative VHCN uptake scenarios under different market and regulatory conditions. The quantitative model would be used in conjunction with the qualitative model to support the strategy development. Quantitative modelling will require operator level data, and this will require close collaboration with an NRA to ensure access to data.

2 Introduction

2.1 Study scope and requirements

There is an established political consensus in Europe that Very High Capacity Networks (VHCNs) are required to create the "Gigabit Society"[2] that will drive economic and social growth and the competitive position of the European Union. VHCNs, including Fibre to the Premises (FTTP) and fibre backhaul to mobile base stations to support 5G services, will be needed to meet demand for high speed communications and access to the Internet for video and other data-rich applications.

Recognising this drive for VHCNs, BEREC has sought to better understand the various factors which influence investment in VHCNs, some of which may be susceptible to influence through actions by National Regulatory Authorities (NRAs). Actions might be intended to accelerate, increase or otherwise improve the level of investment in VHCNs, but might unintentionally have the opposite effect.

BEREC also considered that new tools and approaches should be explored to best represent the complexity of VHCN investment within regulated markets and understand how the underlying structures, path dependences and actions of all stakeholders in this system have and will influence observed behaviours.

The new tools and approaches have centred on the application of the System Dynamics approach (this is introduced at Annex A.1). The System Dynamics (SD) modelling approach is a way to capture how various factors might influence investment in VHCNs. It is a well-structured and proven methodology to study dynamic complexity both qualitatively and quantitatively. The system in which VHCN investment takes place is complex, comprising regulators and operators each adopting behaviours and strategies in response to the other. Complexity arises because this market system is:

- Dynamic – change occurs over different timescales. Infrastructure investment may require long pay back periods.
- Tightly coupled – regulators, operators and investors interact strongly with one another.
- Governed by feedback – actions feedback on themselves. This is observed, for example, in investment cycles. System Dynamics is a methodology centred on discovering and analysing such closed loops. (see Figure 1 below for an illustration of closed loops). This illustrates how the market will influence and be influenced itself by the demand and supply capacity. These closed loops underpin the way markets will behave.
- Non-linear – need to explicitly recognise non-linear responses between cause and effect.
- Counterintuitive – cause and effect are distant in time and space and can demonstrate that policies can cause very different behaviours over the short and long term.

[2] As set out in European Commission (2016) *Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society*

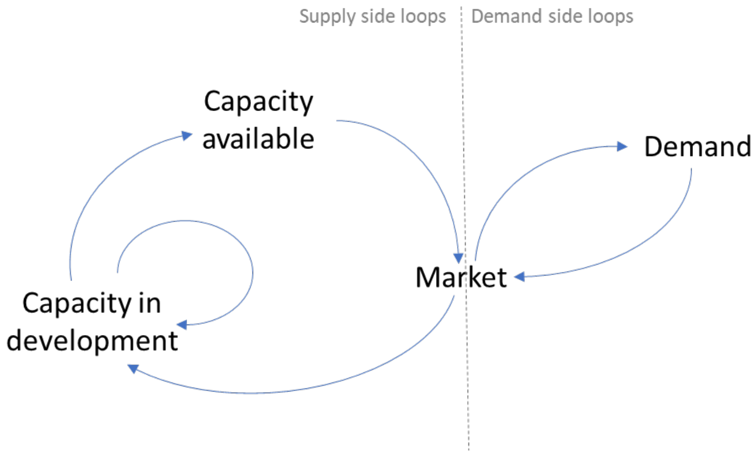


Figure 1: Illustration of causal feedback loops occurring in market systems

The study requirements laid out a research-based work plan reflecting this novel systems-based approach. This comprised:

- Creating a comprehensive repository of current published work on investment and role of regulation across European telecom markets.
- Engaging with stakeholders across the market sector to understand determinants of investment and the decision-making processes for operators, regulators, financiers and technology providers.
- Developing a qualitative System Dynamics model that could capture as a whole system the determinants of investment, their role in corporate decision making and in turn how these decisions play out in operator and market performance.
- Demonstrating how these qualitative models can provide insight into how markets have developed or will develop in the future and provide guidance for regulators on alternative courses of action available.
- Assessing if and how the qualitative tools and analysis can be taken forward to provide quantitative simulation-based tools. This powerful extension of the System Dynamics method can be used to substantiate qualitative findings and provides a scenario planning toolset for the NRA community.

This set of requirements has been reflected in the study work and reporting which includes:

- Volume 1 Technical Report (this document) – providing a full description of the study approach, model development, analysis and conclusions.
- Volume 2 Literature Review – comprehensive synthesis of published work on regulation and investment.

In addition, the study team has developed internal working papers to consider options for further work including development of quantitative models.

2.2 VHCN ambitions across European markets

On 11 December 2018 Directive (EU) 2018/1972 of the European Parliament and of the Council established the European Electronic Communications Code (the EECC).

The EECC notes that requirements concerning the capabilities of electronic communications networks are constantly increasing, and that while in the past the focus was mainly on growing bandwidth available overall and to individual users, other parameters such as latency, availability and reliability are becoming increasingly important. The EECC is technology neutral but aims for Very High Capacity Networks (VHCNs) that for a fixed network is equivalent to network performance achievable by an optical fibre installation up to a multi-dwelling building, while for a wireless connection corresponds to network performance similar to that achievable based on an optical fibre installation up to the base station. The EECC target (and working definition of a VHCN's speed capabilities) is the availability to all households of networks capable of providing at least 100 Mbps which are promptly upgradeable to gigabit speed.

The regulatory framework should, in addition to the existing three primary objectives of a) promoting competition, b) the internal market and c) end-user interests, also d) pursue an additional connectivity objective of widespread access to and take-up of very high capacity networks for all citizens and businesses of the European Union (EU). This should be on the basis of reasonable price and choice, effective and fair competition, open innovation, efficient use of radio spectrum, common rules and predictable regulatory approaches in the internal market and the necessary sector-specific rules to safeguard the interests of citizens of the Union.[3]

The EECC states that both efficient investment and competition should be encouraged in tandem, in order to increase economic growth, innovation and consumer choice. Competition can best be fostered through an economically efficient level of investment in new and existing infrastructure, complemented by regulation, where necessary, to achieve effective competition in retail services. An efficient level of infrastructure-based competition is the extent of infrastructure duplication at which investors can reasonably be expected to make a fair return based on reasonable expectations about the evolution of market shares. It is necessary to give appropriate incentives for investment in new very high capacity networks and vital to promote sustainable investment in the development of those new networks, while safeguarding competition and boosting consumer choice through regulatory predictability and consistency.[4]

The EECC provides a rough working definition of a VHCN's speed capabilities and places an obligation with BEREC that by 21 December 2020, BEREC shall, after consulting stakeholders and in close cooperation with the Commission, issue guidelines on the criteria that a network is to fulfil in order to be considered a very high capacity network, in particular the down- and uplink bandwidth, resilience, error-related parameters, latency and its variation[5].

[3] EECC recital 23.

[4] EECC recitals 26 – 28.

[5] EECC article 82.

3 Study Approach

The overall study seeks to develop a systemic understanding of the drivers for investment in VHCNs and provide a qualitative System Dynamics model that illustrates these drivers in the context of the electronic communications network business system. This will provide a mechanism to understand how and why VHCN infrastructure investment has flourished in some countries but not others, and to learn lessons for further roll-out of VHCNs across the EU. The qualitative model can also provide a base design for any quantitative System Dynamics model, along with an evaluation of data sources.

3.1 Why whole systems models are needed

Several studies and academic papers have addressed drivers of investment in Next Generation Access (NGA) in general and a smaller number have addressed drivers of investment in VHCNs in particular[6]. It is clear, when looking historically at investment in NGA, that different conditions exist in the characteristics of markets across the EU that impact investment. Further, these conditions are multifaceted and should be considered together to understand past investment and when considering policies to promote future investment. A further complication is that some conditions are not static and can change over time, partly as a result of previous decisions and partly in response to the current generation of telecoms infrastructure. Some of these conditions can work together to accelerate the level of investment in VHCN while others can act as limits to the rate of investment.

Box 1: Spain and Sweden take different routes to high VHCN coverage

As noted in the introduction, individual firms in different countries are subject to market forces that affect their investment decisions. Examples of how a combination of conditions along with policy can affect investment in VHCN are illustrated by Spain and Sweden case studies. Both are exemplars for achieving high levels of availability of VHCN but have achieved this in different ways.

Spain

Spain has FTTP coverage of 78% for households across the country, and Ultrafast (FTTP + Cable DOCSIS 3.x) coverage of 88% of households as of June 2018. These figures represent very high coverage in urban areas, including multiple networks in many areas, but Spain has significantly lower coverage in rural areas. Nevertheless, Spain exceeds EU coverage even in these rural areas by more than twofold: 32% vs 14% on FTTP and 40% vs 16% on Ultrafast coverage. The Spanish regulator set conditions to encourage investment in FTTP in 2008 by regulating access to the incumbent's ducts while at the same time restricting the wholesale obligations for the incumbent Telefonica to providing 30 Mbit speed. This meant that Telefonica could gain competitive advantage over LLU and wholesale tenants by being able to offer considerably superior speeds via FTTP infrastructure. At the same time, competitors could respond to the threat by deploying their own FTTP infrastructure, so creating the conditions for infrastructure competition. In addition, cable with close to 50% coverage provided an existing form of infrastructure competition with higher speeds than copper. Together with appropriate regulation, the success of this approach was also dependent on Spain's existing high-quality duct system to premises in urban areas, and a high proportion of multi-dwelling units (MDUs) allowing relatively low installation costs for FTTP compared with most EU countries. It also required active enforcement of duct access obligations and symmetric building wiring obligations for the approach to be successful. Historically demand-side drivers for VHCN in Spain have not been strong, though by 2018, with 100 Mbit prices now being the same as copper prices, 30% of households subscribe to connection speeds of at least 100 Mbit/s (compared with EU average of 20%). In 2016, in order to ensure competition while spurring investment, Spain reinforced the current regulation with a geographical segmentation imposing price flexible access to FTTP in non-competitive areas for ultrafast broadband services.

[6] See Cadman et al (2019) *Study on the determinants of investment in VHCN – a System Dynamics approach, Volume 2: Literature Review*.

Sweden

Sweden also has high FTTP coverage of 77% and Ultrafast coverage of 78% as of October 2018. In rural areas coverage is lower (41% FTTP and Ultrafast coverage). Subscription rates to Ultrafast broadband (at least 100 Mbit/s) are the highest in the EU with 54% of households subscribing, representing a very high proportion of those households with Ultrafast coverage subscribing to it. Several factors have contributed to the relatively high rollout of FTTP in Sweden. Much of the initial lead for FTTP rollout was undertaken by municipalities providing publicly owned fibre infrastructure, most of which provide dark fibre or wholesale only services although a proportion sell directly to consumers. Sweden also has many village fibre cooperatives providing fibre in more rural areas. As a result, Sweden has over 500 fibre stakeholder organisations and over 1000 village fibre schemes. Cable networks cover 38.5% of households. Copper loops in Sweden tend to be long, reducing the effectiveness of FTTC as a lower cost alternative to FTTP or cable. The incumbent Telia responded by rolling out its own fibre network, including to more expensive single dwelling units. Sweden is also characterised by high demand for fibre, including a high willingness to pay for connection to the fibre network with a one-time fee of around €1,900 for a single dwelling unit. Connection to fibre broadband tends to increase the value of properties by a similar amount, as well as allowing landlords to charge higher rents. Internet usage in Sweden is one of the highest in the EU in terms of MB per person and Sweden has well developed online access to public services.

As the Spain and Sweden examples show, there are multifaceted drivers of investment in fibre in countries and the prime drivers can differ between countries. While Spain and Sweden may be exemplars for widespread FTTP deployment, replicating their approaches is unlikely to be similarly successful for all EU countries due to several factors, including differing legacy infrastructure and geographic conditions. Belgium, Germany, Ireland and UK incumbent operators, having very good copper networks, initially focused on FTTC deployment in response to speed increases available from cable operators. France, despite having good duct access in dense urban areas, has a much lower population density within its semi-urban and rural areas (even though it has a similar percentage of rural population to Spain), compared with some of the aforementioned countries. Italy has no cable operators and so lacks cable competition as a driver for FTTP investment. Belgium and Netherlands, on the other hand, have almost total cable coverage. Internet usage and demand for speed differ considerably across the EU but there is a clear trend for increased demand across all countries. See DESI (2019)[7] for information on coverage and subscription rates for different technologies.

A whole systems model provides the ability to understand the drivers of investment in the context of the whole telecoms system. System Dynamics has been selected as the mechanism by which the whole systems view will be captured. It provides a mapping technique by which the structure of the system of interest can be captured diagrammatically and for interrogating how the structure generates dynamic behaviour. System Dynamics[8] also allows quantification by incorporating equations into the structural model and utilising a simulation engine to step through time and calculate the state of the system at each time step.

The aim is to build a whole systems model that can apply to the telecoms market of any EU country. This would use a common structure for all countries, but different narratives can be told based on measures of the conditions. For example, all countries would have a representation of availability of high-quality ducts/poles but the quantile for the measure can change the narrative considerably. Good availability of high-quality ducts/poles will reduce the capital costs for deploying fibre and improve the business case for investment in FTTP as well as increasing the likelihood for infrastructure-

[7] DESI (2019) *Digital Economy and Society Index report 2019: Connectivity.*

[8] See Annex A for an introduction to System Dynamics.

based competition. Poor availability or quality of ducts/poles will require more substantial infrastructure work requirements for deploying fibre and so increase capital costs and so have a negative impact on the business case for FTTP infrastructure investment.

3.2 Overview of approach

Figure 2 presents an overview of the approach in terms of core study activities undertaken from January to October 2019. Given the current large body of work/analysis published on regulation, a formal literature review was undertaken. The intention was to collate insight to inform the new systems based qualitative models. It was recognised by the consultants that to gain insight into the corporate investment decision making, stakeholder engagement would be critical, and a comprehensive interview programme was established covering NRAs, operators, financiers, technology companies and trade bodies. These collectively provided the evidence base to collate an exhaustive list of drivers of investment and further to represent them within a qualitative model of the network operator's business system. This model could then be used to undertake qualitative analysis to describe national market VHCN evolution and draw conclusions on the dominant determinants of investment in each case. This qualitative analysis can also inform a market typology to cluster markets with similar characteristics.

Figure 2: High level overview of study approach

3.3 A participative approach

A participative approach was used, and a wide range of stakeholders was consulted throughout the study. Stakeholder engagement has been a critical component:

- Gain insight into the investment decision making processes for a broad range of network operators across different European markets.
- Given the novelty of the System Dynamics approach, it was important to involve NRAs and operators throughout the study to build confidence and understanding in the approach and the difference to other modelling approaches.

The contribution of this participative approach is illustrated in Figure 3 below.

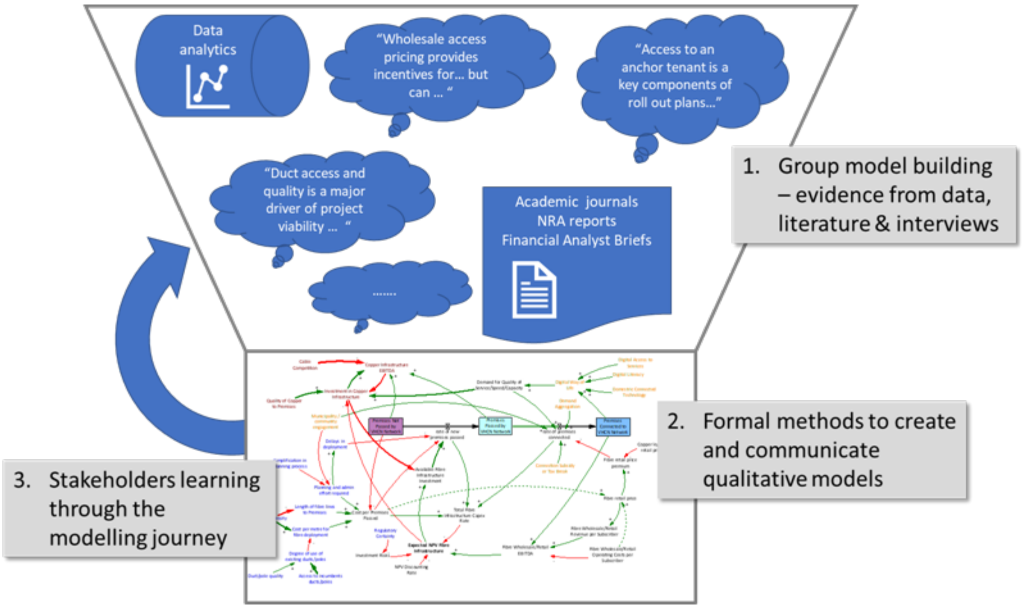


Figure 3: Participative approach to collect evidence and communicate qualitative model and insight

3.4 Literature Review

The literature review has been published in a separate volume[9]. In summary, it has reviewed over 100 papers by academia, regulatory authorities, operators and professional service organisations.

The literature survey insights were organised to collate and compare how different authors represented and explained network investments. A wide range of methodologies and approaches could be found in the papers including detailed econometric modelling of NGA uptake in specific geographies as well as theoretical models of regulated markets and actors within them. There was no evidence found of any attempt to represent a whole systems model for a network operator market with the ambition of the current study.

There was a large body of knowledge/work/analysis on regulatory policy on markets but less on understanding and articulating in detail how corporate decision making is undertaken around network investment. It was this latter paucity of knowledge that made the stakeholder engagement and interviews particularly important to this study.

The literature survey did provide valuable pieces of evidence about how markets behave and the underlying structures that can drive these behaviours. The literature survey framed this evidence as sets of simple causal diagrams, a core methodological component of the System Dynamics approach (see Annex A.2). These were then taken forward for consideration as part of the design for the final whole systems model described in sections 7 and 8. In this respect, it should be noted that the Literature Survey has not been intended as a design for the final models but rather an audit of potential evidence which when combined with the stakeholder engagement and interviews led to the creation of the final qualitative models.

A final part of the literature survey was to explore other applications using the System Dynamics approach in the area of telecoms. Only limited work was identified that could be used directly to support the current study.

---

[9] See Cadman et al (2019) *Study on the determinants of investment in VHCN – a System Dynamics approach, Volume 2: Literature Review*.

3.5 Stakeholder engagement and interviews

It was recognised that there was a need to get an understanding of the corporate investment decision making processes and the drivers considered by different operators who may have very different business models. Other key stakeholders were NRAs and the interviews and workshops with contributing NRAs provided further critical evidence used to develop the qualitative whole system models. Perspectives were also sought from financiers and technology companies. The balance of interviewees is shown below – there was a marked weighting towards Western European operators who came forward to contribute.

Figure 4: Interview Sample Structure

The table below lists the organisations interviewed by sector.

Stakeholder	Organisation	
NRA	ACM BNetzA CNMC DBA	ARCEP RTR PTS
Incumbent Operator	Deutsche Telekom Orange KPN	Telefonica Eir
Entrant Operator	Vodafone Colt Fastweb CityFibre Bouygues	Eurofiber Deutsche Glasfaser Masmovil Liberty Global Tele2
Technology Provider	Ericsson Google Fibre	Google Mobile
Trade Association	ETNO ECTA	FTTH Council Europe
Finance	EIB New Street Research	Cube Infracapital

Structured interview guides were developed to support the interviewees. These asked specific questions on decision preferences in different investment scenarios but also included open questions to allow discussion on investment strategy, opportunities and fears from competition and regulatory frameworks. An outline of the questionnaire format is shown in Annex B.

The interview responses generated a large body of insights that was combined with that from the literature survey and taken into the design and development of the qualitative whole systems model.

It was important to recognise that stakeholders may frame their responses to reflect their own interests and so challenge was built in during the interview process and as part of the subsequent analysis. The study team concluded that stakeholders as a collective group did present a coherent set of drivers and recognition of market behaviour but that the emphasis on the drivers of investment could differ.

The study team adopted "challenge" questions for itself during the evidence gathering from the stakeholder interviews:

- Did an operator or NRA identify the driver/structure as a determinant?
- If operators differ in opinion, could this be explained by the market conditions in which they operate or their business model?
- Structures were then incorporated into the generic model and where appropriate literature papers identified as supporting the view.

These were used to determine inclusion or otherwise within the overall model.

4 Challenges of VHCN roll-out for stakeholders

4.1 Challenges for Operators

There is a wide variety of telecoms operators playing some sort of role in the roll-out and retailing of fixed line VHCN. All operators, even publicly owned organisations, need to operate in a commercial manner. Therefore, it is not enough to provide VHCN, even as a public good, if it cannot be supported financially. Most VHCN roll-out projects will require some sort of financing with enough returns on investment, so it is necessary to have a business case that can pass scrutiny.

Moreover, there are further complications and risks that create challenges for operators. These include:

- **Technology choices** – while FTTP is often seen as the future-proofed end-state for fixed line broadband, there are several potential interim steps that stop short of FTTP. These are:
  - **Incumbent's copper network** – incumbent operators have a legacy copper network with existing retail customers and wholesale customers using LLU or bitstream services. Depending on the quality and lengths of copper, speed increases can be achieved through vectoring (though unlikely to be at VHCN levels) for considerably less cost and time than FTTP. Incumbents investing in FTTP networks need to maintain and support their copper networks for a time and so incur operating costs for both copper and fibre networks.
  - **Existing LLU or bitstream operator on an incumbent's copper network** – Operators relying on a form of wholesale access to the copper network are likely to lose customers to rivals using an NGA network. To survive in the longer-term such operators must migrate to their own fibre (or cable) infrastructure, secure wholesale access to another network operator's fibre infrastructure or await availability on the incumbent's NGA network.
  - **New entrants to the infrastructure market will most likely employ FTTP** as the future-proofed technology since it costs no more to deploy (and is likely cheaper) than any other fixed-line technology.
  - **Cable operators can incrementally increase speeds** through a variety of means using DOCSIS 3.0 and then DOCSIS 3.1 systems. Coaxial cable suffers from contention issues with performance falling with concurrent users on the same coaxial node. Running fibre closer to consumers reduces contention, and ultimately removes it if fibre is run to the home.[10] DOCSIS can run on a fully fibre system and most new cable installations use fibre since they are cheaper to deploy than coaxial and have lower operating costs (source: Interviews).
  - **Fixed wireless offers an alternative to running a line** to the end-user's property. No current technology provides VHCN speeds though 5G has the potential to do this over short distances and may be an option in areas where trenching is problematic.
- **Uncertain demand** – demand for higher speed connections is increasing. Subscriptions for 100+ Mbit/s have increased from 2% of homes in 2012 to 20% of homes in 2018 (DESI, 2019)[11] but the willingness to pay a price premium for significantly faster speeds appears to be limited in many countries (BEREC, 2016)[12] and evidenced by DESI 2019 which reports that the take-up 100+ Mbit/s subscriptions in 2018 is around 1/3 of the homes where it is available. The biggest current drivers for higher inter speeds are HDTV and 4KTV streaming which require no more than 8 Mb/s and 17 Mb/s respectively (Cisco, 2019)[13].

[10] Analysys Mason (2014) *Future capability of cable networks for superfast broadband*, Report for Ofcom.
[11] DESI (2019) *Digital Economy and Society Index report 2019: Connectivity.*
[12] BEREC (2016) *Challenges and Drivers of NGN Rollout and Infrastructure Competition*.
[13] Cisco (2019) *Cisco Visual Networking Index: Forecast and Trends, 2017–2022*, Cisco white paper.

- **Regulatory certainty** – business cases for new roll-out of VHCN will make assumptions on regulations. Uncertainty on future regulation changes creates risk which generally makes finance more expensive Regulators are aware of the importance of regulatory certainty and are following the principle of predictability.
- **Potential for increased competition** – operators that do not upgrade their infrastructure face the potential of an entrant being first to market and are competing for market share. New entrants investing in fibre as first to market face the potential of overbuild by an incumbent seeking to protect its market share. Cable operators are also a threat to traditional telecoms operators since they can incrementally improve broadband speeds in line with demand at lower expense than most traditional telecoms operators.
- **Market expectations from investment funds** – different operator types may find that financial institutions have different expectations on returns on investment. A wholesale only infrastructure provider with a business model may be able to access finance from a low-risk investment fund with a long payback period that is not available to a vertically integrated fixed/mobile operator which is seen as having a much more complex business model.
- **Concurrent investment in 5G infrastructure** – at the same time as the push for fixed VHCN investment, there is also a push for 5G investment. Whilst there is some opportunity for economies of scope from joint investment in FTTP and 5G fibre backhaul infrastructure, there will also be competition for finance.

4.2 Challenges for Regulators

As stated in section 2.2, EECC formally adds an objective that was implicit in the previous regulatory framework to pursue an additional connectivity objective of widespread access to and take-up of very high capacity networks.

The challenge for regulators is to create a regulatory environment that protects end user interests in a dynamic manner, i.e. incentivising operators to invest in VHCNs while promoting competition, which inevitably involves substantial capital investment from which a return is expected. In addition, this extra investment for VHCNs could further distract from investment in broadband for rural areas by diverting operators' and governments' attention and funding away from rural coverage and towards meeting targets for VHCN coverage.

VHCN investment decisions by operators will be dependent on some factors (such as demand and uptake) that are largely beyond the control of regulators.

4.3 Challenges for National and local governments

National and local governments want a broadband infrastructure that is fit for purpose and ready for current and near future needs of businesses and consumers. It needs to be future proof so that it is ready for the next generation of applications in the global technology marketplace.

Given the time it takes to deploy VHCN infrastructure across the country or within the municipality, it is sensible to start the process as early as possible. However, the challenge is to encourage operators to invest in VHCN infrastructure in advance of the demand (and therefore revenue). Government must also operate within EU state aid rules in any actions that it takes.

5 Introducing a VHCN ecosystem

The fixed broadband market (and particularly focusing on VHCN) system can be viewed as an ecosystem comprising of different stakeholders fulfilling roles, termed here an *ecosystem* because of their interacting roles in the investment and operation of the electronic communications system.

5.1 Components of the ecosystem

Figure 5 shows the roles of organisations within the VHCN ecosystem. Note that in some cases an organisation may fulfil multiple roles. Roles include:

- **Network operators** – network providers through investment and deployment of the network, and operation of the network. These may be private companies or partially state-owned companies, municipalities/local authorities, or local community cooperatives. Some operators may offer a wholesale-only service, others may be vertically integrated and also offer retail services. These operators are central to understanding determinants of investment in VHCN but are dependent on other roles and organisations in the system.
- **Retail operators** (ISP) – provide telecoms services to consumers, either via their own network (vertically-integrated) or by using a network operated by a different organisation, or independently functioning part of their own organisation.
- **Financial investors** – it is extremely rare that a network operator can completely finance investment in a network from its own financial resources and must instead seek financial investors who will charge interest and expect a level of return on their investment or raise capital from the bond market.
- **Subscribers** – households and businesses that subscribe to services are the main source of revenue for operators.
- **National regulators** – set regulations specific to the electronic communications system (and may have wider roles) related to consumer protection, effective competition and encouraging conditions for efficient investment.
- **National governments** – set wider policies that can affect the electronic communications system such as national targets, tax regimes, education and decisions on state aid.

Figure 5 shows several layers within the graphic indicating multiple actors as well as multiple regions. There are clearly multiple organisations involved in the system in terms of operators, investors and consumers. There will also be multiple products on offer to consumers representing different packages of services (multi play) and different performance levels for broadband, which will not just vary by network technology but also speed and capacity offerings at different price points on the same network technology.

The final slice, shown by the red boxes represents different regions within a nation. Due to differences in population density, terrain and distance from the fibre backbone, as well as existence or absence of existing infrastructure, the investment per premises for VHCN can differ considerably. This can affect the degree of investment in VHCN and the type of competition (infrastructure, retail or an absence of investment) in those regions. Some NRAs have identified sub-national markets for the purposes of regulation, which affect the obligations NRAs can place on operators in different parts of the same country and therefore the actions they can take to promote investment. Regional differences are also reflected by the European Commission classification with regards to the applicability state aid, classified as Black, Grey or White as follows:

- **Black** – clear conditions exist for commercial investment in VHCN for two or more competing VHCNs. No case for state aid to support the roll-out of VHCN, which could crowd out investors.

- **Grey** – there is a commercial case for one VHCN infrastructure, but unlikely to support two competing VHCN infrastructures. Further detailed analysis is required to determine if state subsidies are appropriate, if commercial conditions are met or if other remedies are required.
- **White** – there is a clear case for state subsidies to support development of VHCN in the area that would otherwise be unfulfilled on a commercial basis, with no prospect of private investment in high speed broadband in the next three years.

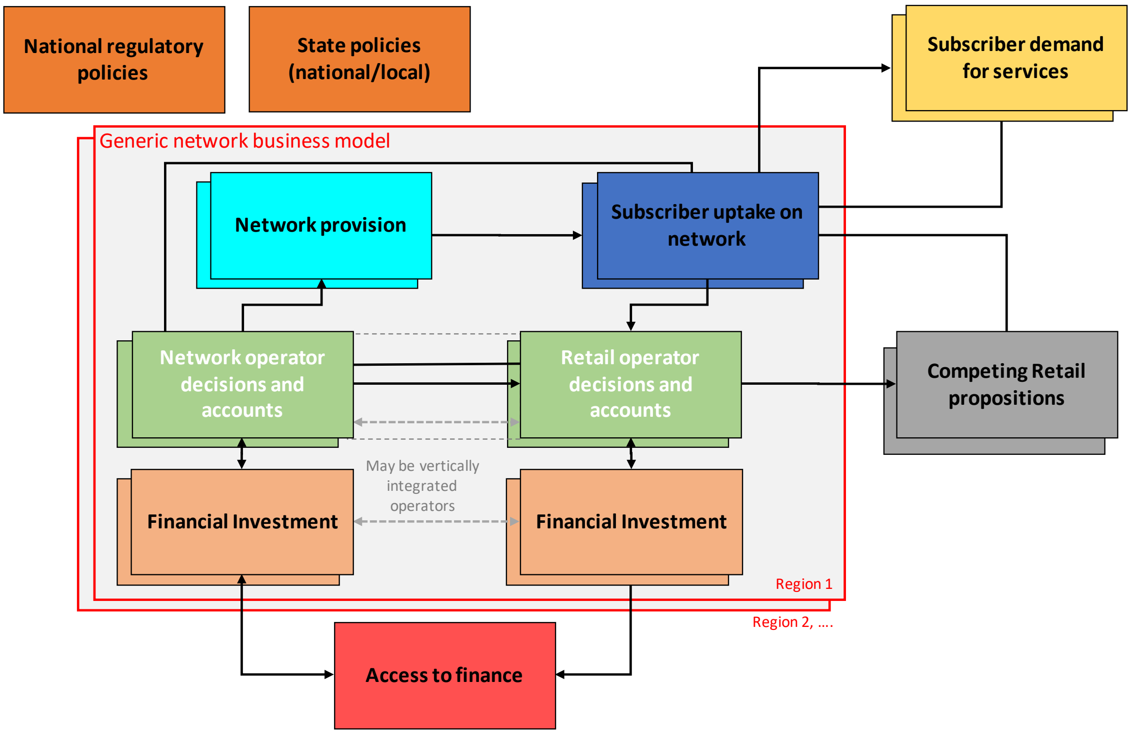


Figure 5: Roles within the VHCN ecosystem

Excluded from this scope are content developers and providers of Over The Top (OTT) services such as the various third-party video streaming services. These are important driving increased demand for bandwidth but are not typically directly involved in the delivery of that bandwidth, but it could certainly influence the operators' ARPU.

5.2 Diversity of operators

An ecosystem of different types of telecoms infrastructure providers exists, to fill different roles and niches within the VHCN system. Broadly these can be classified into six categories and the SD model has been developed to represent any one of these types. Descriptions of each of these categories will not exactly match all operators, but represents a stylised operator of that type:

- **Incumbent** – Historically owners and operators of national copper telecoms infrastructure. Typically, they are privatised former national utilities, in which governments may retain some ownership. Incumbents will provide national scale telecoms and generally aim to protect market share. In many cases they invest in infrastructure to counter competition from cable or FTTP entrants through deployment of FTTC or FTTP depending on corresponding cost of deployment and viability of copper infrastructure. Initial priority will tend to be in areas with cable competition (usually those areas with higher urban density), then to counter fibre entrants with FTTP in semi-urban areas (potentially pre-empting the threat), while rural is lowest priority, since it will tend to have the highest cost per property passed. Most incumbents are deemed to have SMP (Significant Market Power) status and will be subject to asymmetric regulation on access and wholesale pricing. Incumbents as owners of legacy copper infrastructure, in most locations must operate and support that infrastructure in parallel with any FTTP infrastructure. Incumbents are typically subject to a Universal Service Obligation (USO) and often the focus for governments wishing to meet national speed and coverage targets.

- **Cable** – Cable companies historically provide cable TV via Hybrid Fibre-Coaxial (HFC) network and have moved into multi-play offerings, involving voice and broadband services. They utilise existing cable network with incremental upgrades to increase broadband speeds to meet demand for current applications. Most cable networks use the DOCSIS 3.0 standard with plans to introduce DOCSIS 3.1 as part of the incremental upgrade plan. When extending the cable network to new areas they will tend to use FTTP since this is usually cheaper to deploy than coaxial and is future-proofed. Cable operators are not usually subject to regulation, but some have SMP status and so face some wholesale obligations, for example in Belgium and the Netherlands.
- **Nationwide AO** – Non-incumbent alternative operators (AOs) offering national level telecoms, often using a variety of infrastructure platforms. They will generally use the most cost-effective mechanisms to extend network: fibre re-seller, co-investment, take or pay anchor tenant (this also helps manage risk), buy existing cable or fibre networks, build own infrastructure. Many of these operators will have LLU experience and will still be operating these in some areas.
- **First-Mover AO** – These are FTTP infrastructure providers with a focus on areas with no existing fibre networks. They usually seek to avoid cable areas as well as existing fibre infrastructure. They are mostly wholesale infrastructure providers but may have a retail arm to support speedy adoption. Typically, they aim for high penetration due to limited competition at the performance levels that they can offer. They also seek to develop close relationships with municipalities/communities, and/or anchor tenants. First mover AOs may be privately owned companies, joint-venture mechanisms or wholly owned by municipalities and in some cases have access to sources of finance that accept long payback periods.
- **Subsidy specialists** – First-Mover AO focussing on areas with government subsidies. These operators generally focus on rural communities and specialise in approaches to reduce deployment costs. Local community engagement is key and cooperative ownership of the infrastructure is a common model.
- **Business customer specialists** – Operators that specialise in tailored services for business customers. There is a focus on larger customers with very high bandwidth requirements. However, the capabilities of domestic fibre infrastructure are creating erosion of their customer-base.

5.3 VHCN and non-VHCN technologies

There is not yet a full formal definition of VHCN. However, the EECC has a definition of VHCN as follows:

"very high capacity network means either an electronic communications network which consists wholly of optical fibre elements at least up to the distribution point at the serving location, or an electronic communications network which is capable of delivering, under usual peak-time conditions, similar network performance in terms of available downlink and uplink bandwidth, resilience, error-related parameters, and latency and its variation; network performance can be considered similar regardless of whether the end-user experience varies due to the inherently different characteristics of the medium by which the network ultimately connects with the network termination point" (Article 2, paragraph 2).

In the EECC, BEREC has been tasked to determine guidelines by 21 December 2020 that specify the criteria that a network needs to fulfil to be considered as a VHCN (Article 82). The EECC sets objectives for fixed broadband capability that have been adopted in study as a rough working definition of VHCN capabilities, as follows:

"availability to all households in each Member State of electronic communications networks which are capable of providing at least 100 Mbps, and which are promptly upgradeable to gigabit speeds" (paragraph 24).

While this report attempts to be agnostic on VHCN technologies, there are nominally some technologies that are treated as clearly VHCN, some that are not VHCN and some that may be VHCN but only under certain conditions.

VHCN technologies

- **Fibre to the Premises (FTTP)** – This generic term is used to include Fibre to the Home (FTTH) and Fibre to the Building (FTTB). This technology is the standard for VHCN and is currently capable of offering symmetric speeds of 1 Gbit/s
- **Cable** – This term historically represents HFC systems that were originally designed for transmission of TV but have been expanded by nearly all cable operators to include broadband. Most cable networks use fibre for transmission to local nodes where coaxial cable is used for transmission to premises. Most cable operators offer at least 100 Mbit/s download speeds. Cable operators have a range of upgrade pathways[14] to increase speeds and reduce latency, including migration from DOCSIS 3.0 to DOCSIS 3.1 and extending fibre closer to customer premises. Products offering download speeds over 500 Mbit/s using DOCSIS 3.0 are currently available, while download speeds of 1 Gigabit per second are available in some areas with DOSCIS 3.1. Widespread current speeds over 100 Mbit/s per second with clear upgrade routes to 1 Gbit/s mean that cable is typically treated as meeting the VHCN definition. In addition, most new cable network deployments use fibre to the premises which can use DOCSIS 3.x modems.

Non-VHCN technologies

- **Copper –** Legacy networks are based on copper lines. Basic copper lines from the exchange (ADSL/ADSL 2+) offer limited speeds of less than 30 Mbit/s with speeds dropping off with distance from the exchange. Fibre to the Cabinet (FTTC) extends fibre to local distribution points with copper used for the final connection to premises and can offer speeds up to 120 Mbit/s. Technologies such as G.fast can be used to increase these speeds but they drop off rapidly with the lengths of copper to the cabinet. Potentially developments of G.fast could reach 1 Gbit/s speeds, meeting requirements for VHCN, but only for very short lengths of copper (usually less than 150 meters) so that it would only be suitable for a small proportion of premises in case of FTTC. While FTTC is not generally considered to be VHCN capable, it is a migration route towards FTTP, since it extends the fibre network closer to premises and goes some way to protecting market share against competition from other technologies.
- **Fixed WiFi** – This is used in some rural areas as an improvement over ADSL over long copper lines but does not come close to being VHCN capable.
- **Satellite** – This offers broadband to very remote areas but is not close to VHCN capable. The OneWeb LEOS satellite system is reported to be aiming for 50 Mbit/s download speeds.[15]

[14] Analysys Mason (2014) *Future capability of cable networks for superfast broadband*, Report for Ofcom.
[15] De Selding P. (2015) *Virgin, Qualcomm Invest in OneWeb Satellite Internet Venture*, retrieved October 19, 2019 from http://spacenews.com/virgin-qualcomm-invest-in-global-satellite-internet-plan.

- **4G mobile networks** – A few EU countries have seen a significant substitution effect of 4G mobile being used instead of fixed line broadband (e.g. Austria) but this is not widespread across Europe. It does not come close to VHCN capable but can deliver speeds above the top end of ADSL.

Potential VHCN technologies

- **5G mobile networks –** These are not yet in widespread use but could be counted as VHCN with fibre backhauling to base station. However, in practice 5G masts would be shared among multiple concurrent users so the actual reliable speeds would be much lower. In addition, the fastest 5G spectrum only covers a short range from the mast and does not penetrate hard surfaces well. A much higher density of 5G masts would be required compared with 4G, and external aerials for 5G mobile technology to be a practical VHCN solution. Sub 1GHz 5G spectrum potentially provides a broadband solution for rural areas as an alternative to Fixed WiFi but will only be VHCN capable if the number of users per cell is very low.
- **5G small cells and microcells –** There is some interest in using 5G small cells or microcells to transmit short distances from fibre to nodes to properties as a replacement for running fibre from the node to the premises. This will require an external or window mounted aerial on the premises. It is of interest for urban areas with severe restrictions on civil works. This has the potential for being VHCN capable provided that the 5G cells services a small number of premises. There is also interest in microcells as hot spots in business areas.

6 The components for a model for VHCN investment

Prior to the building a whole system model to examine the drivers of investment for VHCN the evidence base for the components of such a model and for inclusion of drivers will be examined. This will be based on literature and interviews with national regulators, operators and financiers.

6.1 Representation of coverage and adoption

An annual assessment of broadband infrastructure coverage across EU countries is undertaken by HIS & Point Topic and published by the European Commission. This provides data on coverage by technology type on a national level and specifically for rural areas for EU countries. In addition, the European Commission Digital Economy and Society Index (DESI) reports provide information on market share by technology type in each EU country. These are key measures of to capture the degree of rollout and adoption of VHCNs.

From the perspective of an individual customer (household or business premises), each can be in one of 4 mutually exclusive basic states in relation to their ability and choices to adopt VHCN, illustrated in Figure 6. These states are:

- **Premises not passed by VHCN** – the customer has no VHCN passing the property and therefore has no opportunity to connect to and subscribe to a VHCN. This can only be changed by an infrastructure provider building infrastructure out to close to the premises.
- **Premises passed by VHCN not connected** – a VHCN passes the premises but the premises is not physically (or wirelessly) connected to the VHCN. In most cases it is the customer's or landlord's decision if they want to connect to the VHCN.
- **Premises connected to VHCN not subscribing** – the premises is connected to a VHCN but the customer is not subscribing to the VHCN and therefore the operator is not receiving revenue for the customer. It is treated as distinct from not connected since if the household or business chooses to subscribe the capital costs for connection do not need to be incurred again. This state can occur if:
    - The premises is connected to the VHCN as part of the rollout of the infrastructure (e.g. new build or replacing a copper connection) but the household has never subscribed;
    - A multi-dwelling unit is connected to the VHCN, but some households/businesses do not subscribe;
    - A household/business previously subscribed to the VHCN but is no longer subscribing and uses a different network infrastructure.
- **Premises connected to VHCN and subscribing** – the customer subscribes to the VHCN and the infrastructure operator receives revenue as a direct retailer or as a wholesale provider.

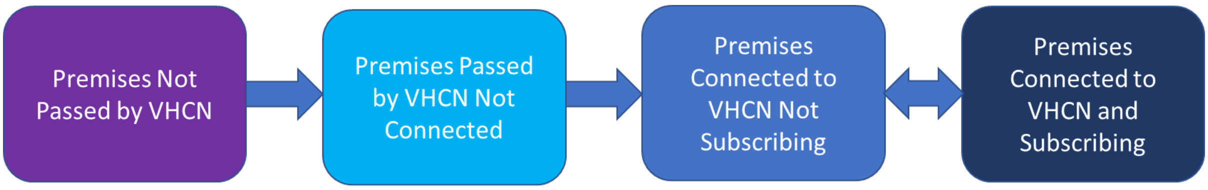


Figure 6: VHCN status of a premises

As well as representing the VHCN status of a single premises, these categories can also be used to measure the number of premises within a nation or region in each of these states. Note that from the

IHS & Point Topic[16] data it is possible to determine the number of properties passed and not passed by VHCN but not the subscription status. From DESI data it is possible to determine the market share for FTTH/B and Cable technologies (almost all cable is now DOCSIS 3.x) and so calculate the number of premises subscribing to VHCN. Combining the data together allows the number of premises passed by the VHCN but not subscribing to be determined but it is not possible to determine whether these premises are connected to the VHCN. The relevance of the connection status is for use in a financial model to determine if the connection cost has been incurred or not for a property.

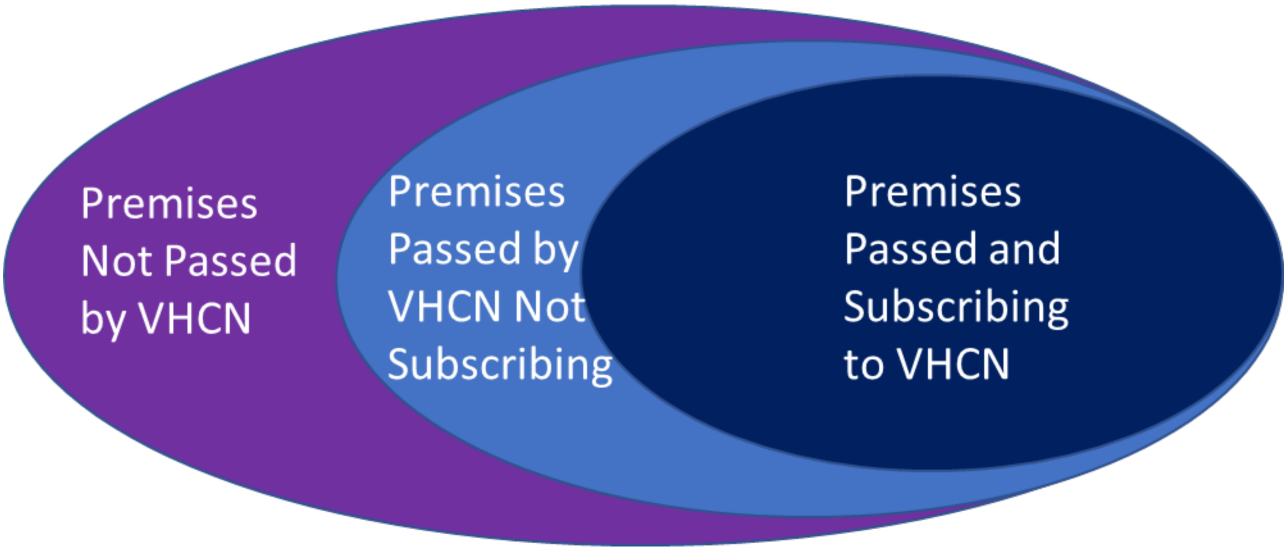


Figure 7: Venn Diagram showing premises VHCN states that can be determined from EC Annual Reports

6.2 Competing investment decisions for network operators

Investment decisions can be made treating areas of a country as individual infrastructure projects. Infrastructure operators have alternative investment decisions, with options varying dependent on their existing infrastructure. Examples are:

- **Do nothing** – no new capital expenditure but continue receiving revenue (and incurring operating costs) for customers on existing infrastructure, but likely to experience erosion of customer base from competition by superior performing networks. This option does not need to be permanent and can represent a stage in a wait strategy before applying one of the other investment options, e.g. waiting for technology maturity, watching projects in other areas to determine level of demand for different investment options.
- **Invest in improving performance of existing copper network** – operators of an existing copper network can choose to invest in improving the speed and performance of the existing copper network through technologies such as FTTC and g.Fast. This is unlikely to match the performance of other competing VHCNs but may satisfy demand for increased performance for a period and so protect the existing customer base. Depending on regulations, the operator may be required to make this increased performance available to tenant operators on the copper network.
- **Invest in improving performance of existing cable network** – operators of an existing cable network have opportunities to incrementally invest in changes to improve the speed and performance of the cable network. Many changes can be made to improve the performance of a DOCSIS 3.0 network before needing to adopt the DOCSIS 3.1 specification, for example by extending the fibre element of the network closer to customers. This investment can be made

[16] IHS & Point Topic (2018) *Broadband Coverage in Europe 2017*, European Commission.

over time to meet the increasing demands for broadband performance for the majority of consumers.[17]

- **Invest in FTTP** – all operators have the option to invest in FTTP for an area if they can make a viable business case and raise the capital. For incumbent copper infrastructure owners, this investment will gain revenue from new subscribers but also reduce direct retail and/or wholesale revenue from the copper network. LLU and bitstream operators gain revenue from new subscribers but lose revenue from copper subscribers that switch to the new technology. New operators to an area can gain retail and/or wholesale customers depending on their business model. Cable operators can expand their cable network using FTTP and are able to maintain DOCSIS 3.x compliance.
- **Co-invest in FTTP** – co-invest with other operators to reduce capital spending by sharing civil works for overbuild of fibre infrastructure or for sharing the same fibre infrastructure.
- **Buy or rent existing infrastructure** – an operator may opt to buy or rent existing VHCN infrastructure or acquire other organisations that own that infrastructure. This does not increase the amount of VHCN infrastructure nationally but does provide that operator control of existing VHCN infrastructure. For example, in 2019 Vodafone acquired Liberty Global's operations in Germany, Hungary, Romania and the Czech Republic for €18.4 billion, thereby increasing Vodafone's fixed line VHCN capable presence in those countries.

6.3 NPV based decision making

As noted by Frontier (2018)[18] competing investment decisions (including business as usual) are typically evaluated using Net Present Value (NPV) or the very similar Return on Investment (ROI) if using an internal rate of return (IRR) on cashflow. The simplest determinant of investment in VHCN is, therefore, whether an investment in a VHCN project will earn a higher profit than the next most profitable use of investment funds over a period. The alternative project may be with the same technology in a different location, e.g. a different country, or a different technology that is expected to make higher returns. What investors want to establish is whether the expected cashflows from an investment will exceed the expected costs, including a discount rate that represents the cost of capital. This is the Net Present Value (NPV) of an investment.

The NPV equation is well known in corporate finance and shown below:

$$NPV = -K + \Sigma_{t=1}^{T} \frac{\pi_t}{(1+r)^t}$$

The investment capital (K) is made a time t = 0 and generates a cash flow at each future period of time (π_t) which has a present value at period 1 of $\pi_1/1+r$, where r is the threshold, or hurdle, rate of return required by the investor, and so on for each period for t from 1 to T (where T is the total number of time periods).

The threshold rate r will vary depending on how risky the investment is (reflecting uncertainty about the revenue stream) with a higher threshold required for riskier investments. The number of periods T can also vary based on the type of investor, reflecting the time allowed to break-even (i.e. achieve an NPV > 0). Investors will only invest if NPV is positive in a given timeframe and will choose the highest NPV if there are a range of options.

Interviews with operators identified that NPV type analysis was commonly being used for the business cases for fibre infrastructure projects. This is most easily observed where targeted investments are being made by Alternative Operators supported by investor finance, but arguably it will still be the

[17] Analysys Mason (2014) *Future capability of cable networks for superfast broadband*, Report for Ofcom.
[18] Frontier Economics (2018) *Future Telecoms Infrastructure Review*, Annex A, Report for DCMS.

case for larger scale rollouts of fibre infrastructure in terms of determining the scope and sequencing of rollout.

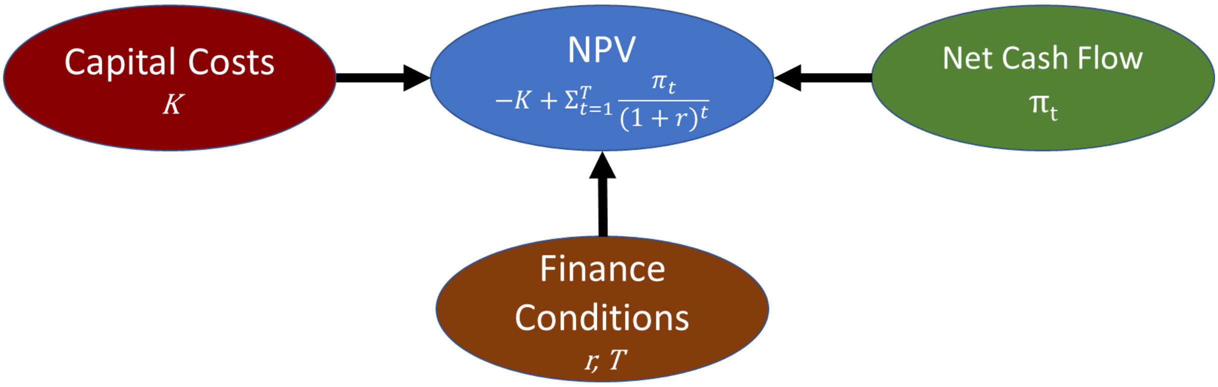


Figure 8: Main constituents of the NPV consideration

The three main constituents of the NPV calculation are shown in Figure 8. For the rollout of a VHCN these can be considered as:

- **Capital costs** – costs of deploying the VHCN including planning and administration, equipment and materials, earthworks and labour. This covers any costs related to passing premises and connecting premises.
- **Net cash flow** – revenue from operations minus costs of operation of the network. This can include retail and wholesale costs and revenues. In accounting terms, government grants for capital expenses and recovery of costs from end-users (e.g. fees for connection) would be recognised as revenue.
- **Finance conditions** – the rate of return and payback periods required by investors. This will vary based of the perceived risk, the type of finance funds and the type of operator. Some capital costs could be self-financed by operators from retained income, which may not have the same conditions as external investors but would still require a solid business case and return on investment.

To represent investment decisions a model will need to represent the capital costs (and factors that impact those costs), and sources of revenue and operating costs to capture net revenues. NPV decisions will evaluate these for new projects, but these evaluations in part will be built from observations costs and returns for existing projects.

Operators and investors will be estimating NPVs since capital costs and to a greater extent net cash flows are uncertain. There is downside risk that the investment does not generate the expected revenues, as well as upside 'risk' that it actually performs better than expected. Finance conditions will tend to reflect the degree of risk in terms of the required rate of return.

6.4 Capital investment

The capital investment part of the NPV decision relates to the direct costs of deploying the VHCN infrastructure but excludes ongoing operations costs. There are two parts to the physical deployment: i) VHCN infrastructure from the existing fibre backbone to the point that it passes properties; ii) VHCN infrastructure for connection to the premises including any internal wiring that the network operators retain ownership of. Connection to the premises will usually be physical (fibre or coaxial for VHCN) but could potentially be wireless (e.g. 5G microcells). In most cases the connection to premises will be done on demand and may occur over a number of years after deployment of the infrastructure passing the premises. In some cases, the connection could be done by default, e.g. for new builds or where existing connections are being upgraded or replaced for most or all premises in the area.

Activities and costs related to capital investment include:

- **Deploying infrastructure to pass premises**
  - Administration costs directly related to working on planning permission and wayleaves for infrastructure deployment.
  - Labour and plant costs related to civil works for deploying infrastructure from existing backbone to passing premises within the area to be covered by the project.
  - Equipment and materials costs.
- **Connecting premises to the network passing them**
  - Wayleaves and permissions for connection to premises where connection is being made to properties by default (i.e. not by request), where connection involves land owned by a third party or landlord, and where internal wiring work is required for a building with a landlord.
  - Labour and plant costs related to civil engineering for connection to premises and any internal wiring.
  - Equipment and materials costs.

Significant savings can be made to capital costs by leasing existing ducts and dark fibre, but these leases will increase operating costs for the network.

6.5 Operating costs and revenues for the network

Infrastructure operators may be providing a wholesale only service to reseller, selling only direct to end-users, or both. The net cash flow component of the NPV decision will be EBITDA (Earnings before interest, tax, depreciation and amortization) comprising of revenues minus all maintenance and operating costs for the network included in the project.

From the perspective of the infrastructure operator, revenues can be generated by:
- Charging for wholesale access to re-sellers.
- Revenue for leases for owned ducts, dark fibre and internal building wiring.
- Direct sales to consumers.

Operating costs are incurred for:
- Operation and maintenance of the network.
- Leases paid to owners of ducts, dark fibre and internal building wiring.
- Retail services and supplied digital content if the operator sells directly to consumers.

Revenues are generally the most uncertain part of the NPV decision and will usually be highly dependent of the degree of penetration in terms of claiming market share. Some projects may have mechanisms that guarantee a certain amount of revenue and therefore reduce the risk of the project. Potential sources of revenue are as follows:

- **Household and business subscribers** – the core source of revenue will be the end-user subscribers, which may be through direct sales or indirectly through payments by access seekers to the infrastructure. Most NPV business cases will have a target penetration rate for subscribers. Incumbents or operators using access to existing legacy copper network must discount their revenue lost from their legacy network customers switching to the new network.
- **Anchor tenants** – public organisations or large business may act as an anchor tenant for deployment of a new network. This creates a guaranteed revenue stream, with the infrastructure then being expanded to the local area.

- **Take or pay contracts** – an infrastructure builder may have a guaranteed wholesale customer that can provide a minimum revenue stream. The take or pay wholesale customers may or may not have exclusivity rights for a period of time.
- **On demand clients –** infrastructure built on demand for a business will have guaranteed revenues to cover build costs and an agreed subscription mechanism.

6.6 Competition and consumer choice

Two forms of competition exist to give consumers choice for fixed broadband: infrastructure competition and access-based competition. There may also be infrastructure competition from mobile networks.

- **Infrastructure competition** is derived from alternative physical infrastructure from different operators. Where infrastructure competition exists, it will usually be between copper lines, cable and/or fibre (FTTP). In some locations there will be multiple FTTP infrastructures available to premises.
- **Access-based competition** is from multiple retail operators providing services over the same core infrastructure. These retailers will be making use of a network (or at least part of a network) provided by the same infrastructure operator. Access might be granted voluntarily or may be imposed as a consequence of state aid rules or significant market power (SMP).

If infrastructure competition is limited, then the infrastructure operator (usually the incumbent) has SMP status in the market. In this case remedies will be imposed on the operator with SMP to protect consumers and promote competition.

Competition from other networks will have an impact on market share (of the wholesale and/or retail market) and therefore revenues, which will reduce the net cash flow part of the NPV calculation.

Different forms of competition can exist:

- **Inferior technology** – competing infrastructures with significantly inferior speeds and/or latency are less of a threat to revenues if that technology is not meeting the demand of a significant proportion of end users in the areas.
- **Superior technology** – competing technologies with significantly superior speeds and/or latency are a severe threat if there is significant demand for that capability. With the "do nothing" option of sweating existing copper assets it is potentially a serious threat to existing market share.
- **Equal technology** – other infrastructures with roughly equal capabilities will divide market share between them, with price and/or multi-play options being differentiators.
- **Potential competition** – infrastructures that are not yet present but could be implemented later are a threat to future revenues. The likelihood and timing of potential competing infrastructures of equal or superior infrastructures are likely to be factored into future net cash flow in the NPV decision.

Frontier Economics (2018)[19] relate that the threat of potential competition could result in some areas not covered by a VHCN even if there is enough demand to support a VHCN. Alternative operators may need high penetration rates in an area to justify investment, but an incumbent choosing to overbuild in that area could undermine the business case. On this basis the alternative operators may choose not to build a VHCN and this reduces the incentive for the incumbent to build a VHCN – i.e. merely the threat of overbuild is enough.

[19] Frontier Economics (2018) *Future Telecoms Infrastructure Review*, Annex A, Report for DCMS.

Interviews with some alternative operators that specialise in rural areas suggest that these areas are more attractive to them than higher density areas since they are much lower on the priority list for the incumbent and much less likely to have overbuild, particularly if subsidies are available for a first mover only.

Each actual or potential competitor has the same basic NPV type investment decision. However, their existing infrastructure in the area and market share will differ, and the type of organisation they are will affect their access to finance and the terms of that finance. This can lead to significant differences in the type of investment option, capital costs and consumer or wholesale charging policies in terms of connection costs and lease or subscription prices. An SMP operator under asymmetric remedies has less freedom for pricing than an alternative operator. An operator with national coverage will usually have less opportunity to vary prices to take account of regional conditions than a small local operator.

7 Determinants for corporate investment and systemic corporate behaviours

7.1 Purpose of this section

This section will examine different drivers of investment in terms of conditions that encourage or discourage investment and affect corporate behaviours. It sets the concepts and the evidence base for the System Dynamics model that is described in section 8. It is designed to be read as a stand-alone section and aims to provide a wide-ranging system analysis on the drivers and determinants of investment such that it:

- Captures and adds to the body of knowledge on the determinants of investment that is of use for readers familiar in the subject.
- Can act as a primer for readers who are new to telecoms that want to read into the subject or wish to develop models.
- Sets the context for the System Dynamics model and adds background detail for those wishing to use the model to analyse their countries in support of policy development and evaluation.

Diagrams shown in this section are not parts of the final System Dynamics model described in section 8 but aim to capture how the various factors affect investment decisions in a systemic manner. These concepts will be reflected in the System Dynamics model so that this section is a way of easing readers into the nomenclature and concepts of the System Dynamics approach. Some areas of the System Dynamics model will be less detailed than this section in order to manage the complexity of the diagram. When reviewing the System Dynamics model from the perspective of a particular country, information in this section could be useful as a guide for details to consider when evaluating the strength of a driver for investment for that county.

The literature review in Volume 2 of this study provides background information for this section, but readers are not expected to have to cross-reference with that document. The literature review looks at traditional literature on NGA and VHCN investment with a focus on regulation. This document will summarise the concepts highlighted in the literature and may refer the reader to the literature review for more detail. However, this section has a much broader scope and will examine areas not touched or only briefly mentioned in the literature review.

7.2 NPV as a central instrument for understanding investment decisions

The determinants for investment will be examined using the NPV concept as the basis for structuring the analysis, which examine drivers of investment that make investment more or less likely.

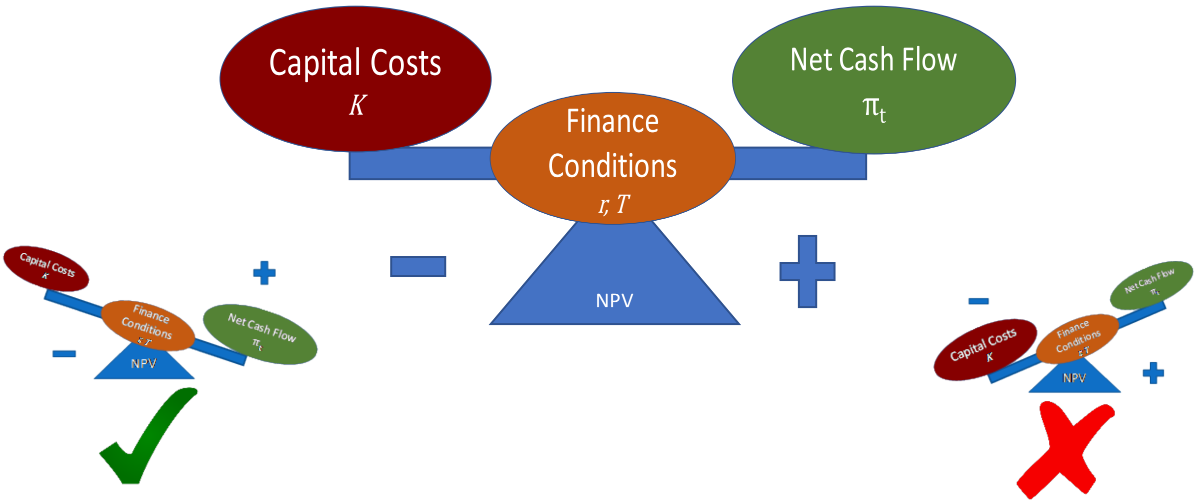


Figure 9: NPV represented as a decision balance, positive if discounted revenues exceed capital costs, otherwise negative

As shown in Figure 9, the NPV can be viewed as a balance which is positive only if discounted net cash flow exceeds capital costs. Any drivers that reduce capital costs or increase net cash flow will improve the NPV. Drivers that bring net cash flow forwards, reduce the cost of capital or extend the payback period will improve the NPV (i.e. by increasing the discounted value of the net cash flow).

These drivers may depend on the existing infrastructure, national or regional features (e.g. population densities), financial market conditions, as well as national government and regulator policies. Due to these differences, a strong driver for investment in one country or region may not be a significant driver in another. Similarly, the drivers may be important for some types of operator and not others.

In some cases, the same driver may affect different aspects of the NPV decision and possibly have both positive and negative impacts on the NPV decision. Drivers may also have an increasing or diminishing impact over time due to structural changes in the telecoms systems or other exogenous impacts.

The analysis will consider the drivers for investment in isolation first before applying System Dynamics mapping to understand the systemic impacts of the drivers.

7.3 Capital costs

Capital costs capture capital expenditure (CAPEX) of undertaking all activities involved in deploying the infrastructure. This capital expenditure:

- Increases the number of premises passed by the operator's network and/or connects premises to the network – typically this will involve FTTP deployment (including FTTP deployment for new cable networks); or
- Increases the capability of an existing network connected to premises – typically this will be measures to increase the speed of a copper network, such as FTTC, or increasing the capability of an existing cable network.

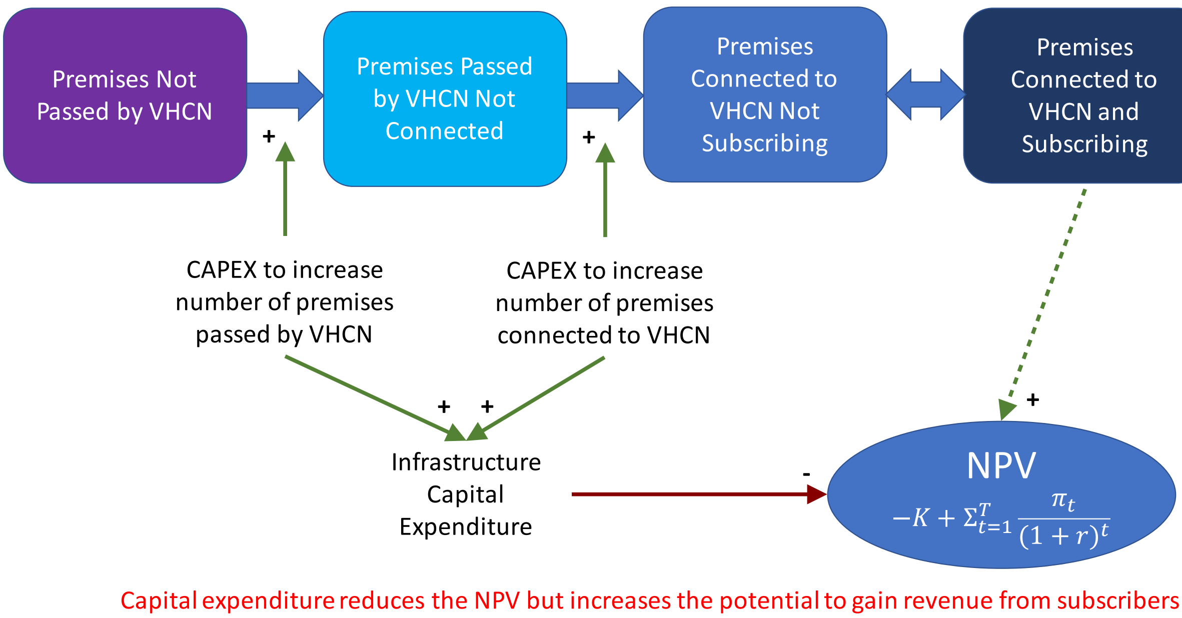


Figure 10: Impact of capital expenditure for new networks on NPV calculation

Figure 10 shows the progression of premises from not passed by a VHCN through to connected and subscribing. Green arrows with a plus on the arrowhead, for instance from "CAPEX to increase number of premises passed by VHCN", show that an increase in this measure will cause an increase in the *measure at the arrowhead end of the arrow, i.e. the more CAPEX is spent on network infrastructure the more premises will be passed. A red arrow with a minus on the arrowhead shows the opposite relationship so that spending more on "Infrastructure Capital Expenditure" will reduce the NPV value due to higher capital expenditure. On the balancing side, consumers subscribing to a network will generate cash flow that increases the NPV value (dotted line because this relationship hides a lot of detail that is expanded on later in this section). This type of representation will continue to be used in later diagrams.*

As shown in Figure 10, capital expenditure for a new VHCN increases the number of premises passed by the operator's network. Those premises then have the potential to be connected to the network. Premises that are connected and subscribing to the VHCN, either directly with the operator or via another operator with wholesale access, will contribute revenue. The capital costs are a negative influence on the NPV calculation but enabling operators to generate revenue supports the positive side of the NPV calculation.

The lower the capital costs are per premises passed and per premises connected, the more properties can be connected per €1M spent on capital and the more properties become enabled to potentially generate revenues. Therefore, lower capital costs benefit both sides of the NPV calculation. Potential drivers of capital costs per premises are shown in Figure 11 and described below. *Note that this diagram has a red negative arrow between "Cost per premises passed / connected" and the rate of passing and connecting premises. This means that the higher the cost per premises the lower the number of premises passed for a certain level of capital investment, so lower costs are desirable.* The figure shows drivers that can increase and decrease costs for passing and connecting premises.

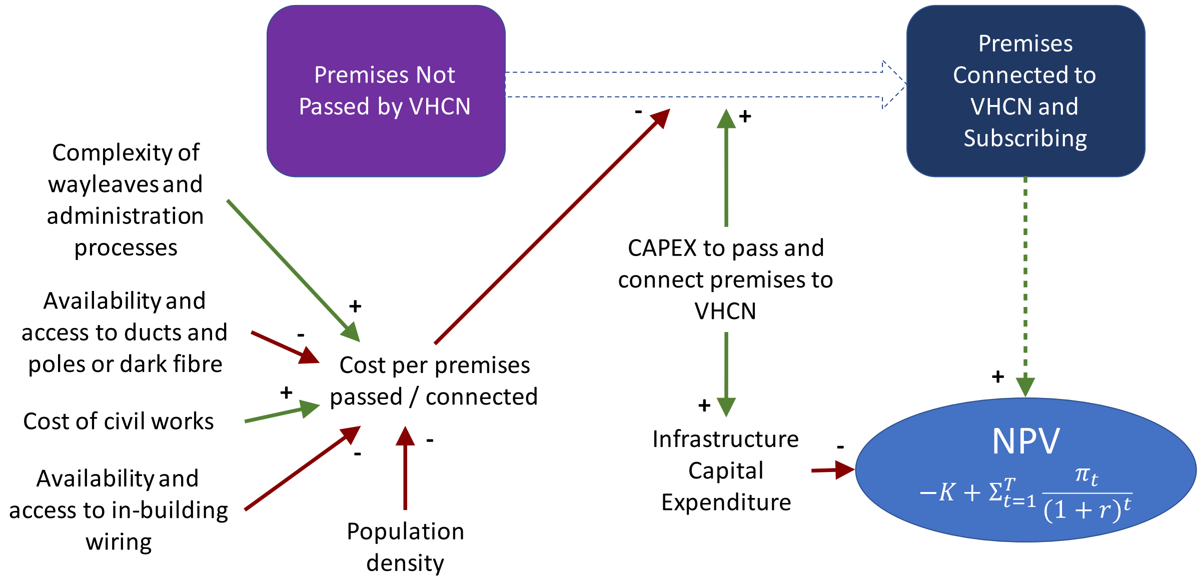


Figure 11: Drivers of VHCN cost per premises passed and/or connected

7.3.1 Population density

Areas with a higher population density and, in particular, a high percentage of the population living in urban centres tend to have earlier and faster deployment of VHCN on the basis that there are smaller distances between businesses and dwelling units so more people can be reached for a certain investment. This impact is well documented in literature looking at drivers of investment[20,21,22]. The

---

[20] BEREC (2016) *Challenges and Drivers of NGN Rollout and Infrastructure Competition*.
[21] WIK Consult (2015) *Competition & investment: An analysis of the drivers of superfast broadband*.
[22] FTTH Council Europe (2017) *The Cost of Meeting Europe's Future Network Needs*.

level of multi-dwelling units vs single dwelling units also reduces costs, however, depending on internal building wiring, this may come at the expense of reduced speed per household or business.

These patterns can be seen in the deployment of cable and fibre networks to rural areas versus the country as a whole. Figure 12 shows a comparison of FTTP and cable coverage between total coverage and rural only coverage for EU countries. While there is considerable variation between countries, in nearly all cases the whole country coverage is significantly higher than the rural coverage (exceptions are cable coverage in Malta, Netherlands and Switzerland, FTTP coverage in Denmark). For the EU28 the total cable coverage is 44.7% vs 10.8% rural, while total FTTP coverage is 26.8% urban vs 11.3% rural (June 2017).

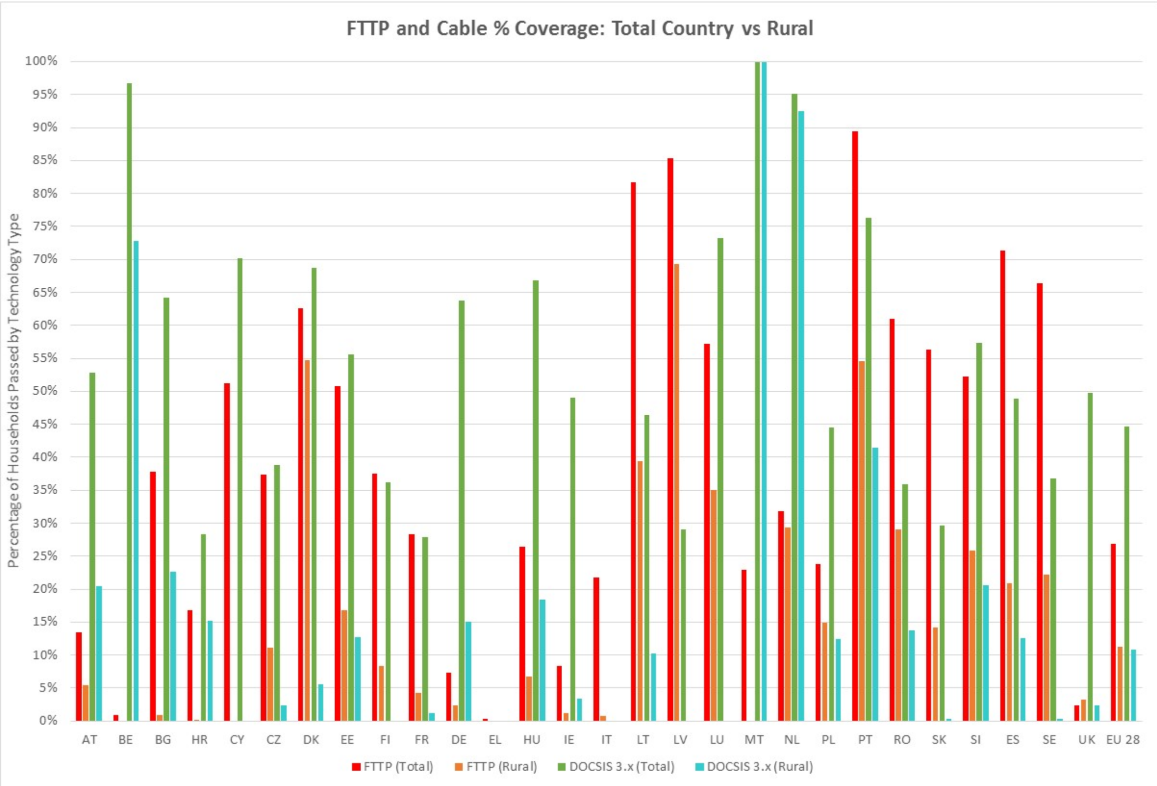


Figure 12: EU countries FTTP and DOCSIS 3.x cable coverage for Total country and rural only (data June 2017)[23]

Urban density is an important driver for reducing cost per premises passed but is not the only factor. There may be difficulties in deploying trenches for new installations in certain heavily built-up cities that can be avoided in less dense urban areas. Several operators with localised (i.e. not national coverage) business models have focused on smaller cities for deployment. An interview with one operator indicated that the big cities in their country have relatively low fibre rollout compared with smaller towns and greenfield sites.

Interviews with operators included several organisations that focused more on rural areas. These noted that proximity to a dark fibre backbone significantly increased likelihood of selection for FTTP projects, as well as the point that while distances of fibre per premises passed were longer, the nature of the groundworks meant that the cost per metre for trenching was usually cheaper in rural areas than urban areas.

[23] Data from: IHS & Point Topic (2018) *Broadband Coverage in Europe 2017*, European Commission.

7.3.2 Wayleaves and administration for deployment of infrastructure

One of the network operators interviewed during the study specified that whilst physical infrastructure accounts for around 60% - 80% of network build, planning and administration accounts for a further 15% of the cost[24]. Analysys Mason (2017)[25] identifies some of the elements of this cost (in the UK) as complying with:

- Noticing and permit schemes.
- Restriction notices that prevent street works within a time period of the previous works.
- Road traffic management.
- Planning permission.

Local property taxes may be added to this list if they apply to fibre networks.

Several of the operators interviewed for the study that undertook more localised projects touched on the administrative processes and the importance of developing a good relationship with municipalities. Some areas that otherwise had promising characteristics for the deployment of fibre would be moved lower in the target list if there was a lack of engagement with the local authorities, since this would likely mean too much administrative burden and delays in getting permits. One operator outside Europe indicated that they would often pay for temporary staff to be added to local planning offices to deal with the amount of administration required for fibre deployment in an area. Therefore, as well as the direct costs involved in getting permits and charges for local traffic disruption, an operator's capacity to deal with the required amount of administration as well as delays in receiving permissions can significantly influence the time taken to rollout a network for an area and the number of concurrent rollouts that can be undertaken.

Some literature[26,27] refers to spillover effects where a first mover incurs time and costs to obtain administrative authorizations, to gather information on existing civil works or paths of way, while a subsequent operator deploying telecoms infrastructure will benefit in terms of reduced time and costs. On the other hand, in an interview for this study with an entrant operator it was noted that the incumbent operators had advantages that they already had pre-existing wayleaves from their current infrastructure while the entrant did not and needed to apply for them, which was particularly problematic for private land.

7.3.3 Access to existing ducts and poles

Building a broadband network from scratch is largely a civil engineering project. An investor needs to dig trenches to lay cables, usually in a duct of some description. In some areas it may need to erect poles from which to hang cables. Estimates vary about the proportion of the cost of network build accounted for by civil infrastructure, but a commonly used estimate is around 60% - 80%[28,29].

Re-use of existing physical infrastructure has the potential to significantly reduce the capital investment cost per premises. For this to be realised, several factors need to be in place:

---

[24] Interviewee response, unable to confirm figure from published documents.

[25] Analysys Mason (2017) *Lowering barriers to telecoms infrastructure deployment*, report for the Broadband Stakeholders Group UK.

[26] Bourreau, M., Cambini, C., & Doğan, P. (2012) "Access pricing, competition, and incentives to migrate from 'old' to 'new' technology". *International Journal of Industrial Organization*, 30(6), 713-723.

[27] Bourreau, M., Cambini, C., & Hoernig, S. (2012) "Ex ante regulation and co-investment in the transition to next generation access". *Telecommunications Policy*, 36(5), 399-406.

[28] FTTH Council Europe (2014) *White Paper: Innovative FTTH Deployment Technologies*.

[29] DCMS (2016) *Broadband Cost Reduction Regulations: Government consultation response*. UK Government Department of Culture Media and Sport.

- **The existence of ducts and poles** – for historical, economic or geographic reasons some existing cables are directly buried in the ground rather than using ducts or poles, so there is no opportunity for re-use.
- **Sufficient quality of ducts and poles and space for new fibre lines** – ducts and poles may exist, at least for part of a network but need to be usable. Where new fibre lines cannot be deployed easily in existing ducts a significant amount of new civil works would be required to repair ducts or deal with blockages. Similarly, poles may have insufficient capacity for more lines. The location and number of problem areas may be unknown, making it difficult to plan work and estimate costs.
- **Fibre on poles**- fibre is deployed on poles in some countries. It has additional challenges compared with underground deployment in terms of security of supply from environmental conditions but strengthened sheath jacketing can reduce these risks.
- **Knowledge of duct routes** – the degree of knowledge of duct routes may differ between countries ranging from fully documented routings to a complete lack of documentation. Some countries have instigated a database of infrastructure to centrally capture information on telecoms and non-telecoms infrastructure.
- **Access rights to existing ducts and poles at fair price** – entrants must have access rights to existing ducts and poles at fair price to be able to gain benefit from them. Incumbents appear reluctant to grant access to any ducts and poles that they control based on competitive advantage, using up finite capacity (space in a duct, loading on a pole) that they may wish to use at a later data, responsibility for maintenance, etc. The 2014 Broadband Cost Reduction Directive (BCRD)[30] sets out the obligation on Member States to ensure telecoms operators can access the physical infrastructure of a variety of utility networks for the purpose of building broadband networks. Further, Art. 72 of the EECC empowers NRAs to place an obligation on an undertaking with SMP to provide access to its existing ducts and poles. As well as these obligations, NRAs must also be active in policing disputes on access and price.
- **Wayleaves** – an access seeker might have the right to use the duct in terms of the incumbent access obligation but have to separately gain the land owner's permission. If this latter step is too difficult or costly it can undermine the effectiveness of the access. This applies to telecoms and non-telecoms assets.
- **Availability of dark fibre** – where available, use of existing dark fibre is an alternative to use of ducts and poles. Several NRAs have stipulated that incumbents must lease dark fibre if duct and pole access is not available. Development of fibre infrastructure in Sweden was led by municipalities investing in a fibre infrastructure which have been made available to ISPs in the form of a wholesale model or as passive infrastructure (i.e. dark fibre).

Interviews with entrant operators and finance companies indicated that the ability to re-use existing ducts and poles was an important factor in business cases. However, some operators assumed in their business cases that they would be building their own trenches because of a lack of quality ducts and poles, or no expectation of being able to access and use them in a timely manner due to delays in permissions, or dependence on an incumbent to repair damaged ducts or to deploy fibre in ducts that they owned. Where physical infrastructure access is available, therefore, it is seen as a bonus rather than essential to their business plan.

Deployment in some areas has been facilitated by use of non-telecoms passive infrastructure such as for electricity supply and, to a lesser extent, sewers. For example, several municipalities in Sweden

[30] European Commission (2014) *DIRECTIVE 2014/61/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communications networks*.

own the electricity distribution system and made use of that to deploy fibre networks. SIRO in Ireland has deployed fibre networks to homes in conjunction with electricity provider ESB using overhead cables and underground ducts.

Interviews with operators identified that for those providing fibre infrastructure to rural and semi-urban areas, access to a dark fibre backbone nearby was an extremely important factor in selecting locations for potential investments and would often create hubs with several sites being developed in an area. Most alternative operators favoured asymmetric duct access obligations but were against symmetric obligations because they did not want to lose control of their ducts. Several were more open to leasing their dark fibre at fair price.

7.3.4 Reducing cost of civil works

Since civil works are a major contributor to capital costs and a key part of the NPV-based business decision, mechanisms to reduce cost of civil works are of considerable interest. Aside from the previously discussed administrative process and passive infrastructure access discussed above, there are other mechanisms that can be used in the cases that civil works are required. These include:

- **Co-investment in civil works** – multiple operators sharing infrastructure works can reduce costs for both. Co-investment is discussed in 7.2.4 below.
- **Overhead and/or building surface/roof-space wiring** – overhead wiring is only used in some EU countries, but generally offers considerably lower costs for fibre deployment where existing ducts are not available. For example, in Latvia some deployment of cable and fibre networks has been achieved through loft spaces and overhead cables connecting roofs, while in Belgium building facades can be used.
- **Alternative trenching/deployment techniques** – alternatives to deep trenching can reduce civil works costs. Micro-trenching, narrow-trenching, shallow-trenching and other proprietary trenching systems, as well as mole-ploughing (for soft terrain) or directional drilling are all methods of laying fibre/ducts at lower cost than traditional trenches.
- **Voluntary labour for trench laying** – some rural installations for fibre have reduced the cost of deployment by getting landowners and cooperatives to dig trenches and lay fibre micro ducts themselves through private land.

7.3.5 Access to internal building wiring

The access to internal building wiring is regarded as an important consideration when deploying fibre to multi-dwelling units (MDUs). As discussed in section 7.3.1 on urban density, MDUs provide the opportunity to reach a larger number of households for a particular length of laid fibre but connections to households and business within the premises is usually dependent of internal wiring. An inability to gain access to internal wiring without the permission of the building landlord can mean too many buildings having to be missed out and so reduces the number of customers that can be connected, reducing the revenue side of the NPV business case. Even in single dwelling units, uniformity of connection to internal wiring makes switching infrastructure providers easier and cheaper and so promotes effective infrastructure competition.

The BCRD lays down obligations for member states regarding in-building wiring for new and refurbished building. According to WIK Consult (2017)[31], effective access regulations for in-building wiring is essential for achieving infrastructure competition. France, Spain and Portugal, where some

[31] WIK Consult (2017) *Best practice for passive infrastructure access*, report for Vodafone. The WIK study for the Commission on the BCRD is missing, WIK (2018) Study on the implementation and monitoring of measures under Directive 61/2014 – Cost Reduction Directive.

degree of infrastructure competition has been achieved, all have symmetric legislation that predates the BCRD.

Almost all operators and investors interviewed supported the principle of symmetric legislation on access to internal wiring (as opposed to no regulation) with fair pricing for re-use of internal wiring. Gaining access to buildings was important for all operators since access was a bottleneck. One operator notes that they would not want use of existing wiring to be mandated if it were found to be inadequate or overly complicated, while another operator raised concerns regarding technology specifications being imposed by national regulations and did not feel that cost sharing was fair.

7.4 Finance and co-investment

Operators require finance to invest in the deployment of VHCN infrastructure. This can be through retained earnings but in most cases significant external finance will be required. Capital can be raised on the bond market or on the debt market. Equity investors can buy shares in companies (usually using a portfolio to spread risks) and companies can raise capital by issuing new shares.

External Investors, regardless of the mechanism, require a return on their investment. Even where funds come from retained earnings, shareholders will still have criteria for return on investment. The expected return (threshold r in the NPV calculation) and the time horizon for payback (T) will depend on the nature of the investment, type of operator and the expectations of investors.

Figure 13 shows factors that impact the cost of finance in terms of impacts on the threshold (discounting factor) and the payback period. In terms of the increasing NPV value, a lower threshold *(hence red arrow to indicate a higher value lowers NPV)* and a longer payback period *(hence green arrow)* will both increase the discounted value of net cash flow.

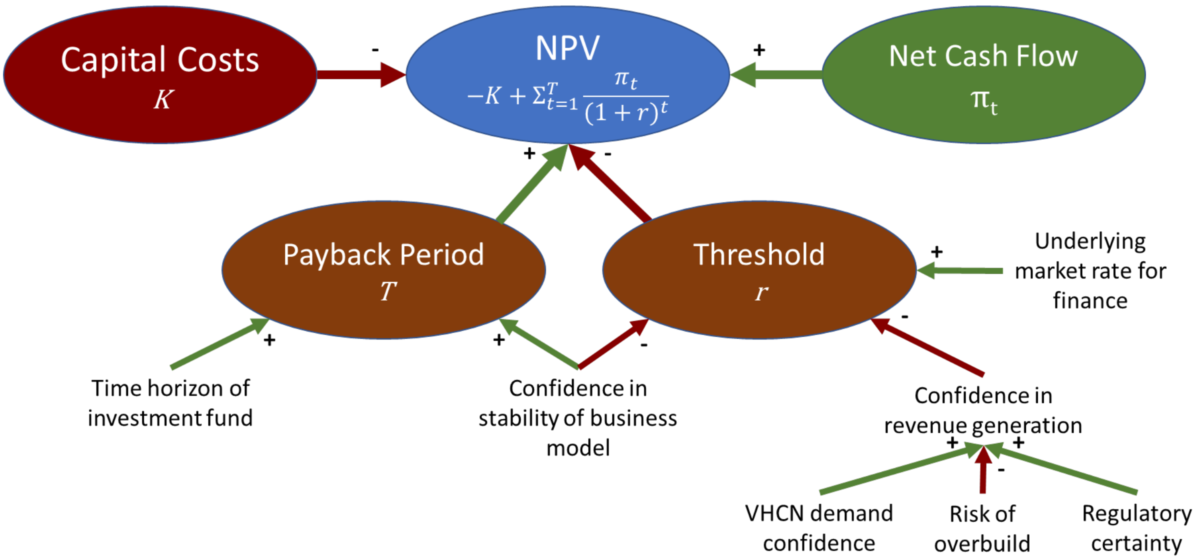


Figure 13: Cost of finance and payback period impact on the NPV calculation

There will be an underlying cost of finance across world and national finance markets related to national bank interest rates and the state of the world and national economies. There will also be a view of opportunities and underlying risk for the telecoms industry in relation to other industries. These will affect the underlying market rate for finance. Added to this are more project related and operator related considerations for finance. The fundamental parts of the capital costs and net cash flow will determine in large part whether a project is attractive or not for finance, but the degree of risk and uncertainty will affect the type and cost of finance available.

7.4.1 Telecoms investment funds

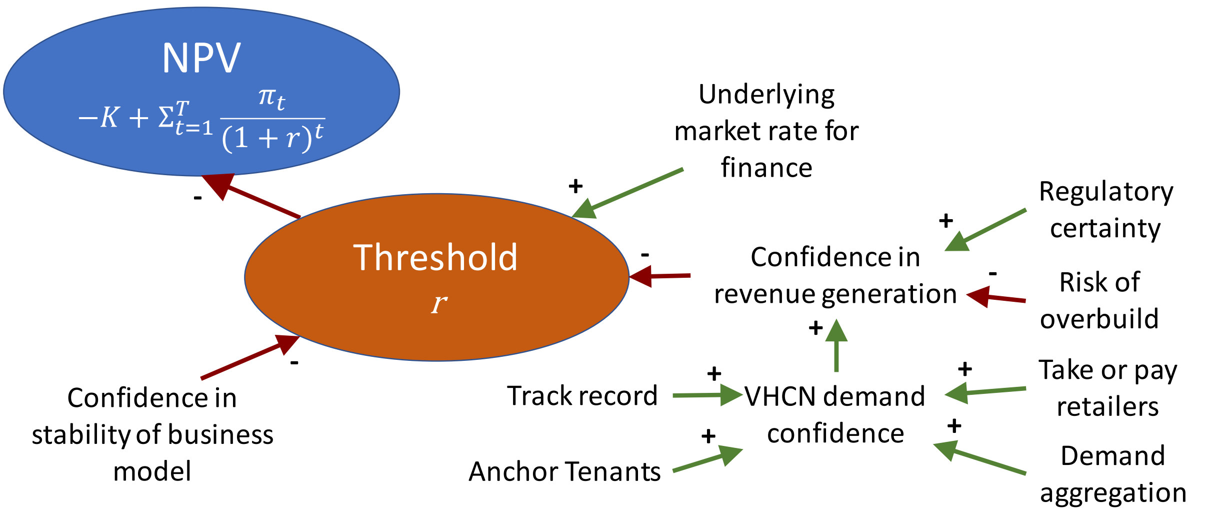
Different types of investors and investment funds are willing to accept different degrees or risk and time horizons for investment. Interviews with operators and investors provided a consistent message that the type of funding available differs considerably between a wholesale only infrastructure operator and a multinational telecoms retail operator. We were told "patient finance" (investment funds looking for long-term stable returns) finds telecoms infrastructure provided on a wholesale only basis an attractive low risk investment, while investment in larger more complex retail operations include a number of threats to share price including the success or failure of takeovers and mergers.

Della Croce (2012)[32] states "*Infrastructure investments are attractive to institutional investors such as pension funds as they can assist with liability driven investments and provide duration hedging. Infrastructure projects are long term investments that could match the long duration of pension liabilities*". Barclays (2018)[33] identifies the opportunities for wholesale-only infrastructure investment where the market conditions are appropriate. They see opportunities for alternative wholesale infrastructure operators in markets where incumbents have underdeveloped FTTP rollouts and there is a lack of infrastructure competition. An operator must be able to have efficient CAPEX per home passed and have secured established retail operators to operate on the network. Barclays use Open Fiber in Italy as an example where this model can operate effectively and attract significant levels of finance.

For retail operators seeking to achieve national and international coverage, support to investment by wholesale operators is an attractive proposition when those operators can attract finance at considerably better rates and timescales than the retail operator be able to achieve. This phenomenon can be seen with Open Fiber[33] in Italy and CityFibre[34] in the UK.

7.4.2 Confidence in revenue generation

The more confident investors are of revenue generation, the lower their risk and so the lower the cost of capital. Drivers that affect revenue generation are discussed in section 7.5, but factors that impact the degree of risk for revenue generation, by increasing the likelihood of a core level of revenue at an early stage of the project or by creating a threat to future revenue are shown in Figure 14 and described below.



[32] Della Croce, R. (2012) *Trends in Large Pension Fund Investment in Infrastructure*, OECD Working Papers on Finance, Insurance and Private Pensions, No.29, OECD Publishing.
[33] Barclays (2018) *The rise of the wholesale-only model*, European Telecom Service Equity Report.
[34] Bradley O. (2018) *Why investing in a 'full fibre utility' for Britain has become so attractive,* retrieved October 16 2019 from https://www.cityfibre.com/news/investing-full-fibre-utility-britain-become-attractive.

Figure 14: Drivers that increase confidence in revenue generation

- **Demand aggregation** – measures that increase the likelihood of high early penetration rates will significantly reduce risk and improve the NPV calculation.
- **Take-or-pay retailers** – for wholesale only operators the presence of retailers offering guaranteed revenue on a take-or-pay basis. This type of arrangement has been used in strategic partnerships between wholesale infrastructure providers and major telecoms retailers.
- **Anchor tenants** – the presence of anchor tenants for an area can bring guaranteed revenues which reduces the risk for the business case. However, expanding from one or a few anchor tenants to all premises in an area can still represent a major delta in capital costs that must be recovered through revenue.
- **Risk of overbuild** – existing competitor infrastructures are known and can be factored in on revenue calculations, but potential competition creates a degree of risk to revenues. Even where no VHCN competitor exist a reasonable likelihood of overbuild by a competitor can significantly diminish the business case. This can also create a first to market strategy response if operators believe they will be able to defend their subscriber base.
- **Track record** – track record for an operator's previous VHCN infrastructure projects will reduce risk if it confirms the assumptions used in the business case and the ability to secure subscribers. This can lead to a pattern of small investments to test the market for VHCN before committing to a larger more widespread investment.
- **Regulatory certainty** – longer-term revenue projections can be affected by changes in regulations, so regulatory certainty can increase confidence in projections. Greater regulatory certainty means that underlying assumptions for net revenue more likely to remain true in the business case. This is dealt with in more detail in section 7.9.11.
- **Regulated WACC** – The regulated WACC (Weighted Average Cost of Capital, see section 7.9.7.3) is set by the regulator in line with the principles of Art. 13 AD and Art. 74 EECC as well as taking into account the WACC Notice of the Commission published on 7th November 2019.The WACC feeds through into prices and if the price allowed by the regulator is too low, it would mean that the regulated company could not generate the return needed on the project to make the NPV positive. This could result in the investment not taking place.

7.4.3 Co-investment

Co-investment by rival operators may be used to reduce capital costs. A risk in the business case is that capital investment is made but that a response by a competitor to overbuild reduces revenues to the point that the investment is unprofitable and performs poorly against other options. Co-investment will usually confer advantages of lowering capital costs by sharing them, at the expense of reducing revenues through retail competition. Risk is reduced through the smaller capital investment required while revenue, though lower, will be more predictable.

Co-investment can take several forms, including (with examples from BRG, 2017[35] unless otherwise specified):

- **Sharing of network rollout costs** – This type of co-investment retains infrastructure competition among two or more operators but has the potential to significantly reduce capital costs for network rollout. This may take several different forms: two operators could agree to share civil engineering works to lay multiple fibres and maintain completely separate infrastructures, or

[35] BRG (2017) *Co-Investment and Commercial Offers*, report for Vodafone.

sharing of costs for shared network infrastructure for the last drop (e.g. co-investment approach in France with share of either building access or concentration point aggregating 100 units in very dense areas, or connection points for 1000 households in less dense areas[36]).

- **Network sharing with joint ownership** – two or more operators may co-invest in a single network and have shared access to it. In some cases, the operators will use a separate investment vehicle with a share of ownership. This reduces infrastructure competition between the operators but maintains retail competition and may lead to VHCN deployment where two competing networks would otherwise be uneconomic (e.g. Telecom Italia and Fastweb).
- **Network sharing single ownership** – two operators may have an agreement not to overbuild and to choose to invest in infrastructure in different areas but allow access to each other's networks. This reduces infrastructure competition between the operators but maintains retail competition and may lead to quicker and more widespread VHCN deployment across a country (e.g. Telefónica and Jazztel).
- **Take or Pay contracts (not strictly a co-investment but rather a co-business case)** – the business case of a wholesale infrastructure operator is boosted by guaranteed revenue from a client retail operator, possibly with exclusive access for a period of time. While not strictly a co-investment (only one operator is investing, and the EECC specifically excludes this as a type of co-investment) this type of agreement significantly strengthens the business case of the infrastructure operator by guaranteeing a minimum revenue stream, while giving the retail operator VHCN access to the region. Potentially the infrastructure operator can get cheaper "patient" finance than the retail operator could so it can provide a significantly cheaper route to VHCN for the retail operator than building their own infrastructure. (e.g. Open Fiber & Vodafone).

The EECC promotes the idea of co-investment as a means of reducing uncertainty and therefore the cost of capital. It states: "*Due to current uncertainty regarding the rate of materialization of demand for very high capacity broadband services as well as general economies of scale and density, co-investment agreements offer significant benefits in terms of pooling of costs and risks, enabling smaller-scale undertakings to invest on economically rational terms and thus promoting sustainable, long-term competition, including in areas where infrastructure-based competition might not be efficient.*"

As well as entering into co-investment arrangements completely voluntarily to spread risk and lower costs, regulation may also encourage or enforce co-investment. In Portugal, where the wholesale obligation to allow access to FTTP networks (above copper speeds) was not imposed, co-investment became the feasible route for some alternative operators that previously were retail only to gain access to the market and retain market share (more recently non-obligated wholesale access has become available to other operators). In less densely populated regions of France there is a regulatory requirement for an operator to announce the intention to roll-out an FTTP network, and allow other operators to co-invest in 5% allotments (it is also possible to invest after installation) in order to gain access to the infrastructure (see Aimene, Lebourges & Liang, 2018[37]). In Spain's non-competitive areas, co-investment agreements were struck immediately on regulatory imposition of access to FTTP in 2016.

7.4.4 State and local government aid

State aid consists of some level of state subsidy that is paid directly or indirectly (e.g. via subsidies paid to consumers) to infrastructure operators to pay all or part of the costs for infrastructure deployment

[36] WIK (2017) *Co-investment and incentive-based regulation*, preliminary report presented at 28th European ITS conference, Passau, July/August 2017.

[37] Aimene, L., Lebourges, M., & Liang, J. (2018). Estimating the impact of co-investment in fiber to the home coverage. Mimeo

and/or operation. The state aid is usually in the form of finance that does not need to be paid back, but in a few cases comprises of soft loans with generous repayment terms and conditions. Any state aid must be granted within the rules set out by the European Union to prevent a distortion of competition.

Mölleryd (2015) [38] summarises the European Union rules for state aid and conditions in which municipality involvement would not be considered state aid. An area classified as "White", with no high-speed broadband coverage and no likelihood of commercial investment in the next three years, is compatible with state aid. The European Commission has cleared numerous cases involving state aid for the deployment of high-speed networks in locations that are classified as white areas.

Municipality and other local community involvement in deploying or supporting VHCN infrastructure would not be regarded as state aid in the form of subsidies if the deployment is being financed on a commercial basis, or if the local authority is procuring services on a commercial basis. A municipality or local authority can also act as an anchor tenant for provision of VHCN infrastructure (see 7.5.2).

Feasey, Bourreau & Nicolle (2018)[39] note conditions under the 2014 General Block Exemption Regulation which avoid the need to notify the European Commission under state aid rules, otherwise prior notification is required. In either case the network receiving state aid must provide wholesale access.

In the NPV business case representation, state aid can be treated as a source of finance for capital investment with a low threshold term. State aid in the form of a full or partial grant can be best represented as shown in Figure 15, where the full capital investment K reflects the value of the assets being created, while the grant is a source of revenue at time period 0 that offsets all or part of the capital investment, significantly improving the NPV business case.

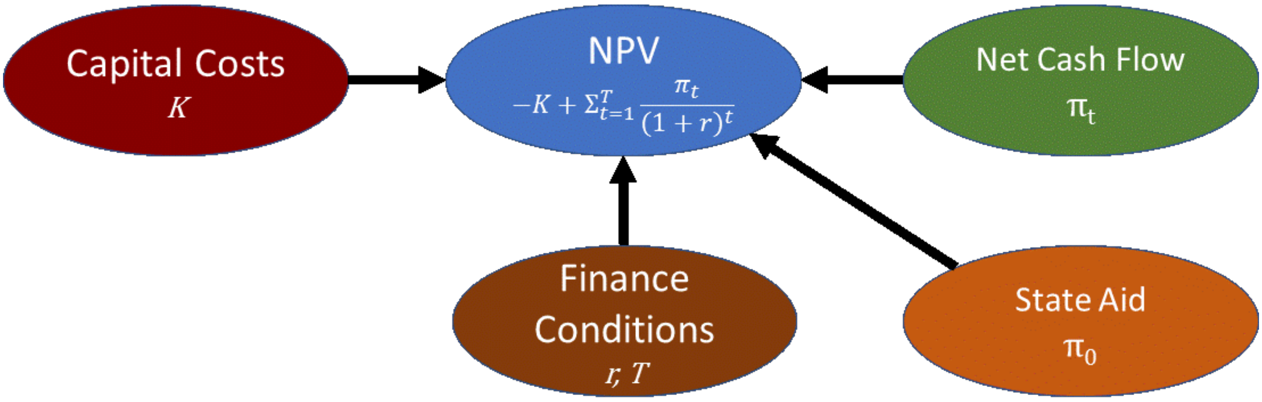


Figure 15: Representing state aid in the NPV business case

Another format for state aid is the use of voucher schemes and tax relief for consumers. These are primarily aimed at boosting demand and their impacts will be described in section 7.5.2. The impact on capital costs is when the voucher schemes or tax relief are used to partly offset connection costs where, like grants, they provide a source of revenue to cover at least part of the capital costs for connection.

[38] Mölleryd, B. (2015), "Development of High-speed Networks and the Role of Municipal Networks", OECD Science, Technology and Industry Policy Papers, No. 26, OECD Publishing, Paris.
[39] Feasey, R., Bourreau, M., & Nicolle, A. (2018) "State Aid for Broadband Infrastructure in Europe: Assessment and Policy Recommendations", Centre on Regulation in Europe.

7.5 Net Cash Flow

The positive element of the NPV business case calculation is net cash flow. This is effectively the EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) from operating the VHCN. Sufficient EBITDA is required over the horizon of the NPV calculation to exceed the capital costs with increasing discounting of the value of future EBITDA.

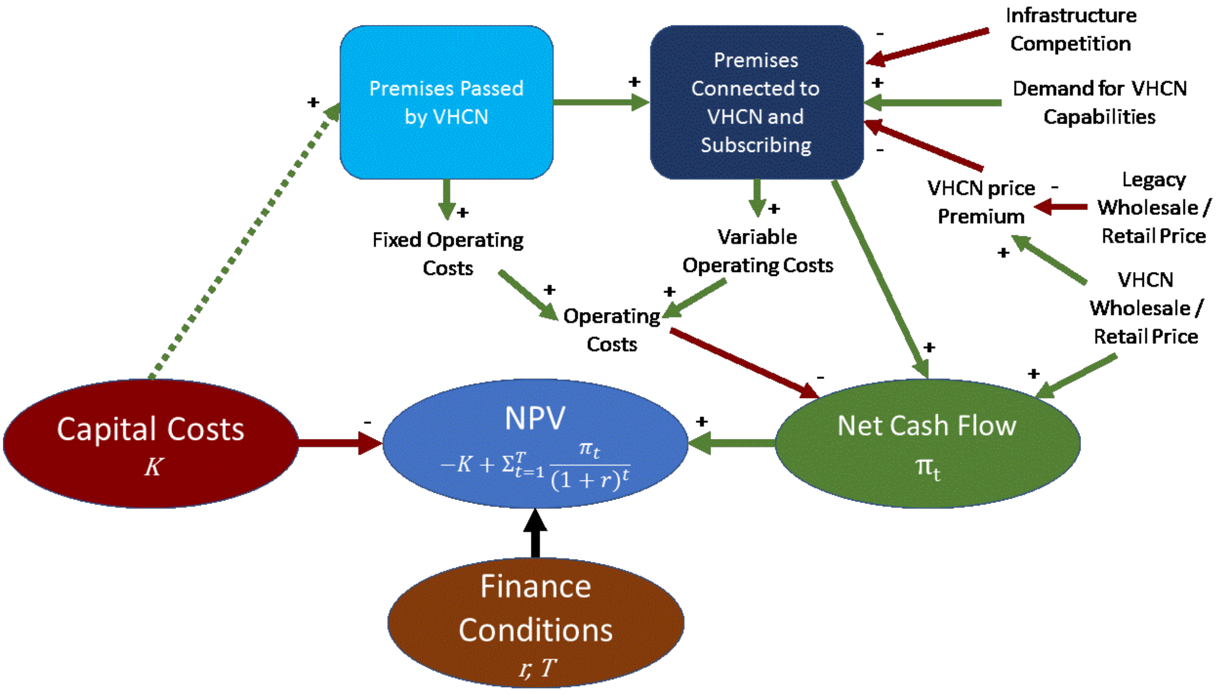


Figure 16: NPV calculation showing key constituents of Net Cash Flow

As shown in Figure 16 the Net Cash Flow consists of revenue minus operating costs. Several factors impact revenue and operating costs:

- Revenue is dependent on the number of subscribers and the revenue per subscriber based on wholesale price (for subscribers via a retail operator) or retail income (via direct retail subscribers).
  - Subscribers can only be gained if their premises are passed by the VHCN. Capital spend will increase the footprint of the network but higher capital costs per property passed will reduce the number of properties passed per €M spent (see section 7.3).
  - The amount of demand for VHCN performance will increase the percentage of subscribers gained for properties passed. Demand for performance is a distribution ranging from people who do not use the internet or smart devices to people requiring very high capacity and low latency. The shape of the distribution determines the demand for VHCN and the extent to which other inferior technologies (e.g. VSDL) are enough for needs.
  - In most locations there will be infrastructure competition with at least a legacy copper network (ADSL and/or VDSL). There may also be competition with other VHCNs in the form of cable and/or FTTP.
  - Infrastructure competition will reduce the degree to which a particular network can gain subscribers. The relative success of the network will depend on the ability to meet customer needs compared with other available networks, relative pricing (e.g. price premium versus a legacy network) and the attractiveness of multi-play offerings.
  - Revenue gained per subscriber will be depend on the subscription price (wholesale or direct retail as appropriate).

- Revenue may also be gained for rental from other infrastructures using the network owner's ducts or poles, in-building wiring and dark fibre.
- Operating costs will cover non-capital costs related to operating the network. Some of these costs will be incurred for the network regardless of the number of subscribers and other costs will be related to the number of subscribers.

7.5.1 Operating costs

Operating costs have a negative impact on NPV business case cash flow. There are several elements to operating costs, as shown in Figure 17 with key elements described further below.

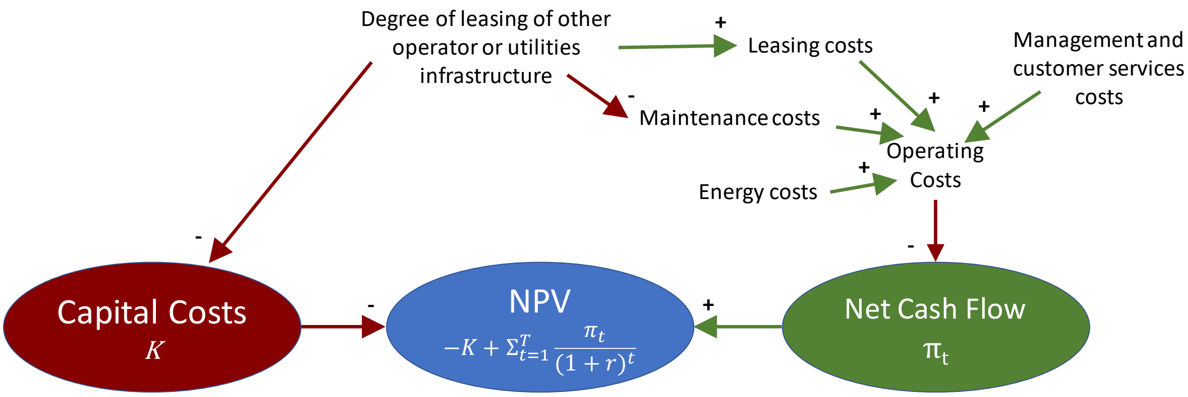


Figure 17: Operating costs

- **Leasing costs** – leasing dark fibre, ducts/poles and in-building wiring leased from other operators will reduce capex at the expense of higher opex. In addition, there may be leasing and other costs related to buildings for exchanges. WIK Consult (2018)[40] suggests that fibre requires considerably less floorspace than copper in exchanges, providing an opportunity to reduce the footprint of exchanges. Leasing costs for the core network will be incurred regardless of the number of connections, while leasing of in-building wiring is only likely to be incurred for current subscribers.
- **Energy costs** – active equipment requires energy in an exchange and at switching points/ connection nodes. WIK Consult (2019) suggests that FTTH can consume 40-60% less energy than a copper network. However, FTTP networks are unpowered to the customer so, depending on regulations, operators may need to provide power backups for vulnerable customers.
- **Maintenance costs** – fibre networks are considered more reliable than copper networks. WIK Consult (2018) reference Verizon, US reporting 70-80% better reliability and an overall maintenance cost saving of 40-60%, however it does not make clear the extent to which the impact of the type of equipment vs replacing old network new equipment impacts the reliability.
- **Management and customer services costs** – these are likely to be like copper networks, though fibre networks are likely to have higher reliability and so require less customer service costs related to maintenance calls.

Incumbent operators and operators using copper LLU may be faced with a position where they are incurring operating costs from running both a copper and fibre network in parallel. In particular, the operating cost per customer for a copper network will increase as customers migrate to a fibre network and the market share for the copper network falls. It is therefore in the interest of an incumbent operator to shut down the copper network when it is able. Copper switch-off has started in Estonia, Spain and Sweden. Discussions with NRAs suggested that copper switch-off was generally regarded as a commercial decision by operators but that certain conditions would need to be in place

[40] WIK Consult (2018) *Copper switch-off: A European benchmark*, study for FTTH Council Europe.

for a copper exchange to be switched off in an area, including notice periods and plans for migrating existing copper customers. In addition, economies of scale can be realised for operating costs/subscriber on the fibre network a, s the subscriber base grows.

7.5.2 Demand

Demand for VHCN can be related to a country's "digital way of life", i.e. a propensity to require data bandwidth. Drivers for a digital way of life can be underlying global factors such as development of technology, and endogenous drivers where local conditions might encourage demand. Some of these underlying and endogenous drivers of demand are shown in Figure 18 and described below. Demand for VHCN access will also depend on alternatives available. If copper networks can only deliver low bandwidths (due to long lines), demand for VHCN can be expected to be higher compared to cases where the copper network has been upgraded to FTTC with relatively short lengths of the remaining copper sub-loops.

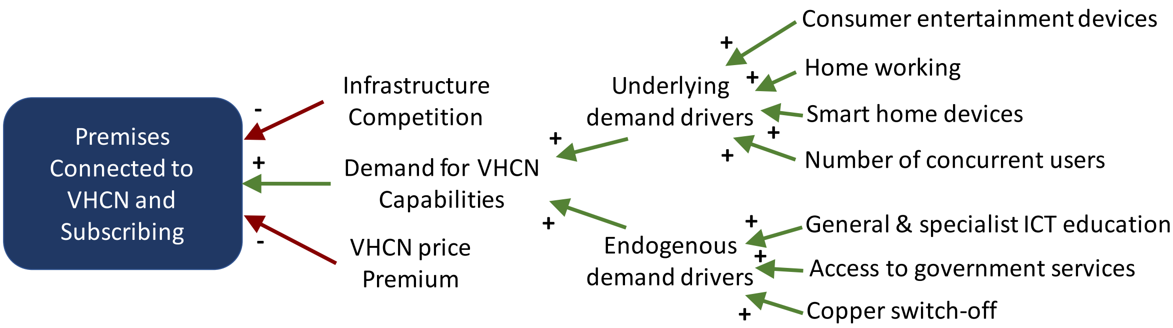


Figure 18: Underlying (global) and endogenous drivers of demand for VHCN

7.5.2.1 Underlying demand drivers for VHCN

Underlying demand can be a worldwide shift in technologies and a digital way of life that requires higher bandwidth and lower latency/higher reliability. This global trend can be an external pressure for increased demand regardless of the level of broadband infrastructure investment within a country or region.

Underlying demand in terms of increased download and upload speeds, and lower latency is expected to continue to build over time, along with requirements for reliability as real time data becomes more important. This is due to the types of technology used in homes and business and the data demands of applications.

Cisco (2019)[41] shows global data usage estimates for 2017 through to 2022, as well as providing some historical contexts for data usage. Figure 19 shows global internet traffic for selected years between 1992 and 2017 with a forecast for 2022. The forecast is internet traffic to more than triple in 5 years from 2017.

[41] Cisco (2019) "Cisco Visual Networking Index: Forecast and Trends, 2017–2022", Cisco white paper.

Year	Global internet traffic
1992	100 GB per day
1997	100 GB per hour
2002	100 GB per second
2007	2,000 GB per second
2017	46,600 GB per second
2022 (Forecast)	150,700 GB per second

Figure 19: Global internet traffic between 1992 and 2017 with forecast for 2022, includes mobile data (data: Cisco 2019)

The historical increases in global internet traffic represent a combination of factors: increased number of users of mobile and fixed data, increased data usage per household and business for existing users of internet data. This represents an increase in demand in terms of number of households wanting broadband connections, and increased demand for higher capacity broadband connections.

Potential near future drivers for increased demand for fixed broadband data capacity and lower latency, include:

- Increased video streaming content available in 4K or 8K format.
- Virtual reality headsets streaming video content.
- Increased use of home working. Greater use of cloud servers for both home and office workers.
- Greater concurrent data usage for video streaming and gaming.
- Increased use of home smart devices, although these do not necessarily require very much capacity individually, they increase concurrent data usage.

Figure 20 shows Cisco's estimates for the bandwidth requirements of different video technologies. The exploded slices of the chart indicate today's common technologies, with the other technologies listed in clockwise order of time in future to become mainstream.

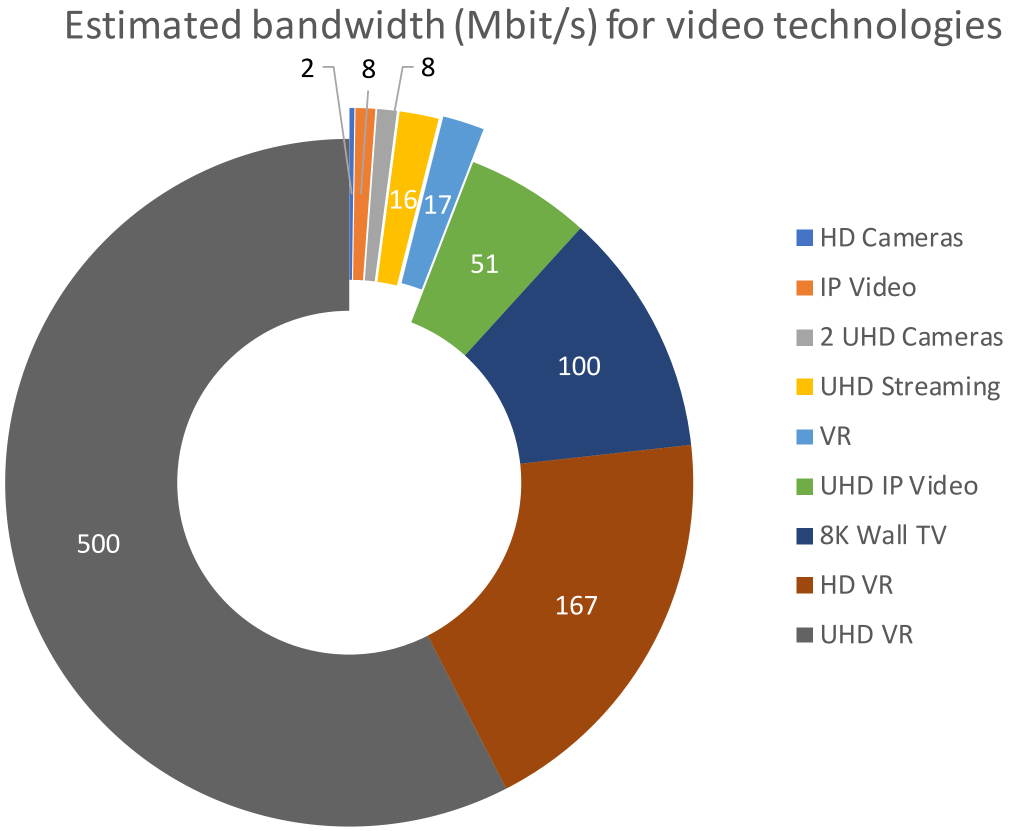


Figure 20: Typical bandwidth for video technologies, common current technologies exploded (data source: Cisco 2019)

Frontier (2017)[42] examines, as part of the study, future demand for broadband bandwidth under moderate evolution and ambition innovation scenarios. They identify several categories of use:

- Audio Visual goods and services – HD and expanded use of 4K representing standard use, with a smaller percentage of people using 8K resolution. Ambitious innovation includes 3D light field TV or holographic transmissions.
- Virtual Reality (VR) and Augmented Reality (AR) video streaming for video transmission – a primary early driver for VR and AR will be the use of the technologies for gaming, but wider application for video entertainment and other applications can also be a significant in the longer term. The moderate vs ambitious scenarios vary in terms of the resolution of devices and degree of adoption, ranging from current games console adoption rates to more widespread applications beyond gaming.
- Small and home office – upload of large documents and other media, analysis of "big data" and video editing. The view is that only 3% to 5% of workers require access to very large data files. The difference between the moderate and ambitious scenarios is related to the size of the files. The benefit from VHCNs would be much lower download and upload times.
- Smart home – monitoring and control devices, though only security monitoring (recording to cloud) and two-way video communication are seen as major uses of bandwidth. The moderate vs ambitious scenarios are related to adoption rates and device resolutions, as well as the number of devices concurrently in use in a household. Reliability of service is seen as important for these technologies.

[42] Frontier (2017) "Future benefits of broadband networks", Frontier Economics Ltd report for UK National Infrastructure Commission.

- Healthcare – telehealth and telecare services would use video-based remote healthcare consultations, real-time vital signs monitoring, home monitoring and social network / online support communities. This could include earlier discharge of patients from hospital with monitors and video-links. The ambitious scenario has higher adoption and higher resolutions.
- Education – online education including video as well as use of VR or AR. This can include asynchronous (accessible any time) and synchronous (scheduled times for multiple participants). The difference between moderate and ambition adoption lies in the degree of use of high bandwidth technology to deliver education and the proportion of people using distance learning that would make use of high bandwidth technology.

Logically one can see a link between income and the ownership of the types of technologies that would require VHCN capabilities as well as willingness to pay a price premium for VHCN. Also, looking at the types of technology identified by Frontier (2017) as well as concurrency of use, it is highly plausible that there is a generational effect, including households with children at school having a higher likelihood for VHCN subscriptions.

7.5.2.2 Endogenous demand drivers

As well as exogenous global trends in demand growth for broadband capability, there is also recognition of the potential for endogenous demand growth, where having wide access to infrastructure that is capable of very high capacity will increase both the demand and availability for applications that make use of that higher capacity. Availability of applications that requires higher bandwidth (such as 4K TV) in a local language will logically be influenced by availability and adoption of technology that can make use of that content.

The Frontier (2017) study notes that there is not necessarily a high correlation between high coverage of VHCNs in a country and high subscription rates for broadband connections (noting Japan as an example with high coverage but average broadband subscription rates).

Nevertheless, there are differences in adoption rates between countries with similar economic conditions that suggests some country specific effects. This may be expressed as a "digital way of life" which represents how engaged a population is with online interaction and application, which varies between countries. Sweden is viewed as a country with a "digital way of life"[43] and was an early adopter of FTTP through investment by municipalities, and a willingness to provide online access to services. Sweden has high availability of VHCN and high adoption rates of 100+ Mbit/s connections.

While it is difficult to deny the logic of endogenous demand being enabled by access to adequate broadband connections, it does not necessarily require VHCN type capabilities. There are likely to be several factors involved in encouraging a digital way of life, including state and local government programs for education and access to services.

In conclusion, endogenous demand drivers almost certainly exist, but there is little or no empirical evidence on the degree of correlation with VHCN availability, and there are likely to be several other factors that affect digital way of life and VHCN adoption rates. Therefore, despite a lack of empirical evidence it is worth recognising influences of endogenous demand drivers and identifying actions that can encourage these.

States and local communities can take actions that increase the "digital way of life" for communities. Part of this is through education, starting in schools, which will tend to diffuse into households and grow over time as IT educated children grow into adulthood and start families. Adult education can also help to spread aware and skills in older generations, and new technology will bring more of a connected way of life into people homes with a lower technical hurdle (e.g. smart devices). On the application side, states and local government can increase a "digital way of life" by making services

[43] OECD (2018) *Going digital in Sweden OECD reviews of digital transformation*.

more convenient to access online. At the simplest level this can be via websites, but more advanced applications through video, real time data monitoring and in the future, Virtual Reality, could create the ability to interact with services in a way that currently requires physical travel.

7.5.2.3 Managing demand and reducing revenue risk

As well as underlying and endogenous demand drivers for VHCN capabilities that will influence subscription rates for VHCNs, there are also actions that individual operators can take to increase subscription rates for their individual services. For an individual infrastructure operator subscription rates through direct retail or via wholesale provision of infrastructure are key to the revenue side of the NPV decision model. In its simplest terms, no subscription means no revenue from a household or business.

The Florence School of Regulation (2011)[44] found four statistically significant demand factors that influenced broadband adoption (note that this was not specifically VHCN adoption), which were:

- Demand aggregation policies (these are policies that require households to commit to purchasing broadband connections within a given timescale).
- Direct subsidies.
- Promotion through e-government services.
- Promotion of private demand and business, which is stated as other incentives for adoption (at a lower significance).

These and other demand drivers have been referenced by interviews with operators, NRAs and have been observed in action in some countries. These are addressed below, with specific emphasis on VHCN adoption, although some evidence of their use is extrapolated from other NGA investment such as for VDSL (FTTC):

- **Demand aggregation** –mechanisms that encourage people in a particular area to commit to subscribing to a broadband network if made available in their area ensuring a certain minimum level of demand and revenue, reducing the risk for the business case. It is also a useful indicator for the level of demand for VHCN in an area. Analysys Mason (2008)[45] notes that demand aggregation schemes have been used in the UK by the incumbent BT in prioritising its rollout of ADSL, and by smaller entrant operators in UK, Netherlands and Norway. Interviews with entrant operators also indicate that demand aggregation is a method that is used as part of developing a business case for assessing demand and helping to place an area within a priority list for investment in VHCN.

- **Local community support** – slightly less formal than demand aggregation is a determination of local community support, which several entrant operators highlighted during interviews. Support from municipal authorities for investment in VHCN has both supply-side regarding wayleaves (see section 7.3.2) and demand-side advantages in terms of advocacy. Promotion and support by a local council or mayor, especially in smaller communities can boost demand through written and word of mouth advocacy leading to higher adoption rates. Analysys Mason (2008) give an example of Eindhoven where local ambassadors from the community were to explain the benefits.

- **Consumer subsidies, tax breaks and price or service offers** – demand can be boosted by reducing the costs to the consumer of connection or subscriptions. Several different models of tax breaks and subsidies have been used to boost demand. Analysys Mason (2008) reports that in Sweden where connection charges to consumers are high compared with the European average,

[44] Florence School of Regulation (2011) *Broadband diffusion: drivers and policies*, study for IRG.
[45] Analysys Mason (2008) *Models for efficient and effective public sector interventions in next-generation broadband access networks*, final report for the Broadband Stakeholder Group

substantial tax relief could be gained for connections. Analysis Mason (2008) reports rural subsidies being used in Nuenen, Netherlands to provide one free year for subscribers and achieved 97% subscription rates, dropping to 85% after the first year. Bourreau, Feasey and Hoernig (2017)[46] suggest that tax relief and subsidies should be time limited in order to encourage early adoption of VHCN. It is also common practice for retail operators to offer discounts for a period of time to new customers or for broadband packages upgrades which can used to attract adoption of VHCN through price reductions. While this reduces revenue per subscriber in the short term, the operator gains through higher adoption rates.

- **Contract durations** – longer contract durations can reduce churn rates and give a period of guaranteed revenue from VHCN subscribers before they can switch to an alternative VHCN provider or switch to a different technology. This can be particularly important for first-mover VHCN providers gaining early market share to ensure that they can maintain that revenue for a known period in the face of second-mover VHCN competition. EU rules state that a maximum contract length can be 24 months for broadband, while Italy for example, does not allow any contract lock-in so consumers are free to change providers at any time.
- **Anchor tenants** – installation of VHCN for a client in an area, often a local authority, can be used as a basis for guaranteed revenue from which to strengthen a business case for expanding the VHCN to other business and household premises. A local authority anchor tenant usually represents a good working relationship so there are several non-financial advantages, as described for local community support.
- **Anchor retailers** – wholesale operators can strengthen their business case via a take-or-pay arrangement with a retail operator, effectively sharing the risk of the investment between infrastructure provider and retailer. A wholesale-only operator with a less complex business model than a retail operator may have access to "patient capital" requiring a lower return on capital. Vodafone (as retailer) and CityFibre (as wholesale-only operator) announced such an arrangement on November 2017[47].
- **E-government services and education** –government actions on building a digital way of life can impact underlying demand for broadband and filter through to increased demand for VHCN. Greater availability of online government services may encourage more people to adopt broadband which gets them on the ladder and may eventually result in adopting VHCN. Bourreau, Feasey and Hoernig (2017) suggest that opportunities to try ultra-fast broadband (i.e. VHCN) in libraries and schools may encourage people to adopt it in their own households when they realise the speed benefits over their existing broadband connections.
- **Copper switch-off** – Certainly, copper switch-off would force adoption of VHCN or some other substitute for cooper telephony/broadband (e.g. mobile). This could be considered an end-state action that can only occur when there is full VHCN coverage of an area, i.e. when significant investment in VHCN has occurred.

7.5.3 Overbuild and competition

Revenue from a VHCN is based on subscription rates (either direct retail or wholesale depending on the relationship between the infrastructure operator and the end-customer). Even if there is consumer demand for VHCN, overbuild of VHCN infrastructure can split that demand between infrastructure operators. In addition, the capabilities of non-VHCNs and their ability to meet household and business needs will also impact subscription rates for a particular VHCN. As well as

[46] Bourreau, M., Feasey, R, & Hoernig, S. (2017) *Demand-Side Policies to Accelerate the Transition to Ultrafast Broadband*, CERRE Project Report.

[47] See https://mediacentre.vodafone.co.uk/news/vodafone-cityfibre-bring-gigabit-speed-fibre-uk/

capturing customers from other technologies (see section 7.6 on fixed network technologies, and section 7.8 on 5G and fixed wireless access), churn can occur between infrastructure operators and technologies, as shown in Figure 21.

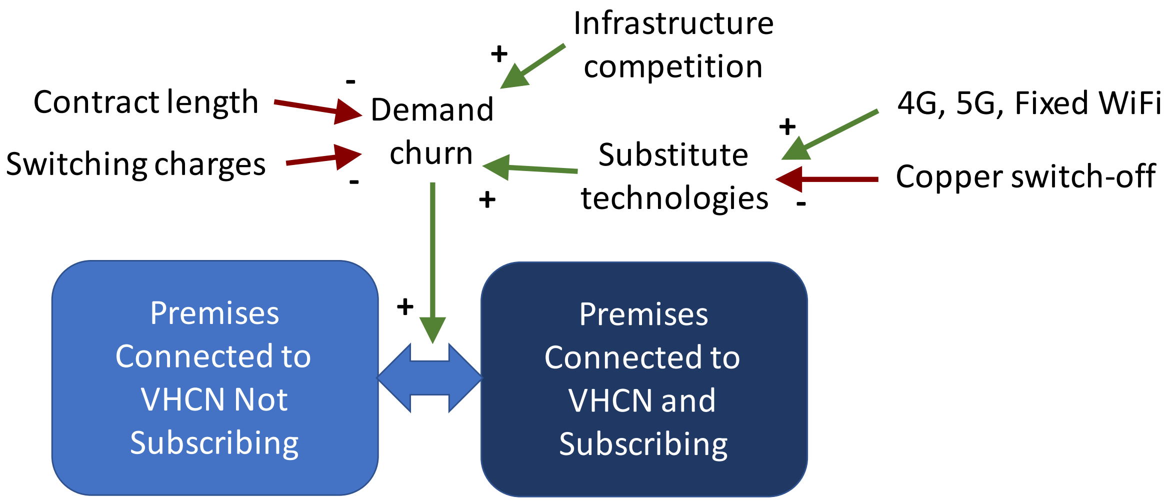


Figure 21: Churn between infrastructure operators and technologies

The share of demand that one VHCN can capture will depend on:

- The number of VHCN infrastructures available at a premise. Overbuild of VHCN creates more choices of infrastructure for consumers and more competition between networks. For an NPV business case, overbuild will split VHCN demand between networks and will reduce revenue. Retail competition between VHCNs for customers may also have a downward impact of prices and margins, ultimately prices might be expected to converge.
- Competition with non-VHCN will reduce demand if the non-VHCN has capabilities that meet the needs of a proportion of consumers. VHCN will get more competition from a VDSL network than ADSL network because a greater number of consumers will be able to meet their broadband needs with VDSL and there will be less of an incentive to switch providers. Even if VHCN has no price premium over older technologies, inertia may reduce demand for VHCN if consumers are content with their current broadband capability. Interviews with alternative infrastructure operators suggested a preference order for competing against: ADSL, VDSL, cable then other VHCN. Several suggested that they would avoid competition against cable and VHCN unless the capital costs were low for an area.
- Copper switch-off or introduction of new technologies such as 5G or WiFi can change the technology competition in an area.
- Split between infrastructure providers will depend on capability of services and prices compared with willingness to pay. Multi-play offers may also be a discriminator if it provides an overall saving to consumers.
- More capable infrastructures can provide prices based on a range of speeds to better match willingness to pay. While operating costs may not change significantly between speeds, operators may be willing to make a loss at lower speeds/prices in order to capture customers and have more chance to move them up through the price points over time.
- First-mover advantage was specified as important by some entrant operators, particularly in smaller communities. Even if long-run market share is even split between competitors, short-term gains by first-movers (maintaining a higher share initially through contract length, inertia and possibly brand loyalty) is important in an NPV business case where near-term cash flow has higher

value than later cash flow. Higher switching costs can reduce churn but also makes it more difficult to capture new customers. First movers are also likely to skim the customers with the higher willingness to pay.

7.5.4 VHCN prices

Revenue is dependent on the subscriber retail or wholesale prices (either direct retail or wholesale depending on the relationship between the infrastructure operator and the end-customer). Price will also have an impact on subscription rates in terms of comparison with other VHCN infrastructure and legacy infrastructure prices. In addition to subscription prices, there is also the cost to consumers of switching which can create a barrier to switching.

VHCN prices are a trade-off between cost recovery, profit margin and impact on subscription rates. VHCNs are competing with legacy networks as well as potentially other VHCNs. BEREC (2016)[48] describes willingness to pay for NGAs as relative to the price of legacy networks, so consideration of a VHCN price premium compared with the legacy network is required.

7.5.4.1 Connection and switching charges

Connection and switching charges when moving to a VHCN or changing the type of VHCN (e.g. between FTTP and cable) can be significant. The infrastructure operator may need to undertake works to connect the building to the distribution point, with the cost varying with the number of earthworks required. The infrastructure operator or retail operator will also incur costs for active equipment at the premises. Operators may seek to recover some, or all the costs incurred through a connection or switching charge.

Intuitively and in line with economic theory, the lower the connection charge, the more consumers are likely to connect. It is notable though that consumers in some countries, notably Sweden, place a high value on being connected to high speed broadband and are therefore willing to pay a high price for connection. For an NPV business case, connection charges allow some or all the capital costs to be recovered immediately. If the same costs were to be recovered over time through a contract period, then the NPV value of that later revenue is lower. In countries that do not allow contract tie-ins there is no guarantee of recovering the capital costs from subscriptions. On the other hand, high connection costs are likely to act as a barrier to people switching from legacy technology to VHCN and so will reduce overall revenue.

7.5.4.2 Wholesale and subscription prices

In almost all cases retail price is unregulated but any Significant Market Power (SMP) price regulation is applied further upstream, which will usually have an impact on the retail price for the SMP operator, and any retailers using the SMP infrastructure. Alternative VHCN operators will have their retail or wholesale prices indirectly affected through competition with the SMP network. Typical SMP price regulation mechanisms (discussed in more detail in section 7.9) are:

- Cost orientation.
- Economic replicability tests / Margin squeeze.
- Anchor pricing.

The EECC sets efficient infrastructure competition as an aim for BEREC and NRAs if conditions make those infrastructures commercially viable. It does not state how much infrastructure competition is sufficient to avoid price regulation. Some countries have removed price and wholesale access regulation for VHCN under the current regulatory framework, for example Romania and Bulgaria, while in France, Spain and Portugal forbearance on access and price regulations for VHCN in high

[48] BEREC (2016) *Challenges and Drivers of NGN Rollout and Infrastructure Competition*.

density urban areas has supported or been a consequence of regulation on access to good quality ducts which has encouraged the development of infrastructure competition, leading to competition between 3 or more VHCN infrastructures[49]. This degree of infrastructure competition can effectively remove SMP status from any of the operators and therefore the need to have SMP-related regulation.

Even where there is no formal regulation on VHCN wholesale prices, the price for VHCN will typically be constrained by copper network prices, as well as competition between VHCNs.

Willingness to pay for faster broadband relative to legacy network prices will have an impact on VHCN subscription rates. It should be noted that basic broadband prices differ across Europe, with France, Latvia and Romania at the cheaper end, while Spain and Portugal are above the European average. These price differences appear to be little to do with the amount of VHCN infrastructure (Latvia has high levels of NGA coverage and a high 100+ Mbit/s subscription rate while Spain and Portugal also have high VHCN coverage but also have higher than average copper prices)[50].

Different technologies will impose speed limits, but it is common for different pricing structures to be used even with the same infrastructure network. While there may be little operating cost difference between different speeds on a fibre network, lower price differentials between copper and lower speed FTTP can be used to attract consumers on to the network, while higher prices are charged for higher speeds. Figure 22 shows the average of the lowest price in EU28 countries by bundle type and speed in 2017.

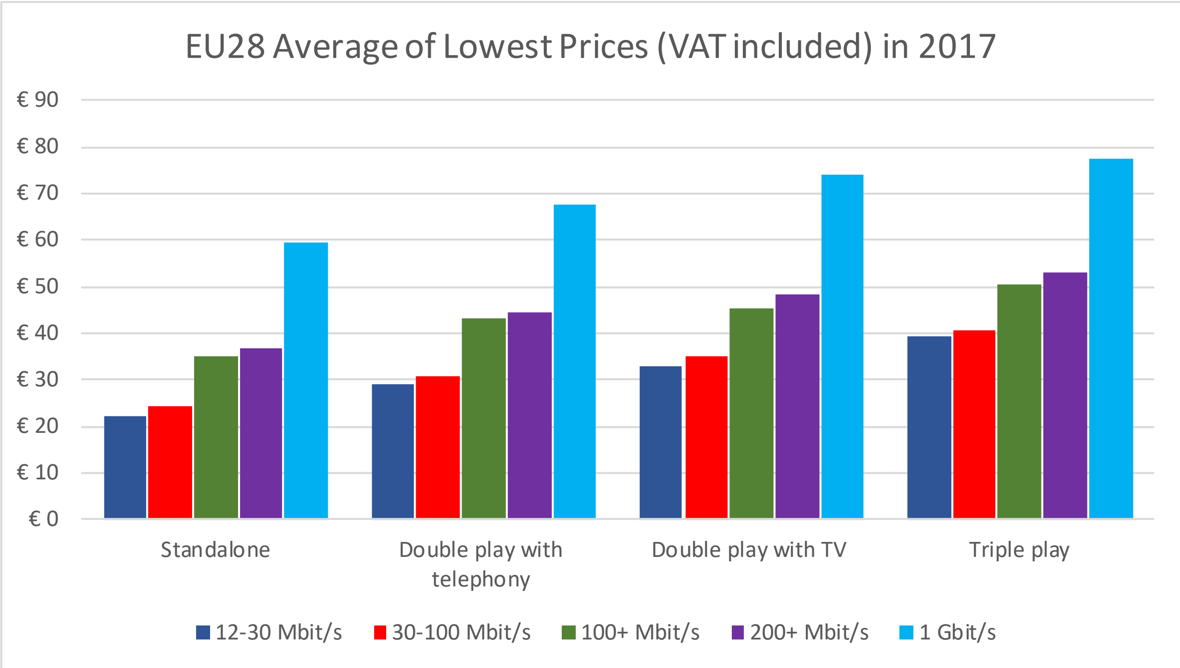


Figure 22: EU28 average of lowest country prices by service bundles and speed bands, data source: Empirica (2017)

From an NPV business case perspective, pricing (wholesale or retail, depending on business model) will affect revenue positively in terms of cash flow per subscriber, but higher pricing compared with legacy networks and other VHCN competitors will reduce subscription rates.

[49] WIK Consult (2019) Prospective competition and deregulation: An analysis of European approaches to regulating full fibre, report for BT.
[50] Emprica (2017) Fixed Broadband Prices in Europe 2017, report for the European Commission.

7.6 Competition between fixed network technologies

Two types of competition are widely recognised: service-based and facilities-based. The former is competition in retail markets provided by firms that use wholesale access to the incumbent operator's network, also known as access seekers. The latter is competition between firms with their own network infrastructures and so are not reliant on the incumbent's network. Here we consider the impact of facilities-based competition as a driver for investment in VHCNs.

BEREC (2016) notes that a number of studies have shown facilities-based competition is a main factor driving NGA deployment. BEREC provides a figure showing a positive correlation between cable coverage and coverage of FTTC/FTTP.

Correlation does not necessarily mean causality since investment in alternative NGAs to cable may imply that the conditions that made cable investment attractive also make other NGA investment attractive. However, interviews with operators as well as observations on historical patterns of investment (e.g. see section 10.6) has helped to fill in more of a picture on technology competition and its impact on investment in VHCN. It must be stressed though that some of the competitive interactions outlined below are anecdotal more than evidenced through data.

7.6.1 Impact of infrastructure competition on NPV decision

At its simplest level, competition between infrastructures through overbuild splits subscribers between those infrastructures, which reduces potential revenue. Three competing infrastructures with roughly similar capabilities and roughly similar prices might expect to split the subscriber-base into thirds with corresponding impact on the revenue profile for the NPV calculation. The subscribers may not be evenly split due to various factors including:

- **Comparative capability of technologies** – all other things being equal, superior technologies should be more popular. However, this effect will be price sensitive, particularly if the inferior technology is sufficient to meet the needs of the majority of subscribers.
- **Comparative prices** – consumers may be reluctant to pay a significant price premium for one technology over another if both can meet their needs, and the perceived benefits of one over the other is not clear. For example, if both technologies are capable for TV streaming, video conferencing, etc. then the willingness to pay extra for lower latency or faster downloads will be limited except for those minority of subscribers with particular need for the extra capabilities.
- **Multi play offerings** – multi play packages provide the ability to offer price reductions across multiple products. It also makes it more difficult to compare prices on a like-for-like basis. It is an incentive for some operators with mobile telecoms services to gain a nationwide coverage for fixed telecoms in order to compete with multi play packages. However, increased use of "over-the-top" services such as WhatsApp and Skype, as well as third-party subscription services for TV content is creating a change demand for the features of multi play services.
- **First-mover advantage** – first movers can capture a greater proportion of the customer-base if significant unmet demand for broadband capability exists. Costs to change providers and contract lengths can serve to retain customers longer in response to a second-mover infrastructure provider. Early years revenue has greater impact on the NPV calculation than later years due to the threshold factor. This may be enough to discourage overbuild by other operators.
- **Transitioning existing subscriber-base** – it is typically easier to transition existing customers onto a superior infrastructure than to capture customers from a different provider. This can give incumbents and alternative operators with an existing customer base on legacy infrastructure an advantage with market share. However, it also creates challenges in terms maintenance of multiple infrastructures and a more complex NPV calculation covering both infrastructures.

7.6.2 Impact of national scope of operators on patterns of overbuild

Capital costs for passing premises will in large part dictate the number of competing VHCN infrastructure that can be supported through splitting revenues between operators, alongside adoption rates for VHCN and prices. National scope of operators will impact their freedom to pick the regions to invest in. Considerations for incumbents and different types alternative operators are as follows:

- **Incumbent operator** – the incumbent operator is likely to have a duty of universal service for at least basic broadband provision for the whole country and is likely to be under political pressure to provide minimum target levels for broadband performance across the country. A prime driver for incumbents is to protect their existing subscriber base. Their options for an area are to upgrade the existing copper network or overbuild with VHCN. They are most likely to focus investment on areas with the largest subscriber base and the highest likelihood of infrastructure competition. Issues for the NPV decisions are the impacts of investment on the revenues from the legacy network since they will largely be converting subscribers from one network infrastructure to another rather than gaining new subscribers. Price premiums for VHCN and the prospect of direct retail subscriptions rather than wholesale can provide an increase in revenue to offset the capital costs. Incumbents also have the issue of incurring operating costs for both a copper network and a VHCN until they can switch off the copper network.
- **Alternative operator with existing copper user-base** – an operator using wholesale access to a copper network, often with experience of Local Loop Unbundling (LLU), will be in a similar situation to an incumbent in terms of protecting an existing customer-base. The larger operators will likely have national coverage using a range of LLU and bitstream/re-selling. They have several choices in terms of increasing their VHCN footprint and may use a mixture of approaches nationally: build own infrastructure (with a chance of increasing market share from incumbent infrastructure), wholesale access to incumbent VHCN or wholesale access to alternative operator VHCN (if available). Larger operators can also look to buying existing VHCN infrastructure, or co-investing (or providing guaranteed wholesale revenue) with another operator to invest in VHCN infrastructure.
- **Infrastructure entrant with a local scope** – municipalities will potentially invest in fibre infrastructure as an economic benefit for the local area. There is only likely to be an economic case for investment if no other operator is offering widespread fibre infrastructure. A municipality is likely to require a positive business case for investment in order to adhere to EC rules on state aid. However, municipalities may be willing to allow longer for a return on investment than commercial operators and be willing to take higher revenue risk. Any ability to use existing infrastructure to reduce capital costs will make a positive NPV business case more likely.
- **Infrastructure entrant with national scope and no existing copper customer base** – an alternative operator specialising in fibre infrastructure will be looking across a national (or possibly international) scope for areas with the highest potential NPV business case. The operator is likely to have limited access to capital as well as an administrative capacity limit on the number of projects that can be undertaken in parallel, so that it will have a ranked list of target areas for building FTTP networks in. Typically, entrants will require a high customer penetration rate and so will avoid areas with other VHCN competitors. This will often mean that entrant operators will avoid areas that already have FTTP or cable networks. Areas with DSL only provide the best opportunity for high penetration, provided the capital costs are sufficiently low to make the business case. Access to state aid may make the business case economic where otherwise a high price per premises passed would preclude that area. First mover advantage is important, and an expectation of a fast response by incumbents to overbuild will reduce the veracity of the business

case. Depending on the business model of the operator, there may be the opportunity for local pricing for connection and subscriptions.

7.6.3 Incumbent (A)DSL vs Cable technology

Cable technology has been the historical competitor[51] to incumbent copper networks since the late 1990 when cable TV networks added other telephony and broadband services enabled by the DOCSIS specifications. Figure 23 shows DOCSIS versions, release dates and maximum downstream and upstream capacities (actual downstream and upstream capacities will be limited by other factors involving network configurations, hardware, node sharing and contention).

DOCSIS version	Issue date	Maximum downstream capacity	Maximum upstream capacity
1.0	1997	40 Mbit/s	10 Mbit/s
1.1	1999	40 Mbit/s	10 Mbit/s
2.0	2001	40 Mbit/s	30 Mbit/s
3.0	2006	1 Gbit/s	100 Mbit/s
3.1	2013	10 Gbit/s	1–2 Gbit/s
Full Duplex 3.1 / 4.0	2017	10 Gbit/s	10 Gbit/s

Source: Cable Europe

Figure 23: DOCSIS versions showing maximum downstream and upstream capacities

Cable networks are usually a combination of fibre used for core and local rings and coaxial cable used to serve groups of properties, although the DOCSIS specification can be used with fibre to the property. A key feature of cable broadband investment is the ability to increase the speed capability through gradual investment in equipment and network configuration. Most recent new deployment of cable networks used fibre to the property.

Almost all cable networks use DOCSIS 3.0 or above. Download speeds over 100 Mbit/s are widespread among cable operators with some operators offering 500 Mbits/s. A few cable networks have adopted DOCSIS 3.1 and offer download speeds over 1 Gbit/s. In comparison, an all copper network using ADSL2+ is capable of a maximum download speed of 24 Mbit/s.

Cable coverage across EU countries ranges widely from zero presence to close to 100% coverage. Within countries there is often a wide variation in coverage between urban and rural areas.

[51] Note, there can be exceptions. Cable networks can also be operated by incumbents, e.g. TDC in Denmark.

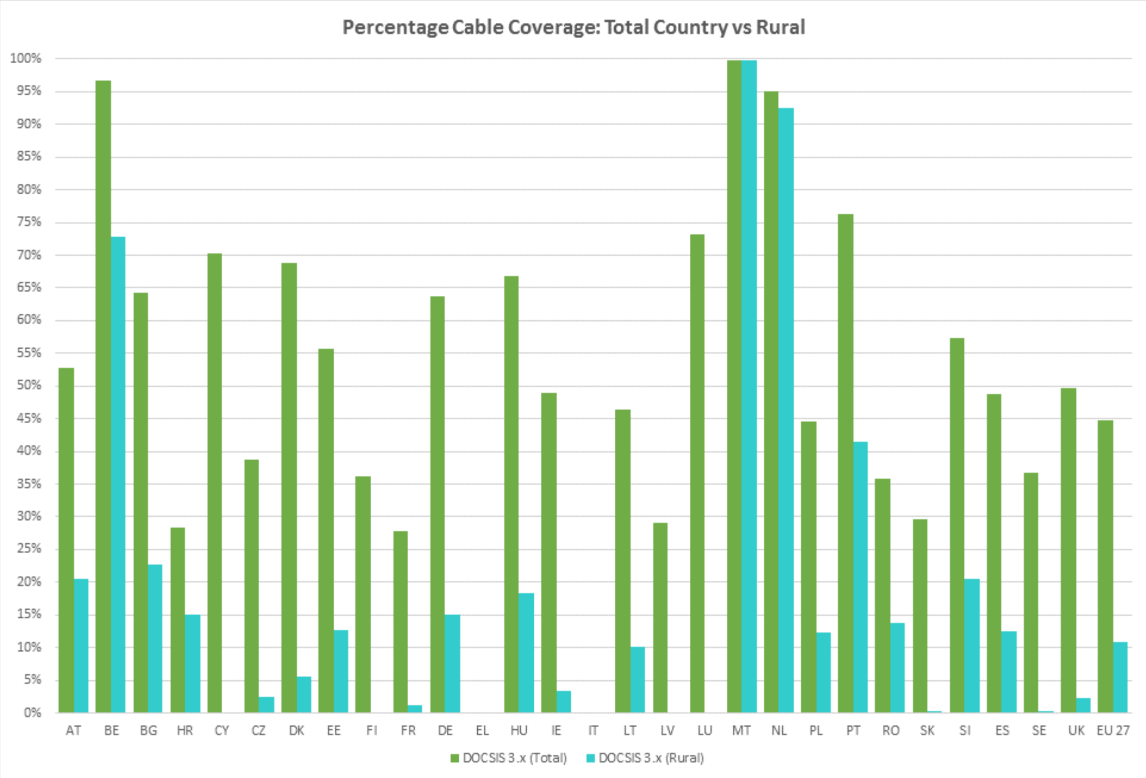


Figure 24: Cable coverage for EU countries comparing whole country vs rural only (June 2017)[52]

Interviews with NRAs indicated that incumbent operators focused on investing in NGA technology first in those areas with cable competition. This was confirmed by some of the incumbents interviewed, who identified that they needed to respond to loss of market share to cable. Additionally, cable TV operators tend to build in the highest population density which are also the lowest cost areas for upgrade or overbuild per premises for incumbents.

Incumbents with copper networks responding to competition from cable networks have two choices:

- **Invest in upgrading network to VDSL (a.k.a. FTTC)** – where there is lack of existing ducts to the premises and there is a good copper system there has tended to be investment in VDSL since this has lower capital costs and less labour efforts. This allows the fastest and most widespread response to cable competition.

- **Invest in FTTP** – where good duct access significantly reduces capital costs, or the copper network is not good quality or has long loops then there has tended to be investment in FTTP. This is seen as a more future-proof option since it capable of much faster speeds than VDSL, has lower latency and better reliability but is more costly and more time consuming and this was also noted in BEREC's 2016 NGA Report[53].

If the VDSL technology option is selected, it would be expected that further investment to FTTP would be required in the future but VDSL would be expected to meet the demands of many households for a number of years.

7.6.4 Entrant vs (A)DSL technology

Interviews with alternative operators indicated that they have a preference to select areas with only DSL competition, all other things being equal. This is because the performance delta between the

[52] Data from: IHS and Point Topic (2018) *Broadband Coverage in Europe 2017*,". European Commission.
[53] BEREC (2016) *Challenges and Drivers of NGN Rollout and Infrastructure Competition*.

existing infrastructure and the proposed VHCN is greater and provides a better prospect for a significant market share for the new VHCN within relatively short timescales.

There is an expectation that the incumbent will be upgrade the copper network or overbuild with VHCN at some point in the future, but first mover advantage is important. Some alternative operators focus on rural areas where there is a much lower likelihood of prompt response by the incumbent.

7.6.5 Incumbent (A)DSL vs FTTP technology

Incumbents operating DSL network faced by competition by FTTP networks would be more likely to respond with FTTP rather VDSL because of the large difference in performance between FTTP and VDSL in terms of speed, latency and reliability. In addition, the deployment of rival FTTP networks has tended to be more gradual than the threat of the upgrades to the already present cable networks, allowing the response to the threat of FTTP networks to be slower.

As well as a second-mover response to alternative operators building FTTP, incumbents may also overbuild with FTTP in areas of interest to alternative operators building FTTP in order to deny them first-mover advantage on FTTP, or to upgrade the copper network to VDSL to reduce the performance delta with FTTP.

Situations have been observed where incumbents with cable competition covered off by VDSL are more likely to deploy FTTP to DSL areas with a higher likelihood of alternative operators FTTP competition before upgrading VDSL areas to FTTP. This is likely due to two considerations: 1) longer copper lengths make VDSL less effective, 2) FTTP infrastructure has a greater performance delta vs VDSL than most the current cable networks.

7.6.6 Incumbent (A)DSL vs no fixed line competition

There is less incentive to incur capital costs to invest in VDSL or FTTP when there is no competition to a DSL copper network and revenue are being earned from subscribers who have little choice of infrastructure. Competition versus 4G (and future 5G) mobile may encourage some investment. Potential competition from an alternative operator FTTP network may encourage first mover investment from incumbent. The ability to charge higher prices for FTTP speeds may encourage incumbent investment in FTTP if there is sufficient evidence for demand to make a business case viable.

7.6.7 Entrant vs Cable technology

Alternative operators will generally avoid areas with cable coverage, where possible, although conditions that made an area attractive to cable in the first place might still make for a strong enough business case for overbuild of an FTTP network.

7.6.8 Entrant vs FTTC technology

After DSL, alternative operators' second preference for overbuilding is against incumbent FTTC since FTTP is significantly superior. However, it is more difficult than DSL areas to capture a very high market share in short timescales unless they can undercut prices because there will be a smaller percentage of potential customers who find the existing infrastructure inadequate.

7.6.9 Entrant vs FTTP technology

Entrant alternative operators would avoid areas with FTTP already since they would not have first mover advantage so gaining required market share would be difficult. An alternative operator seeking nationwide access or with an existing legacy network market share to protect might consider overbuilding FTTP if capital costs were sufficiently low and options for wholesale access to the existing FTTP network were unavailable or uneconomic.

7.7 Wholesale access

Obligated wholesale access to FTTP networks is a regulatory tool, alongside some form of wholesale price regulation, to ensure sufficient levels of retail competition. It is deemed necessary where the cost base for VHCN prevents commercially viable infrastructure competition. Even without obligated access to networks, there have been instances of FTTP infrastructure providers are providing wholesale access to their networks with wholesale pricing being determined on a commercial basis. For example, Orange Espagne became the first alternative operator in Spain to allow commercial wholesale access to its FTTH network after it reached an agreement with MásMóvil in October 2016. There

7.8 Role of 5G and Fixed Wireless Access

5G will, in the long term, have a potential role in a future digital society, particularly for machine-to-machine communication of the type needed to support a road network of autonomous vehicles.

There are two aspects in this study for consideration of 5G and wireless access. One is as a substitution for fibre/cable to the property to deliver 'fixed' VHCN broadband to the home, or at least its role in slowing investment in VHCNs. The other is to consider the impact of fibre backhauling to 5G masts on the investment business cases for FTTP.

7.8.1 Mobile substitution and Fixed Wireless Access for VHCN at the premises

7.8.1.1 Existing use of data only 4G and WFA / WiMax

Use of mobile access as a substitute for fixed broadband connection is not a widespread phenomenon across EU countries but has gained high leverage in some countries. Using the proportion of SIM cards that are data only as an indicator of substitution for fixed broadband, it can be see that Austria leads the list (27.3% of all SIMs were data only in 2017), with moderately high percentages also in Finland, Latvia, Poland and Denmark (source tefficient, 2018[54]), as illustrated in Figure 25.

4G LTE with carrier aggregation/MIMO is capable of more than 150 Mbit/s download speeds in the lab but practical speeds in the real world are reported in the region of 18-24 Mbit/s which makes it an upgrade on most ADSL fixed broadband connections, while 3G allows more modest average download speeds of 3Mbit/s. High prices and data limits have provided a curb on 4G substitution but moderately priced data only and multi play packages including a 4G router for fixed broadband with unlimited data usage are becoming more widespread in Europe.

[54] tefficeient (2018) "Unlimited moves the needle – but it's when mobile addresses slow fixed internet that something happens", Industry Analysis #1 2018.

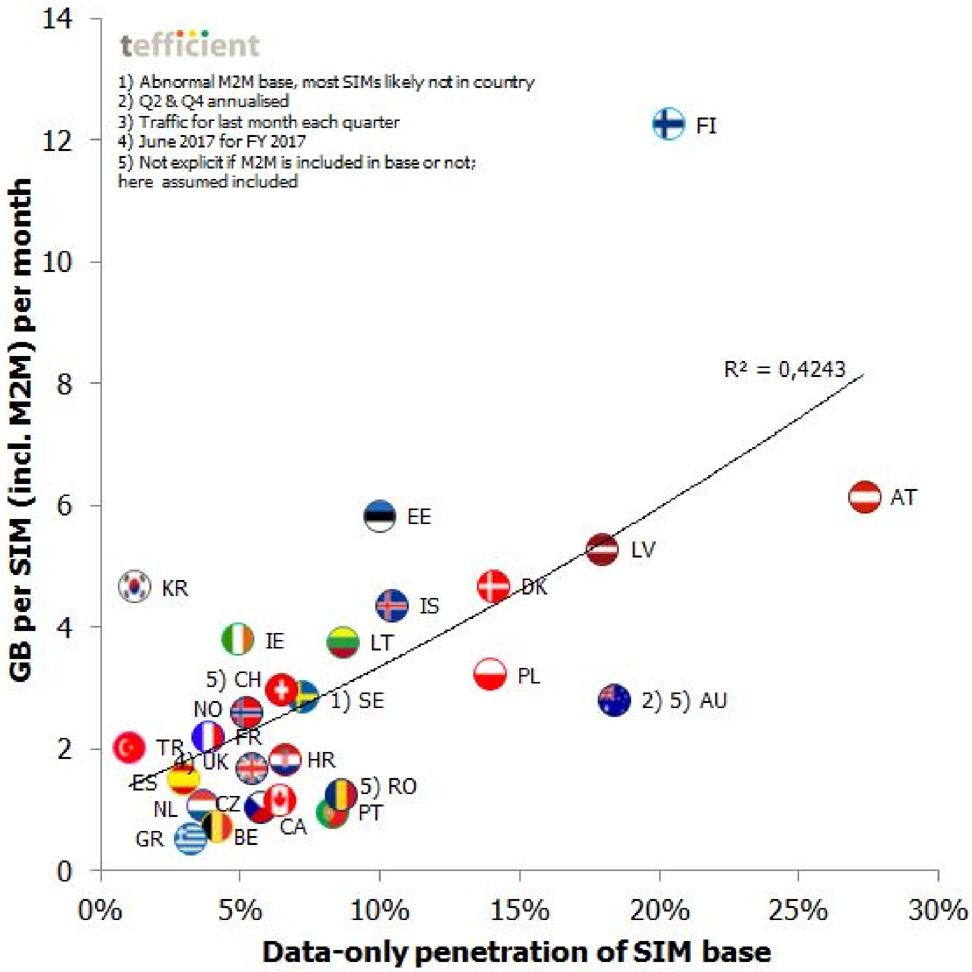


Figure 25: Data only SIM card penetration vs monthly GB per SIM (all SIM types), source: tefficient (2018)

WiMax, WiMax-2, WFA and WFA+ are common in some countries, offering an alternative to wired fixed broadband, and can offer speeds from around 6 Mbit/s and 100 Mbit/s depending on subscription type, technology, distance from the transmitter and contention effects. Coverage differs greatly across EU countries, as shown in Figure 26.

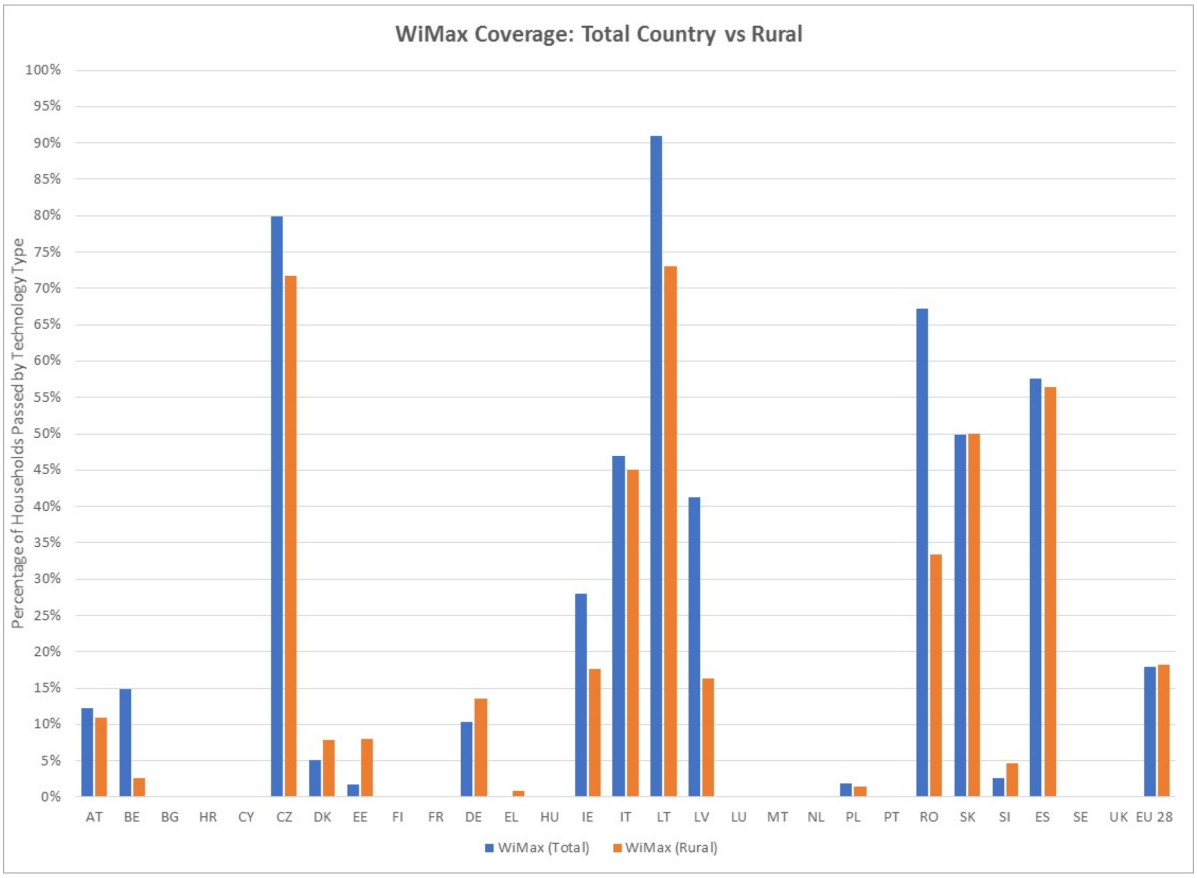


Figure 26: WiMax coverage across EU countries showing whole country and rural only (data June 2017, IHS & Point Topic)

These fixed wireless technologies are not VHCN capable, but some at least have the ability to meet current and near future broadband needs for households and may dampen the demand to subscribe to VHCNs.

7.8.1.2 Potential of 5G as a substitute for fixed VHCN

Further consideration is required for the role that 5G could have as a substitute for fixed VHCN technology. In addition, there is the impact that 5G microcells could have in delivering VHCN at lower cost by avoiding the need to run fibre from the local node to the premises, and instead providing connection between households and the fibre network via localised 5G transmitters.

While VHCN-type capabilities are sometimes quoted for 5G mobile networks, issues around contention rates, penetration through walls (for indoor use) and short ranges for the medium and high frequencies) mean that practical speeds are expected to be much lower in practice if not external antennas are used. Trials and limited deployment give some ideas of real-world speeds, but these typically have limited infrastructure and a low user-base.

A theoretical study by Wisely, Wang & Tufoli (2018)[55] looked at urban performance based on different scenarios of densities using macrocells (700 MHz), microcells (3.5 GHz), 26 GHz arrays and WLAN indoors. They conclude that 700MHz provides almost 100% coverage at lower data rates (typically 30 Mbit/s) making it an ideal for the umbrella coverage but not capable of meeting 100 Mbit/s speeds. 3.5GHz technology with 100MHz of bandwidth at a with a micro base-station density of 256 per km^2 (e.g. deployed on lampposts) can provide outdoors coverage at 100 Mbit/s but penetrates poorly into building and is not adequate for indoor coverage unless the micro base stations are located within the

[55] Wisely, D., Wang, N., & Tafazolii, R. (2018) “Capacity and costs for 5G networks in dense urban areas”, *IET Communications* 12 (19), 2502-2510.

buildings. 1GHz of spectrum at 24.5-27GHz) can provide a significant increase in capacity (100 -1000x 4G capacity) out of doors but doubts remain over the timescales and costs of the technology. It is not suitable internally because of very low penetration so either 3.5GHz base stations will need to be deployed internally, Distributed Antenna Systems (DAS) added or upgraded to 5G or 802.11ac technology will require integration within 5G to provide 1 Gbit/s capability. They estimate that the cost of deploying a 100Mbps everywhere network that has x100 capacity increase will be in the order of 4-5 times that of an LTE network.

Some mobile service providers are offering routers with a 5G SIM card. In the near-term, it would seem unlikely that 5G using a data only SIM could provide VHCN type capabilities in many areas. Over time, with considerable infrastructure investment it might be possible that consistent speeds over 100 Mbit/s could be possible but speeds approaching 1 Gbit/s are much further away.

5G mobile cannot be confidently treated as a VHCN substitute, but the threat to market share of fixed VHCNs is at least as great as 4G, probably greater given the expectations around 5G. However, none of operators that were interviewed as part of the study expressed a fear of substantial competition from 5G.

7.8.1.3 Hybrid FTTN / 5G for VHCN

Another way that operators could use 5G for VHCN is for a FTTN (Fibre to the Node) / 5G hybrid. This would use fibre to a local neighbourhood node and then a 5G microcell (or array) to connect to individual households in the neighbourhood. Best performance would be achieved using an external antenna or window-mounted antenna in line-of-site of the 5G microcell. Such a system is being offered by Verizon in the US but only at a very limited number of locations, with typical speeds around 300 Mbit/s.

Interviews with operators indicated mixed interest in the concept. Several operators were interested in the concept of FTTN/5G, with one actively testing the technology. Other operators had reservations about the need to lease spectrum for 5G and the reliability and latency compared with FTTP. One specialist provider for rural and semi-rural area felt that most of the cost would be involved in running fibre to the node in a rural location, with the final run to the property from the node being relatively cheap (cost per metre for narrow trenching tends to be cheaper in non-urban locations) compared with setting up and operating a 5G microcell. The concept could be of interest in areas where there are restrictions or significant costs involved in running fibre to the building and particularly for larger operators that operate mobile networks and will have already acquired 5G spectrum.

7.8.2 The impact of 5G backhauling on FTTP investment

Implementation of a nationwide 5G network will require considerable investment in infrastructure. This investment is likely to be incremental to a) increase coverage and b) increase speed and capacity. Some of this investment will involve upgrading existing masts that do not yet have fibre backhauling (most likely a requirement for some rural areas which use backhauling via microwave or satellite), increasing the density of masts, and adding 5G microcells to existing infrastructure (e.g. rooftops and lampposts). The upgrade of existing masts and adding new 5G transmitters will require 5G backhauling.

There are several potential impacts on investment in VHCNs:

- Extension of the fibre backbone to rural areas – this can reduce the cost of building out to a rural area since dark fibre installed as part of 5G backhauling can be leased, reducing the of fibre installation needed to connect to the town or village. This is evidenced by experience that once a particular town or village is connected to an FTTP network, there is often a cluster effect where other towns or villages nearby are also connected (e.g. case studies from FTTH Council Europe, 2016 for rural communities in Austria, Finland and Germany[56]).

- Expansion of 5G networks to create microcells on buildings and lampposts – backhauling fibre to 5G microcells could be combined with efforts to run fibre to local nodes to share costs. This would require the timing of the investments for 5G and FTTP (or G.fast) to coincide. Alternatively, if one investment occurred before the other then, if dark fibre was available, there could be leasing opportunities, either reducing capital costs for FTTP or providing an additional source of revenue.
- Competition for finance – investment in 5G infrastructure could inhibit roll-out of VHCN by competing for finance available within an organisation or from financial institutions.

7.9 Government and Regulatory levers

National Regulatory Authorities (NRAs) have available a range of powers they can use to apply on both an asymmetric and symmetric basis. These powers are chiefly derived from the 2002/2009 Regulatory Framework (soon to be replaced by the EECC) and other Directives, such as the Broadband Cost Reduction Directive (BCRD), as transposed into national law in each Member State. There are also recommendations and guidelines from the European Commission that set out how directives can be applied. In addition, national governments have powers to intervene directly in the market through State Aid and a range of other policies. These are discussed below.

7.9.1 Physical access to ducts and poles infrastructure

The BCRD sets out rules regarding access to the physical infrastructure of all utilities for the purpose of building broadband networks. It also covers in-building wiring and wiring guidelines for new buildings and major refurbishments. It should be noted that some governments already had similar rules in place prior to the 2014.

There are several levels of scope for which the policy could be applied:

- NRA Regulation – **Asymmetric regulation** requiring **SMP** operators to make ducts, poles and other access points available to other operators for the purpose of rolling out VHCN infrastructure.
- NRA Regulation – **Symmetric regulation** requiring all telecoms operators (including cable) to make ducts, poles, etc. available to other operators to roll out VHCN infrastructure.
- Government Regulation – **Regulation for all telecoms and other utilities** to make ducts, poles and other access points available to other operators for the purpose of rolling out VHCN infrastructure. This would represent the implementation of the BCRD but extends beyond the remit of most NRAs so would need wider government regulation. However, the implementation and management of the regulation would likely rest with NRAs.

Within the general principles of access to physical infrastructure, there are several details on how it is implemented and administered. Some of these are addressed in the BCRD to a greater or lesser extent, some are not.

Interviews with operators indicate that there is generally a positive response to the option to use other operators' ducts (i.e. asymmetric regulation preference by entrants, and symmetric access obligation preference by incumbents), but a reluctance to allow others to access their own ducts. It is a common view that ducts are finite strategic resource over which operators want to maintain control. One entrant operator was clear that it was very much against allowing access to its ducts but much more open to leasing its dark fibre. A number of interviewees did not have strong opinions on the matter because they operate in countries with poor duct and pole infrastructure, or they are niche operators in areas where there is no realistic likelihood of duct access, and their business is geared to low cost deployment of long lines of fibre.

[56] FTTH Council Europe (2016) "Case Studies Collection".

Several operators also raised concerns about the practical application of access to physical infrastructure, with issues on information on existing infrastructure, the mechanisms and timeliness of dealing with collapsed ducts, and lack of response from enquiries about infrastructure (particularly noted when dealing with non-telecoms utilities). Some of these issues meant that they preferred to deploy their own infrastructure on a known cost and schedule rather than the potentially cheaper route with higher risk to cost and schedule.

Relevant areas of detail for enacting regulations for access to physical infrastructure are:

- **Dark fibre** – BCRD does not specifically address dark fibre other than in the definitions section where it is specifically listed as not included within the definition of physical infrastructure. Depending on the lease/rental terms, dark fibre could be seen as equivalent to duct access (other than the removing the need to lay the fibre) or could be subject to very different terms and conditions.

- **Information on physical infrastructure** – knowledge of the availability and routing of ducts is essential for planning and deployment. The existence of such information and the mechanism for other operators to access this information is important. Electronic information through a single point of access is the most desirable mechanism. Written requests for paper-based information is less desirable due to timeliness, administrative overhead as well as potential commercial implications of announcing interest in a particular area to a competitor.

- **Fair and reasonable price, terms and conditions** – the BCRD states that fair, non-discriminatory and reasonable price, terms and conditions should be offered. This should allow the infrastructure owner to fairly recover costs and take account of impact on their business plan. This will include the terms under which an infrastructure owner can be within their rights to refuse permission for access.

- **Availability, space and condition of ducts and poles** – the usability of existing infrastructure is a major factor in the success of infrastructure access regulation. In the event of a very high incidence of directly buried cables or microducts, regulations on access to ducts and poles is unlikely to make any practical difference to infrastructure deployment costs. It is more complicated where ducts and poles do exist, but there are issues with the space and condition of that infrastructure making some parts of the infrastructure effectively unusable without further action. Regulators will need to determine responsibilities, mechanisms and charging regimes for dealing with sections of the system where the condition (e.g. collapsed ducts) makes them unusable, or where pinch points exist that effectively block running new fibre through a section. Actions may involve repair, expansion or re-routing. Operators wishing to make use of ducts and poles should be able to be confident of their ability to run fibre along sections without being subjects to unexpected delays and/or costs due to poor condition or pinch points.

- **Entitlement to undertake works** – in terms of rights of access to infrastructure, there is the issue of who has rights to undertake work, and the type of work that they can undertake. For example, and alternative operator may secure rights for fibre to be run using incumbent's ducts system but may not have rights to undertake the work to do this themselves, instead having to rely on the incumbent's workforce to undertake the task. This can have an impact on costs and schedule for a project.

- **Enforcement and mediation** – BCRD mandates that dispute settlement is managed by one or more competent bodies. NRAs are the most obvious candidates for this role, though the situation may become more complicated where utilities from other sectors (e.g. electricity, water) are involved. A key role for NRAs will be enforcement of information sharing and resolution of disputes. It is very likely that telecoms infrastructure owners will be reluctant to provide access, which may result in slow response rates and discouraging cost rates and conditions for access.

Other utilities may be reluctant to commit effort required for information sharing. NRAs can play a role in resolving disputes, setting standards and helping to create a smooth process for information sharing, requests, granting of access and actioning the infrastructure works.

Several areas of the NPV business case can be impacted by application of physical infrastructure access regulations. The maximum potential impact of physical access regulation will be dependent on the degree of coverage and quality of existing ducts and poles, or the availability and coverage of dark fibre.

- Reduction in capital costs for passing properties with VHCN.
- Reduction in capital costs for connecting properties passed by VHCN.
- Increase in operating costs due to lease and rental costs for physical infrastructure (unless up-front payment on long-lease terms can be placed on the balance sheet as capital investment).
- Possible improvement in the coverage and quality of ducts and poles for overbuild when an incumbent or entrant invests in VHCN infrastructure (depending on build approach and scope of access regulation).
- Possible improvement in quality of ducts and poles through enforcement of remedial action on existing infrastructure.

7.9.2 In-building wiring

BCRD also addresses access and re-use of in-building wiring, as well as wiring guidelines for new buildings and major refurbishments. New and refurbished buildings should have internal wiring for high speed internet with easily accessible access points for broadband operators. For older building operators should have the right to terminate networks at the premises of the subscriber provided that in minimises the impact on third party building owners.

In interviews with operators there was a mixed response among operators with regards to regulation on in-building wiring, with some preferring rights of access to other operators wiring and some preferring no regulation. One operator indicated a strong preference for rights of access on that basis that the inability to get landlords permission for access to in-building wiring would mean more buildings in an area being missed out and lower subscription rates. Few other operators had strong preferences.

Potential impacts on the NPV business case are as follows:

- Reduction in capital costs for connecting properties passed by VHCN where internal wiring already exists.
- Increase in operating costs due to lease and rental costs for access to in-building wiring infrastructure (unless up-front payment on long-lease terms can be placed on the balance sheet as capital investment).
- Reduced administration for gaining rights to building access.
- A higher proportion of households that can be connected (i.e. not blocked by landlord), leading to higher subscription rates.

7.9.3 Administrative processes for physical works

BCRD provides recommendations to reduce the administration burden seeking permits for civil works by specifying the use of a single point of information and time to respond to applications as being within 4 months. It also aims to increase transparency of planned works and the creation of opportunity to share civil works. These aim to reduce costs and ensure timely response to prevent bottlenecks in application.

The EECC expands on these provisions, noting "*Unnecessary complexity and delay in the procedures for granting rights of way may therefore represent important obstacles to the development of competition. Consequently, the acquisition of rights of way by authorised undertakings should be simplified. Competent authorities should coordinate the acquisition of rights of way, making relevant information accessible on their websites.*"[57]

Analysys Mason (2017)[58] reports the results of interviews with UK telecoms operators and local authorities. A major finding was that the one of most significant challenges faced by operators was the variation between the notice and permit schemes operated by local authorities. Our own interviews with operators across the EU found that the process for wayleaves and permits varied by municipality so that new processes must be learned for different municipalities. This inevitably leads to extra administration costs as well as delays when the proper procedures are not followed.

Potential regulatory options to reduce the burden of regulatory processes include:

- **Greater uniformity of notice and permit schemes for telecommunications civil works** – common processes across the nation, preferably with a single portal for application and review, would reduce the administrative burden of applications and reduce delays through misunderstanding of procedures.
- **Transparency of applications and grants for civil works, procedures for sharing civil works** – costs and disruption could be reduced by identifying opportunities for sharing civil works. A common portal for viewing applications and grants, and appropriate systems for applying for sharing of civil works would be required.
- **Formal notification and co-investment schemes for regions** – a more formal co-investment mechanism could be employed to give operators to right to co-invest in civil works and/or a single network infrastructure. See Regulated co-investment in section 7.9.5.

Potential impacts from regulations on administrative processes for physical works include:

- Reduction in administration effort and associated costs.
- Greater capacity to undertake concurrent investment projects.
- Reduced capital costs per premises passed.
- Reduced capital costs for premises connected.

7.9.4 Restrictions on physical deployment mechanisms

Laws and regulations on deployment on cabling can differ between countries and within countries. In the absence of available ducts for telecoms cabling, these can significantly affect the choice of deployment options for fibre optic and other cables, affecting the cost of deployment of physical infrastructure.

Since planning regulations differ greatly, and many deployment mechanisms are available, the potential regulatory option is specified as follows:

- **Relaxation of building and planning regulation** – relaxation or unification of planning regulations could allow use of a wider range of mechanisms to deploy fibre in order to reduce infrastructure costs, e.g. overhead and building facias, alternative methods for trenching.

---

[57] DIRECTIVE (EU) 2018/1972 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 establishing the European Electronic Communications Code, paragraph 104.

[58] Analysys Mason (2017) *Lowering barriers to telecoms infrastructure deployment*, report for the Broadband Stakeholder Group.

- **Clear publication of cable routes** – combined with any measures to allow shallow deployment of cable, policies to ensure transparent electronic publication of cable routing can help to minimise damage and disruption to VHCN cables.

Potential impacts from these regulations:

- Lower capital costs per premises passed.
- Lower capital costs per premises connected.
- Higher operations costs (high rate of repair for damaged cables).

7.9.5 Regulated co-investment

Co-investments often occur on voluntary commercial grounds (for example, the agreement between Vodafone and CityFibre in the UK) and provide a mechanism for cost reduction and risk sharing. In Spain, for example, all fixed network operators have participated in some form of co-investment agreements regarding the rollout of FTTH infrastructure. However, targeted regulations can be put in place to oblige operators to offer co-investment opportunities. Such an approach has been used in France.

The EECC addresses co-investment in several places, in particular Article 76, requiring regulators to assess the impact of co-investment in VHCN on the imposition of SMP status during a market analysis. EPRS (2018)[59] outlines major elements in the EECC that address co-investment, as well as the position of the European Commission, European Parliament, BEREC and several industry bodies on Article 76:

- **Co-investment obligation** – detailed symmetrical rules and a dispute settlement mechanism, whereby all operators deploying a VHCN must offer other operators the opportunity to enter into a co-investment project to build the last section of fibre networks. This includes the ability to enter into co-investment after the infrastructure is built.
- **Relaxation of regulations in the event of co-investment** – regulations in terms of SMP obligations may be relaxed in the event of an open co-investment allowing downstream competition by co-investors and meeting regulatory requirements on effective competition.

As noted in section 7.4.3 there are several forms of co-investment, so regulation related to co-investment may recognise some forms of co-investment for regulatory relaxation but not others. Co-investment can involve sharing of civil works and possibly local loop infrastructure or could involve co-investment on the whole network in an area leading to network sharing. One form of co-investment is likely to lead to more overbuild and therefore more infrastructure competition, another to less overbuild but more retail competition. In some cases, regulators may wish to recognise different forms of co-investment depending on area, e.g. only recognise co-investment where it results in overbuild in 'Black' areas, but any form of co-investment in 'Grey' or 'White' areas (using convenient labels from EC state aid rules as a shorthand for different levels of economic infrastructure competition).

Potential impacts of regulation are:

- Increased co-investment resulting in lower capital costs.
- Lower cost of capital (if co-investment reduces risk of investment, particularly if reduced overbuild).
- Increased overbuild **or** reduced overbuild depending on nature of co-investment.

[59] EPRS (2018) "EU electronic communications code and co-investment: Taking stock of the policy discussion ", European Parliamentary Research Service briefing.

- Greater VHCN wholesale pricing freedom under certain forbearance terms.

7.9.6 VHCN deployment notifications

Frontier (2018)[60] highlights the problem of "hold up" areas where demand and deployment costs are such that a single VHCN would be economically viable, but operators are unwilling to invest for fear of being overbuilt such that it would no longer create a positive NPV. For example, an alternative operator might be willing to invest in an area and is able to generate a positive NPV but avoids investment for fear that the incumbent will respond with overbuild and cut the revenues from the investment. Once the incumbent has demonstrated a willingness to do this in a few areas, it only needs the threat of overbuild and does not actually need to invest in the area, so it can continue to sweat the copper assets. This can leave these "hold-up" areas without VHCN while other areas with higher population densities, or more rural areas that the incumbent is less interested in, get VHCN investment. This might typically happen in some Grey areas that would otherwise attract VHCN investment.

Arce published a decision in 2010[61] for French telecoms operators in order to prevent unnecessary overlaps and to maximise the cost-effectiveness of investments in less-dense areas. The decision detailed the framework governing the process of meshing regions by technical fibre rollout area.

Operator build declarations for a VHCN should be fulfilled within a defined time period for an entire area – when an operator deploying fibre in given location declares the service area of the concentration point a "target rollout area," this declaration should be followed rapidly by actual deployments. The declaration thus marks the starting point for meeting the obligation to cover the entire area, within the defined timeframe.

The aim is to prevent pre-empting strategies of officially announced rollout plans with no rapid follow-through, which acts as a deterrent to another operator that might perform rollouts more quickly. It also seeks to prevent cherry picking where rollout schemes that do not plan to cover the most costly lines, while making it economically impossible for another operator to do so.

The potential impact of regulation and policies along these lines are:

- Reduced incidence of overbuild in Grey and White areas.
- Increased incidence of build in Grey and White areas.
- Increased incidence of co-investment where operators coordinate plans for investment.

7.9.7 Regulated network access and pricing mechanisms

A staple area of regulation for legacy networks with an SMP infrastructure regulator involves ensuring that other operators have access to the network and that the infrastructure operator cannot abuse market power on wholesale and retail prices. Access and price regulations on the legacy network can impact pricing on a VHCN. It is also possible to regulate a VHCN using the same types of regulations as for a legacy network. Additional price regulations are possible using anchor pricing to link legacy network pricing to a base level of pricing for a VHCN.

7.9.7.1 Forms of wholesale access by technology type

The configuration of both the legacy network and the VHCN can limit the options for the type of network access.

- ADSL network – Resale, Bitstream, LLU

---

[60] Frontier Economics (2018) *Future Telecoms Infrastructure Review*, Annex A, Report for DCMS.

[61] *Décision n°2010-1312 précisant les modalités de l'accès aux lignes de communications électroniques à très haut débit en fibre optique sur l'ensemble du territoire à l'exception des zones très denses* *https://www.arcep.fr/uploads/tx_gsavis/10-1312.pdf*

- FTTC/VDSL – Resale, Bitstream, VULA (Virtual Loop Unbundling, a form of Bitstream that is treated as equivalent to LLU Market 3a for regulatory purposes).
- Cable (HFC) – Resale, Bitstream (DOSCIS 3.0 & 3.1, requires upgrade, costs and impacts on network service quality is disputed[62]).
- FTTP (AON / Point-to-Point) – Resale, Bitstream, VULA
- FTTP (PON / Point-to-Multipoint) – Resale, Bitstream, VULA, Wavelength unbundling (same fibre different wavelengths), Fibre unbundling (multi-fibre with each operator using their own strand, mono-fibre with a single fibre utilised any of the operators using a fibre cross-connect)[63].

7.9.7.2 Wholesale access regulation

Access regulations apply to SMP operators, which is usually the incumbent operator, but SMP status has also been applied to cable operators in Netherlands and Belgium. In addition, access obligations may be imposed as a result of mergers or acquisitions, or as a condition for state or other subsidies (see section 7.9.8).

Imposition or removal of access obligations for different technologies can be mechanism for regulators to encourage operators to invest in VHCN in order to create infrastructure competition, or to provide retail competition in the absence of infrastructure competition.

Assuming that access obligations are applied to SMP legacy networks (at least until conditions allow copper switch-off), the following access obligation regulation options exist with regard to VHCN.

- **Regulated access obligation to VHCN at all speeds** – requires that the infrastructure operator grants other operators access to the fibre network for retail operations. The type of access may cover all or a sub-set of the technical access options available for the particular VHCN technology. This is typically applied when it is deemed that there is likely to be insufficient VHCN infrastructure competition, so is applied as a retail competition remedy.
- **Regulated access obligation at lower speeds** – requires that the infrastructure operator grants wholesale access to the fibre network but is only obliged to offer access up to a specified speed (e.g. when applied in Spain this was 30 Mbit/s, slightly above highest-end ADSL speeds). This regulation was used to allow copper network retailers access to the incumbent's fibre network at basic speeds but also to provide a competitive incentive to invest in fibre infrastructure to gain advantage or prevent a competitor gaining advantage.
- **No access obligation** – total forbearance on VHCN wholesale access regulation on a temporary fixed duration basis (a "Regulatory Holiday"), or on a permanent basis (subject to periodic market review). Permanent forbearance is unlikely to be used pre-emptively while there is an incumbent with strong SMP status, but an understanding that forbearance would be the outcome of effective infrastructure competition can be used to encourage incumbents to invest in infrastructure as well as cooperating on allowing other operators to access to ducts/poles and other infrastructure. In 2017 Portugal granted forbearance in urban areas where effective infrastructure competition is in operation..

The examples of partial and total forbearance above for Spain and Portugal above were not done in isolation, but in conjunction with duct (or dark fibre in the absence of duct space) access to the incumbent's network, along with the presence of good quality ducts. In the case of Portugal forbearance was only granted when effective infrastructure competition was in place.

[62] ERG (2005) *Wholesale broadband access via cable: Consultation report*, ERG (05) 24.

[63] FTTH Council (2016) *FTTH Business Guide*, Edition 5.

Forbearance on wholesale access regulation does not necessarily mean an absence of wholesale access. An incumbent may offer wholesale access or enter into a co-investment agreement with other operators which may in some instances been driven by strategic positioning.. A prime example can be found in the Spanish market, where Telefónica provides commercial wholesale access to all three of the alternative fixed network operators. Similarly, alternative operators without any wholesale access obligations may also offer wholesale access and may build their business model on being wholesale only.

7.9.7.3 VHCN wholesale price regulation

Virtually all legacy copper networks have some sort of price regulation for incumbents. This is not necessarily the case for VHCNs, either because there is no access obligation for the incumbent or because the price regulation on copper is deemed to act as an anchor price for VHCN since in the event that VHCN prices are set too high, demand for VHCN will be low since it will not offer sufficient value for money compared with the legacy network.

Most forms of price regulation that are used for copper networks can also be applied to VHCNs. This includes anchor pricing for different speed bands within copper networks (e.g. anchoring VDSL prices to ADSL prices) but can be applied between technologies to anchor lower speed VHCN access to similar ADSL or VDSL prices. Retail price caps are an ultimate sanction for an uncompetitive telecoms industry but are rarely used in recent times and will not seriously be considered for VHCN in this analysis.

When the NRA sets a price, it allows the regulated operator to earn a return on assets (sometimes those assets used to deliver the regulated service only – the Regulatory Asset Base) equivalent to its Weighted Average Cost of Capital (WACC). The regulated price is the [opex + (assets*WACC)]/volume. This WACC is normally estimated by the NRA and so may not be the same as the actual WACC faced by the operator.

The NPV calculation contains the variable r, which is the threshold rate of return on assets the project is required to generate to make the project NPV positive. This threshold rate is similar to the WACC, which is be the minimum return the project needs to generate to meet the needs of the firm's debt and equity holders.

Whilst the WACC used in the price control directly affects the regulated entity only, there is a spill over effect on other companies that need to compete with the regulated firm's prices. If this spill over effect brings down prices to a level where the entrant cannot earn a positive NPV either, investment is not likely to take place.

EC (2013)[64] provides costing and wholesale pricing recommendations to NRAs for both copper and NGA networks (including VHCNs). The following will focus on VHCN wholesale broadband access (WBA) price remedies. A number of these remedies can be used in combination.

Cost plus WBA pricing – e.g. Long run incremental cost plus (LRIC) or long run average incremental cost plus (LRAIC) bottom up approaches to determine the actual or theoretical cost of providing the type of broadband access plus a fair return on capital. The aim is to determine a fair cost-plus charge for access based on the cost to provide that access and so prevent overcharging leading to unreasonably high profits for the provider, along with competitive advantage in the retail market by

[64] EC (2013) "COMMISSION RECOMMENDATION of 11 September 2013 on consistent non-discrimination obligations and costing methodologies to promote competition and enhance the broadband investment environment (2013/466/EU)".

forcing other operators to absorb a much higher cost base in their retail prices. Approaches are discussed in more detail in Oxera (2013)[65].

Economic Replicability Tests – to assess whether the margin between the retail price of the relevant retail products and the price of the relevant regulated wholesale access inputs covers the incremental downstream costs and a reasonable percentage of common costs. A lack of economic replicability exists if the SMP-operator's downstream retail arm could not trade profitably on the basis of the upstream price charged to its competitors (see BEREC, 2014 for a fuller explanation)[66]. The aim is to prevent the incumbent using their market power to knock out retail competition by setting their retail prices such that an efficient operator using the access could not trade profitably and therefore would not be able to survive to a competitive retail environment.

Price caps – usually applied as a percentage change from the previous year and may be a positive percentage range (maximum price increase) or a negative percentage change (representing cost reductions through expected minimum efficiency improvements).

Anchor pricing – The anchor pricing approach anchors the price (and quality) of existing services to the legacy technology, even if the services are provided over a new technology. Typically, by anchoring the lower level performance of the network, the investor can gain rewards from selling higher speed and quality services to those consumers willing to pay a price premium. This allows pricing freedom as a reward for the investment risk, but presence of the anchor acts as a constraint to the price of higher premium services by setting the base for the willingness to pay decision. For more details see Williamson (2013)[67].

Potential impacts of wholesale broadband obligation and price regulation can be complex since the difference between legacy and VHCN prices may be as important as the absolute pricing, and behaviours in the presence of forbearance not necessarily being that different from a price regulated market. Therefore, impacts are caveated by the nature of the competitive environment, operator business models and the possibility that incumbents may behave in constrained manner despite having market power in order to avoid further regulation.

7.9.7.4 Impact of legacy network wholesale prices

Wholesale price setting for legacy networks can also impact investment behaviours, particularly by incumbents and alternative operators offering legacy network retail services through unbundling, bitstream or re-sale. The relationship between legacy wholesale prices and incentives to invest in VHCN (or NGA) are the subject of many academic papers examining the impact in likelihood of different operator types investing in NGA or VHCN). This is discussed in much more detail in the literature review in Volume 2 of this study.

A summary of key points is as follows:

- **Low wholesale legacy prices incentivise incumbents to invest due to low opportunity cost** – low legacy wholesale prices relative to costs create a low profit margin for the incumbent operator, so the opportunity cost from lost NPV value for the legacy network is lower, reducing the threshold that the VHCN NPV must exceed.
- **Low wholesale legacy prices disincentivise alternative operators from investing due to high opportunity cost** – low legacy wholesale prices relative to retail prices creates a higher profit

[65] Oxera (2013) "Price control principles for current generation wholesale broadband products", report for Comreg.
[66] BEREC (2014) "BEREC Guidance on the regulatory accounting approach to the economic replicability test", BoR (14) 190.
[67] Williamson, B. (2013) "Anchor product regulation retrospective and prospective".

margin for alternative operators retailing legacy broadband using the incumbent's legacy network, so the opportunity cost from lost NPV value for the legacy network is higher, creating a higher threshold that the VHCN NPV must exceed. This is termed the "replacement effect" by Bourreau, Cambini & Doğan (2012)[68]. In efficient markets it would be expected that high profit margins would attract more retail operators and so over time competition would cause retail prices and margins to be squeezed.

- **High wholesale legacy prices incentivise alternative operators to investing due to low opportunity cost** – high legacy wholesale prices relative to retail prices offer a lower profit margin for alternative operators retailing legacy broadband using the incumbent's legacy network, so the opportunity cost from lost NPV value for the legacy network is lower, reducing threshold that the VHCN NPV must exceed.
- **High wholesale legacy prices disincentivise incumbents to invest due to high opportunity cost** – high legacy wholesale prices relative to costs create a high profit margin for the incumbent operator from legacy network wholesale, so the opportunity cost from lost NPV value for the legacy network is higher, increasing the threshold that the VHCN NPV must exceed. Bourreau, Cambini & Doğan (2012) term this the "wholesale revenue effect". Further, they point out that the incumbent risks triggering alternative operators to build their own VHCN in retaliation, losing wholesale revenue for the incumbent for both its old and new networks.
- **Low legacy wholesale prices restrict VHCN prices** – Bourreau, Cambini & Doğan (2012) argue that low legacy wholesale prices lead to low retail prices for legacy broadband, which in turn will restrict VHCN retail prices since operators must offer low VHCN prices to encourage consumers to switch. They term this the "migration effect". As discussed in section 7.9.7.3, even without formal VHCN price regulation, there can be an informal anchor pricing impact from legacy network prices at least during the transition period where operators are looking to persuade consumers to switch to the VHCN.

During interviews with operators, there was one counter argument to this set of principles. It was argued that a period of high legacy wholesale prices had limited profits for an alternative operator and so had limited the ability to fund investment in VHCN. Conversely, when regulated access prices were lowered, the extra profit margins provided the opportunity to invest funds in building their own VHCN infrastructure. It is possible to apply logic to this argument. While retained profits from legacy network operations are unlikely to provide a high proportion of the total capital required for VHCN investment, they do contribute to a measure of business health which is a criterion that investors will look at in determining the risk of an investment, which in turn will impact the cost of capital. This creates an impact as follows:

- **Legacy wholesale price impacts on the profitability of an operator affect the cost of capital for VHCN investment** – higher profit margins from legacy operations can lower the risk profile of an operator and enable it to access capital at lower cost, improving the NPV business case for VHCN due to a lower discounting threshold. This works counter to the opportunity cost arguments above for both incumbents and alternative operators with legacy network retail operations.

7.9.7.5 Trade-offs between regulated wholesale prices of legacy and VHCNs

Bourreau, Cambini & Doğan (2012) suggest that their most interesting finding is that "regulators cannot treat the two access prices to the two different technologies independently". Looking at it from the NPV business case perspective both incumbents and alternative operators with a legacy network retail operation have NPV trade-offs and opportunity costs:

[68] Bourreau, M., Cambini, C., & Doğan, P. (2012). "Access pricing, competition, and incentives to migrate from 'old' to 'new' technology". *International Journal of Industrial Organization*, 30(6), 713-723.

- Incumbent: Legacy network NPV + VHCN infrastructure NPV.
- Alternative operator: Legacy network retail NPV + VHCN infrastructure NPV or VHCN retail NPV.

The relative wholesale prices and achievable retail prices of the legacy and VHCNs will affect all these NPV trade-offs and are clearly interdependent. Not only do these have revenue and demand impacts on the net cash flow side of the NPV but potentially also on the investment risk due to profitability and health of the overall basis as well as the relative risk/reward profiles for the alternative operator building their own VHCN infrastructure vs seeking wholesale access.

A suggestion by Vodafone referred to as the "copper wedge" is reviewed by NERA Economic Consulting (2017)[69]. It is suggested that it can weaken the conflicting impacts of legacy wholesale prices on incumbent and alternative operator VHCN investment incentives, as follows:

- The "copper wedge" refers to a gap between the price charged to access seekers for copper network services and the price received by the infrastructure owner. Access seekers pay more than the incumbent receives, which should increase the incentives for both to invest in fibre networks (i.e. lowers the NPV for both incumbent's and alternative operators' copper businesses). The "copper wedge" difference can be used by the regulator for other purposes, such as contributing to a universal service fund.

Changes to pricing regulation encourage investment behaviour cannot ignore the current regulation, particularly in relation to current legacy network wholesale prices, and needs to take account of expectations from operators and consumers. Cave (2014)[70] notes:

"Clearly, unbundling which forces down the price of copper broadband is likely to have a restraining effect on fibre investment, by reducing the price of current generation broadband and thus the price which owners of fibre networks can charge. However (…) copper access decisions are mostly irreversible by now: policy makers and regulators must now lie upon whatever unbundled copper bed they have made." (p. 679)

This does not mean that legacy wholesale cannot be moved in a desired direction, but the starting point and acceptable speed of that change (to operators and consumers) are likely to be constrained.

7.9.8 EU, state and local government subsidies

The concepts of state and local government aid and the impact on the NPV business case is dealt with in detail in section 7.4.4. This section will summarise key policy intervention types and potential impacts. State aid here relates to finance, while government and municipality actions to build or support demand are dealt with separately (see section 7.9.9). Forms of EU funding is also covered here, since it contributes funding for VHCN telecoms infrastructure but is above state level.

Feasey, Bourreau & Nicolle (2018)[71] provide an overview on EU funding and state aid focussing mainly on grants and soft loans for capital investment, which forms the basis of the list below:

- **EU funding sources** – several sources of EU funding exist, which include investment in VHCN in their remit. The Regional Development Fund (ERDF) has a budget of €290 billion over the 2014-2020 period and the "digital agenda" is one of several priority areas of the fund, with an explicit objective of this fund to reduce regional inequalities and improve social cohesion. The Agricultural

---

[69] NERA Economic Consulting (2017) *Balancing incentives for the migration to fibre networks.* Report for Vodafone Group plc.

[70] Cave, M. (2014). "The ladder of investment in Europe, in retrospect and prospect". *Telecommunications Policy*, 38(8-9), 674-683.

[71] Feasey, R., Bourreau, M., & Nicolle, A. (2018) "State Aid for Broadband Infrastructure in Europe: Assessment and Policy Recommendations", Centre on Regulation in Europe.

Fund for Rural Development (EAFRD) has funds of €100 billion in the period 2014-2020 some of which have also been applied to broadband. The European Fund for Strategic Investments (EFSI), is co-funded by the EC and the European Investment Bank (EIB) to a total of €33.5 billion up to 2020 and covers several priorities including "digital agenda" and aims to attract private finance by reducing the business risk of projects. The Connecting Europe Broadband Fund has €240 million from public funds alongside €250 million of equity finance from other public and private investors, and is used for early stage equity finance rather than debt, aiming to invest in 7-12 broadband projects a year, at levels of €1-30 million per project.

- **The European Investment Bank (EIB)** – provides funds in its own right for broadband infrastructure on commercial terms, but is usually willing to take on higher risk projects than commercial banks, and has considerable experience in lending for broadband infrastructure projects. Typically lending for broadband projects in is the region of €2-3 billion per year. It is listed separately from other EU funding sources since it does not constitute as state aid and so is not subject to all the conditions of state aid.
- **National and local government** – funding for grants and soft loans can be provided by national, regional and local governments, subject to EU competition rules. Notification is not required for grants less than €70 million provided that conditions are met. In additional, other measures can be employed in terms of tax relief on organisations investing in VHCN, and business rates on exchanges and other facilities housing VHCN equipment. Demand side funding for voucher schemes or tax relief for connections and subscriptions for business and households can also be provided by states and local government. Almost all of these mechanisms for subsidies are likely to count as state aid under EU regulations, except that tax relief to households and business for broadband connection costs may not count since they are non-selective (I.e. open to all individuals or businesses). See BIS (2011)[72] for more information on EU definitions of forms of state aid.

The European Court of Auditors compiled a report on broadband in the EU in 2018, which captured EU funding for broadband in the periods 2007-2013 and 2014-2020, showing funding specifically for broadband. The table from their report is reproduced in Figure 27. This table only includes central funding, not funding provided directly by nation states.

[72] BIS (2011) "The state aid guide: Guidance for state aid practitioners", UK Department of Business Innovation & Skills.

Source of funding	Type of support	Amount in programme period (€ Millions)	
		2014-2020	2007-2013
European Structural and Investment Funds (ESIF):			
• European Regional Development Fund (ERDF)	Grants	6 019	2 456
• European Agricultural Fund for Rural Development (EAFRD)	Grants	921	282
European Fund for Strategic Investments (EFSI)*	Loans	2 032	-
Connecting Europe Facility			
• CEF Debt instrument	Loans	16	-
• WIFI4EU Initiative	Grants	120	
Connecting Europe Broadband Fund (CEBF), of which:	Equity		
• From the Commission		100	
• From the EIB and EFSI		140	
European Investment Bank	Loans	5 600	
Total available		**14 948**	**2 738**

* EFSI amounts as of end of June 2017

Figure 27: EU funding sources for broadband investment (source: reproduced from ECA, 2018)[73]

Impacts of EU, state and local government subsidies can differ depending on how they are applied. Most grants will provide funding for capital costs, but some other forms of subsidies to business and individuals for connection and subscriptions can also impact demand. Areas of impact are as follows:

- Funding for capital costs – grants for capital costs do not reduce the capital spend but instead covers some or all the funding for that spend. In terms of an NPV business case, this is best treated as an early net cash flow so that it does not affect the capital value of the assets.
- Soft loans or lower than commercial rates for capital costs – these types of subsidies will not add to net revenue by will likely lower the discounting rates and/or increase the number of NPV periods in consideration, both of which will improve the NPV business case.
- Funding for connections – grants for capital costs to connect customers can be treated as early cash flow related to customers connected. Similarly, subsidies or tax relief to consumers for connections provide net cash flow for the NPV decision. Direct grants to infrastructure operators do not necessarily reduce connection charges to consumers since this is a pricing policy by the operator, although grants reduce the business pressure to charge high connection fees. Subsidies and tax relief direct to consumers will reduce connection fees for consumers. Lower connection fees should increase demand for subscriptions as part of the overall value for money / price sensitivity assessment of the VHCN offer by consumers.
- Vouchers and tax relief for subscriptions – subsidies for subscription will reduce the retail price to the affected consumers for a period and so should increase demand for VHCN subscriptions. At the end of the voucher or tax relief period some loss of subscribers might be expected if cheaper alternative technologies are available, although experience of VHCN may change customer's willingness to pay.
- Wholesale access – most forms of subsidies will be accompanied with an obligation to provide wholesale access and wholesale-only business models may be favoured for EU grant applications.

[73] ECA (2018 "Broadband in the EU Member States: despite progress, not all the Europe 2020 targets will be met", European Court of Auditors Special Report No 12, 2018.

- Regional variations for subsidies – White areas should have a much higher incidence of state and local government subsidies than grey areas, and there are likely to be very view instances in Black. It is possible that White areas experiencing state aid may become grey areas over time through increasing demand making more infrastructure competition financially viable for other operators. It is also possible that endogenous increases in demand through experience of VHCN in an area, enabled by state aid, could cause a White area to migrate to becoming a Grey area.

7.9.9 Demand building policies, reducing revenue risk

In addition to providing subsidies to business and household consumers (see section 7.9.8), government policies can also help to build demand for VHCN through awareness, skills development and applications that make use of VHCN capabilities. Policies and local authority activities can also help to reduce revenue risk through creation of guaranteed revenue streams that can then underpin a wider deployment of a VHCN. Confidence in the revenue stream an important aspect of the business case, with lower revenue risk likely to reduce the cost of capital.

Demand is an important factor in generating a positive NPV business for any circumstances, but particularly in those cases where lack of access to quality ducts and poles makes deployment costs higher. Even where deployment costs are lower, there is a greater likelihood of overbuild with competition likely to squeeze revenues, so the demand side of the NPV is vital. Higher demand has two key impacts: firstly, it creates a higher willingness to pay so price sensitivity compared with legacy broadband prices will be higher improving revenue per subscriber; secondly, and related to the first, it is likely to increase the number of VHCN subscribers. Both these impacts will increase the net revenue side of the NPV business case.

Other than measures that influence price, as discussed in section 7.9.7, there are other ways in which demand can be influenced. Mechanisms for managing demand and reducing revenue risk have been discussed in section 7.5.2.3. Some of these approaches can be influenced by government policies and actions by local government, without being regarded as state aid, as summarised below:

- **Local community support** – evidence from interviews, as well as published case studies (e.g. FTTH Council Europe, 2016[74]) indicate alternative operators that target areas which are of less interest to incumbents and larger alternative operators will typically be looking at high early penetration rates for subscribers in order to justify the NPV business case for VHCN infrastructure. An important weapon in achieving those high penetration rates is local community engagement.

- **Anchor tenants** – anchor tenants can provide a guaranteed revenue stream for a project and allows a fibre backbone to be built which can be further expanded to local business and properties.

- **General Education** – general education on I.T. and more specialist high-tech skills in schools, further education and adult education can create more of a digital culture as well as encouraging development of jobs that utilise those skills and create both business and household demand for faster broadband connection. These are however policies that will have a longer-term rather than short-term impact on demand. In the shorter-term, there are several mechanisms to increase IT literacy and knowledge of broadband technology as well as providing opportunities to experience VHCN.

- **Experience and knowledge of VHCN** – knowledge of the capabilities for VHCN in comparison with other technologies may increase specific demand for VHCN, such as access to VHCN in libraries and schools, provided that their application demonstrates the capabilities of VHCN (i.e. beyond simple web surfing). Clarification of differences between architectures (i.e. FTTC versus FTTP or

[74] FTTH Council Europe (2016) *Case Studies Collection*.

FTTH) and greater clarification in the advertising of "fibre" broadband may help create more demand for VHCN.

- **E-gateways for services** – easier access of government and public services through the internet helps to encourage broadband adoption and create a digital society. Applications that utilise ultra-high definition two-way video or virtual reality are likely further away in the future, but the reliability afforded by VHCN for real-time monitoring for health and social care may be nearer-term applications. Ability to access government services and information through a wider range of technology, such as smart devices (TVs, voice-controlled assistants, etc.) may also encourage wider adoption of broadband in households.
- **Contract durations** – longer contract durations provide greater revenue certainty for first mover investors in VHCN since it provides a longer period of revenue before a consumer can switch to a second-mover provider or a different technology. Current EU law sets a maximum contract duration of 24 months, but individual states can set lower maximums or may even prevent any contract lock in.

Potential impacts of demand building and revenue risk reduction initiatives are as follows:

- Local community support may support demand aggregation efforts leading to greater confidence in subscription rates and therefore benefiting the NPV business case. This may also bring VHCN earlier to Grey and White areas which would otherwise not generate enough revenue for an NPV case. This type of initiative is likely to have more impact in encouraging nice alternative operators that specialise in local engagement and target high adoption rates, rather than with larger national operators where the scale of their investment and existing customer base means that they are more likely to target higher density areas first.
- Anchor tenants can bring VHCN to an area where it might otherwise be uneconomic. Local authorities and services can benefit from additional data capacity. For the local communities the anchor tenant can cover the costs of bringing the fibre spine into the local area, as well as providing the operator with a guaranteed level of revenue.
- Building up of a digital culture through education, gateways to services and experience of VHCN capabilities may increase levels of demand for VHCN, though impacts on VHCN adoption could be marginal in the short-term.
- Longer contract durations could reduce one-time connection charges and subscription fees by allowing one-time costs to be absorbed into a longer contract period. This could increase demand for VHCN by the price delta over legacy networks.
- Longer contract durations can reduce churn rates, benefitting first-mover investors, particularly of longer contract lengths are allowed compared with legacy networks.

7.9.10 Copper switch-off

Copper switch-off can benefit the incumbent by removing the need to incur operating costs for both a copper and a VHCN in an area. It can also benefit all VHCN operators by increasing demand for VHCN by removing an alternative technology for provision of broadband and voice communications. However, depending on pricing policies for those services, some customers switching from copper to fibre (e.g. voice-only) may be low value in terms of revenue but still incur the full connection costs.

Knowing the conditions under which copper switch-off can occur would greatly help the incumbent's business case for investment in VHCN. It is likely that copper switch-off would have a positive benefit to the incumbent's NPV business case (compared with operating two networks) through operating cost savings, but an understanding of any liabilities with regard to universal service provision and migration of copper customers to the fibre network would need to be factored in.

Experience on copper switch-off exists from some countries that have already started a programme of full copper switch off or PSTN (analogue calls) switch-off. This provides evidence of some of the factors that operators and regulators need to consider. WIK Consult (2018)[75] provides an overview of progress on copper switch-off in Europe. Plum Consulting (2018)[76] provides guidance and case studies for PSTN switchover to IP. Areas for regulatory guidance could include:

- **Mandated copper switch-off dates** – regulators could indicate whether copper switch-off is treated as a commercial decision should minimum conditions be met with the timing at the discretion of the incumbent, or whether earliest and/or latest dates are specified for switch-off.
- **Universal service provision** – the conditions that constitute meeting universal service provision for voice and broadband, and the technologies that could be employed to meet the required service.
- **Emergency calls and protecting vulnerable customers** – requirements on incumbent or other operators for providing access to emergency calls in the event of a power cut and supporting vulnerable and other customers that are reliant on analogue systems (e.g. care alarms, security alarms, etc.).
- **Equipment support for migrating customers** – while customers that voluntarily migrate from copper to VHCN may be expected to pay for modems and other hardware as part of the migration, a determination needs to be made on equipment for consumers that are forced to migrate due to copper switch-off.
- **Connection costs for migrating customers** – the extent to which customers migrating to the VHCN need to cover connection costs or whether they will be borne by the operator.
- **Pricing for migrated services** – the extent to which services on the copper network will be migrated to the VHCN and the cost of those migrated services. Potentially an operator could incur high connection costs but receive low value revenues.
- **Partial copper switch-off** – the ability of operators to remove ADSL broadband services but retain FTTC in areas where FTTP is not available, or at least not provided by the incumbent.
- **Removal from sale** – an interim policy of removal from sale may be allowed, prior to full copper switch-off, such that any customer moving property or switching from another supplier will not be able to choose a copper-based service unless that is the only infrastructure available.
- **Notice periods for copper switch-off** – regulators will need to determine notice periods to customers for copper-switch off before copper exchanges are switched off. This has been determined in some EU countries, typically ranging from six months to five years and often depending on the existence of copper wholesale access and VHCN wholesale availability.

In terms of impacts on retail operators, the relative difference between wholesale prices for copper versus whole prices for VHCN access will substantially affect the economic case for alternative retail operators migrating service offerings from copper to VHCN and the knock-on impacts on retail choice and retail prices for consumers.

PSTN switch-off is scheduled for a number of EU countries, meaning that some issues around universal service for voice, emergency calls and protecting vulnerable customers may already have been dealt with for that transition, depending on the nature of the PSTN switch-off and treatment of legacy equipment.

---

[75] WIK Consult (2018) *Copper switch-off: A European benchmark*, study for FTTH Council Europe.
[76] Plum Consulting (2018) *Preparing the UK for an All-IP future: experiences from other countries*, study for Broadband Stakeholder Group (BSG).

Potential impacts of copper switch-off are as follows:

- Capital costs for connection and equipment – copper switch off is likely to result in an increase in connection costs for the incumbent operator. It may also create demand for alternative infrastructure operators where overbuild is available for customers who decide to switch from incumbent copper network to an alternative operator's VHCN, resulting in connection costs for those operators.
- Copper operating costs and revenue – copper switch off may incur some initial costs in shutting down the exchange but will then reduce copper operating costs and copper revenues to zero. It may also result in some write-down of capital assets.
- VHCN demand – demand for VHCN will increase as customers switch from the copper network to a VHCN. Where overbuild exists it is likely that there will be some split between infrastructure operators' networks. However, a number of the new VHCN subscriptions are likely to be at the low revenue end of service offerings.
- VHCN wholesale and retail prices – requirements to offer equivalent VHCN wholesale products and prices to the previous copper products may result in an initial decrease in average wholesale and is likely to have a corresponding impact on retail prices. This impact may be temporary.
- Retail wholesale costs and revenues – depending on conditions for VHCN wholesale access, the cost and revenue base for VHCN may change compared with copper. This will change the NPV of the copper retail business (as it is effectively removed from the market) and the VHCN retail business. These changes may benefit or harm profitability of retail operators and could lead to a change in the options available to consumers, as well as a change to retail prices over time to adjust for the new cost base.
- Longer-term, changes to regulated VHCN wholesale prices may occur as the infrastructure cost base of the incumbent's VHCN changes due to short-term capital cost increases and long-term savings in operating costs from the copper switch-off.

7.9.11 Regulatory processes and applicability

Regulatory processes themselves can be a determinant of investment in VHCN in terms of how they are messaged, the likely duration of regulations (and frequency of reviews) and the scope of their applicability.

7.9.11.1 Regulatory certainty

In interviews with operators and financiers one of the most commonly cited messages was that they valued regulatory certainty. While these comments might have been prompted by the ability to send a message to the BEREC target audience, it is notable that there was no prompting question that guided this point other than "Is there anything else you would like to add?" In terms of making investment decisions with NPV periods ranging between 5 and 15 years (depending on capital finance decisions) a potential change in regulations reflects a potential risk to revenues and therefore creates more uncertainty in the business case, usually reflected by higher cost capital in terms of a higher discounting threshold or shorter periods for return on investment.

The European Commission recognises the need for regulatory certainty. This is clearly stated throughout EC (2013)[77] with an emphasis on regulatory predictability and in the EECC, where, for example, Recital 188 states:

[77] EC (2013) "COMMISSION RECOMMENDATION of 11 September 2013 on consistent non-discrimination obligations and costing methodologies to promote competition and enhance the broadband investment environment (2013/466/EU)".

"National regulatory authorities should, when imposing obligations for access to new and enhanced infrastructures, ensure that access conditions reflect the circumstances underlying the investment decision, taking into account, inter alia, the roll-out costs, the expected rate of take up of the new products and services and the expected retail price levels. Moreover, in order to provide planning certainty to investors, national regulatory authorities should be able to set, if applicable, terms and conditions for access which are consistent over appropriate review periods."

With the aim of regulatory certainty in mind, the EECC extended the maximum period for market reviews from three years to five years. National regulators can perform market reviews for frequently than this, but five years represents a maximum that can be applied by NRAs.

NRAs have competing challenges of consumer protection and well as incentivising investment. There is potential in the telecoms market for significant changes in patterns of demand for telecoms and impact of technology on capacity and quality requirements for broadband, relationships between major operators (mergers, sale of infrastructure, co-investment, etc.), changes to the macro-economic environment. Some of these may require more frequent interventions to make timely adjustments to ensure a fair competitive environment and a fit for purpose public utility.

In terms of increasing regulatory certainty, other than applying the maximum market review period, NRAs can indicate strategy and direction of thought so that investors can understand the conceptual framework in which future reviews will be done. This potentially allows NRAs to indicate how they would react to certain outcomes in the market without requiring exact pre-emptive regulation to be spelt out.

NRAs wishing to increase regulatory certainty have the following options:

- **Apply maximum market review period** – NRAs can opt to apply the maximum market review period, which gives a degree of certainty for investments, though uncertainty can increase as a market review is due which may create a cyclic nature to investments.
- **Provide clear signposts for future direction on regulation** – NRAs can indicate their strategic goals and indicate likely regulation in response to market outcomes and challenges. This can provide some additional confidence to investors whilst still providing a degree of flexibility for setting of regulation in response to the actuality of future circumstances.

Potential impacts of regulatory certainty:

- The degree of regulatory certainty is likely to impact the uncertainty and risk mitigation in NPV business cases. Higher uncertainty may result in downgrading of revenue forecasts, discounting of revenue through higher discounting thresholds, and a requirement for an earlier return on investment resulting in a shorter NPV review period.

7.9.11.2 Regional regulation differences

Some NRAs across Europe have established that there are sufficiently different levels of competition in geographic regions within their country that there is no longer a single national market for the purposes of regulation of some product markets. Instead the country can be divided into two or even three geographic markets[78]. This may lead to a removal of asymmetric regulation in some areas, as no operator is found to have SMP, and differing levels of regulation in other areas.

Whilst access to unbundled local loops may have created different geographic markets for copper based broadband access, it is not necessarily the case that the same geographic markets exist for fibre networks.

[78] BEREC (2018) https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/8308-berec-report-on-the-application-of-the-common-position-on-geographic-aspects-of-market-analysis

This regional approach for segmenting VHCN infrastructure aims and encouraging what it regards as the most efficient use of capital for national infrastructure investment has been extensively used by France in terms of encouraging different forms of co-investment for different regions (described by WIK Consult, 2019[79]), identifying some regions as "Very Dense Zones" where economic infrastructure competition is viable and other regions where a lead operator can register and is then required to offer co-investment opportunities for the FTTP infrastructure. A map is available via the ARCEP website showing the Very Dense Zones ("Zones très denses") and those identifying a lead operator.

The potential impacts of geographic markets are diverse since potentially any of the regulations specified in section 7.9 could vary by geographic region or not be applied at all in areas deemed effectively competitive.

7.10 Summary of determinants of investment

This chapter has described in detail a very broad range of drivers of investment that has been identified through the research. In summary these drivers can be captured in the table below.

These drivers can be represented collectively, using the System Dynamics approach, within a single generic business network model that will be introduced in Section 8

[79] WIK Consult (2019) *Prospective competition and deregulation: An analysis of European approaches to regulating full fibre,* report for BT.

Drivers of investment	
Capital costs	• Population density • Wayleaves and administration for deployment of infrastructure • Access to existing ducts and poles • Dark fibre – backbone access and leasing revenue opportunity • Reducing cost of civil works • Access to internal building wiring
Technology competition	• Cable vs DSL operator • Cable vs FTTP entrants • FTTP entrants vs DSL operator
Finance & co-investment	• Telecoms investment funds • Confidence in revenue generation – anchor tenants • Regulatory certainty • Co-investment • State and local government aid
Wholesale access	• SMP obligated wholesale access on VHCN and legacy networks • Wholesale only access as core business model (including municipalities) • Wholesale access obligated through state aid regulations
Pricing & operating costs	• VHCN price premium vs legacy network services (wholesale and retail) • Connection and switching costs • Operating costs – lease, energy and maintenance
Demand	• Digital way of life • eGovernment services • Demand aggregation policies • Direct subsidies and tax breaks • Contract durations to allow churn
5G and wireless	• Use of data only 4G/WiMax • 5G substitution of fixed VHCN • Hybrid FTTN/5G for VHCN • 5G backhauling on FTTP investment
Regulatory levers	• Infrastructure Access o Duct and pole access and terms o Ease of access to Rights of Way o Use/Take up of Directive 2014/61/EU on Reducing cost of rollout of VHCNs. • Cost of access o Costing/pricing mechanisms to reward investment o Interrelation of price regulation of current and next generation access • Regulatory positioning o Increase regulatory certainty o Regulatory forbearance on fibre investment o Use of symmetrical obligations by NRA • SMP obligations o Obligations placed on SMP operator in 3A/3B markets o Effect of SMP regulations on other players o Conditions for copper switch off o Co-investment

8 Generic network business model as a system

This section describes in detail the development of a generic representation of a network operator business system using the System Dynamics approach (see Annex A.1), describing it visually through links of cause and effect. The resulting maps capture the components introduced in section 7 and can be used as the starting point for qualitative analysis of markets and operators.

8.1 Aim and scope for the Generic Network Business Model (GNBM)

The aim of producing a generic network business model has been to capture within a single visual representation, a model that can be applied to any national market, region or operator. It needs to represent completely the variety of operator business systems observed internationally. This variety of operators was introduced in section 5.2 as part of the wider VHCN ecosystem that also includes financiers, regulators, consumers and retailers.

The Generic Network Business Model (GNBM) must reflect:

- Drivers of investment discovered through the interviews, literature reviews and analysis.
- Wide variety of operator business models (at different stages of maturity across EU markets).
- VHCN infrastructure as part of technology evolution that cannot be separated from existing Copper/Coax Cable-based network operations.
- Existence of geographical market segmentation.
- Endogenous nature of competition – the network model must reflect the influence of other operators within the market.

The resulting model is complex in its attempt to capture the ensuing variety. However, it can be simplified for application to a specific market/region/operator where not all the components are relevant (often due to path dependence), and this approach has been applied for country analyses that will follow in section 10.

Before describing this model, it is important to emphasise the model is qualitative but provides a toolset to "think" about and articulate what is observed in markets, hypothesise and use to explain how operator behaviour may unfold. As stated elsewhere, the qualitative map has been built up through evidence and logical mapping of cause and effect.

8.2 The sectors of the generic network operator model

Although the resulting network operator model is complex, breaking it down into sectors provides an intuitive way to describe the structure in a manageable way. Figure 28 depicts the model in its entirety but the focus for this figure is to illustrate that different parts of the final model can be clustered to represent sectors, and each will be considered in turn. These include:

- VHCN provision – this sector represents premises within the market and the infrastructure implementation activity to bring VHCN capability.
- VHCN subscriber uptake – this represents VHCN new connections and development of an active VHCN subscriber base.
- Legacy network provision – this represents implementation of investments on a legacy copper network if the operator current possesses such an asset.
- Legacy network subscriber uptake – representing the acquisition and retention of subscribers on the legacy network.
- Network operator decisions and accounts – this provides a representation of the management accounts for the operator.
- Network financial investment – represents how and where network investment will be directed.
- Retailer operator decisions and accounts – Retailers are part of the business system using the network (e.g. via VULA) to compete for and acquire a subscriber base. The network operator with a vertically integrated operation will also be part of this competitive retailer market.

- Competing VHCN subscriber propositions – represents the competition between VHCNs, retailers on these networks and the legacy Copper based propositions.
- Consumer VHCN demand – this captures the fundamental demand for VHCN dependent services and consumers demand for 1Gbit low latency connections.

This approach was used to best reflect the underpinning NPV-based approach to describe VHCN investment determinants. This has meant that regulatory levers appear across this model but as will be shown, any analysis of impact of these levers can be traced systematically through the model.

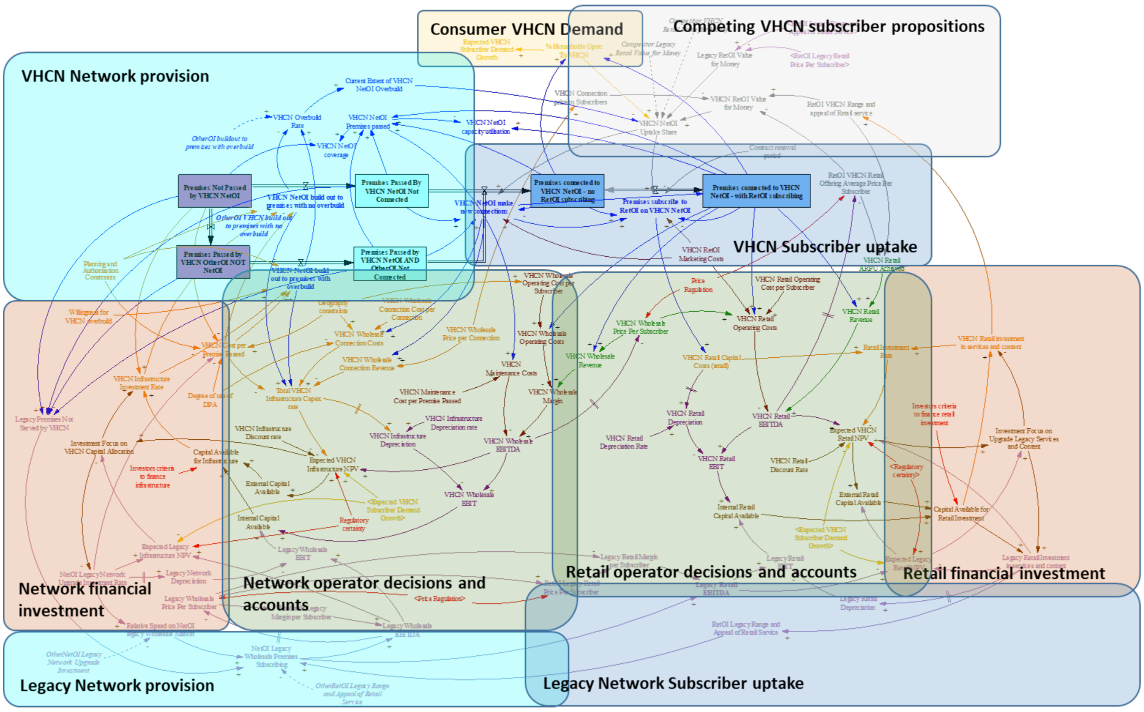


Figure 28: High level sector map of the generic network operator model

8.3 Representing the NPV concept within the Generic Network Business Model

As will be shown later, the NPV based representation of corporate decision making is embedded in the Generic Network Business Model. Figure 29 is another overlay. Again, without need for reference to the underlying detail of the map, it illustrates how VHCN investment decision making is developed through the components of capital, net cash flows and financing conditions.

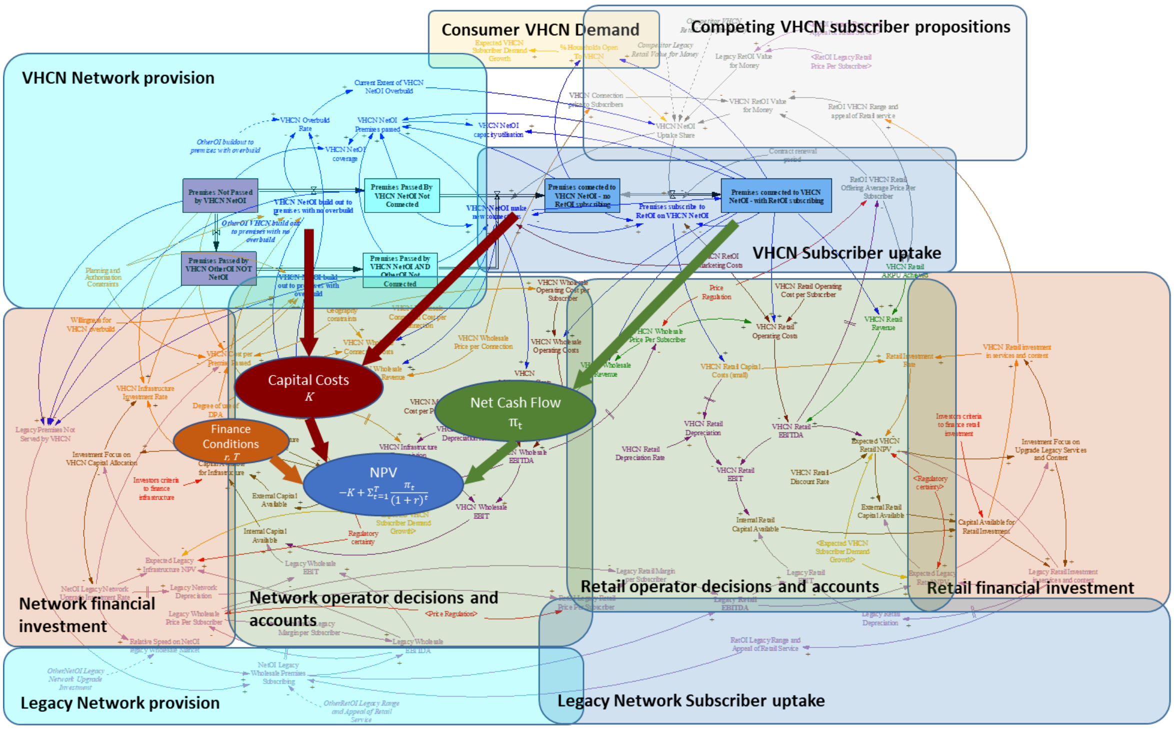


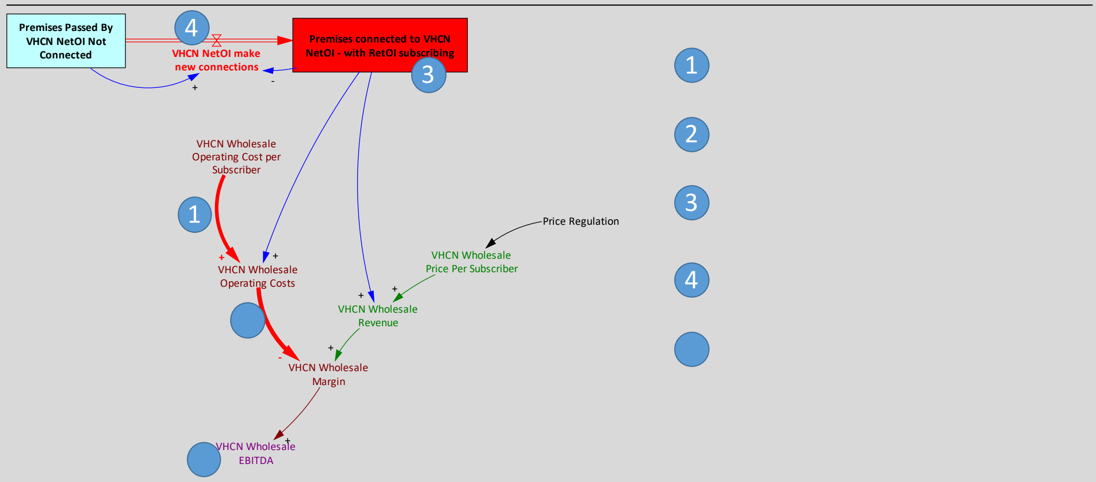
Figure 29: Overlay highlighting the NPV components for VHCN investment within the generic network model

8.4 Building up the Generic Network Business Model by sector

Model sectors are used to organise a structured description of the generic model. The model was built as a causal loop diagram and this approach is described in Annex A.2. Key concepts for the maps are included in the box insert below for quick reference.

Quick summary of causal loop diagram basics (for more detail refer to Annex A.2)

Conventions



8.4.1 VHCN infrastructure – premises passed and subscribers

The spine of the Generic Network Business Model represents premises that are categorised into a set of mutually exclusive segments reflecting VHCN coverage, connection and subscription. In Figure 30 below, the core segments are shown. Later, this segmentation will be extended to include explicitly where VHCN competition occurs (see section 8.4.7). The diagram is represented in the form of a stock and flow diagram and the approach and symbology of these types of diagrams is given in Annex A.3. The boxes represent a stock of premises and these premises transition through the rates connecting them. The VHCN investment and uptake journey are represented by moving from left to right through this set of premise states and transitions.

The diagram below and those described later have used terminology to unambiguously identify the stakeholder in the generic network model that the map concept refers to. The glossary for these terms is shown below in the box insert.

Glossary
Natori = Network Operator of Interest
RetOI = Retailer Operators of Interest on Network of Interest
OtherOI = Competitor Network Operator of Interest - competing with NetOI
Legacy & Upgrade = Cable 2.x, 3.0, ADSL, VDSL, FTTC
VHCN = Cable DOCSIS3.1, FTTP

The Network Operator of Interest (NetOI) is the focal stakeholder in the Generic Network Business Model.

This operator may be vertically integrated or wholesale only, but the network will have one or more retail operations using its network. These retailers are referred to as RetOI.

As will be described later, the network of interest is part of a potentially wider competitive market and other network operators (OtherOI) may also be investing in VHCN. Finally, the generic network model may include explicitly legacy networks (Legacy) whether cable or copper based if the operator of interest should own and operate these. These legacy networks may also have investment funding dependent on the operators' strategic positioning and the relative NPV attractiveness.

Returning to Figure 30, the premises are segmented into four states:

- "*Premises not passed by VHCN Net OI*" – premises (both individual and MDUs, business and homes) passed by the operator's VHCN. These premises are likely to have access to a legacy network – Copper based if the operator of interest is an incumbent. If a cable operator of interest, then a fraction may have non-VHCN cable connections (below DOCIS 3.1)
- "*Premises Passed by VHCN Not Connected*" – premises where there is no physical or wireless connection to the VHCN although it passes the premises and is available
- "*Premises connected to VHCN NetOI – no RetOI subscribing*" – premises have connection to VHCN either as part of the operator's rollout or past subscription (now terminated)
- "*Premises connected to VHCN – with RetOI subscribing*" – revenue generating segment with active subscriber premises using the VHCN of the operator of interest. This may be further segmented (arrayed) to explicitly represent retailer categories (retail operations by the operator of interest if vertically integrated, access seekers).

Note that these states correspond directly to the description introduced in section 6.1. Also included are the rates through which premises transition between states. As will be shown, these rates are causally driven by the other sectors of model.

The causal maps demonstrate how the balance of these states provides a logical calculation of key network metrics routinely reported, namely:

- *"VHCN NetOI Coverage"* – this is based on premises passed by the network operator of interest (NetOI)
- "*VHCN NetOI Premises Passed*" – this is the sum of all the premises segments passed (whether connected or not)
- "*VHCN Capacity Utilisation*" – this a measure of the take up within the network of interest. This is important as a key target for operators as they execute roll out.

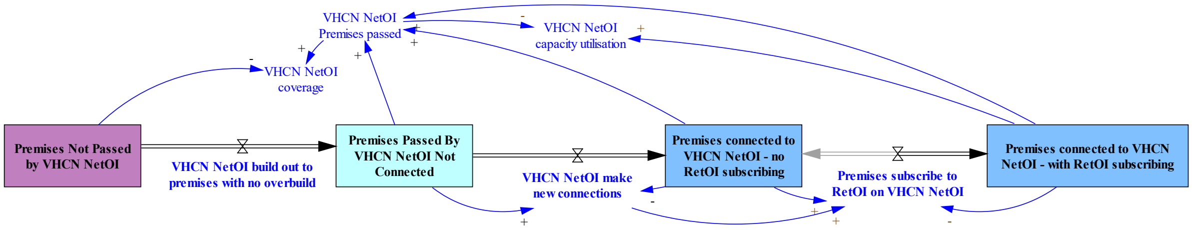


Figure 30: Stock flow diagram of premises acquiring and taking up VHCN

8.4.2 Capital investment and build rate

This section describes how capital investment is causally connected to the rate of VHCN build out. The structure represented in Figure 31 refers to VHCN capital investment by the network operator of interest (NetOI).

The rate at which VHCN investment takes place ("*VHCN Infrastructure Investment rate*") is influenced by the capital available and the operator's focus on the VHCN versus other allocations (these concepts are endogenous to the model and in turn will be described in a later section). Another logical influence is the requirement to have premises without VHCN to be targeted.

The rate at which premises is built out is influenced by the rate of investment and the unit "*VHCN Cost per premises Passed*". This unit cost is a critical component in determining the NPV attractiveness in many cases. Discussion and evidence for included concepts is provided in section 7.3 and the causal loop diagram (CLD) has incorporated these reflecting both the regulatory regime through to inherent characteristics of the market. These include:

- Duct and pole access regulation.
- Simplification of planning procedures – this can also influence the rate of build out.
- Duct and pole quality.
- Urban density influencing the line lengths and cost per metre of deployment.
- Geographical constraints – reflecting any constraints beyond the simple urban density that could reflect topography.

There is also a link with a negative causal influence from the stock of premises not passed – this reflects the distribution of unit build cost across the market and the stock without VHCN is depleted, those remaining are likely to be more expensive to reach. This is an example of closed feedback of cause and effect – and is discussed in more detail in the context of a specific market narrative developed using the model (See section 10.3). Note here that a negative causal relationship in these descriptions of the model does not necessarily imply an adverse or unwanted outcome but imply the nature of the causal relationship.

The CLD also incorporates the costs associated with VHCN connection and has also been brought as a further capex element within operators' corporate accounts. These connection investments are driven by the rate at which premise connections are carried out and unit costs are influenced by similar drivers to the build out.

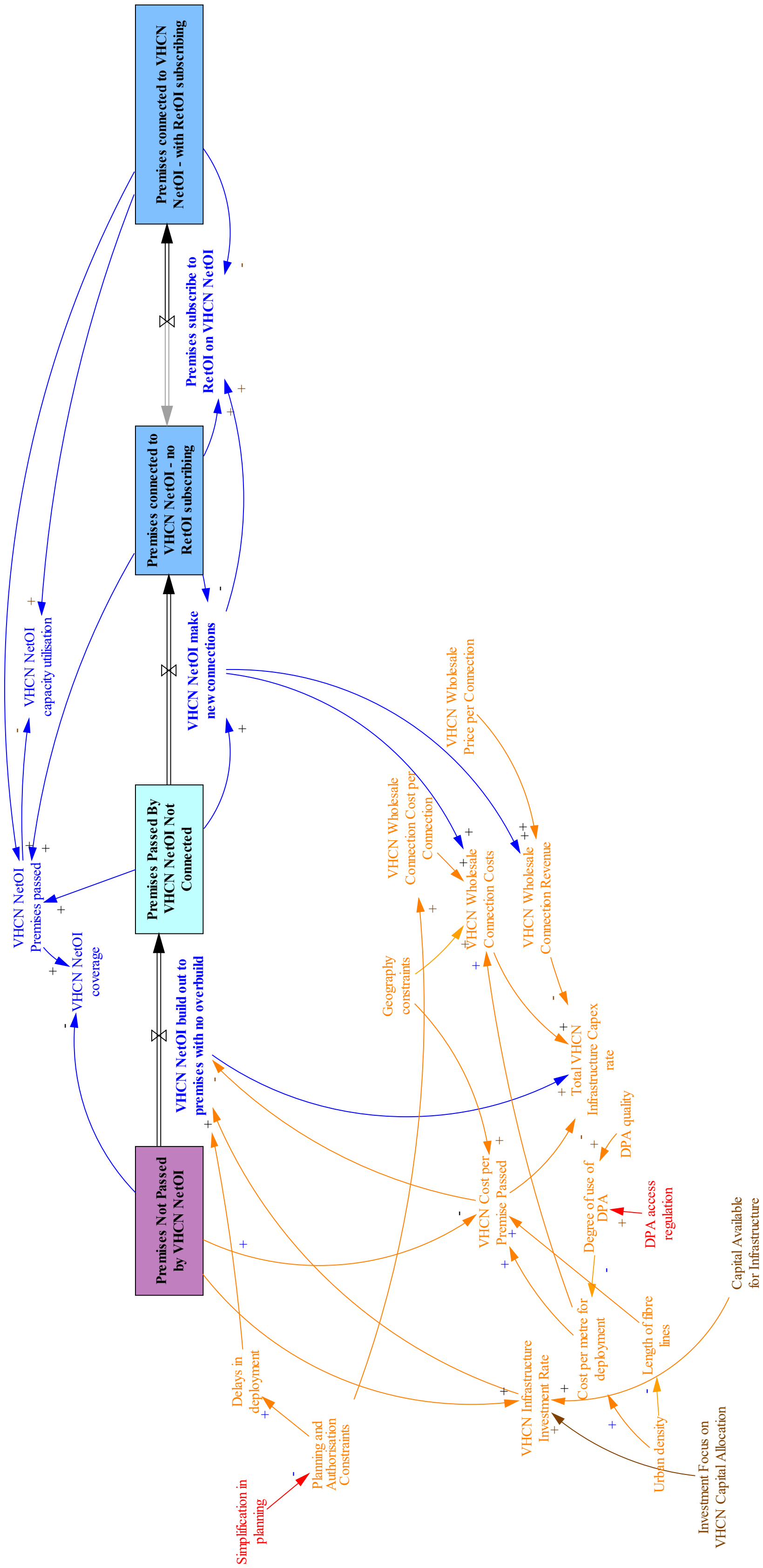


Figure 31: Causal Loop Diagram describing VHCN capital investment on premises coverage and connection coverage

8.4.3 Sources and cost of finance

The network operator of interest (NetOI) bases future VHCN investments on the capital that can be raised and the attractiveness of the investments (as articulated through the NPV and its trend).

Figure 32 extends the CLD shown in the previous section and now includes the VHCN NPV concept in the map together with contributions that VHCN business activities will make in cash flows and access to future capital. These components are discussed in detail in section 7.2.

Referring to the figure, "*Expected VHCN Infrastructure NPV*" is influenced by the cash flow expressed through *"VHCN Wholesale EBITDA",* the investment through "*Total VHCN Infrastructure Capex Rate*" and the discounting rate, "*VHCN Infrastructure Discount Rate*". The NPV calculation also needs to consider how the future cashflows may change and included is the underlying demand for VHCN services ("*Expected VHCN Subscriber Demand Growth*"). Finally, the discount rate will reflect underlying risks and in turn is influenced by the "Regulatory Certainty". Risk can also be mitigated by co-investment initiatives.

"*VHCN Wholesale EBITDA*" is generated through revenues generated from retailers using the network minus operator costs maintaining and operating the network. These will be shown explicitly in a later sector view (see Figure 33).

The VHN NPV outlook will influence the ability to make "*External Capital Available*" and in turn this contributes to the "*Capital Available for Infrastructure*". The operator will also be able to raise capital internally based on its own retained profits influenced by *"VHCN Wholesale EBIT"*. The EBIT is influenced by VHCN asset depreciation rates. There is also recognition that investors will have criteria (positive or not) towards infrastructure investment. Finally, operators may have competing needs from available infrastructure capital but that the more positive the VHCN NPV case is, the more will be committed for VHCN build out.

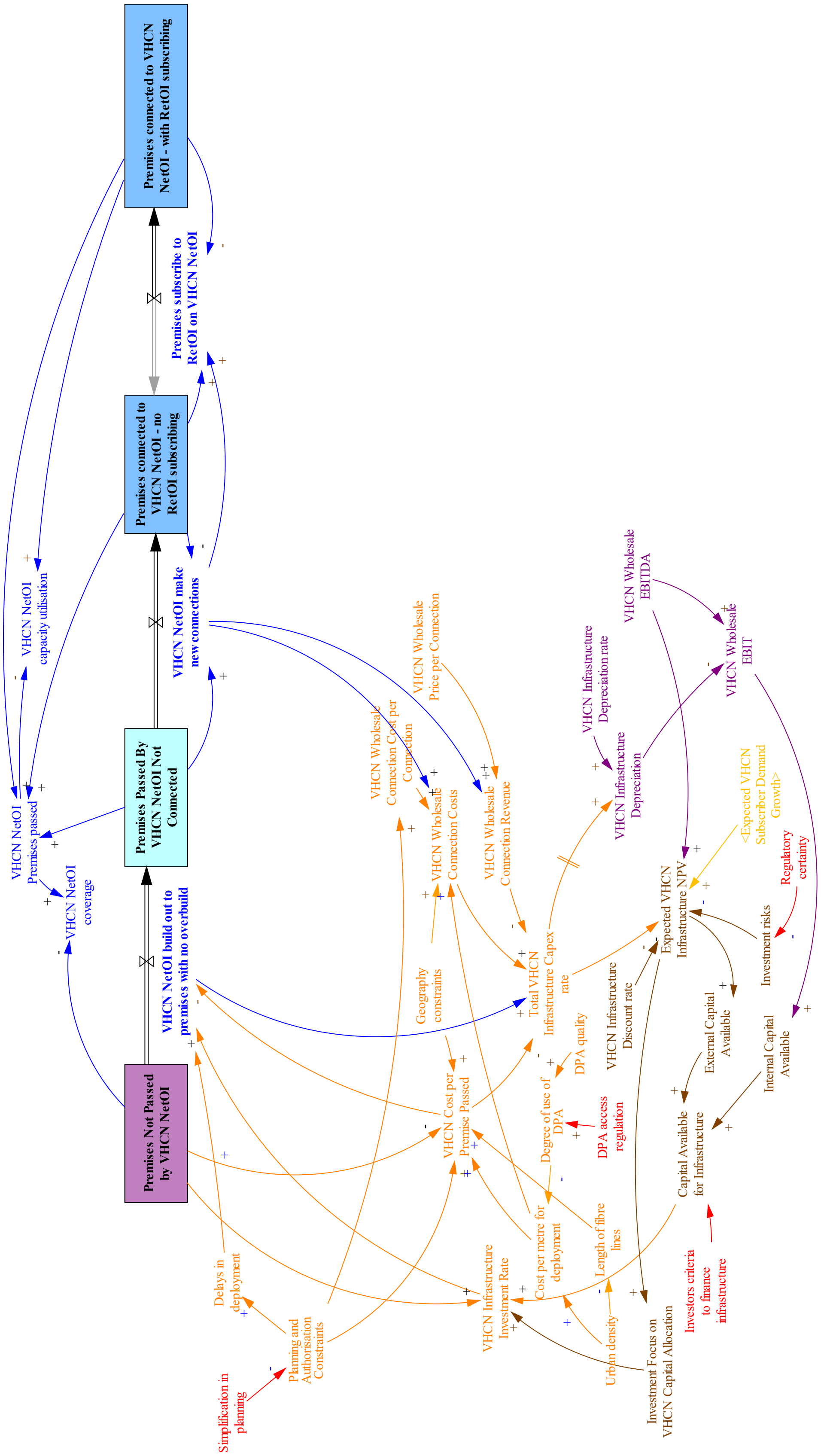


Figure 32: Causal Loop Diagram describing VHCN NPV trend assessment

8.4.4 Representing network operator's VHCN EBITDA

The earlier figure identified that the network operator's "*VHCN Wholesale EBITDA*" is governed by revenues and operating costs. These are shown in Figure 33 where both VHCN revenue and operating costs are represented in the CLD. The underpinning evidence for these is described in section 7.5. "*VHCN Wholesale Revenue*" is influenced by the number of subscribers on the network of interest (represented by the size of the premises stock segment "*Premises Connected to VHCN NetOI- with RETOI subscribing*") and the "*VHCN Wholesale Price Per Subscriber*". The wholesale price will be influenced by regulatory price regulation, if in place, and other measures such as forbearance, allowing freedom of pricing over a defined period. In the map, the price is influenced by the operator EBITDA to consider management pricing response along with any regulatory constraints. Combining the revenues with the "*VHCN Wholesale Operating Costs*" creates the "*VHCN Wholesale Margin*". Completing the management accounting of EBITDA, is the inclusion of the maintenance costs ("*VHCN Maintenance Costs*"*)*. Note that the CLD recognises that the maintenance costs need to support all premises passed NOT just those connected with active subscribers.

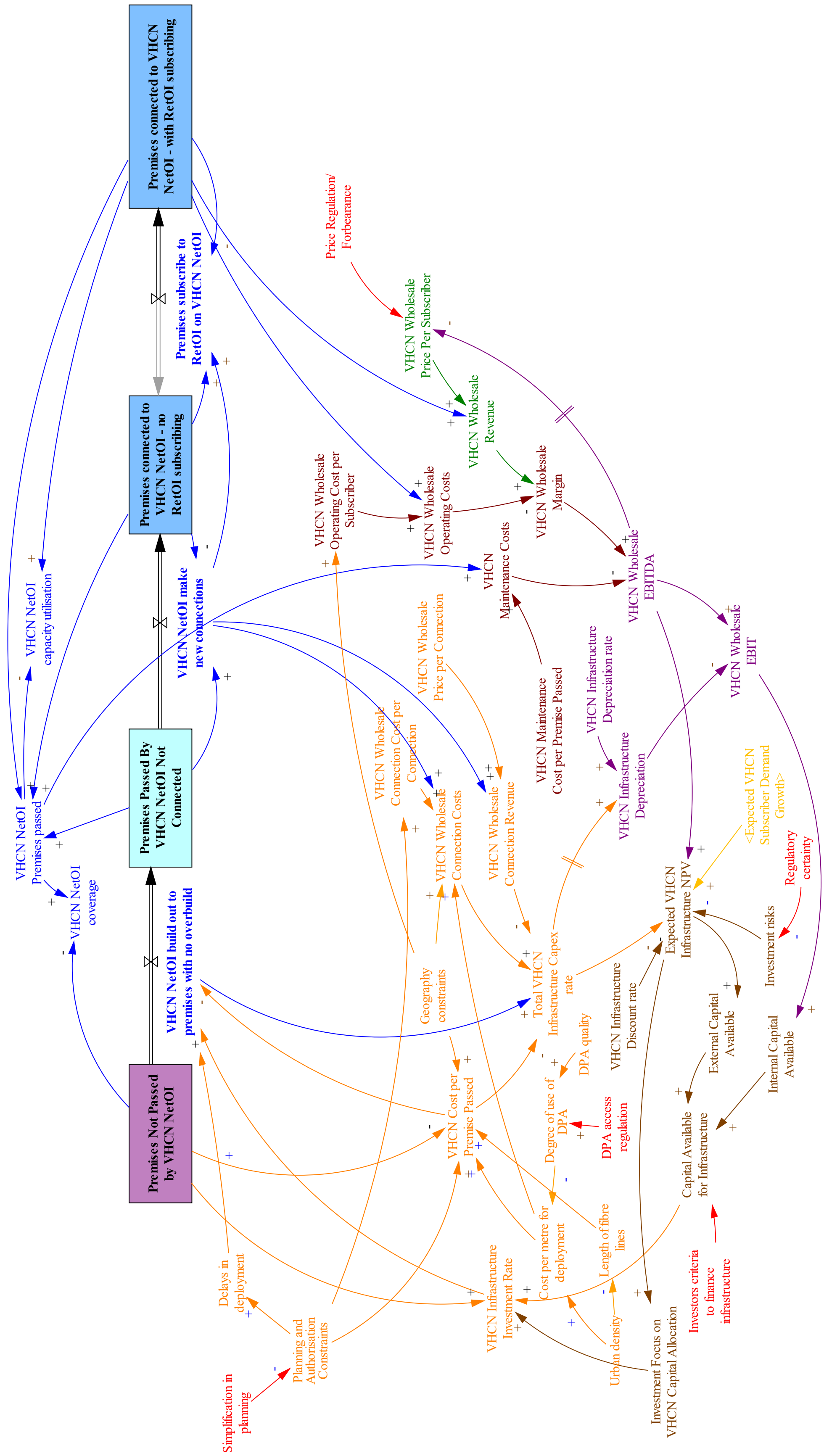


Figure 33: Causal Loop Diagram extending description of VHCN EBITDA drivers

8.4.5 Legacy networks

The generic network model needs to represent the entire business system of an operator. Both incumbent telco and cable operators are likely to own and operate existing networks before VHCN investment. From a company investment strategy perspective this creates choice for flow of capital – to upgrade existing copper or cable networks or build new VHCN fibre/DOCIS3.1 assets. The model represents the legacy network using consistent and complementary structure albeit at a simpler level reflecting the core study focus on VHCN investment.

Figure 34 illustrates how the legacy network's position with the overall generic network map. Figure 35 provides a more detailed extract.

Subscribers on the operator of interest's legacy network must necessarily be sourced from those premises not served by a VHCN connection. This is shown through the concept, "*Legacy Premises Not Served by VHCN*" which in turn influences the premises subscribing ("*NetOI Legacy Wholesale Premises Subscribing*"). Other influences on the subscribing rate are the quality of the service provided both at the network level ("*Relative Speed on NetOI Legacy Wholesale market*") and the services offered by retailers on this network ("*RetOI Legacy Range and Appeal of Retail Service*").

The map illustrates similar structure to represent the legacy network upgrade where the rates of upgrade ("NetOI Legacy Network Upgrade Investment Rate") is influenced by the relative attractiveness of the NPV case versus that for VHCN and the total capital available for infrastructure.

Management accounting for legacy network EBITDA ("*Legacy Wholesale EBITDA*") is developed through margin per subscriber and the number of subscribers. Legacy cash flows and NPV outlooks also contribute to sourcing internal and external sources of capital.

It should be noted here that the VHCN demand growth has a negative influence on the NPV for legacy network investment (it was a positive influence of course for the VHCN NPV). It is these competing NPVs that drive the operator to choose how to direct its investments (at overall market level or within geographically segmented regions).

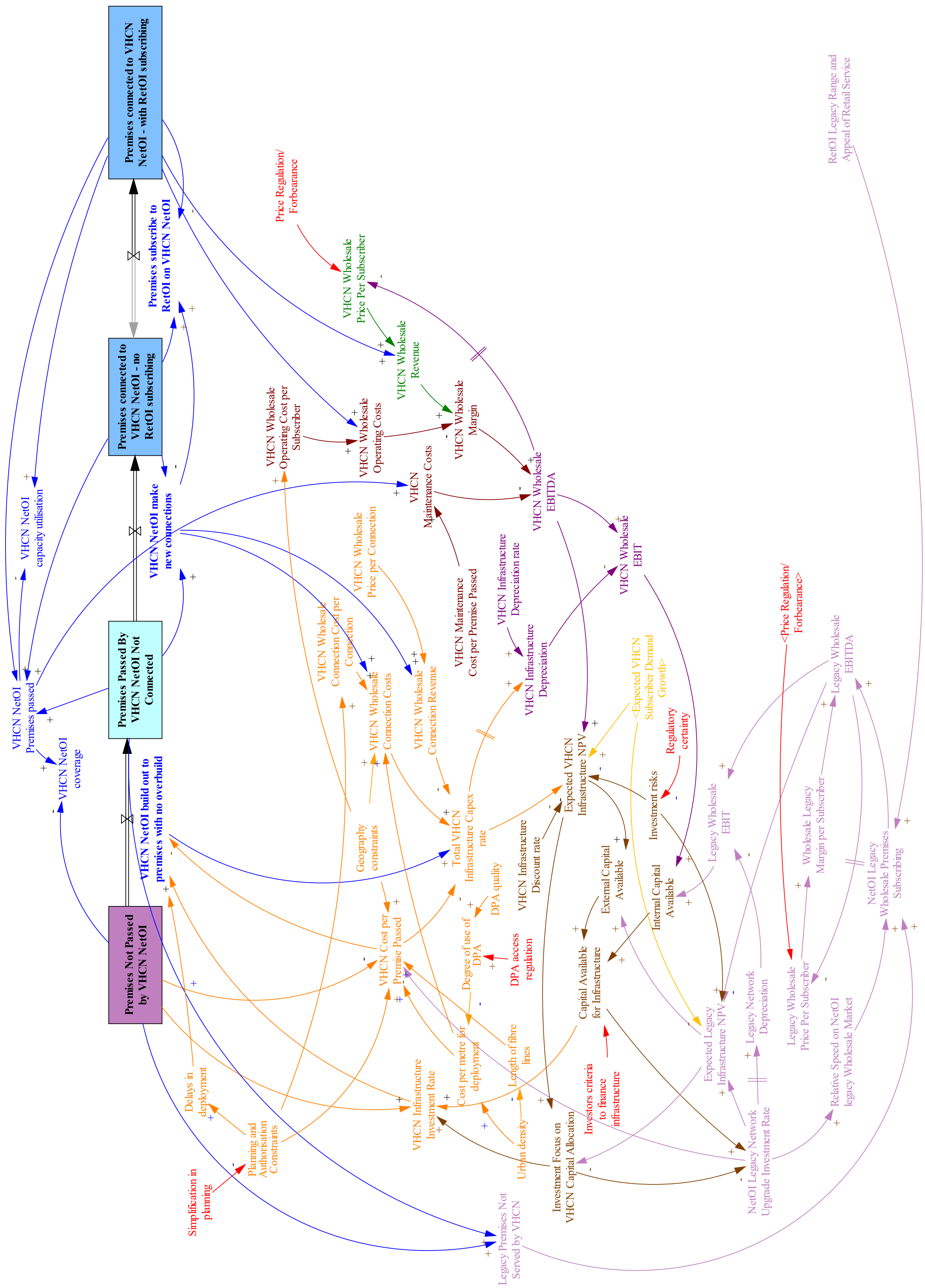


Figure 34: Causal Loop Diagram with inclusion of Legacy network investment

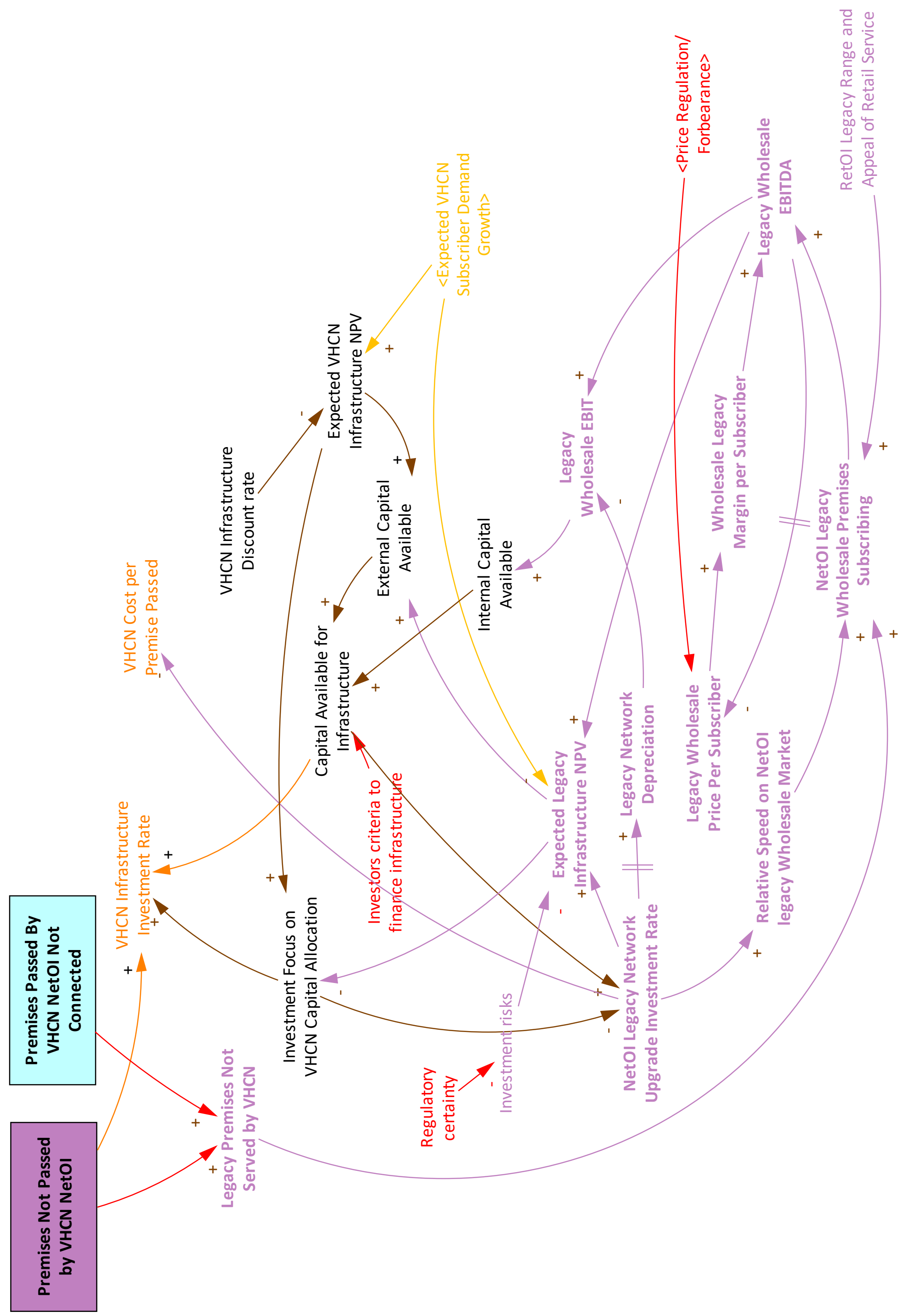


Figure 35: Causal Loop Diagram – detailed extract for Legacy network investment

8.4.6 VHCN demand and subscriber network choice

Representing VHCN demand is an important element of the generic model and is recognised through the research and stakeholder engagement as a key area of uncertainty and risk for VHCN investors. This presents subscribers with choice:

- To remain on a legacy network
- To subscribe to the VHCN of interest.

In fact, there is further choice to use a rival network and this will be introduced later (see section 8.4.7).

Choice will be made through rational value for money assessments by consumers reflecting the quality of service and price offered by the network and retail operators across VHCN and legacy networks.

Figure 36 and Figure 37 illustrate the representation of these subscriber choices in the generic model. The former presents it in the context of the complete generic model and the latter is an expanded view focusing on the area of interest.

VHCN demand is discussed in detail in section 7.5.2 of this report that includes both exogenous and endogenous drivers of inherent demand. *"% Households Open to VHCN"* represents the level of openness to consider VHCN. This may be influenced endogenously through word of mouth from current subscribers. This feedback structure (a causal loop through *"VHCN NetOI Uptake Share"* → *"Premises Subscribe to RetOI on VHCN NetOI"* → *"Premises connected to VHCN NetOI – with RETOI subscribing"* → *"% Households Open to VHCN"* → *"VHCN NetOI Uptake Share"*) provides a growth dynamic observed through the well-known Bass Diffusion model[80] commonly observed in technology adoption.

In addition, the demand is influenced by increases in "*Digital Access to Services*", "*Digital Literacy*" and "*Domestic Connected Technology*". These are discussed in section 7.5.2 and the first two offer opportunities for national and local government to influence demand.

The model represents the causal drivers that will determine the uptake of VHCN by a subscriber base if the network is available ("*VHCN NetOI Uptake Share")*. This is influenced by the underlying VHCN demand described above combined with the rational value for money choice between legacy network products and the VHCN service. In turn, value for money reflects the appeal of the service and the retail price that is presented to consumers by retail operators on the network.

It should be repeated at this point, as elsewhere in this report, that the model being described is a "canvas model" – it presents the structural components of the operators' business models. As will be shown in later sections of this report, this complete and exhaustive structural model can be used to develop narratives for a market under study – these narratives may simplify the complete model, direct research, form the basis for a quantitative analysis, or allow causal tracing of regulatory action.

The uptake share ("*VHCN NetOI Uptake Share")* influences the rate at which premises connect and start subscribing (or disconnect if the required uptake should decline rather than grow). The model does recognise that the rate at which consumers do respond will be dependent on retail operators' marketing ("*VHCN RetOI Marketing Costs*" and also contract renewal periods ("*Contract Renewal Period")*. The latter present touch points for subscriber action – adoption or switching.

[80] Bass, Frank (1969). "A new product growth for model consumer durables". Management Science. 15 (5): 215–227

Greenwood Strategic Advisors

SPC Network

strategy dynamics

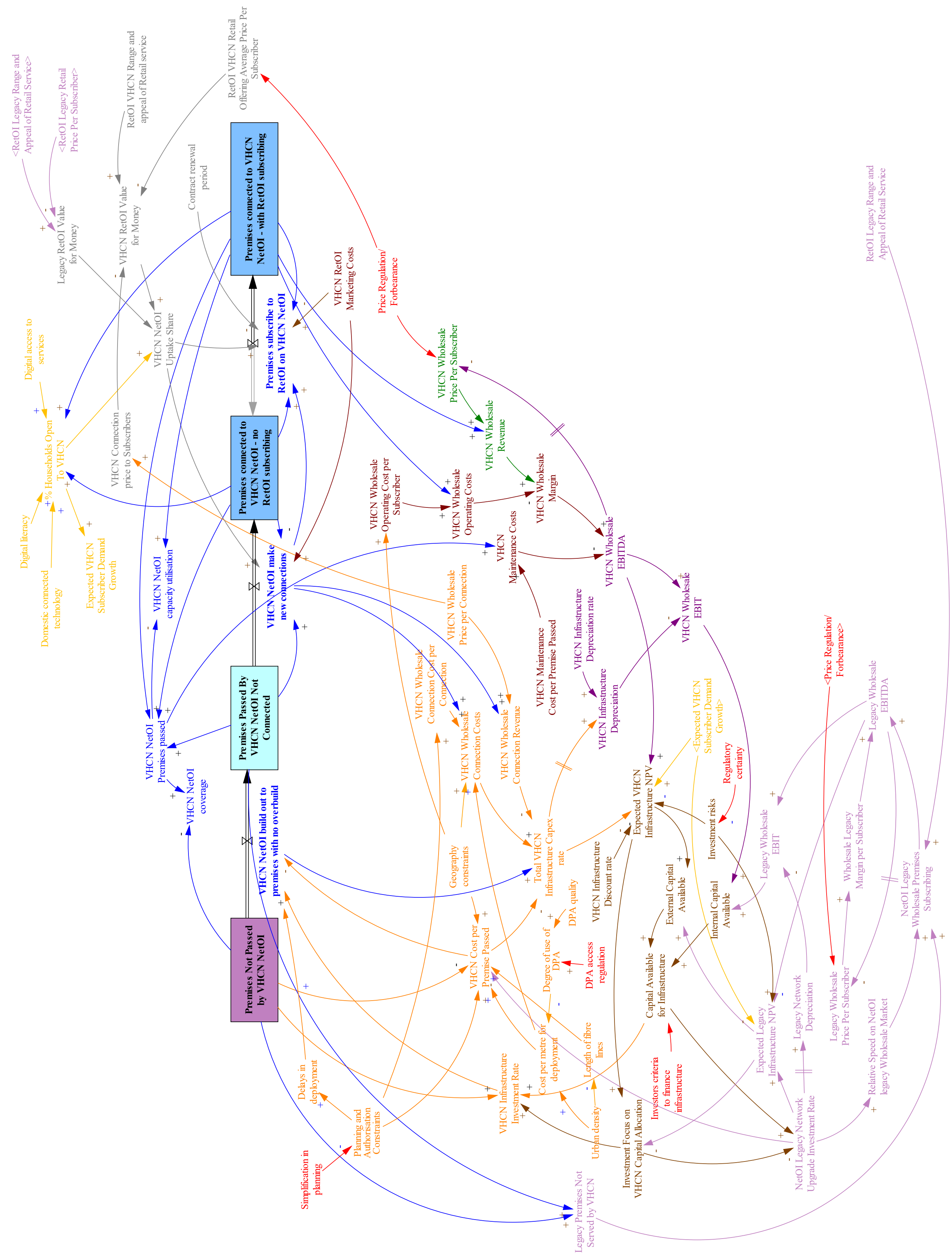


Figure 36: Causal Loop Diagram – extending model to include subscriber demand and choice

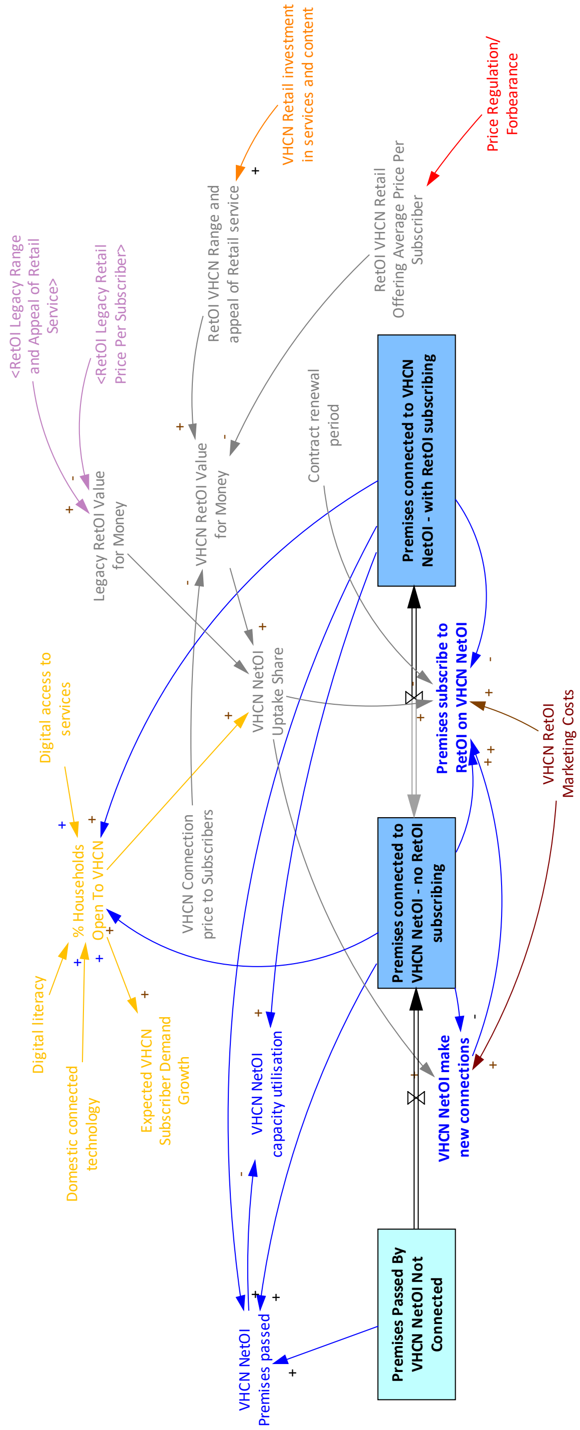


Figure 37: Causal Loop Diagram – detailed extract for subscriber demand and choice

8.4.7 Representing Competition and VHCN overbuild

Competition may occur between network operators and or between retail operations on a network. The generic model accommodates both although the focus has been to ensure that VHCN investment competition is represented in detail. The description below adds additional structure to the model by appending influences of other network operators (and associated retail operations on these networks).

As described in earlier sections, network operators face various forms of competition:

- Rivalry to gain first mover advantage to introduce a VHCN option to a premise
- VHCN overbuild – willingness to overbuild and response to competitor initiated overbuild
- Legacy network upgrade competition – incremental upgrading of Copper or cable networks
- Competition to attract retail operators to the network.

Retail operations will also seek first mover/preferred status on a VHCN subject to regulatory conditions and of course will engage in competitive rivalry on that network with other retailers to gain subscriber share.

Representing the dynamics of overbuild requires an extension of the core VHCN premise build out stock flows that were introduced in section 8.4.1. This extension is shown in Figure 38 below. The premise segmentation now includes two new stocks (collectively all the stock segments will remain MECE i.e. mutually exclusive and completely exhaustive). These two new segments are:

- "*Premises Passed by VHCN OtherOI NOT NetOI*" – these represent premises that a rival network operator (OtherOI) has passed and where the network operator of interest (NetOI) has not yet invested in.
- "*Premises Passed by VHCN NetOI AND OtherOI Not Connected*" – these represent premises with overbuild present offering multiple choices of VHCNs.

The network operator of interest will have strategic positioning in its willingness to overbuild (*Willingness for VHCN Overbuild").* This positioning will be shaped by regulatory access, protecting existing subscribers and the market's ability to support multiple positive NPVs across network operators. This was discussed in detail at section 7.5.3.

The CLD represents the overbuild rate ("*VHCN Overbuild Rate*") based on the fraction of new premises passed with overbuild by the network of interest and other operators *("OtherOI buildout to premises with overbuild*") and will influences the extent of overbuild the network operator is experiencing ("*Current Extent of VHCN NetOI Overbuild*"). This is turn will negatively influence *"VHCN NetOI Uptake Share".* As shown in the figure, the investment rates are now the sum of separate build out rates. However, the same basic structural causal relationships introduced earlier apply.

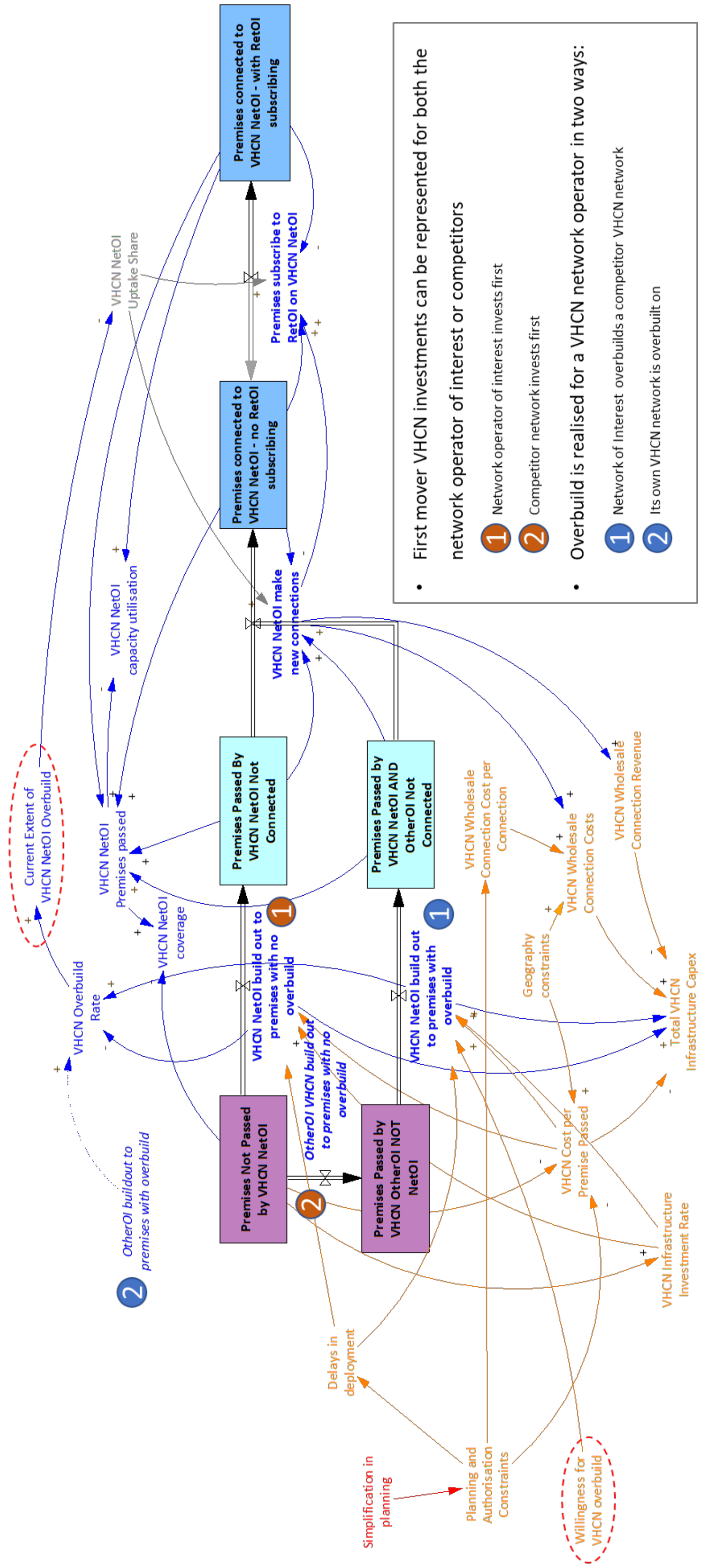


Figure 38: Causal Loop Diagram – detailed extract illustrating extension of premises migration to represent network infrastructure competition

Overbuild will certainly impact the network operator of interest subscriber uptake (along with the various demand influences discussed earlier in section 8.4.6). The competitor VHCNs and the attractiveness of propositions offered by retailers on these networks will impact the VHCN uptake share. This requires again an extension to the structure to explicitly capture this as contributing influences on a rational choice by those subscribers with multiple VHCNs available.

The figure below represents this through additional concepts that add in both competitor VHCN services (“*Competitor VHCN Retail Value for Money”)* and also legacy services if the competitor is using other operators’ copper or cable networks (“*Competitor Legacy Retail Value for Money”).*

The final elements of competition that need to be included is where competitor network operators are upgrading legacy networks, and this will influence the relative attractiveness of the network of interest’s legacy network. In addition, retail service quality and range of services on these competitor networks will also impact on legacy network subscriber numbers. This is illustrated in Figure 40.

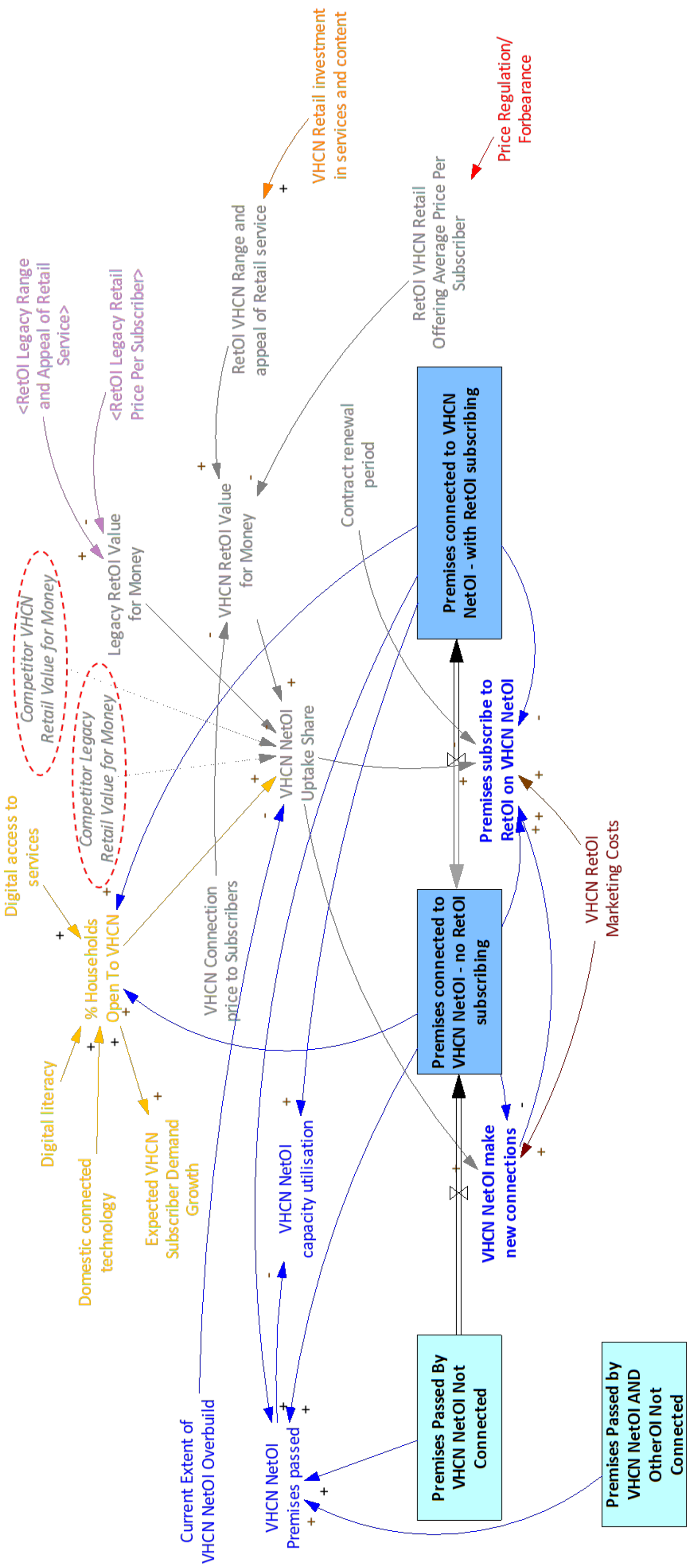


Figure 39: Causal Loop Diagram – detailed extract illustrating extension of subscriber choice to represent competition from other network value propositions

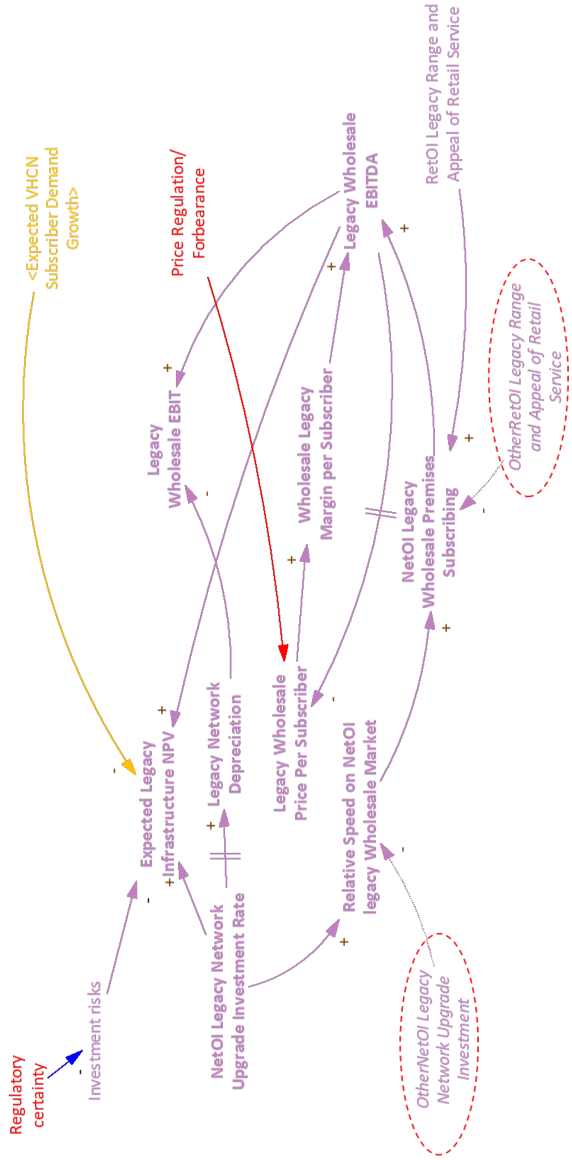


Figure 40: Causal Loop Diagram – detailed extract illustrating extension of legacy network competition

8.4.8 Representing retail operations

Earlier sections have referred to the influence of retail operations on the network of interest on the NPV based attractiveness of investments by the network operator.

Figure 41 shows the causal structure to represent the business system for retail operators on the network of interest. Similar structural elements will apply to the network operator. The retail operators will have NPV trends for any investments made on the operator of interest's legacy network and VHCN if available.

The structure presented below represents the most complex and complete view. As specific operators are considered, it is expected that simpler representation of retailers will be used but is represented here for completeness.

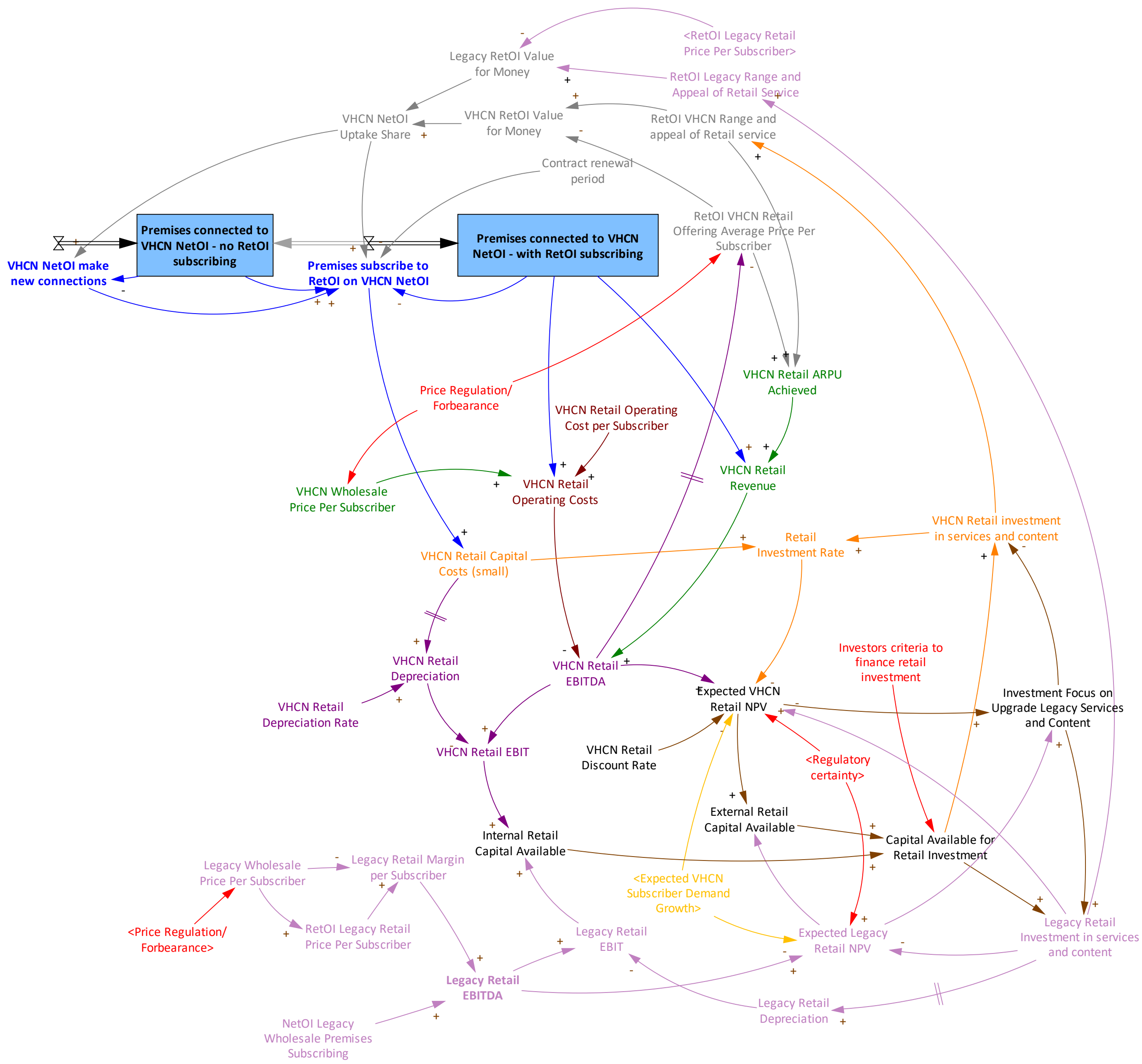


Figure 41: Causal Loop Diagram – detailed extract showing the retail operator business system

8.4.9 Using the Generic Network Business Model to represent entire markets

The generic model has been developed to represent a single network operator. The model captures the impact of competitor actions exogenously as described in section 8.4.7. However, this generic model can be considered as a building block to develop a view on the full national market or geographic region.

This is illustrated in the figure below where the Generic Network Business Model can be replicated to build a stack representing the market. The competitive links can be now considered endogenously within this combined national or regional network model.

The generic network business model can be replicated through this stack to represent competing technologies. The full national model may include layers representing cable operators, national 5G mobile providers and VHCN operators. In each case there may be legacy network assets such as DOCIS2, 3G/4G or Copper.

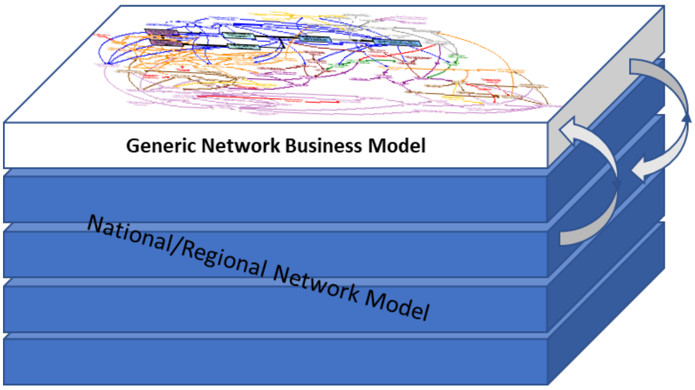


Figure 42: Extending the Generic Network Business Model to represent national or regional markets

8.4.10 How to use the Generic Network Business Model

The maps that have been presented in this section are the result of an iterative process to represent all possible drivers of VHCN investment through rational NPV based decisions by network and retail operators and importantly understand the interdependencies between them. They should be used in conjunction with the detailed descriptions of the determinants laid out in section 7. The final generic network model is shown in Figure 43. This figure is also repeated at Annex C in a larger format for printing.

Collectively these two artefacts (the maps and the determinant descriptions) provide a starting point for a range of analyses that NRAs may wish to pursue. These may include:

- Developing narratives to describe past, current or future behaviours from a market or operator
- Tracing the causal impact of regulatory actions across the model
- Reviewing the model across different markets to identify a typology of market or operator types
- Framing and articulating hypotheses with the model to test and validate through ad hoc quantitative analysis. This may require data collection and analytics

- Designing quantitative planning tools to support specific analysis for NRAs.

Each of these will start with the complete generic network model structure but the analysis journey from the generic to the specific analysis typically will allow some simplification through aggregation and/or omission of elements not pertinent to the area of study. This will be shown in action in the later sections where market narratives are created using the model.

In summary, the generic network model as presented is a qualitative tool for "thinking", framing and describing how VHCNs and the subscriber bases can evolve.

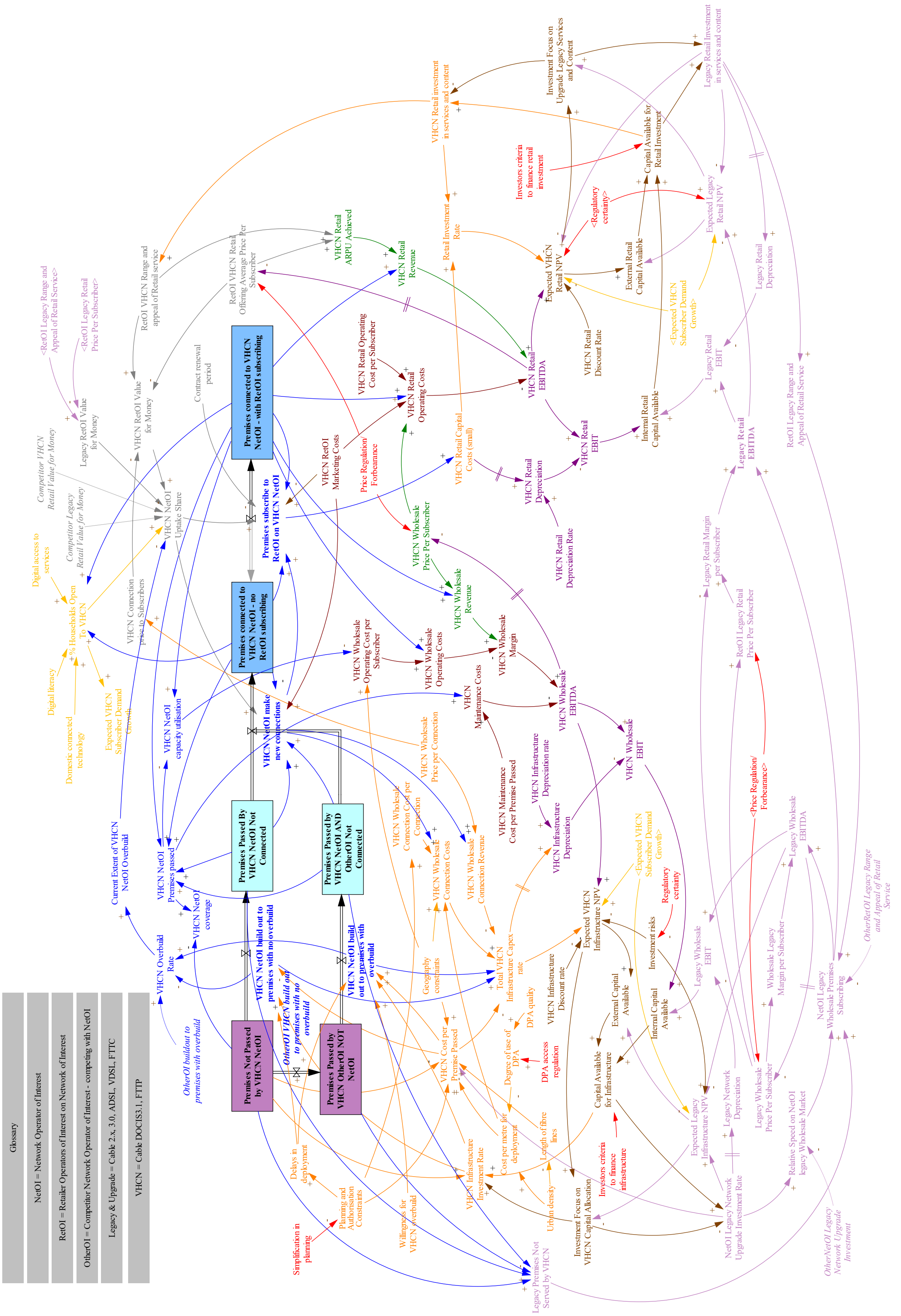


Figure 43: Complete CLD of Generic Network Business Model (see Annex C for enlarged version)

9 Comparison and categorisation of national markets

In determining national and regulatory policy for broadband, and in particular looking at those that encourage investment while maintaining a competitive market and protecting consumer, it is useful to consider and learn from use of similar policies in other countries. It should be clear from the analysis in the previous sections that the effectiveness of policies is dependent on the conditions that are present within a country or region of a country. Therefore, a policy that was successfully employed in one country may not be suitable in another because the market conditions are very different. It is useful to be able to categorise national markets and determine groups of countries that have similar attributes and is the objective for this section of the report. This will be useful in section 10 for the national market narratives, both for understanding the conditions present in those markets and for identifying groups of countries with similar aspects to those markets as well as any key differences.

9.1 Key discriminating attributes

A number of previous studies have analysed regulatory regimes adopted by countries. While these studies have provided descriptions of the national markets, few have tried to categorise the conditions that have shaped the reason for the adoption of those regimes. Some of these narratives do contain clues to those driving conditions. BEREC (2016)[81] goes further in trying to identify factors that influence the type and extent of investment in Next Generation Access. The table builds on the set of attributes identified by the BEREC study.

Attribute	Area of Impact	Notes
Duct & poles quality *Categories: Low, Low/Med, Med, Med/High, High*	Capital costs	The ability to re-use ducts and/or poles for VHCN to premises. Measure represents extent to which existing and re-usable ducts/poles to building is available. Source: BEREC (2016), BEREC (2010), NRA interviews. Information interpreted as (H)igh, (M)edium, (L)ow. Also in between measures are used such as L/M for Low/Medium. The entry is left blank if there was not sufficient information to determine duct quality.
Copper network quality *Categories: Low, Low/Med, Med, Med/High, High*	Legacy network capability	Extent to which the legacy copper network supports FTTC/Vectoring upgrades. This requires good quality copper and sufficiently short lengths between distribution point (usually cabinet) and the premises. Source: BEREC (2016). Information interpreted as (H)igh, (M)edium, (L)ow. The entry is left blank if there was not sufficient information to determine copper network quality.
Percentage of rural household *%*	Cost per property passed, connection cost	Rural properties require longer cable lengths per household passed, although cost per metre may be cheaper than in urban areas. Source: IHS and Point Topic (2018).

[81] BEREC (2016) *Challenges and Drivers of NGN Rollout and Infrastructure Competition*.

Attribute	Area of Impact	Notes
Incumbent retail dominance for fixed broadband *%*	Revenue, competition	The percentage of broadband retail market held by incumbent across all fixed broadband technologies. Source: DESI (2018). Cell left blank if no information in DESI report.
Fixed broadband technology in order of availability as highest capacity infrastructure. Excludes cable. *Types: FTTP, VDSL, ADSL*	Properties passed, Legacy network capability	List of deployed fixed broadband technologies in prevalence order as most capable infrastructure. For example, ADSL would be listed as best available only in areas where FTTP and VDSL are not available. Only listed in percentage > ~15%. Source: IHS & Point Topic (2018). Rules for list order used are: FTTP listed first if > 50%, otherwise VDSL or ADSL listed first. ADSL (or DSL) % = VDSL% - ADSL%.
Percentage of Cable DOCSIS 3.x coverage *%*	Properties passed, competition	DOCSIS 3.x represents a VHCN capable network in terms of speeds at 100+ Mbit/s and capable of being upgraded to 1+ Gbit/s. Source: HIS & Point Topic (2018).
Percentage of VDSL coverage *%*	Legacy network capability	The percentage of households with FTTC/VDSL available. Source: HIS & Point Topic (2018).
Local/Municipality network prevalence *Categories: Low, Low/Med, Med, Med/High, High*	Competition	The extent to which local authorities and municipalities, or local cooperatives build and/or operate FTTP networks. Source: BEREC (2016), DESI (2018), NRA interviews and workshops, other sources. Cell left blank if insufficient information to determine extent of municipal and local authority / cooperative networks. It is a qualitative assessment based on a variety of sources. Some data sources are likely to include non-FTTP networks such as local WiFi in the operator count. Measures are (L)ow, (M)edium, (H)igh.
Predominant competition type *Categories: Infrastructure, Retail, Infrastructure/Retail*	Overbuild / Competition	The extent to which competition is provided by Multiple (I)nfrastructures or (R)etail. Source: BEREC (2016), NRA interviews and workshops, narratives from other data sources.
Ultrafast coverage (FTTP or DOCSIS 3.x) *%*	Properties passed	Source: IHS & Point Topic (2018). Ultrafast data column. Assumes this indicates that a premises has 1 or more ultrafast infrastructure passing it.
NGA coverage (FTTP, DOCSIS 3.x, VDSL) *%*	Properties passed, legacy network capability	Source: HIS & Point Topic (2018). Ultrafast data column. Assumes this indicates that a premises has 1 or more NGA infrastructure passing it.

Attribute	Area of Impact	Notes
Percentage of 100+ Mbit/s subscriptions *%*	Adoption rate	Source: IHS and Point Topic (2018). This indicates subscriptions that use at least the low end of the VHCN definition. Some subscribers may be using VHCN infrastructure but subscribing to speeds less than 100 Mbit/s, i.e. not using the VHCN capabilities.
Broadband price index *Index: 0 (high prices) to 100 (low prices)*	Retail price	This is an index based on prices of a mixture of 12 prices based on 3 speed groups and 4 packages of 1*, 2*, 3* 4* multi-play. Note that a higher index indicates a lower average price. E.g. an Index of 94 for France compared with EU28 Index of 87 indicates that broadband prices are generally lower than the EU average. Source: DESI (2018). Cell left blank if no information in DESI report.

Figure 44 overleaf shows summary data for the 28 EU countries, or blanks where unknown. This data comes from a variety of data sources, as specified in the attribute description table. Key data sources were: BEREC (2016)[82], BEREC (2010)[83], DESI (2018)[84] and IHS & Point Topic (2018)[85].

[82] BEREC (2016) *Challenges and Drivers of NGN Rollout and Infrastructure Competition*.
[83] BEREC (2010) *Annex to the BEREC Report Next Generation Access – Implementation Issues and Wholesale Products.*
[84] DESI (2018) *The Digital Economy and Society Index*, European Commission.
[85] IHS & Point Topic (2018) *Broadband Coverage in Europe 2017*. European Commission.

	Civil Infrastr. (Ducts Poles)	Infrastr Cu Quality for FTTC	% of Households Rural	Incumbent Retail Dominance % Fixed BB	Technology Fixed Telco (Order, > 10%)	FTTP Coverage (%)	DOCSIS 3.x Cable Coverage (%)	Local or Municpal Network Prevalence	Predom Comp Type	Ultrafast Coverage (FTTP or DOCIS3.x)	NGA Coverage	% 100+ Mbit Subscrip	Price Index High : 0 to 100 : Low
AT	L	H	13.6%	58.0%	VDSL, FTTP, ADSL	13.5%	52.8%	L	R	65.8%	90.0%	7.0%	90
BE	L	H	4.1%	46.5%	VDSL	0.8%	96.8%	L	R	96.9%	99.0%	51.7%	82
BG	M	L	19.9%	26.2%	ADSL, FTTP	37.8%	64.2%	H	I	74.6%	74.6%	11.1%	80
HR		L	22.1%	47.6%	VDSL, ADSL, FTTP	16.8%	28.3%	L	R	34.1%	67.4%	2.0%	65
CY			11.6%	57.6%	FTTP, VDSL, ADSL	51.2%	70.2%	L	R	85.1%	87.5%	0.3%	65
CZ	L/M		14.3%	24.0%	VDSL, FTTP, ADSL	37.4%	38.8%	M	I / R	60.4%	88.6%	21.6%	87
DK	M	H	10.8%	52.4%	FTTP, VDSL, ADSL	62.7%	68.8%	M	R	85.9%	94.6%	21.6%	89
EE			21.3%	57.0%	FTTP, VDSL, ADSL	50.7%	55.6%		I	71.3%	80.4%	11.5%	85
FI	M		18.5%		FTTP, VDSL, ADSL	37.5%	36.2%	H	I	59.1%	75.1%	29.9%	94
FR	H		15.6%		ADSL, FTTP, VDSL	28.3%	27.8%	M	R	41.8%	51.9%	14.5%	94
DE	L	H	8.6%	40.1%	VDSL, ADSL	7.3%	63.7%	M	R	64.9%	84.1%	12.7%	91
EL			20.1%	45.7%	ADSL, VDSL	0.4%	0.0%	L	R	0.4%	49.6%	0.0%	69
HU	M		31.7%	40.7%	ADSL, VDSL, FTTP	26.4%	66.7%		R	74.4%	82.0%	38.3%	85
IE	L	H	33.8%	32.2%	VDSL	8.3%	49.0%	L	R	53.0%	88.8%	23.6%	77
IT	L	H	12.1%	45.5%	VDSL, FTTP, ADSL	21.7%	0.0%	L	R	21.7%	86.8%	8.5%	87
LT	H	L	30.3%	50.4%	FTTP, ADSL, VDSL	81.6%	46.4%		R	81.6%	81.6%	42.0%	87
LV	L/M		28.0%	57.1%	FTTP, VDSL, ADSL	85.3%	29.0%		R	88.1%	91.3%	54.9%	94
LU			11.5%	66.1%	FTTP, VDSL, ADSL	57.2%	73.2%		R	86.6%	94.6%	23.9%	88
MT	L	H	1.0%	49.1%	VDSL, ADSL, FTTP	23.0%	99.9%	L	R	99.9%	100.0%	13.6%	
NL			8.2%	41.4%	VDSL, FTTP, ADSL	31.9%	95.1%	L/M	R	97.3%	98.3%	32.9%	90
PL			20.7%	28.8%	VDSL, ADSL, FTTP	23.8%	44.5%		R	52.5%	66.7%	21.6%	88
PT	H		15.1%	39.7%	FTTP, ADSL	89.4%	76.3%	M/H	R	95.2%	95.2%	49.1%	67
RO		L	21.0%	23.2%	FTTP, ADSL	61.0%	35.9%	H	I	72.8%	74.0%	65.5%	87
SK			28.8%	35.1%	FTTP, VDSL, ADSL	56.4%	29.7%	L	R	68.1%	78.7%	13.8%	88
SI			23.3%	35.2%	FTTP, VDSL, ADSL	52.2%	57.4%	M	R	74.6%	83.2%	17.6%	73
ES	H		18.5%	41.6%	FTTP, ADSL, VDSL	71.4%	48.8%		I / R	83.6%	85.0%	24.0%	74
SE		L	8.9%	37.5%	FTTP, ADSL, VDSL	66.4%	36.8%	H	I / R	73.3%	77.7%	60.8%	87
UK	L	H	8.5%	36.7%	VDSL, ADSL	2.3%	49.7%	L	R	51.1%	93.9%	16.6%	86
EU 28			13.9%	40.3%	VDSL, FTTP, ADSL	26.8%	44.7%		R	57.8%	80.1%	20.4%	87

KEY	H	M/H	M	L/M	L
Team judgement	High	Medium High	Medium	Low Medium	Low

Figure 44: Summary of EU country attributes (data circa June 2017)

9.2 Creating a national market typology

The typology aims to create groups of countries with similar characteristics in terms of determinants of investment. This can be used to provide exemplars in country narratives:

- Improve the understanding of the characteristics that encourage or discourage investment in VHCN
- Where countries have similar characteristics but different levels of investment in VHCN this can be used to try to find a system reason for the differences and identify potential regulatory and policy options that can be used to help increase investment in those countries.

9.2.1 Previous Typologies – BEREC (2016)

BEREC (2016) suggests some key contributing factors to investment in NGA and proposes a flow chart of contributing factors. These factors are:

- Availability of quality ducts and poles
- Good quality copper enabling high-end of speed range for FTTC/VDSL
- High willingness to pay / Digital way of life
- Population density and urbanisation
- Cable competition
- Competition through investment by municipalities.

9.2.2 Data analytics from European Commission data and BEREC information

As far as possible, the available data is used to examine relationships between the characteristics and investment in VHCN. Since cable presence is largely historical and VHCN status is achieved through incremental investment, the analysis will focus on VHCN presence through FTTP. This is not to diminish the role of DOCSIS 3.x cable as part of the overall VHCN provision for a country, but investment of new architectures is likely to be via FTTP-based, with any expansion of cable networks likely to be based on FTTP rather than HCF.

The analysis tends to focus on one driver at a time with some colour coding used to examine another characteristic. This is to identify the strongest determinants of investment. An understanding of the NPV decision process indicates that factors which contribute to the capital cost, net cash flow and cost of finance parts of the NPV calculation all provide some degree of contribution to the investment decision.

<u>Ability to re-use ducts and poles on investment in FTTP</u>

Figure 45 shows the quality of ducts and poles in terms of ability to re-use these to deploy FTTP to premises, including last drop to the premises. Circled areas show groupings where ability to re-use is low (L Category) and coverage of FTTP is low, ability to re-use is moderate (generally available in larger cities, L/M and M categories) and FTTP coverage is moderate (Latvia is an outlier), and where ability to re-use is high (most cities and larger towns, H category) and FTTP coverage is high (France is an outlier). There are a number of countries where no information is given on ability to re-use ducts and poles shown on the right-hand side of the graph. This indicates that there is a strong relationship between ability to re-use ducts and poles infrastructure and investment in FTTP, supporting evidence that the capital cost saving in infrastructure deployment are a major incentive for FTTP investment. This analysis would be further strengthened by more information on the unknown countries.

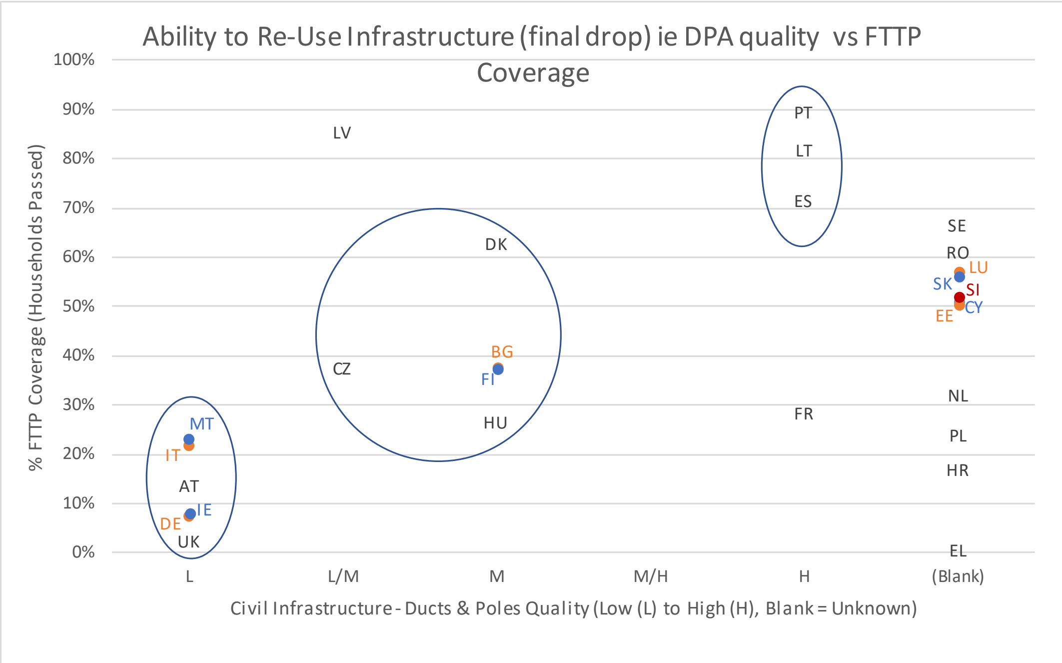


Figure 45: Ability to re-use ducts and poles infrastructure vs % of Households passed by FTTP

<u>Quality of copper network and impact of FTTC/VDSL on investment in FTTP</u>

Figure 46 shows the quality of the copper network in terms of its ability to support higher-end of speed capabilities for FTTC/VDSL. A circle shows a grouping for countries with low quality copper (generally long copper line lengths) and a high level of FTTP coverage (outliers Croatia and Bulgaria). Another circle shows a grouping with high quality copper for FTTC/VHCN and lower levels of FTTP coverage (outlier Denmark). Countries on the right-hand side of the of the graph have no information on copper quality. This indicates that a lack of good quality copper encourages investment in FTTP since FTTC/VDSL will not an effective mechanism for incumbents to deal with competition from a cable. Where good quality copper exists an investment in FTTC/VDSL can be used to increase broadband capability to meet initial competition from cable and possibly FTTP networks. This is further re-enforced by Figure 47 which shows availability of VDSL against FTTP coverage. A clear relationship can be seen between a high degree of VDSL available and lower FTTP coverage, with a few outliers (e.g. Luxemburg). Countries with known high copper quality are shown in green and those with known low copper quality are shown in red. Denmark can be seen to be an exception where good quality copper is reported leading to a reasonable level of VDSL availability but there is also a relatively high FTTP presence.

Note that Croatia is reported by BEREC (2016) to have a copper network that is not suited to FTTC/VDSL but appears to have VDSL available to around 58% of households. It is possible that VDSL is widely available in Croatia but the speed benefits to consumers will be limited by the length of the copper lines.

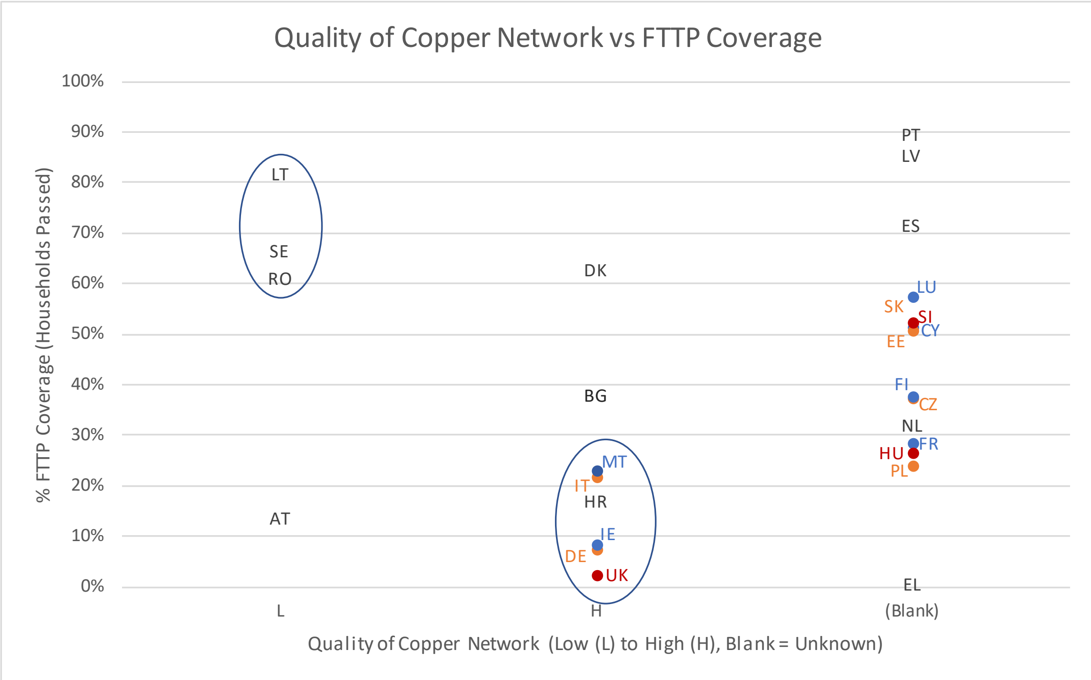


Figure 46: Quality of copper network to support FTTC/VDSL performance vs % of households passed by FTTP

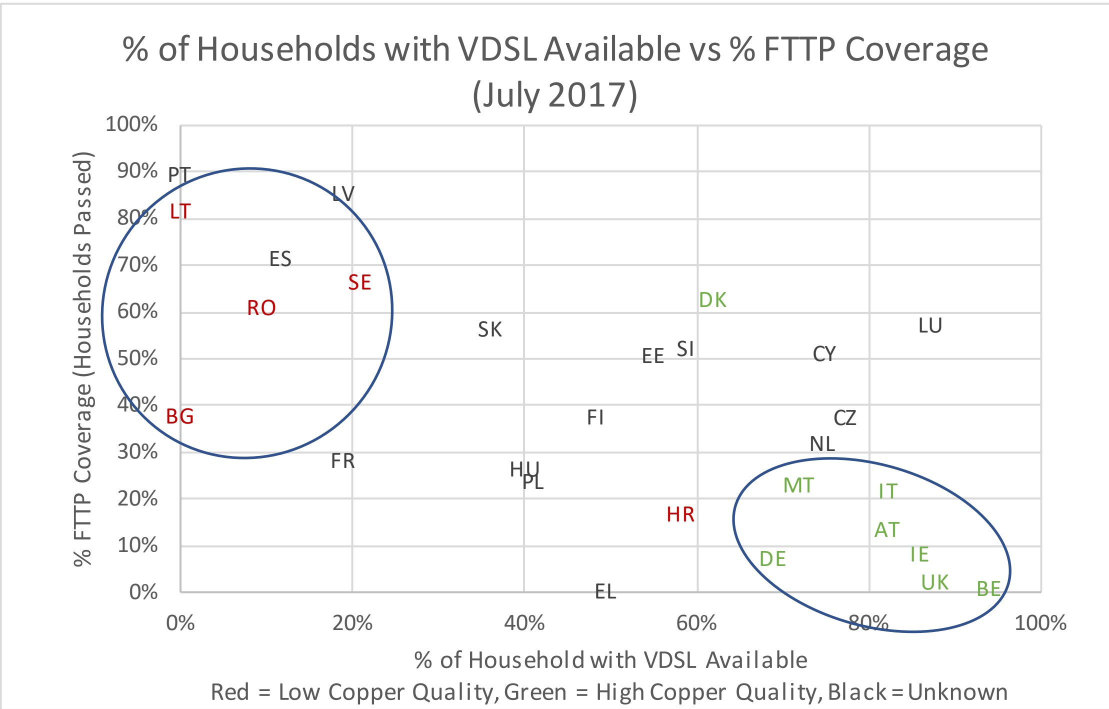


Figure 47: % of Households with VDSL available vs % of households passed by FTTP

Willingness to pay / digital way of life

A higher willingness to pay and a digital way of life can lead to consumers being willing to pay higher retail prices for a higher quality of broadband services and/or lead to higher subscription rates for a particular retail cost. Absolute subscription prices are not necessarily a good measure of willingness to pay. Consumers will be comparing VHCN retail prices legacy network retail prices so the assessment will be relative. Also, willingness to pay can be reflected in willingness to pay higher upfront charges for connection to an FTTP network which could lead to lower retail prices since operators will have recovered some of the capital investment costs through the connection charge rather than through the subscription charge.

Figure 48 shows broadband price indices against % of households passed for FTTP. Note that the index takes values between 0 and 100 and uses high values to indicate lower prices, so the bottom axis scale has been reversed to show lower prices to the left. The EU28 index average is 87, so any country with an index above 87 has below average prices. The price index represents an overall score for a range of speeds and products so does not capture the extent of price premiums for faster broadband. It does give an idea of absolute pricing norms for countries and would indicate where there are typically higher revues per customer. The graph shows there is no obvious relationship between the price index and FTTP coverage. Portugal with the highest FTTP coverage has prices well above average, but Latvia with similar levels of coverage has prices well below average. There is a similar range of prices for countries with a low FTTP coverage.

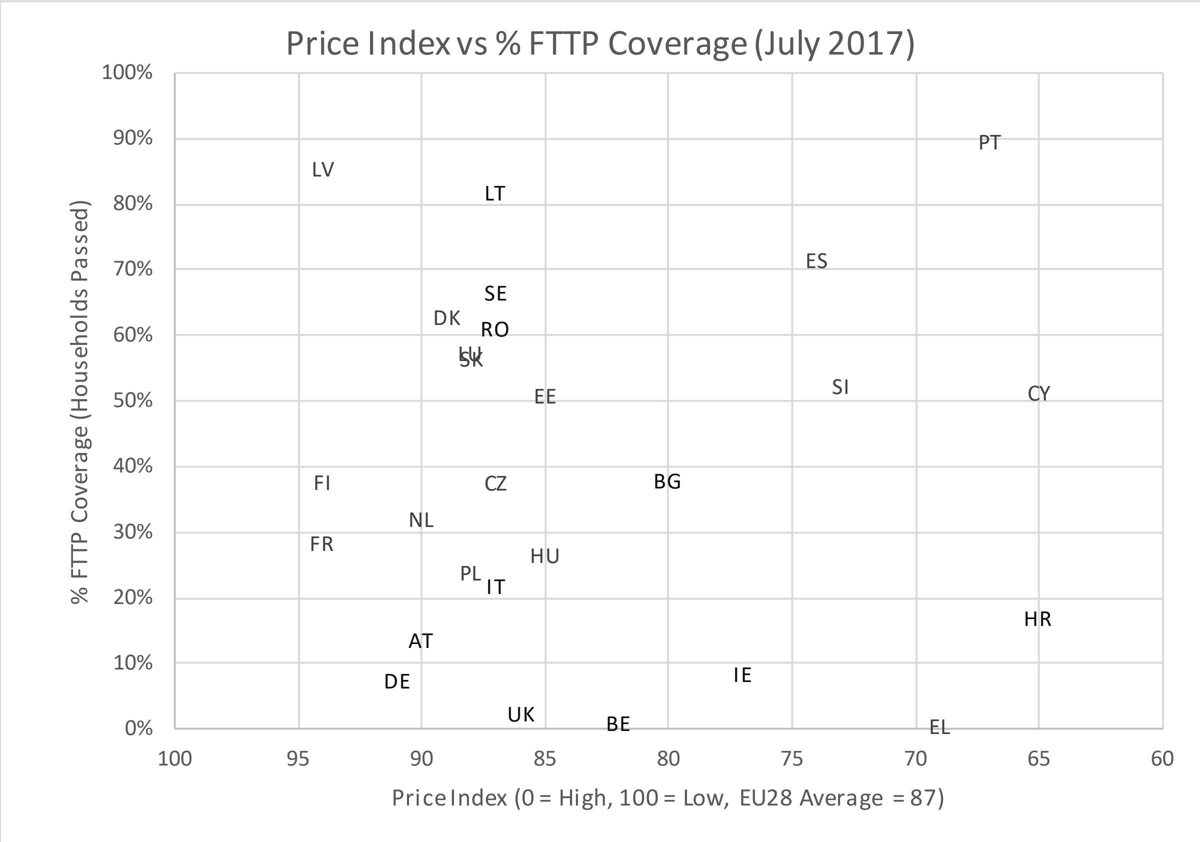


Figure 48: Price index (Low = 100, High = 0) vs % of households passed by FTTP

Figure 49 uses information on 100+ Mbit/s subscription rates to attempt to get a picture of the extent of digital way of life. It uses a normalised measure of % of 100+ Mbit/s subscription ÷ % of households passed by VHCN. This is the percentage of people with an option for high speed internet that have chosen to subscribe to it. It shows that Romania and Sweden have high subscription rates where over 80% of people with access VHCN have chosen to subscribe to higher speed broadband. This compares, for example, with Spain that has high availability of VHCN but significantly lower subscription rates to 100+ Mbit/s plans. Countries marked in red are those with low levels of FTTP coverage(less than 25%) so those with high VHCN coverage have mainly achieved this through upgraded cable networks that were originally built as an investment in TV services rather than a specific investment for broadband access (this is not to downplay that almost all cable networks have invested to upgrade to DOCSIS 3.0 or 3.1 in order to provide high-speed internet access and video-on-demand services).

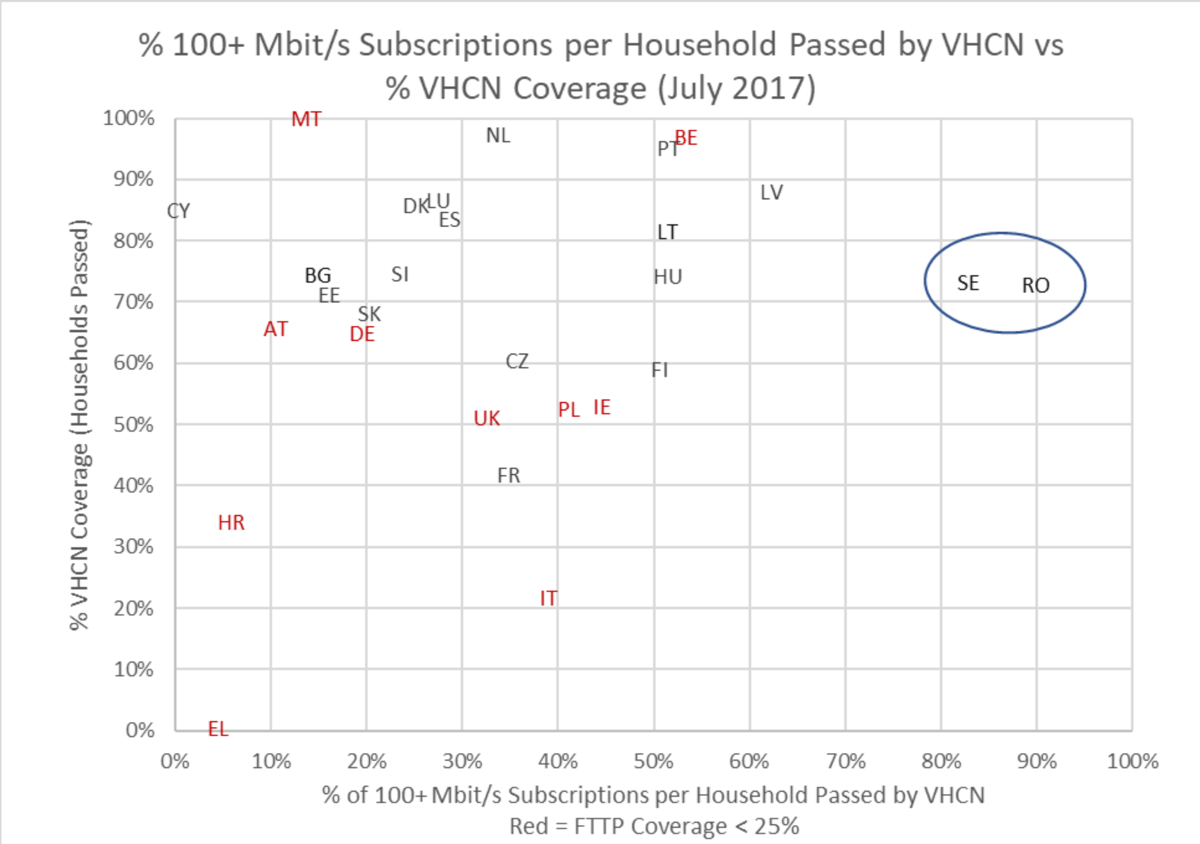


Figure 49: % of 100+ Mbit/s subscriptions per household passed by VHCN vs % of households passed by VHCN

<u>Cable Competition</u>

BEREC (2016) suggests that competition from cable investment in DOCSIS 3.0 encourages investment in NGA by incumbents in order to protect their customer base. Interviews with incumbent operators has typically confirmed this. However, it has also been noted that in the absence of quality re-usable ducts in the final drop to premises, where feasible incumbents have often opted to invest in FTTC/VDSL as a quicker and cheaper mechanism than FTTP in order to counter competition from cable.

Figure 50 compares prevalence of DOCSIS 3.0 and DOCSIS 3.1 cable availability against FTTP availability. Note that FTTP coverage includes entrants FTTP as well as incumbents. Overall there is no clear relationship with the correlation between the two measures close to 0. Adding in green colour coding for countries with VDSL coverage greater than 50% indicates that a lot of countries with significant cable competition have opted for VDSL technology.

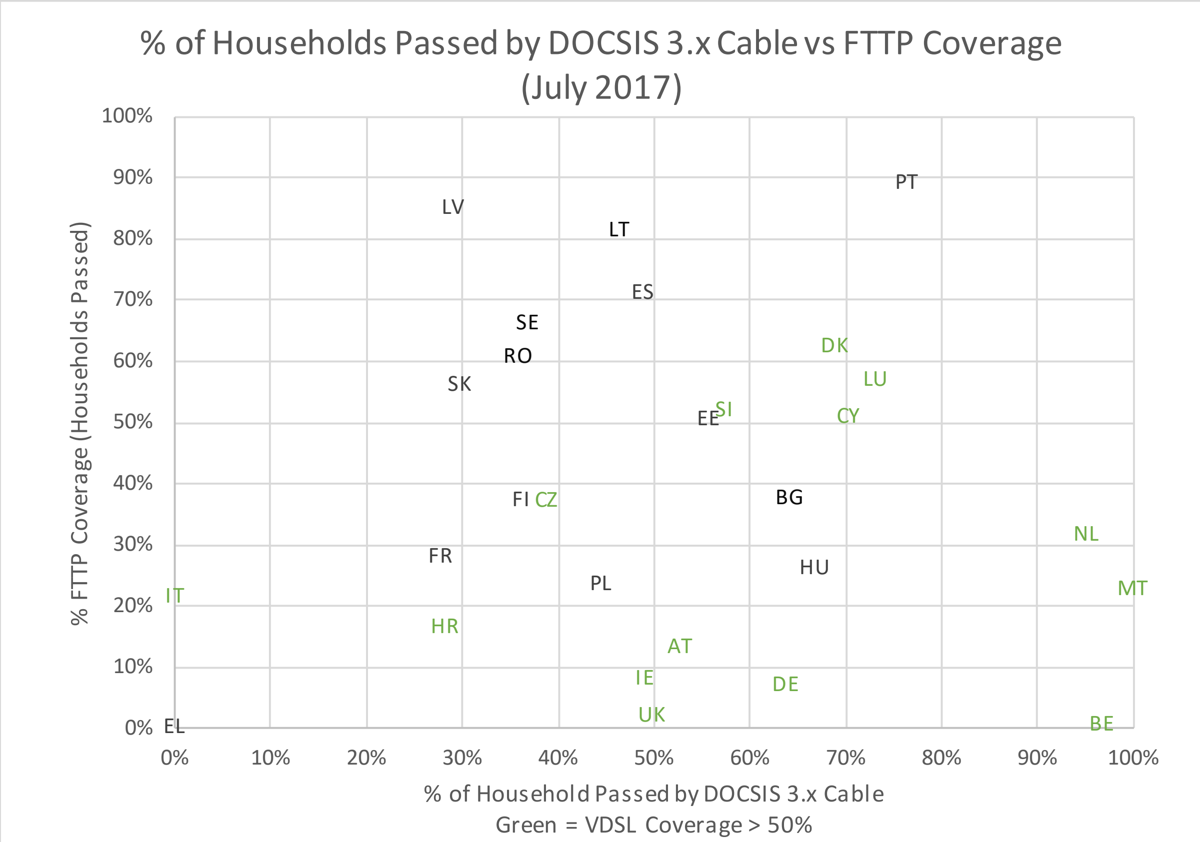


Figure 50: % of households passed by DOCSIS 3.x cable vs % of households passed by FTTP

Urbanisation / Rural Population

Typically, deployment costs for electronic communications infrastructure will be related to distance per households passed. A higher percentage of population in urban areas and a higher percentage of multiple dwelling units should lead to lower costs. A larger rural population means more people with larger distances between premises, as well as larger distances and more branches to be covered by a fibre backbone. On the other hand, while more distance needs to be covered for rural areas the terrain is usually easier for civil works so cost per metre is lower.

The European Commission Broadband Coverage in Europe data has information on the total number of household and number of rural households for each EU country. This has been used to calculate the percentage of rural households in each country compared with the FTTP coverage, as shown in Figure 51. There is no clear pattern to the data, suggesting that other factors are more significant. It should also be noted that the % of rural households does not contain information of the degree of urban density of non-rural houses (e.g. prevalence of multiple dwelling units), the distribution of urban areas (e.g. typically coastal in Portugal) or the area of the rural regions (e.g. France has a very large rural area) which will all affect the cost of deployment.

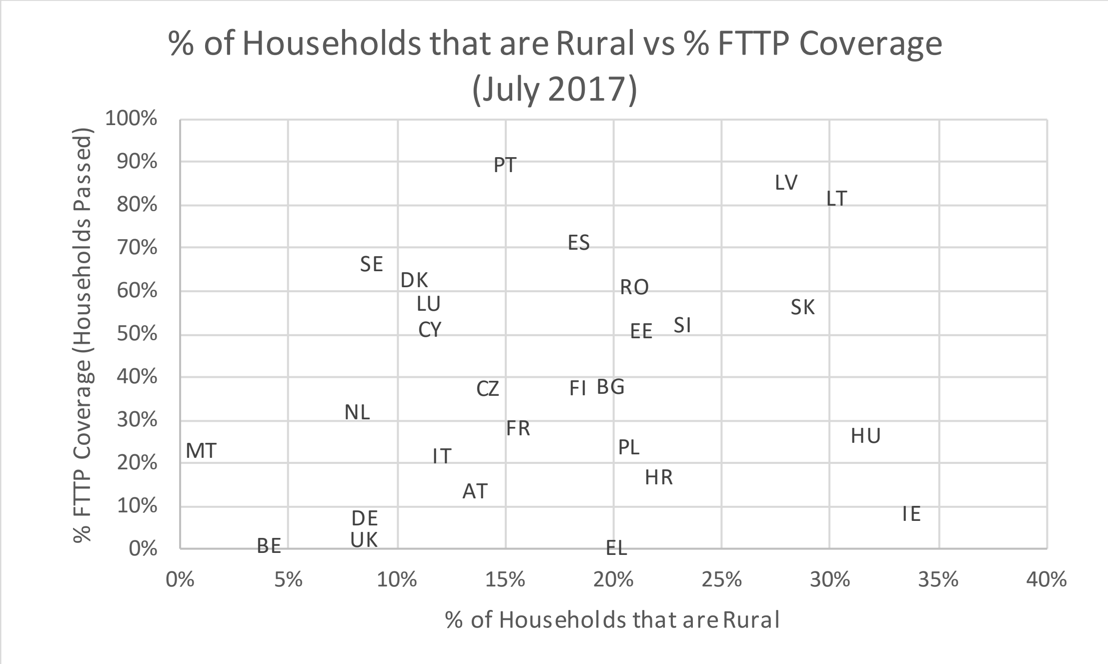


Figure 51: % of households that are rural vs % of households passed by FTTP

<u>Municipality and local network prevalence</u>

Some countries have a large number of smaller local operators of FTTP infrastructure, most of which are providing wholesale access to their networks. It is suggested by BEREC (2016) that these networks drive investment by incumbents in order to protect market share. Typically, these networks are higher speed and quality than cable networks, and so VDSL solutions may be a less effective mechanism for incumbents to counter FTTP competition.

However, local and municipality networks can vary greatly in quantity and nature between countries. In some countries, such as Sweden, urban centres are prevalent in providing an alternative FTTP network to residents and businesses, covering large numbers of people with their networks. In other countries the local networks may predominantly be cooperative and small local networks in rural areas and small towns and so only providing a service to a small number of people. These very small networks are unlikely to prompt investment by incumbents. Some data sources specify the number of other operators but not necessarily the types of networks, so rural local WiFi operators are likely to be included in the count. For example, DESI (2018) reports that Portugal has 4 major operators (which are investing or co-investing in FTTP or cable) and there are 50 active operators, including local operators, but the nature of their networks is not stated.

Figure 52 shows countries categorised by prevalence of municipal and local networks and the percentage of households passed by FTTP. Highlighted groups include countries with low levels of FTTP deployment and low prevalence of municipal networks. Sweden and Romania are highlighted as countries that are documented as having a strong presence of municipal and local FTTP networks providing a significant overall market share and providing strong competition to the incumbent.

While the data analysis does not show a strong relationship between prevalence of municipal and local networks and FTTP coverage, there is sufficient documented evidence in countries such as Sweden where they have had a major impact on FTTP investment and competition for national operators.

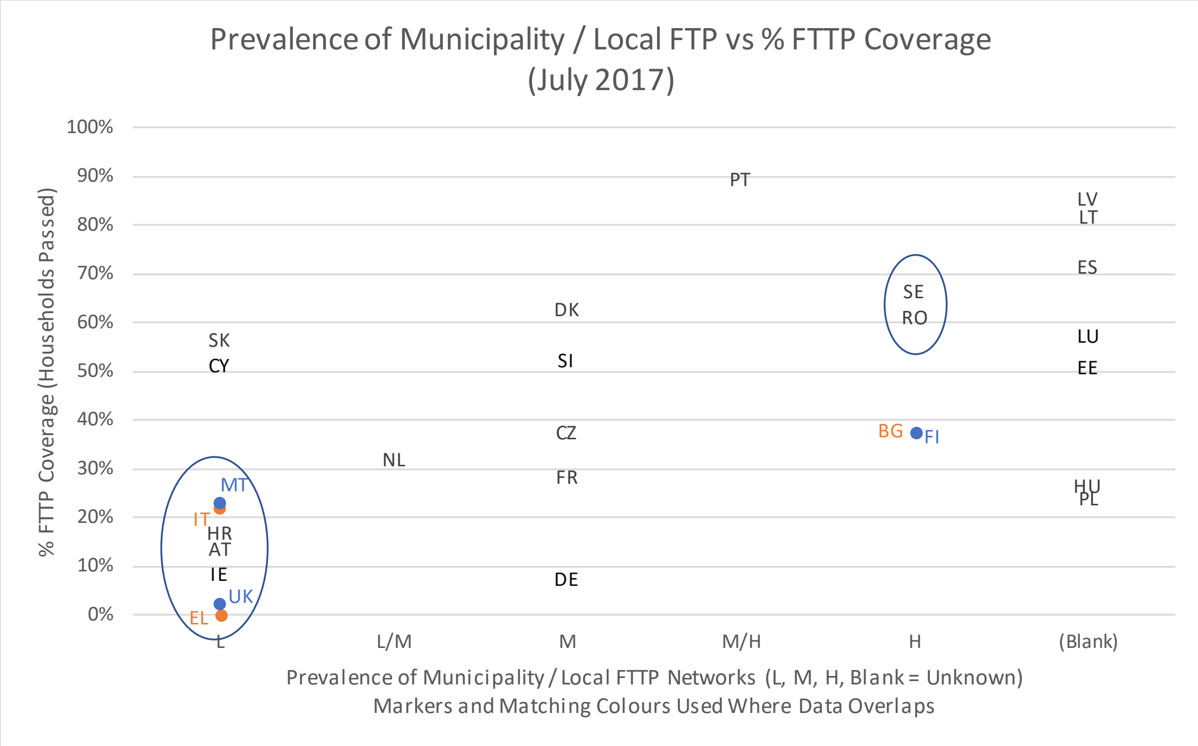


Figure 52: Prevalence of Municipality and Local Networks vs % of households passed by FTTP

9.2.3 Proposed typology grouping

Combining grouping suggested by BEREC (2016), key determinants of capital costs and revenues of an NPV business case for investment in VHCN, and the data analytics, the following typology groupings is proposed. We identify countries that clearly fit into this grouping and identify exemplars with low and high levels of FTTP investment.

- **Widespread availability of ducts and poles for deployment of VHCN** – strong evidence that this as a driver for investment by significantly reducing capital costs. France is an exception where VHCN deployment is much lower (although the pace of investment is reported to have increased significantly in the last few years).
  - High FTTP coverage exemplars: Portugal (PT), Spain (ES), Lithuania (LT).
  - Lower FTTP coverage exemplar: France (FR).
- **Presence of quality copper enabling effective VDSL deployment** – strong evidence that availability of good copper network and extensive investment in VDSL can significantly slow down the rate of investment in FTTP. It is common to see strong cable competition, but not always the case (e.g. Italy). Denmark is an exception where high quality copper is available
  - High FTTP exemplars: Denmark.
  - Low FTTP exemplars: Austria (AT), Belgium (BE), Germany (DE), Italy (IT), Ireland (IE), Malta (MT), UK.
- **Strong digital way of life** – high subscription rates where VHCN is available drives the positive cash flow side of NPV. It is notable that the two exemplars of this group also have a strong municipal operator presence.
  - High FTTP exemplars: Romania (RO), Sweden (SE).
- **Strong municipal / local authority presence** – strong presence of municipal FTTP operators providing significant competition to incumbents.
  - High FTTP exemplars: Romania (RO), Sweden (SE).

10 National market narratives

10.1 Overview of narratives

The national market narratives pick three countries from the typology in section 9.2.3 to illustrate the use of the qualitative System Dynamics approach in understanding how those markets have evolved. The selected countries, and justifications, are:

- **Spain** – presence of quality ducts, regulation to enable access to ducts, regulation changes on wholesale access to encourage infrastructure investment rather than wholesale access to VHCN and on-going challenge for rural areas. Exemplar for "Widespread availability of ducts and poles for deployment of VHCN" typology.
- **Sweden** – strong municipal presence for investment in FTTP and strong digital way of life leading to high subscription rates and willingness to pay for connections. Exemplar for the "Strong digital way of life" and "Strong municipal / local authority presence" typologies.
- **Ireland** – good quality copper and competition from cable companies led to investment in FTTC rather than FTTP by the incumbent. The emergence of entrant infrastructure operators has started investment FTTP in some areas and prompted a switch of emphasis by the incumbent. Rural challenges being addressed in some areas through FTTP. Exemplar for "Presence of quality copper enabling effective VDSL deployment" typology.

Note that data quoted for the narratives makes use of later data (European Commission DESI 2019 data) for June 2018 compared with the typology analysis in section 9.2 which uses data for June 2017 from the IHS & Point Topic 2018 Broadband Coverage in Europe study. This is because more detailed data are available for June 2017 but has not yet been released for 2018. However, for the narratives the later data are available at a higher level, either quoted in the DESI 2019 reports or read from bar charts in the reports.

10.2 High-level narrative models

Presentation of the narratives will make use of simpler models, based on the key concepts of the Generic Network Business Model presented in section 8, but reducing some of the detail.

The Generic Network Business Model provides a detailed set of relationships for drivers of investment, based around the NPV business case decisions faced by operators and potential investors. It contains a range of drivers and conditions for investment for examining the potential determinants of investment and drivers for investment behaviour. It appears complex on first sight and is likely to contain factors that are relevant to some countries but less relevant to others. It is a useful analytical tool but requires a little bit of time and effort to become familiar with, and analysts looking to identify new insights for their markets are encouraged to invest the time to use it for analysis. However, for presentation of key messages to a new audience, the simpler high-level narrative models provide a useful communication tool.

The high-level narrative models differ from the Generic Network Business Model (described above in section 8) in the following aspects:

- Less detailed structure only shows most relevant sectors for the narrative – the narrative models are not complete and use some simplifications. In this sense they are not as "correct" as the full Generic Network Business Model but capture the major points for the narrative. The narrative models are useful for explaining ideas, generating debate and exploring scenarios with a wider audience. It is still recommended that the Generic Network Business Model is used for a more analytical review of ideas and scenarios generated by discussion of the narrative models.
- The nature of positive and negative causal links is highlighted through a simple colour scheme. Positive links shown in green, negative links are shown in red (see below for a description of the positive and negative concepts). The Generic Network Business Model uses '+' and '-' symbols to

show the nature of the links and colours are used to highlight the model sectors. Note that a negative causal link is not necessarily adverse or unwanted – it is simply providing the polarity of the relationship.

- The narrative models use thicker lines to highlight strong positive and negative drivers of investment for the country of interest. This cannot be done in the generic model since the strength of drivers may vary considerably between countries.
- Key feedback loops are shown in the narrative models, whereas including them in the generic model would overwhelm the presentation of the model. A brief overview of the meaning of feedback loops is given below.

A brief overview of the symbology used by the narrative models is shown below. For a more detailed explanation of the System Dynamics concepts see Annex A.

The CLDs use links between the concepts to denote that there is a causal relationship from the concept at the tail of the link to the concept at the head of that link. The colour of the arrow denotes the nature of the relationship:

- **Green** indicates that it causes a change in the **same** direction. This is known as a positive link and also has a '+' indicator on the arrowhead, in common with the generic model.
- **Red** indicates that it causes a change in the **opposite** direction. This is known as a negative link and has a '-' indicator on the arrowhead.

A simple example of these causal arrows is shown in Figure 53 where there are three concepts of "Costs", "Revenue" and "Profit". An increase in Revenue will make Profit go up (all other things being equal), which is a change in the same direction hence a green link. Similarly, if Revenue goes down then Profit will go down, still a change in the same direction so the green link correctly represents this. If Costs go up then Profit will be reduced, a change in the opposite direction so a red link is used. The red link correctly represents that a fall in Costs will lead to an increase in Profit.

Figure 53: Example of causal linked concepts of costs, revenue and profit

Feedback occurs when a set of causal arrows join up to form a closed loop. This indicates that over time there will tend to be some cyclic behaviour where changes in the past tend to affect the future. These loops can be (B)alancing where they tend to push values to an equilibrium state, or (R)einforcing where a change can cause an accelerating relationship either upwards or downward depending on the nature of a change. The type of loop is identified by counting the number of red links in the loop. If there are an odd number of red links then it will be a balancing loop. If there are no red links, or there is an even number of red links then it will be a reinforcing loop. The presence of loops is highlighted by the 'B' and 'R' symbols within a circular arrow showing the direction of the loop. Both types of loop are present in all the narrative models and will be covered in the explanation of the core narrative model below.

10.3 Core narrative model

All the high-level narrative models are based on a common core model showing the most fundamental aspects of the VHCN investment decision. Individual country narratives highlight key determinants of investment in that core model and often add extra detail where it is most relevant to that narrative. The core concept in the full "Generic Network Business Model" and core high-level narrative model is that of the NPV investment decision for VHCN, as shown in Figure 54. Here capital investment is used to build VHCN infrastructure passed premises, which enables those premises to be connected to the VHCN. This requires capital which is a negative on the NPV investment decision. Subscribers to the

VHCN generate revenue, where net revenue (after subtraction of operating costs) generates cash flow that acts as a positive to the NPV investment decision. In common with the NPV approach these future cash flows are discounted.

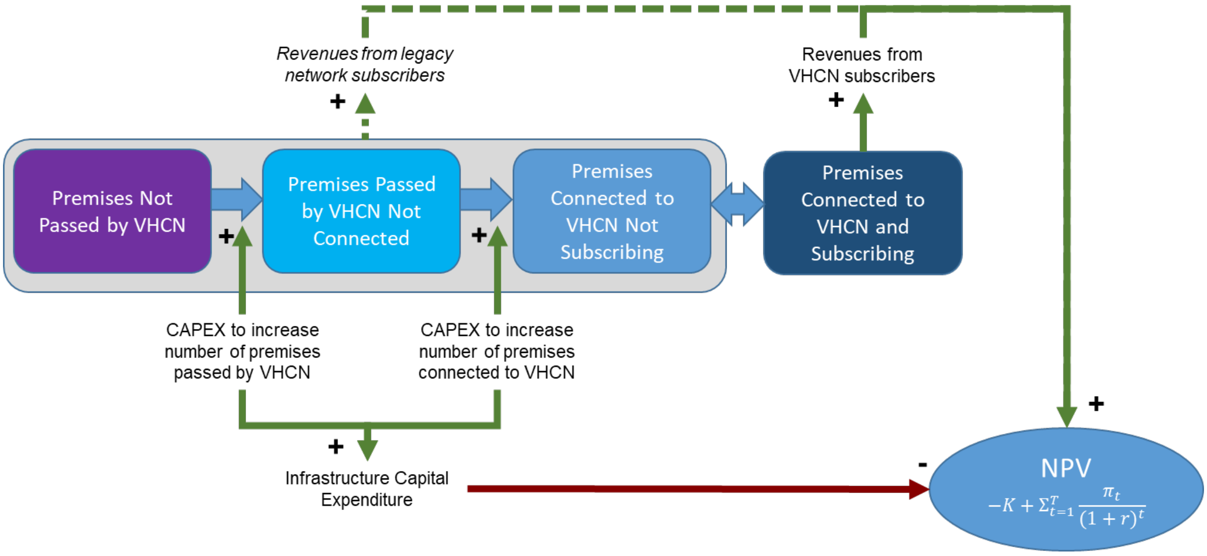


Figure 54: Core concepts of CAPEX and net revenues forming the basis of the NPV investment decision

The core high-level narrative model, shown in Figure 55, simplifies the investment impact on premises slightly by reducing it to 3 states: Premises Not Passed by VHCN, Premises Passed by VHCN (but not connected), Premises Connected to VHCN. In the latter state it is assumed that the household is subscribing.

In the full generic model, a further state is split out where the premises could be connected but the household is not subscribing (e.g. connected by default by operator but using another network, initially connected and subscribing but then switched to another network, or an MDU is connected but not every household in that building is subscribing). The simplification in the narrative model is to reduce the visual complexity, but the same underlying principles of the investment decision remain.

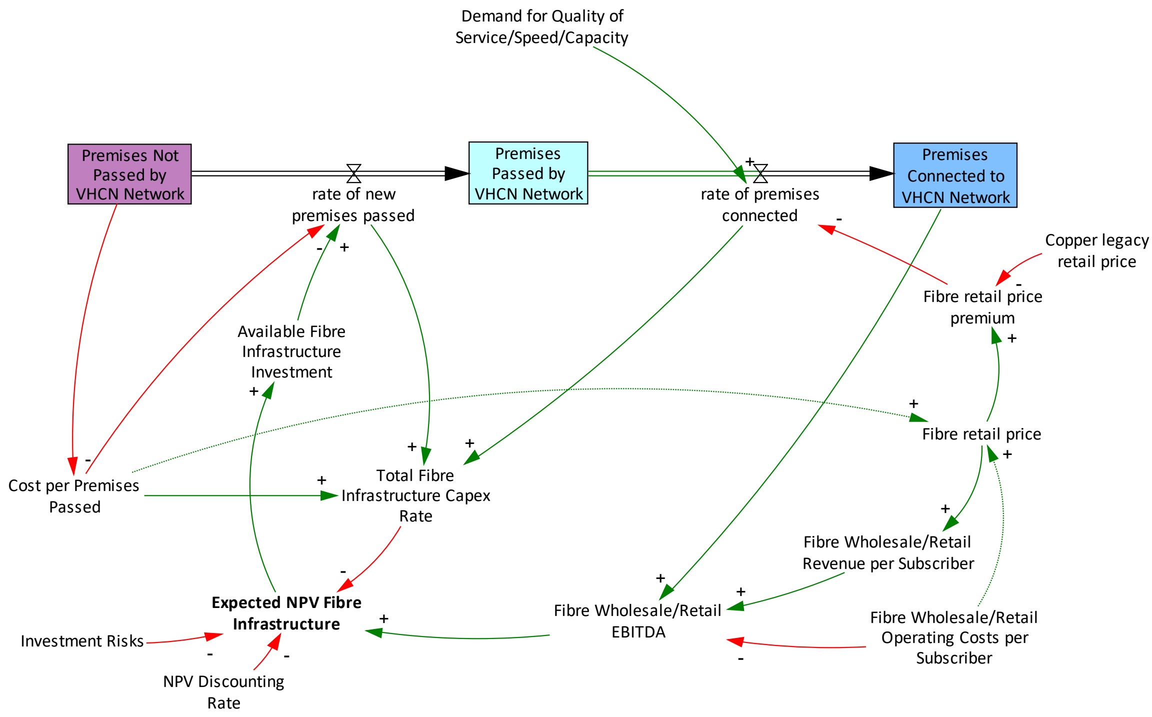


Figure 55: Core high-level narrative model

The rate of investment in VHCN sets the rate that premises are passed by a new VHCN. The number of premises passed for a certain amount of investment will be dependent on the cost per premises passed. A lower cost per premises passed will reduce the CAPEX part of the NPV investment decision. A better return on the NPV investment (both predicted and realised) will enable a greater amount of finance to be available, in terms of the actual business case for a specific future project as well as realised returns from previous projects creating greater confidence from investors. These concepts in the core narrative model are highlighted in Figure 56.

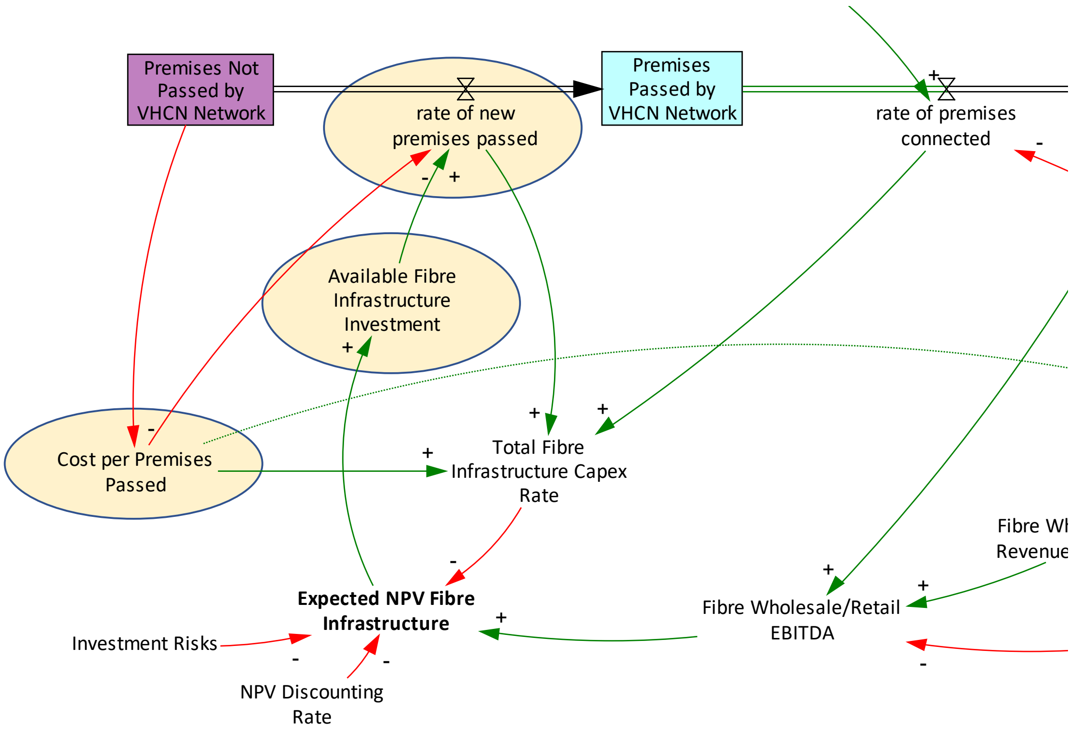


Figure 56: Core narrative model focusing on capital investment to pass properties

On the revenue side of the NPV investment business case, connecting premises to the network will generate revenue for the operator (retail and/or wholesale depending on the business model of the operator). Net revenue after costs will contribute to the cash flow into the NPV projection. Only premises that have been passed by the network can be connected to it, and connection will incur capital costs. These concepts around revenue are highlighted in Figure 57.

Subscription rates for an available VHCN will depend on a willingness to pay for VHCN and relative prices compared with the legacy network. A higher demand for VHCN capability will create a greater willingness to pay allowing the operator to get higher net revenues through the optimum price/demand balance. Typically, subscribers will be evaluating VHCN prices against legacy network prices to determine value for money.

Ultimately EBITDA from retail or wholesale revenue will be dependent on prices and the number of subscribers. Of course, there are also operating costs to be accounted for in EBITDA but these are excluded to simplify the diagram.

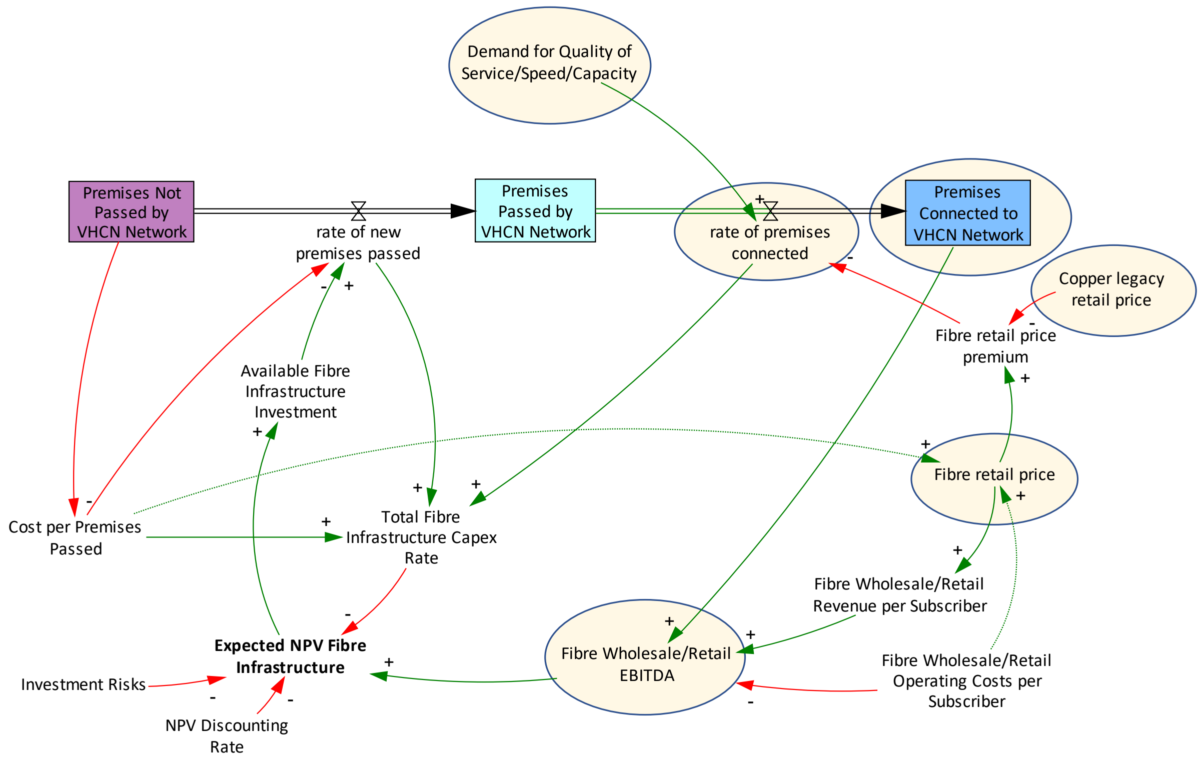


Figure 57: Core narrative model focusing on revenue generation

As experience from past deployment projects show that NPV projects are being met, confidence in the investment increases which makes more finance available for investment. This represents a reinforcing feedback loop, as shown in Figure 58. Reinforcing feedback loops can also work in reverse so that if projects fail to meet their NPV business case projections then confidence in FTTP investments can collapse, leading to a rapid decline in investment.

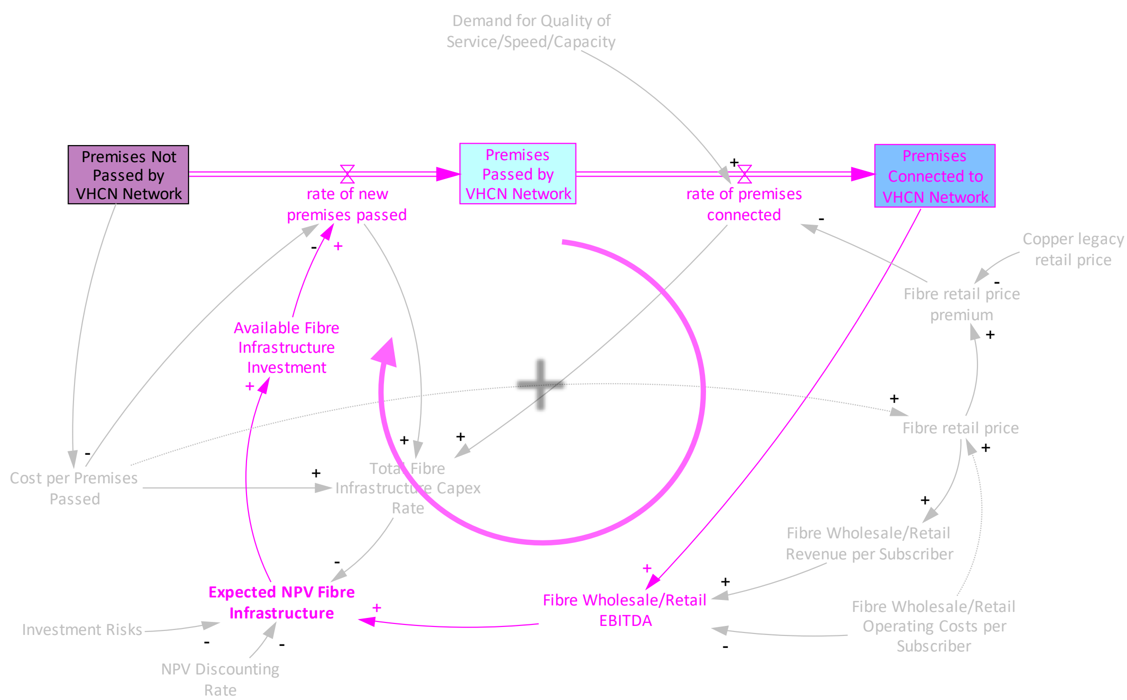


Figure 58: Reinforcing loop for confidence in NPV projects through returns from past projects, can grow or collapse

Cost per premises passed will vary dependent on a number of factors (examined in more detail in country narratives). What is common to all is that cost per premises passed will vary, even within the same region, as well as between different regions. Infrastructure operators and investors will tend to focus on the cheaper premises to pass first, but as more of these are added to the network, the remaining premises that are not yet passed will become increasingly more expensive. From a capital cost perspective, the NPV case will tend to diminish as deployment costs to premises become more expensive. This creates a balancing feedback loop, slowing the rate of investment. Both feedback loops are shown in Figure 59.

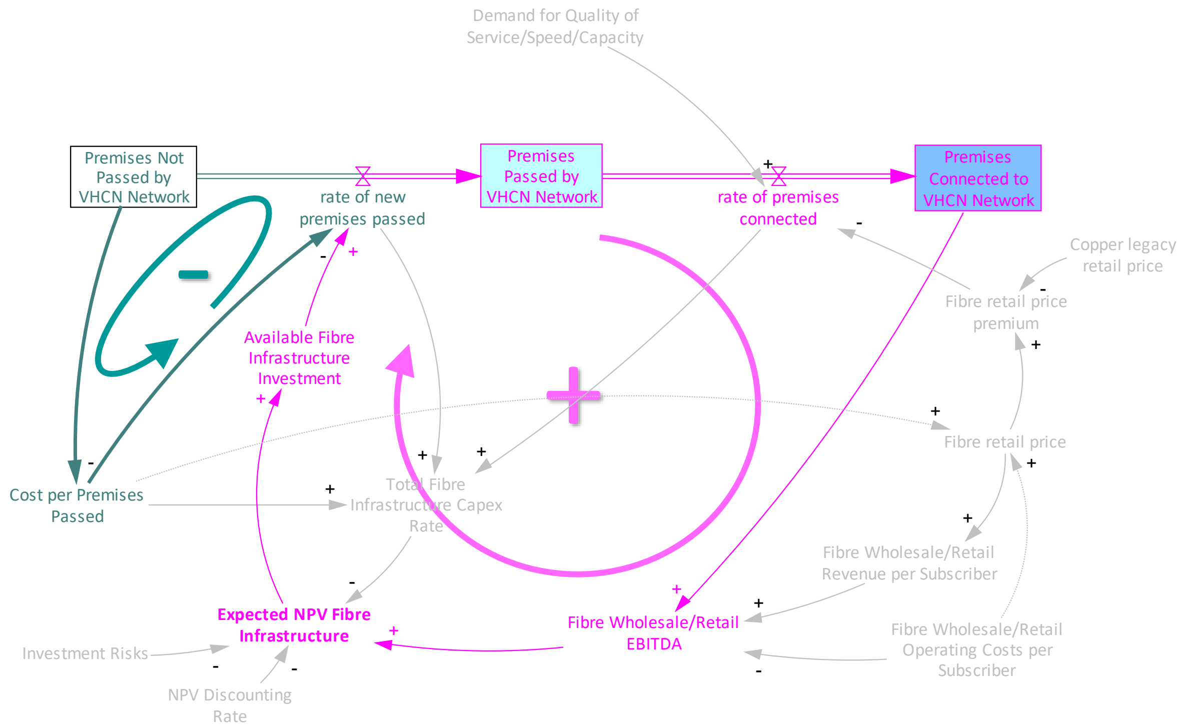


Figure 59: Core narrative model with balancing and reinforcing feedback loops highlighted

10.4 Spain case study

Spain has FTTP coverage of 77.4% for households across the country, and Ultrafast (FTTP + Cable DOCSIS 3.x) coverage of 87% of households as of June 2018 (DESI, 2019 Spain report)[86]. These figures represent very high coverage in urban areas, including multiple networks in many areas, but Spain has significantly lower coverage in rural areas (32% FTTP and 40% Ultrafast coverage).

The high-level narrative model for urban areas in Spain is shown in Figure 60. In urban areas the NPV business case for investment has benefited greatly from a low cost per premises passed due to the ability of infrastructure operators to make use of existing ducts all the way to the premises. Regulation and effective enforcement provided access to duct infrastructure for any operators that wanted to deploy their own infrastructure. Compared with the requirement to dig new trenches for ducts, this can save around 60% of deployment costs. Urban density and high proportion of multiple dwelling units in many Spanish cities also reduced costs for deployment of fibre. These impacts are highlighted in Figure 61.

[86] DESI (2019) *Digital Economy and Society Index (DESI) 2019 Country Report: Spain*, European Commission.

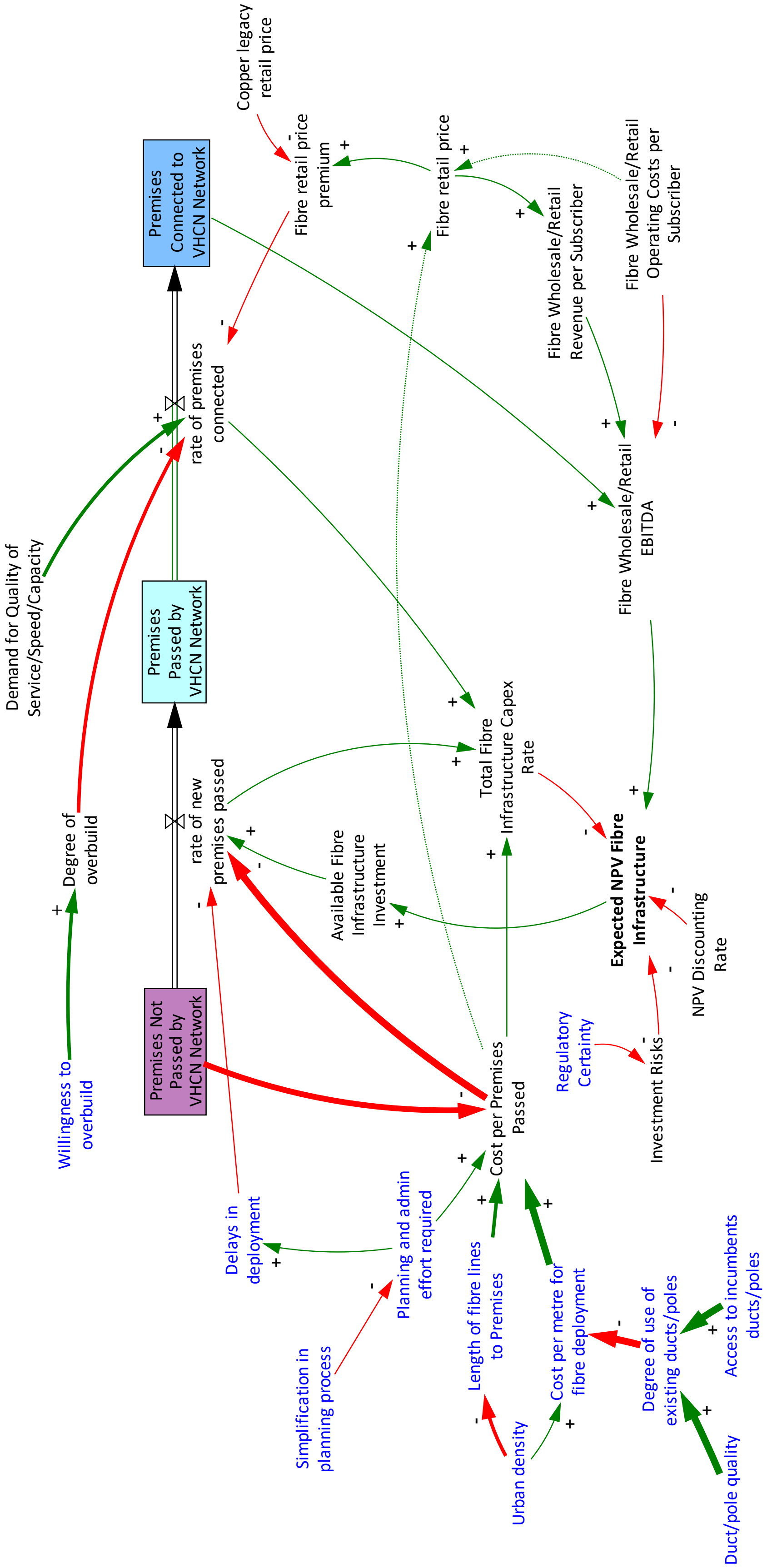


Figure 60: High-level narrative model for Spain (urban areas)

On the diagram, a <u>high</u> "*Cost per premises passed*" <u>reduces</u> the "*rate of new premises passed*" for a particular level of investment, as shown by a red causal link, i.e. the red link shows an opposite or negative relationship. In urban areas of Spain the availability of quality ducts creates a <u>low</u> "*Cost per premises passed*" and so <u>increases</u> the "*rate of new premises passed*" for a given level of investment. The blue up and down arrows show the nature of the conditions in Spain and how they impact on the system.

Low cost per premises passed means a larger number of premises can be passed for a given level of investment, keeping the capital cost side of the NPV business case lower.

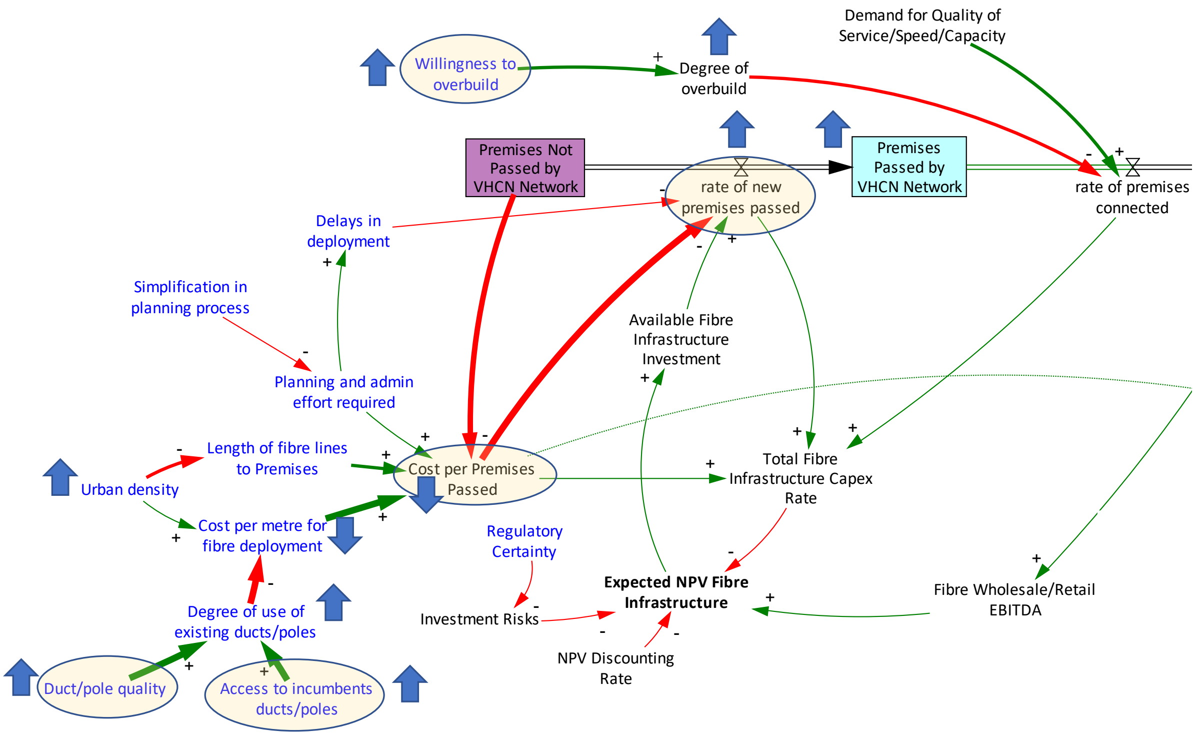


Figure 61: Spain narrative highlighting impact of high duct quality and effective regulation on access to ducts

Despite the low cost for FTTP infrastructure, investment in infrastructure is riskier than continuing to sell broadband access via the existing copper network either as the incumbent or by using LLU and an alternative operator. Two key elements gave operators incentive to invest in infrastructure:

1. Spanish regulators set conditions to encourage investment in FTTP. Initially, in 2008 by restricting the wholesale obligations for the incumbent Telefonica to providing 30 Mbit speed, meaning that Telefonica could gain competitive advantage over LLU and wholesale tenants by being able to offer considerably superior speeds via FTTP infrastructure. At the same time, competitors could respond to the threat by deploying their own FTTP infrastructure using the wholesale duct offer, so creating the conditions for infrastructure competition. Afterwards, from 2016 on, Telefónica had to provide FTTP wholesale access in non-competitive areas for ultrafast broadband services, but Telefónica enjoyed price flexibility, ensuring competition while also fostering investment.
2. Cable, with close to 50% coverage, provided an existing form of infrastructure competition with investment in the cable system enabling higher speeds than copper. This threatened to erode the market share for the incumbent and alternative operators selling broadband via the copper network.

Low deployment costs for fibre, competition from cable and the speed restrictions on wholesale access created a high willingness to overbuild, providing infrastructure competition. This is highlighted at the top of the Spain narrative diagram.

The success of this regulatory approach of restricting wholesale access was dependent on Spain's relatively low installation costs for FTTP, resulting from good duct access and therefore relatively low capital requirements, compared with the majority of EU countries. It also required active enforcement of duct access obligations and symmetric building wiring obligations for the approach to be successful.

Demand-side drivers for VHCN in Spain have not been significantly strong, especially bearing in mind that revenues needed to support overbuild by multiple infrastructure operators. As with most EU countries, subscription rates for higher speed broadband had been low in Spain in past years, with less than 2% of the population subscribing to VHCN (ultrafast) broadband in January 2014 and rising to 18% of households in June 2017 despite 84% of households having access to VHCN and 100 Mbit/s retail prices generally the same as copper prices. However, by June 2018 VHCN coverage was 87% of households and more attractive value propositions had helped subscription rates jump to 30% (DESI, 2019), as compared with an EU average of 20%.

It is arguable whether many EU countries could have successfully applied the same regulatory policies as Spain. The successful implementation of duct access regulations leading to low capital costs for infrastructure deployment meant that the NPV business cases could be made for FTTP investment despite the low subscription rates and with overbuild by multiple operators effectively dividing that subscriber-base between them. The success of these business cases is attested by the fact that they continued to attract investment capital.

Despite the high level of VHCN coverage in Spain, rural communities, in common with most EU countries, are not equally well served by VHCN. In June 2018 rural coverage was 32% for FTTP and 40% for Ultrafast, which was a significant improvement on the previous year. Spain now exceeds EU coverage in rural areas by more than twofold: 32% vs 14% for FTTP and 40% vs 16% for Ultrafast coverage. There is significantly less duct access in rural areas along with longer distances between premises, making the FTTP infrastructure deployment costs higher and so damaging the NPV business case for expansion into those areas. Offsetting this, significant savings in operational costs of a fibre-only network is a factor that seems to be leading to a swift deployment in rural areas. As demonstrated in Figure 59, the balancing feedback loop of increasing capital costs per premises passed for the remaining premises, means that for rural areas the investment cases will diminish and roll out will slows. For many rural areas a different business model is required, including use of state aid, in order to create the economic case for VHCN investment. Investment can be stimulated further by the promise of substantial operating cost gains from transition to a fibre-only network (see Section 7.5.1). Spain appears to be showing this in recent years with Telefonica repeatedly announcing its ambition for full fibre network coverage[87].

10.5 Sweden case study

Sweden has significantly higher FTTP coverage than average at 72% and Ultrafast coverage of 84% as of June 2018. In rural areas coverage is lower (31% FTTP and Ultrafast coverage). Subscription rates to Ultrafast broadband (at least 100 Mbits) are the highest in the EU with 54% of households subscribing (DESI, 2019 Sweden report[88] and DESI, 2019[89]). That represents 64% of households with access to ultrafast subscribing to a 100+ Mbit/s plan. Sweden ranks first in the overall Digital Economy and

[87]https://www.telefonica.com/es/web/sala-de-prensa/-/telefonica-ganadora-de-los-premios-broadband-awards-en-la-categoria-mejor-red

[88] DESI (2019) Digital Economy and Society Index (DESI) *2019 Country Report: Sweden*, European Commission.

[89] DESI (2019) Digital Economy and Society Index (DESI) 2019 *Connectivity: Broadband market developments in the EU*, European Commission.

Society Index, driven not only by connectivity (it is 8th in the EU for coverage) but by being high in the rankings for take-up of subscriptions, internet use, video on demand, online education, and overall IT related general and specialist skills. It is also highly rated for use of business use of the cloud and e-commerce.

The high-level narrative model for Sweden is shown in Figure 62. Unlike Spain, in Sweden the telecoms incumbent does not have a network of high-quality ducts. Instead, a combination of municipality investment as FTTP infrastructure operators and consumer-led demand for VHCN has formed the basis of VHCN coverage in Sweden and prompted the incumbent operator to respond to invest in FTTP. Other potential drivers in Sweden include, cable coverage of a little over a third of households, and VDSL coverage at 21% of households, although the long lengths on copper in many areas do not make the copper network well configured for VDSL.

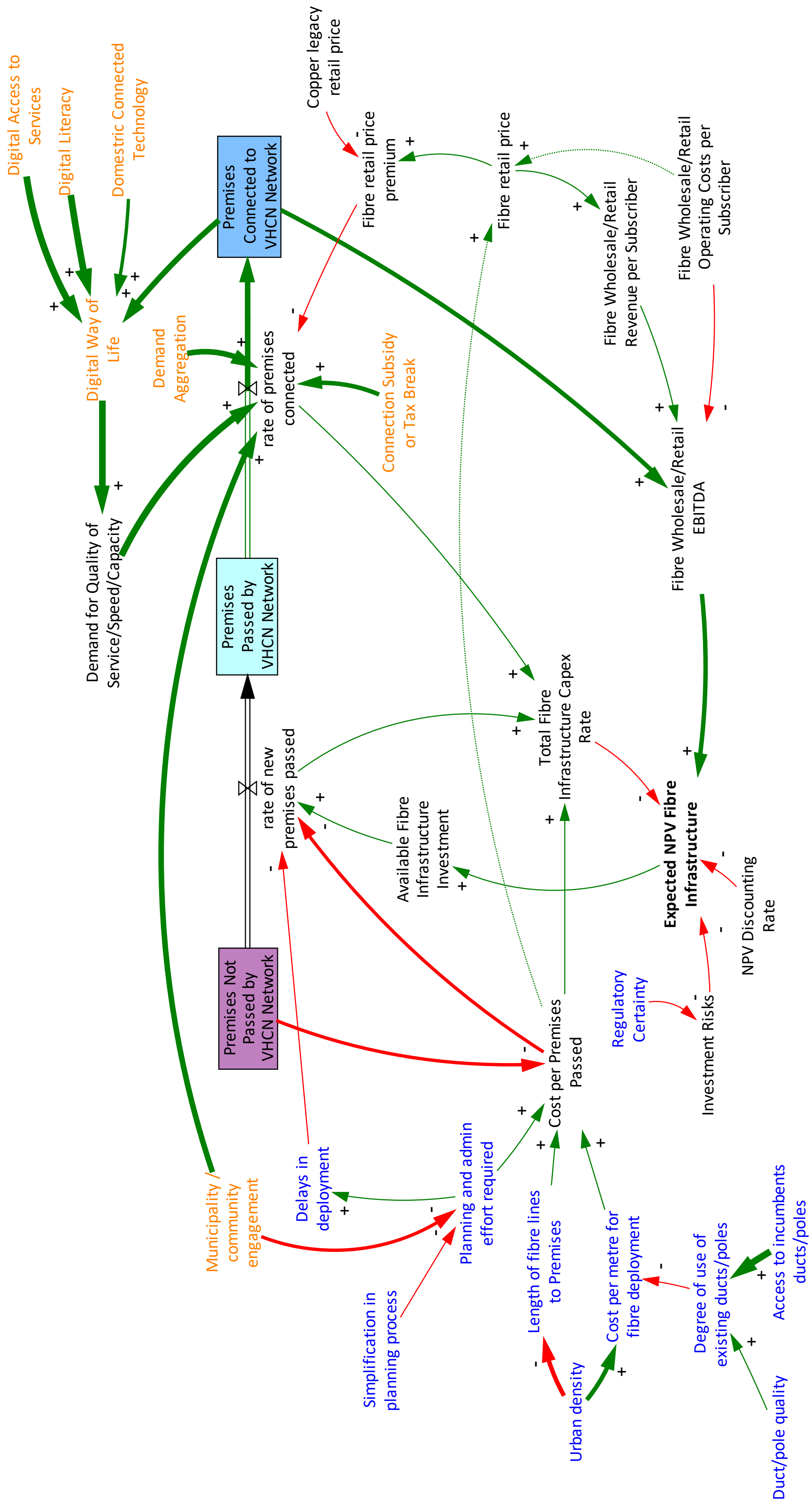


Figure 62: High-level narrative model for Sweden

Sweden has a number of major technology companies, including start-ups that have become major players on the world stage (for example, Skype and Spotify). Internet usage is high, and Sweden is a leading country for general and specialist ICT skills[90]. With high subscription rates for 100+ Mbit/s broadband connection, there is a clear demand for ultrafast broadband. Therefore, while FTTP infrastructure deployment costs per premises passed are high (compared with Spain), the revenue side of the NPV business case is strong with high subscription rates, while average retail prices are very slightly higher than the EU average. The impact of this high level of demand on the NPV investment business case is shown in Figure 63. Referring back to Figure 58, it should also be seen that these strong subscription rates are a major element of the reinforcing feedback loop for investor confidence.

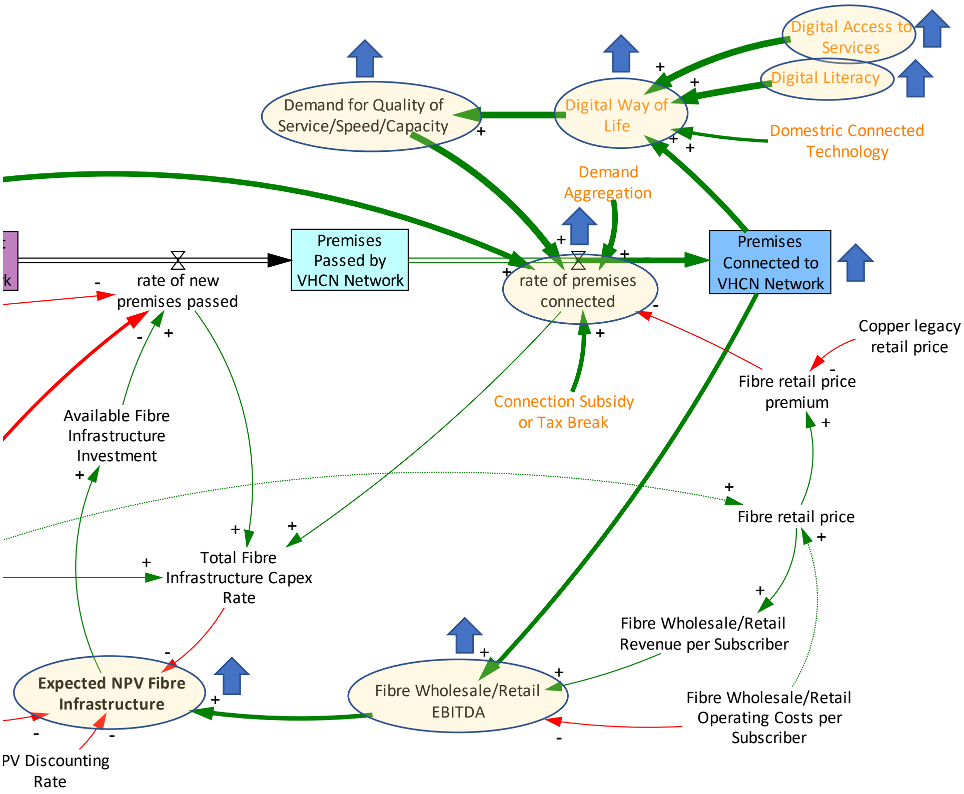


Figure 63: Excerpt from Sweden high-level narrative model highlighting impact of high demand on the NPV investment case

Sweden also has strong municipal investment in FTTP infrastructure, largely provided on a wholesale basis with a range of business models ranging from leasing of (passive) dark fibre to leasing of (active) fibre and equipment, as well as retail operations in some areas. Sweden was a very early adopter of this municipal model of investment with Stockholm city council creating the AB Stokab in 1994. It is arguable that municipality investment both responded to an underlying digital culture in Sweden, but also natured its growth by making the means of high-speed broadband access available. As early as 2013, Stockholm had 90% of households subscribing to FTTP (FTTH Council Europe, 2013)[91]. In 2017, there were 156 municipal fibre networks in Sweden (OECD, 2018)[92] mostly providing operator neural wholesale access. There are also estimated to be around 1000 village fibre providers each with connections in the range of 150 to 200 households.

[90] DESI (2019) *Digital Economy and Society Index report 2019: Connectivity.*
[91] FTTH Council Europe (2013) *Case study: AB Stokab.*
[92] OECD (2018) *OECD review of digital transformation: going digital in Sweden*, Chapter 2.

Municipal networks often have advantages in terms of lowering costs of investment by making use of existing utilities infrastructure operated by the municipality as well as simplifying the planning processes (which are usually in the control of the municipality). Municipality and village fibre often also benefit from high community engagement, allowing demand aggregation to measure the level of support and gain commitments for early subscription to FTTP networks. Experience in Sweden also suggests that there was a willingness to pay towards upfront costs for connection to a fibre network (partially offset by tax breaks), providing early revenue that partially offsets capital costs for deployment. These impacts are highlighted in Figure 64.

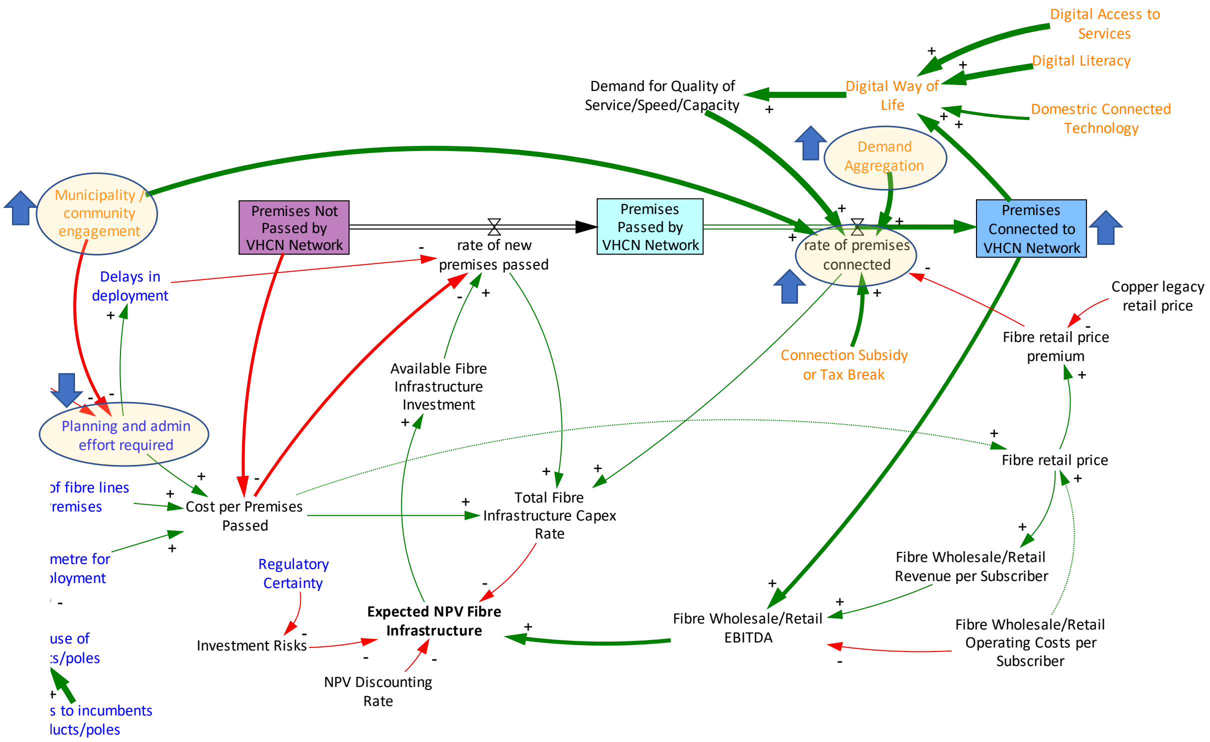


Figure 64: Excerpt from Sweden high-level narrative model highlighting impact of municipality investment

It should be noted that despite village fibre schemes, VHCN coverage in rural areas is still relatively low at around 31%. As highlighted in Figure 59, increasing costs per premises passed for the remaining premises without an FTTP option acts as a slowing constraint on investment, even with a higher willingness to pay for upfront connections. State subsidies provide an option to help connect the final areas as well as other technologies to improve speeds (but not necessarily to VHCN capabilities).

10.6 Ireland case study

Ireland has a good quality copper network in urban areas but long copper loops in rural regions. It has invested heavily in VDSL with 86% household coverage in June 2017, the latest figure available for VDSL (IHS & Point Topic, 2017)[93] but this is unlikely to have changed significantly since. Ireland had 56% VHCN coverage in June 2018, and although this figure is largely dominated by DOCSIS 3.0 cable, there has been a steady increase in FTTP coverage, standing at 13% coverage (DESI, 2019 Ireland report[94] and DESI, 2019[95]). Eir has changed its focus from expanding its VDSL network to expanding FTTP.

---

[93] IHS & Point Topic (2018) *Broadband Coverage in Europe 2017*. European Commission.

[94] DESI (2019) Digital Economy and Society Index (DESI) *2019 Country Report: Ireland*, European Commission.

[95] DESI (2019) Digital Economy and Society Index (DESI) 2019 *Connectivity: Broadband market developments in the EU*, European Commission.

In 2012, Ireland had significant cable coverage at 42% which had been largely converted to DOCSIS 3.0. The copper network was largely ADSL and there was very little FTTP. The investment by cable companies in DOCSIS 3.0 was starting to eat into Eir's market share. The existence of good quality copper in urban areas and a lack of quality ducts to premises prompted Eir to respond to the cable competition through a rapid upgrade of its copper network to FTTC/VDSL. Ireland's VDSL coverage rose rapidly from 0.5% in 2012 to 61% in 2014, covering off those areas of cable competition, and then continued to expand at a slower rate, reaching 86% in June 2017 where most of the network with sufficiently short copper lengths had been converted. The coverage for the main broadband technologies in this period is shown in Figure 65.

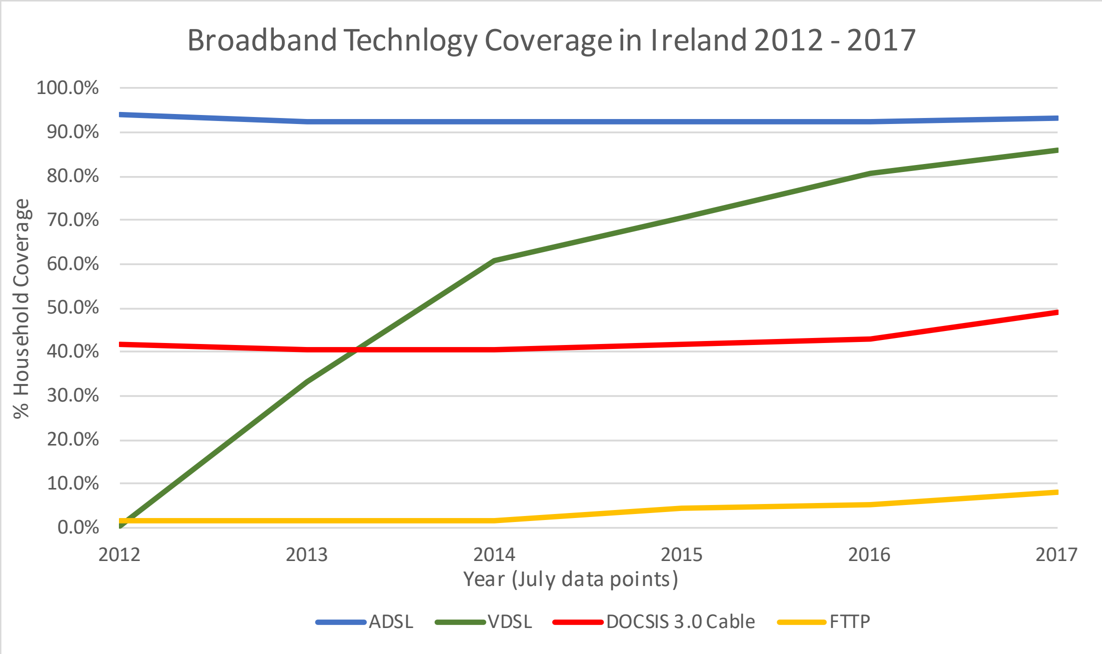


Figure 65: Broadband technology coverage in Ireland 2012 -2017 (data source: IHS & Point Topic, 2013 – 2018)[96]

Given the lack of re-usable ducts, it would not have been possible to employ FTTP nearly as quickly and the costs would have been substantially (and likely prohibitively) higher. From an NPV perspective, the investment in VDSL appears to have been a sensible business decision to improve the copper network sufficiently to stave off significant loss of market share to cable.

The high-level narrative model for Ireland is shown in Figure 66. This shows the basic NPV decisions for fibre with deployment costs and demand drivers, with the addition of a representation for the copper network. This can be thought of as a very simplified representation of an investment structure similar to that if FTTP.

[96] IHS & Point Topic (2013 - 2018) Broadband Coverage in Europe. European Commission. Data compiled from reports covering years 2012 to 2017.

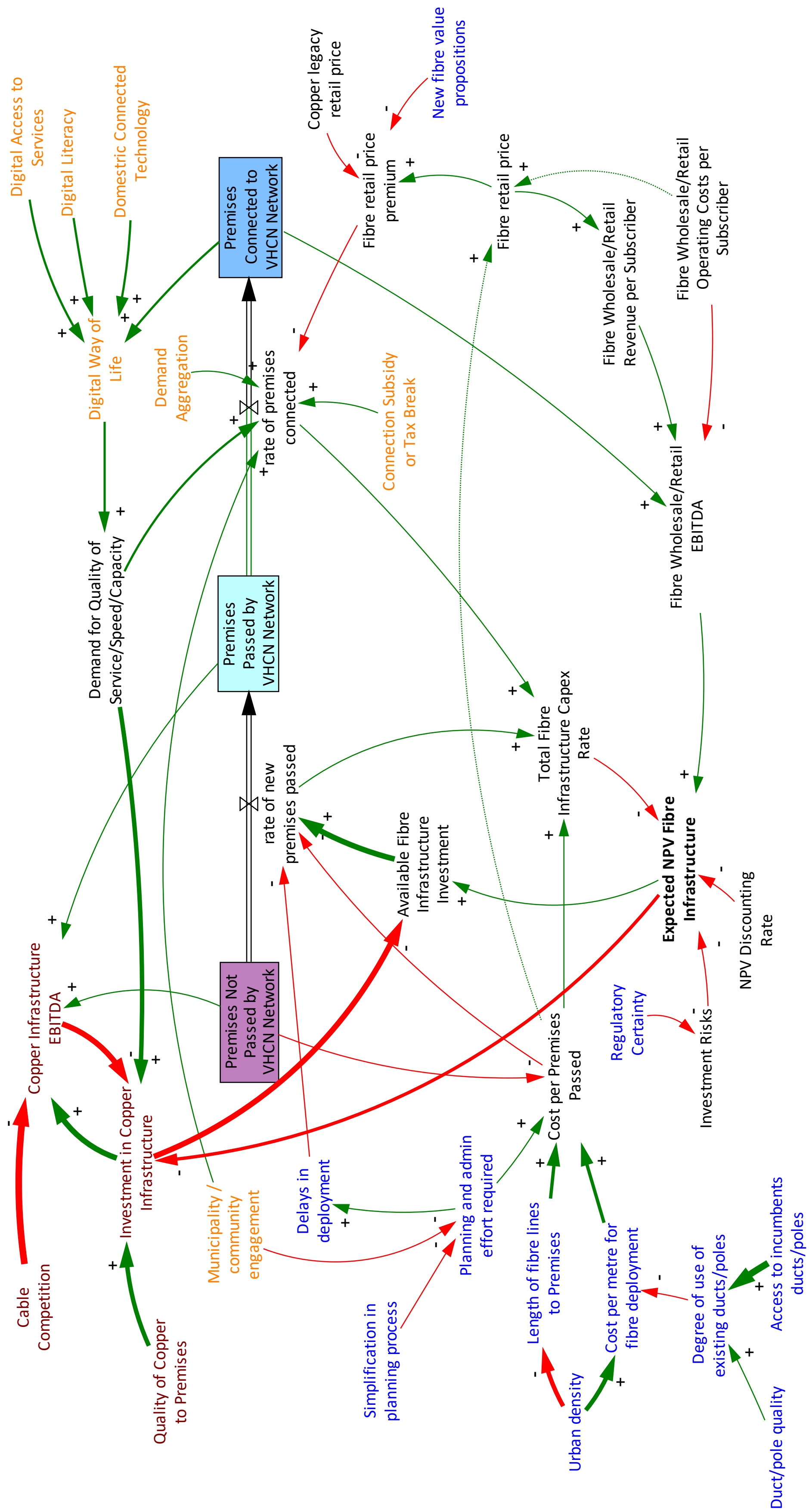


Figure 66: High-level narrative model for Ireland

Key aspects of the copper upgrade decision mechanism are highlighted in Figure 67. Cable competition was eating into the legacy copper network market share putting pressure on the profitability of the network. Market share for ADSL can be seen in Figure 68 with a steady and significant fall between 2009 and 2012. The presence of high-quality copper provides the opportunity to upgrade the existing copper network for FTTC/VDSL to improve capability sufficiently to halt and slightly reverse the loss of subscribers to cable. Investment in upgrading the copper network will tend to slow as the pressure of profits are reduced but continued at a slower pace in Ireland after 2014 until completion of most the network that could be upgraded.

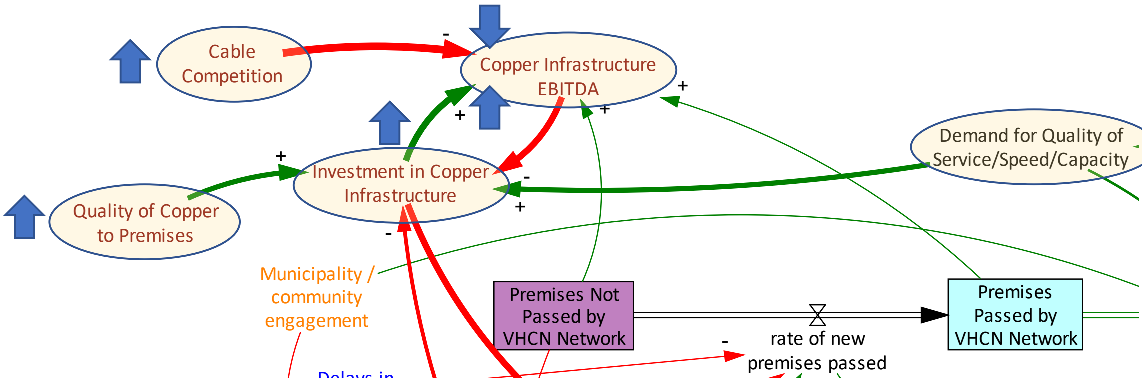


Figure 67: Excerpt of Ireland high-level narrative highlighting the copper upgrade decision drivers

Note that there was little investment in FTTP by the incumbent during this period as resources went into the VDSL upgrade.

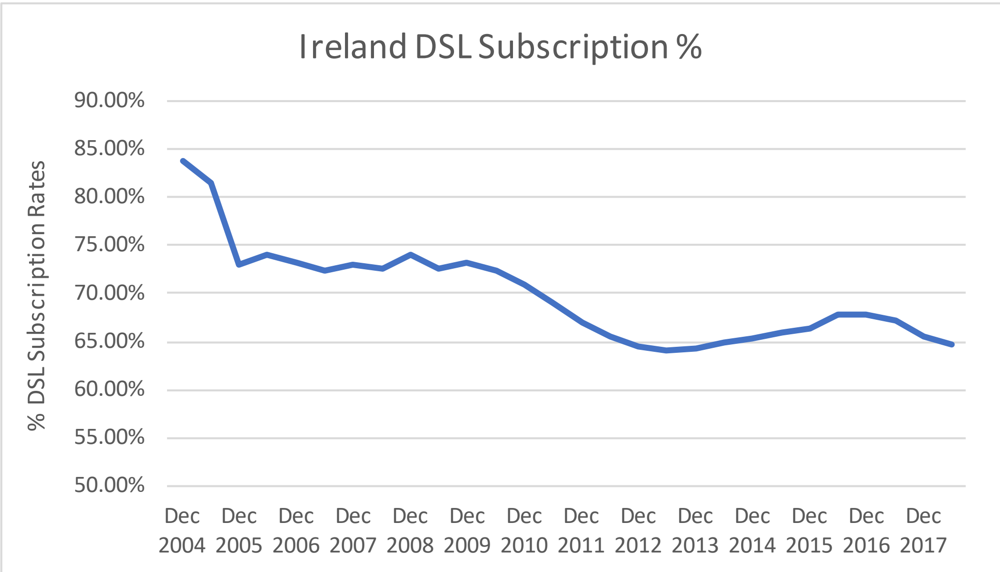


Figure 68: xDSL Subscription % Share in Ireland (data source DESI Digital Scoreboard, European Commission)

FTTP coverage in Ireland has been growing slowly but steadily since 2014, driven initially by entrants. Some investment focused on specific areas around business parks, and a major program of investment deploying in towns that were not served by the cable network in order to avoid direct competition with cable and focussing on areas with poor broadband connections which use of the overhead cable and underground ducts used by the electricity system in order to reduce deployment costs. The incumbent has responded with its own programme of FTTP investment also focused on towns in order to pre-empt competition by entrants.

Rural areas have 82% coverage by NGAs (mainly VDSL with a small amount of FTTP and cable). The economics of investment in FTTP on a purely commercial basis are not sufficient to justify investment in some of the rural areas. Ireland has a National Broadband Programme which is supported by state aid to develop FTTP into these rural areas, offering open wholesale access to operators. However, as of November 2019, this programme is not yet underway.

On the demand side, 20% of broadband subscriptions are 100+ Mbit/s, which is close the EU average. However, compared with those households that are passed by VHCN this represents around 38% of those households choosing fast broadband packages, slightly above average. Ireland has fairly low DESI ranks for general ICT skills, but higher in terms of specialist ICT skills and very high in terms of ICT graduates. Data usage for video on demand is very high, and Ireland has a thriving tech sector leading to high rankings in terms of use of the cloud, e-data and e-commerce. This suggests that consumer demand is currently only a moderate driver for VHCN investment, but not an immediate significant threat to VDSL.

11 Conclusions

The study approach described in this report aimed to collate a very broad set of data (both hard and textual gathered through stakeholder engagement and publications) and synthesise this within a single holistic systems-based model of the electronic communications network business sector. This has been achieved and the study has demonstrated how such a model can be used for cross market comparisons and understanding the determinants of investment choices made by network operators.

11.1 Summary of determinants

The study has revealed a wide range of determinants of investment but each of these can be linked to the fundamental components on investment decision making – capital, future cash flows arising and the terms of the investment. These are summarised in the figure below.

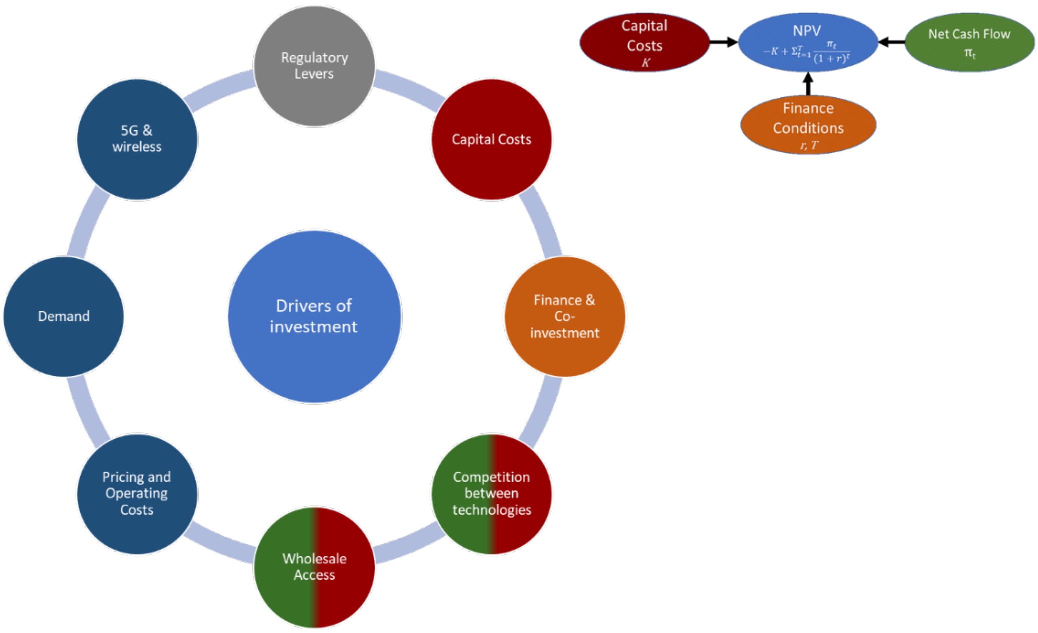


Figure 69: Summary categories of drivers of investment

Many of the drivers within these categories above may be well documented by other studies but adopting the methodology of System Dynamics has demonstrated in a novel way how these determinants are path dependent and interdependent. The table below summarises the broad range of drivers identified and incorporated into the qualitative models. These were introduced and discussed in Section 7 and more detailed cross-referencing is shown in the table.

Drivers of investment	
Capital costs	• Population density (see section 7.3.1) • Wayleaves and administration for deployment of infrastructure (see section 7.3.2) • Access to existing ducts and poles (see section 7.3.3) • Dark fibre – backbone access and leasing revenue opportunity (see section 7.3.3) • Reducing cost of civil works (see section 7.3.4) • Access to internal building wiring (see section 7.3.5)
Technology competition	• Cable vs DSL operator

Drivers of investment	
	• Cable vs FTTP entrants (see section 7.6) • FTTP entrants vs DSL operator
Finance & co-investment	• Telecoms investment funds (see section 7.4.1) • Confidence in revenue generation – anchor tenants (see section 7.4.2) • Regulatory certainty (see section 7.9.11.1) • Co-investment (see section7.4.3) • State and local government aid (see section 7.4.4)
Wholesale access	• SMP obligated wholesale access on VHCN and legacy networks (see section 7.7) • Wholesale only access as core business model (see section 7.4.1) • Wholesale access obligated through state aid regulations (see section 7.4.4)
Pricing & operating costs	• VHCN price premium vs legacy network services (wholesale and retail) (see section 7.5.4.2 and 7.3.3) • Connection and switching costs (see section 7.5.4.1) • Operating costs – lease, energy and maintenance (see section 7.5.1)
Demand	• Digital way of life • eGovernment services • Demand aggregation policies (see section 7.5.2) • Direct subsidies and tax breaks • Contract durations to allow churn
5G and wireless	• Use of data only 4G/WiMax (see section7.8.1.1) • 5G substitution of fixed VHCN (see section 7.8.1.2) • Hybrid FTTN/5G for VHCN (see section 7.8.1.3) • 5G backhauling on FTTP investment (see section 7.8.2)

Regulatory levers	• Infrastructure Access (see section 7.9.1 to 7.9.4)
	  o Duct and pole access and terms
	  o Ease of access to Rights of Way
	  o Use/Take up of Directive 2014/61/EU on Reducing cost of rollout of VHCNs.
	• Cost of access (see section7.9.7)
	  o Costing/pricing mechanisms to reward investment
	  o Interrelation of price regulation of current and next generation access
	• Regulatory positioning (see section 7.9.11)
	  o Increase regulatory certainty
	  o Regulatory forbearance on fibre investment
	  o Use of symmetrical obligations by NRA
	• SMP obligations
	  o Obligations placed on SMP operator in 3A/3B markets (see section 7.9.6)
	  o Effect of SMP regulations on other players (see section 7.9.77.3.3)
	  o Copper switch off conditions (see section 7.9.10)
	  o Co-investment (see section7.9.5)

11.2 Key messages for governments, regulators and industry

A number of broad messages have emerged from the study. These are:

There is a difference between drivers of investment and determinants of investment - the breadth of enquiry identified a universal set of drivers. However, determinants of investment are path dependent, contextual and depend on the conditions within a country, region and will differ between operator business models and not all drivers will be relevant.

There is no universal strategy that will work for all countries - Path dependencies and national/regional conditions can significantly affect the strength of the drivers of investment and the impact of policies on investment rates in individual countries. However, NRAs can learn from other markets as they evolve if the lessons become relevant. For countries that have seen high growth in VHCN investment, many still share the challenges to push coverage to the hard to reach regions.

Conditions are not static – markets evolve and the conditions will change. For example, demand for VHCN evolves which impacts revenue potential; increasing capital build costs as premise coverage increases; experience and technology development reducing capital cost reducing business case risk.

Regulatory and national policies should consider the impact across the range of operator business models – the study has identified a wide range of operator business models that have been able to tune their NPV business cases to meet market segment conditions. Regulators need to consider how their actions will impact each of these operator business models to avoid unintended consequences.

The model and analysis have demonstrated how **deployment cost matters and affect the need to generate revenue.** The NPV model can be used to understand how the costs of deployment effectively set a scale of revenue generation to reach a sufficiently positive NPV that will initiate investment activity. This also provides insight to the likelihood that a market will support infrastructure competition and possible overbuild imposing an even greater challenge to reach enough revenues to achieve a net positive NPV business case. This can be usefully communicated considering the NPV balance shown in Figure 70 below. The balance articulates how smaller capital costs (with the same financing conditions) will tip the balance and provide more headroom on revenue targets to maintain a positive NPV.

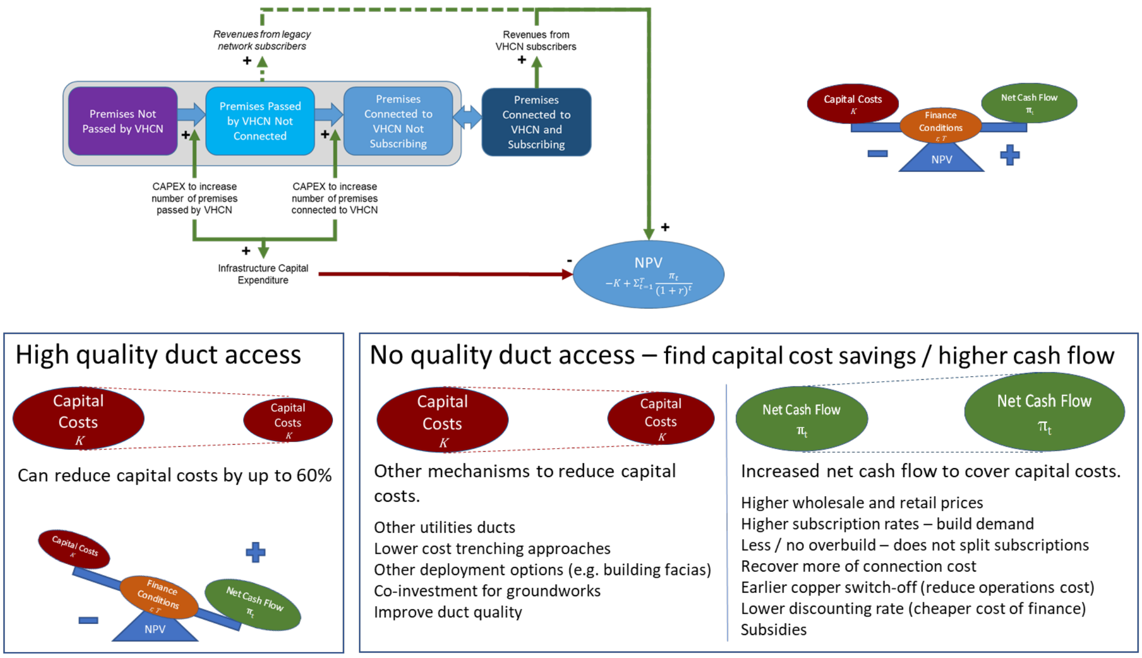


Figure 70: NPV impacts from deployment costs

Applying the same regulations in two different countries or regions may have very different impacts on investment, competition and prices. Regulation on duct/pole access along with the quality of the infrastructure will dominate deployments costs, but such regulation cannot help if much of the incumbent's network is directly buried. This sets the required cash flows through subscriber share and ARPU. Regulation can impact cashflows through choice in access, forbearance and pricing on both VHCN and legacy copper networks.

Business risk profiles affect the cost of finance – the study has identified that incumbent, retail operators and wholesale-only entrants each have very different business models. This has attracted a broader range of sources of capital to the sector with different financing conditions attached. One of these has been increased attention by patient capital. This finance can come with longer return periods and lower discounting rates creating positive NPV based investment decisions, but this has demanded a clearer infrastructure business model. Again, this can be illustrated with the NPV balance at Figure 71.

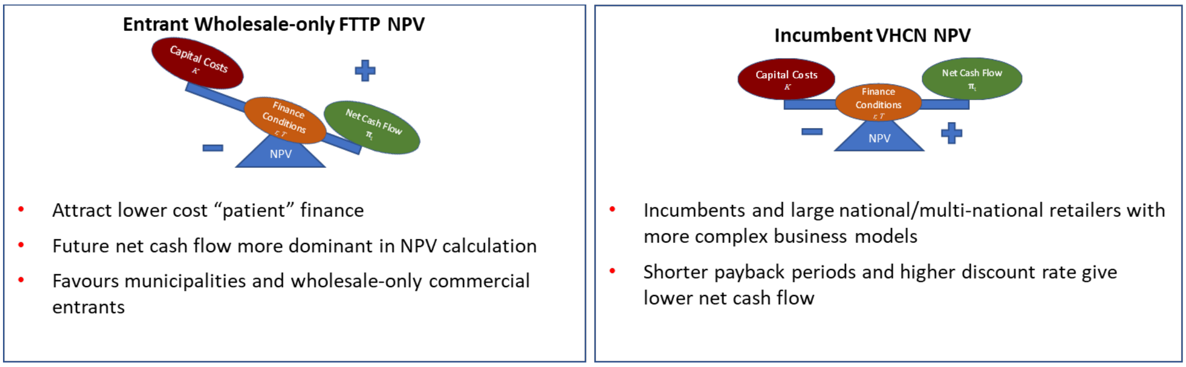


Figure 71: Comparing operator types – impact of financing conditions

Competition does drive investment - Figure 72 summarises the differences that are observed across competing operator types in different competitive markets. The introduction of retail competition that has occurred for copper-based services reduces the incumbent's market share, but this is partially offset by realising wholesale access charges (subject to regulated pricing). Alternate operators focusing on access seeking can develop successful business cases with the low capital needed and aggressive subscriber acquisition.

Where there is infrastructure competition the incumbent is likely to lose further retail and wholesale revenue. Competition creates opportunity for disruptive entrants to invent profitable business models and this, coupled with cable's advantageous incremental upgrade strategies, can force a switch by the incumbent to react with its own investment or lose market share. Across the markets reviewed, incumbents have demonstrated both reactive and proactive VHCN investment responses to such threats.

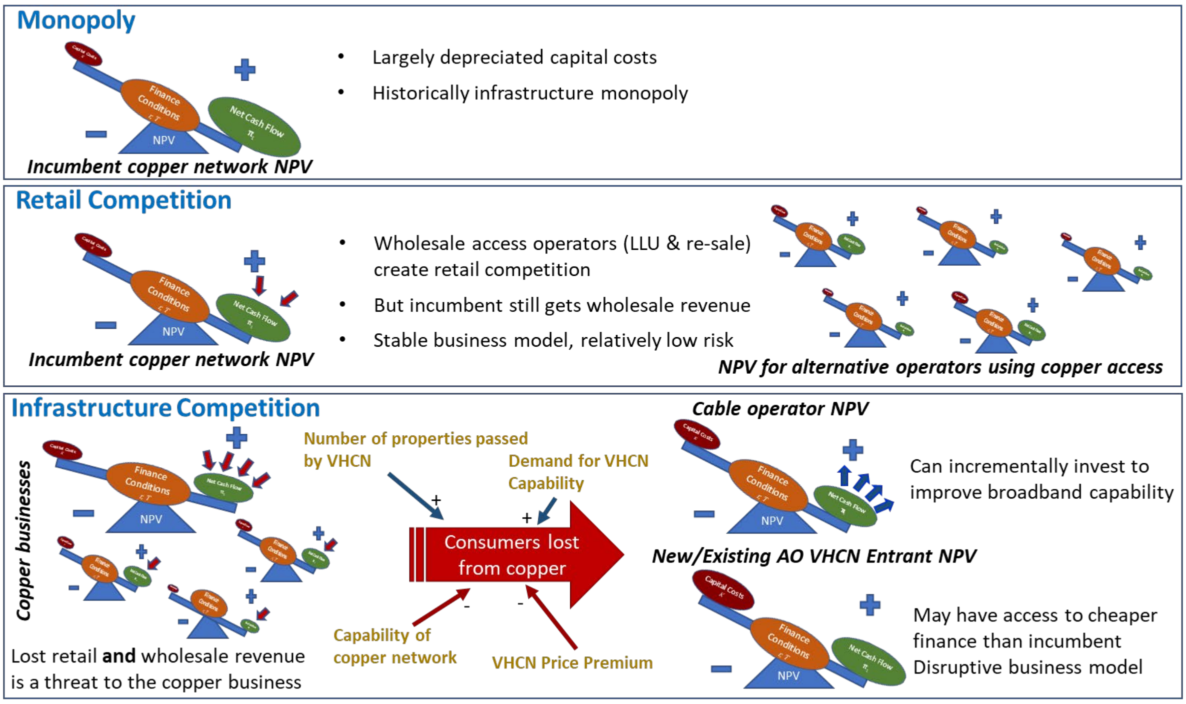


Figure 72: Comparison of competitive markets on NPV investment business cases

11.3 How whole systems modelling has created new insight and its limitations

The whole systems modelling has proven to be an innovative approach to understanding determinants of investment. Creating a **single** model and framework to compare markets, regions and network operators has provided a robust way to consider if insights from one market are relevant in others.

The modelling has demonstrated that markets at very different stages of VHCN penetration and path dependence can still share the same challenges within their VHCN ecosystems. This has been demonstrated for Spain and Portugal where very high coverage and penetration can still mask the challenge for rural areas with high VHCN build costs – a problem shared by most other countries.

The systems modelling approach has been a very different start point for considering VHCN investment determinants – the study team started with a corporate finance framework and the causal modelling process extended this to identify where and how regulation would impact that framework. This contrasts with much of the academic literature that uses the regulatory frameworks as the starting point for analysis and modelling. The systems approach has created a model where regulatory levers can have multiple touchpoints in the corporate investment decision making.

Another advantage of describing corporate business models is to reveal and describe the diversity of the network operators from the largest national operators through new entrant start-ups and municipalities and local communities.

The models described and the supporting analysis have been qualitative and this is aligned to the study requirements. Qualitative analysis does have a limitation in the degree of validity that can be attached and also in generating forward looking estimates for the industry standard metrics to measure VHCN investment and take up. The qualitative approach is valuable at the very earliest stages of NRAs undertaking market reviews and considering candidate regulatory actions.

11.4 Further modelling

In developing the study requirements, BEREC recognised that the qualitative model development and analysis could lead into more detailed modelling. Two areas for this further work have been identified building on the current study. These are:

- Further analyses with the qualitative models incorporating data driven evidence on key metrics. This strengthens the narrative based arguments and the analyses could include a comprehensive coverage of the BEREC member states, specific study of regulatory impacts such as the Broadband Cost Reduction Directive or deep dive comparison of different network operator business models.
- Development of a quantitative model to further substantiate the findings from the qualitative modelling. The quantitative model will not be as detailed as the complete qualitative models presented in this report. Rather they will be at an aggregated and simplified level representing the core NPV components of capital costs, cashflows and financing conditions within a market. Data on operator subscriber coverage and penetration, along with build cost estimates, revenues and costs will be required as well as sector level trends in demand. The resulting calibrated model will be used to generate alternative VHCN uptake scenarios under different market and regulatory conditions. The quantitative model will be used in conjunction with the qualitative model to support the strategy development. Quantitative modelling will require operator level data, and this will require close collaboration with an NRA to ensure access to data.

12 Glossary

Term	Description
ADSL	Asymmetric Digital Subscriber line
AO	Alternative Operators
BEREC	Body of European Regulators for Electronic Communications
BCRD	European Commission (2014) DIRECTIVE 2014/61/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communications networks.
CLD	Causal Loop Diagram
DOCSIS	Data Over Cable Service Interface Specification
DPA	Duct and Pole Access
EBIT	Earnings Before Interest and Tax
EBITDA	Earnings Before Interest, Tax and Depreciation of Assets
EECC	European Electronic Communications Code
EU	European Union
FTTB	Fibre to the Building
FTTC	Fibre to the Cabinet
FTTH	Fibre to the Home
FTTP	Fibre to the Premises
GNBM	Generic Network Business model
HDTV	High Definition TV
HFC	Hybrid Fibre-Coaxial
LLU	Local Loop Unbundling
LRAIC	Long run average incremental cost plus
LRIC	Long run incremental cost plus
MDU	Multi-dwelling Unit
MECE	Mutually Exclusive and Completely Exhaustive
NGA	Next Generation Access
NPV	Net Present Value
SD	System Dynamics
SMP	Significant Market Power
UFB	Ultra Fast Broadband
USO	Universal Service Obligation
VDSL	Very High-Speed Digital Subscriber Line
VHCN	Very High Capacity Network
VULA	Virtual Unbundled Local Access

Annex A. Technical introduction to System Dynamics

This section provides a brief introduction to System Dynamics as a primer to support an understanding of the use of Causal Loop Diagrams which are used in the literature review of drivers of broadband investment. It also provides some examples of the use System Dynamics for policy analysis as an illustration of the way that it is used to capture and understand complex and interdependent problems so that rounded policies can be devised. This provides a greater cognitive challenge than simple linear arguments and solutions, so it is hoped that the review will demonstrate the types of concepts that are considered and both the challenges and the benefits from grappling with this greater level of complexity.

A.1. The Principles of System Dynamics

System Dynamics (SD) is a technique that is used to frame, understand, and discuss complex issues and problems. It can be deployed at two levels:

- The first level consists of a visual mapping technique to capture how people (these can be actors in the system or observers such as academics) believe cause-effect relationships combine in an overall causal structure that generates system behaviour. Such qualitative diagrams, known as causal-loop diagrams or 'CLDs', can be used to explain and communicate how a system's architecture drives behaviour over time - in the context of the current study, how investment in infrastructure will grow over future years. Published research papers and stakeholder interviews can all contribute to this qualitative modelling.
- At the second level of use, elements in the CLD are quantified and causal relationships are formulated with equations to produce a working, quantitative simulation model of the system. The resulting model should mimic the observed and anticipated behaviour of the system of interest, enabling policy-makers to generate numerical analysis over time, to explore scenarios and to test alternative policies.

SD models do not conflict with theories derived from econometric studies, but rather incorporate all those theories into an integrated whole system model – if statistical analysis finds, for example, a relationship between price (or price differential) and adoption rates for a service, then the SD model would include that relationship, and produce a quantified estimate of how profitability and investment would most likely respond to potential price changes over time. This is a key benefit offered by SD models. A further added value is that the same model would also show the consequences of all other causal relationships, including those that result in feedback - for example, how slower investment holds back the industry's physical capacity and constrains customer adoption of the product or service, and how this slower adoption would then further hold back the rate of investment.

System Dynamics was developed in the 1950s by Jay Forrester, initially an extension of control theory to business problems, and was formally presented as a methodology in his book *Industrial Dynamics* (Forrester, 1961)[97]. Several important texts describing the System Dynamics approach have been

[97] Forrester, J. (1961) Industrial Dynamics. MIT Press.

published since Forrester's early books. For example, see Sterman (2000)[98]; Warren (2007)[99] and Morecroft (2015)[100].

System Dynamics encompasses the following features:

- **Dynamic Behaviour** – The ability to conceptualize how systems and organizations behave over time.
- **Cause and Effect** – The ability to link cause and effect between different aspects of the system, based on theory and/or observation to determine plausible explanations for the behaviour in a system. System behaviour is described by the structure of linked sets of these cause and effect relationships.
- **The nature of the cause and effect relationships** – Cause and effect influences between elements can be characterised as having a change effect that pushes the influenced element in the same direction as the causal element (indicated by a '+' or a green link arrow in a diagram in this document) or in the opposite direction (indicated by a '–' or red link arrow in diagrams in this document).
- **Delays** – Influences can also have an immediate impact or may be delayed by either exerting an influence after a period of time or building up over a period of time.
- **Representing relationships in quantitative models** – In quantitative analysis the nature of the causal relationships is captured in the form of equations or functions, while exogenous elements (i.e. inputs) are captured as single values or time-series values (different values can be specified for different time periods, e.g. annually).
- **Closed Loop Analysis (Feedback Loops)** – Chains of cause and effect relationships can often link into closed loops meaning that an element in the system can be influenced (indirectly) by changes to its own values at an earlier point in time.
- **Reinforcing (a.k.a. Positive) Feedback** – Some feedback loops can be reinforcing (or positive) leading to an accelerating impact. A simple example of a reinforcing loop is compound interest in a bank savings account, where money in the account earns interest leading to more money in the account, which then earns more interest in the next cycle. Reinforcing loops (despite often being called "positive feedback loops") are not always good, an economic crash is also an example of a reinforcing loop.
- **Balancing (a.k.a. Negative) Feedback** – Some feedback loops can be balancing, tending to move an element in the system to an equilibrium point (often a goal) or a limit. A business may aim to grow customers, but a limit in the total pool of customers will be a limit on the number of customers that can be gained. As an example of a goal, most managed economies have goals for inflation rates with multiple policies aimed at achieving this goal (the difficulty in achieving these goals is an example of complex systems with multiple influences and feedback loops as well as

[98] Sterman, J.D. (2000). Business dynamics. McGraw-Hill Higher Education.
[99] Warren, K. (2007). Strategic management dynamics. John Wiley & Sons.
[100] Morecroft, J. (2015). Strategic Modelling and Business Dynamics: A Feedback Systems Approach. 2nd edn. John Wiley & Sons.

time delays between actions and measurable outcomes often leading to over-shooting or under-shooting).

- **Hierarchy of Levels of Analysis** – It is often worth analysing system behaviours at a range of levels of detail ranging from broad high-level concepts, through a middle-level covering most of the elements of a system, to a detailed representation suitable for representing in a quantitative simulation model. This hierarchy of levels can introduce readers gradually to the concepts in the system as well as highlighting different "big picture" or "fine detail" aspects of the system behaviour. This hierarchy of levels of analysis was conceptualised by Coyle as a hierarchical cone of diagrams (1996)[101], see Figure 73.

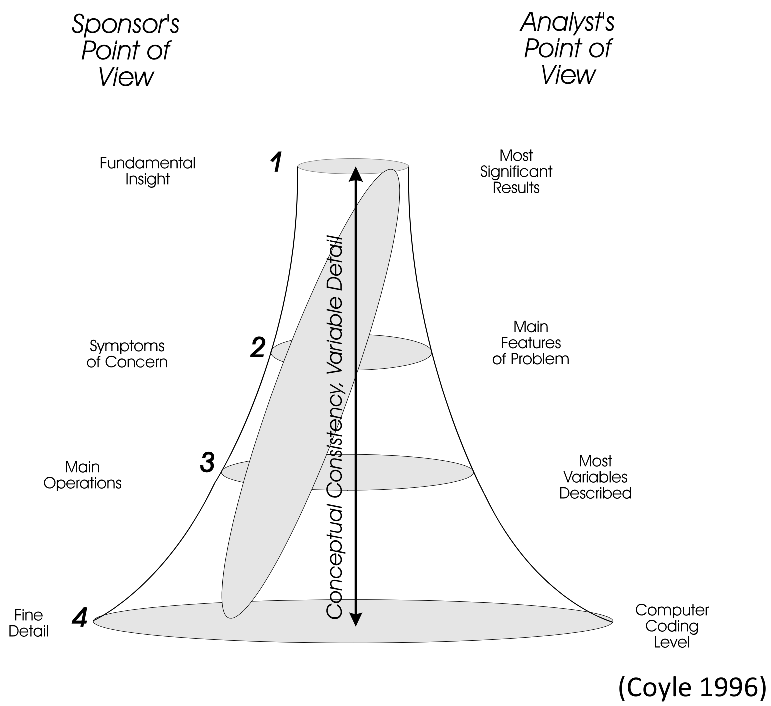


Figure 73: Cone of Diagrams

The visual mapping used by System Dynamics models tends to use one of two formats: "Causal Loop Diagrams" (CLDs) or "Stock-Flow Diagrams" (SFDs). Qualitative models are often presented using Causal Loop Diagrams although Stock-Flow Diagrams are also sometimes used for qualitative models. Quantitative simulation models nearly always use the Stock-Flow Diagram format since they more clearly define the basic building blocks that are needed for a quantitative System Dynamics model. Both formats of diagram encompass the core principles of System Dynamics but have different strengths and weaknesses in terms of communication and analysis of dynamic behaviour. In terms of Coyle's cone of diagrams, CLDs will almost always be used at the top of the cone (least detailed) while SFDs will almost always be used at the bottom of the cone (most detailed). Intermediary levels of the cone may see either CLDs or SFDs used depending on the background of the developer, the requirements of the study and/or the nature of the system being modelled. Both CLDs and SFDs have been used in the current study.

[101] Coyle, R.G. (1996) System Dynamics Modelling: A Practical Approach. Chapman & Hall.

A.2. Causal Loop Diagrams (CLDs)

Causal Loop Diagrams represent systems as a group of causal links represented as directional arrows (from Influencer to Influenced) between pairs of elements in a system. A system will consist of multiple elements and multiple causal links, with structure defined by the chained causal links and sets of links that form into feedback loops. Symbology sometimes differs between diagrams (due to modeller preferences) for the same concepts but the diagrams are subject to a common set of concepts.

The nature of the causal links will often be represented by symbols next the arrow head indicating how a change in the Influencer (at the tail of the arrow) will affect the Influenced (at the head of the arrow).

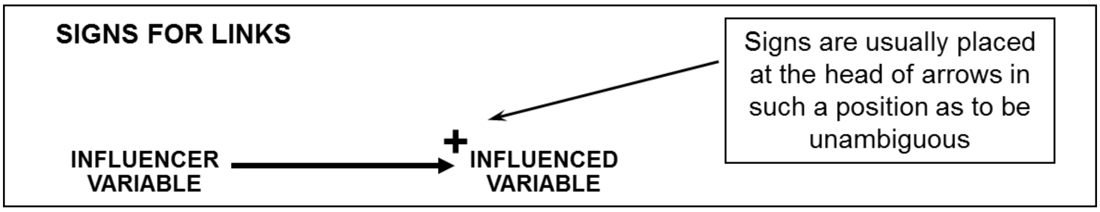


Figure 74: A causal link showing a polity symbol indicating the nature of the relationship

A "+" or "S" (indicating Same) symbol represents a positive relationship where a change in the Influencer will tend to cause a change in the Influenced in the same direction. A "-" or "O" (indicating Opposite) symbol represents a negative relationship where a change in the Influencer will tend to cause a change in the Influenced in the opposite direction.

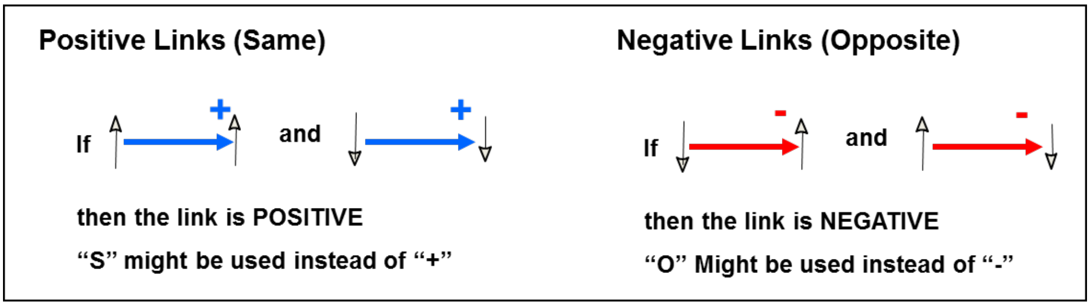


Figure 75: The meaning of positive or S(ame) and negative or O(pposite) causal links

Causal links might represent delayed relationships where the impact on the influenced element occurs after a delay (e.g. a delay between investing finance into telecoms infrastructure and the telecoms infrastructure being available to customers, the delay being due to time to plan and implement the building work and integration into the telecoms network). Alternatively, the strength of the relationship may build over time (e.g. customers' perceptions of the benefits of higher internet speeds). A delayed relationship is usually shown by cross-hatching or a "D" symbol on the arrow, although not all CLDs will explicitly show delay symbols.

Figure 76: Symbology for causal links with delayed impacts

Sets of causal relationships can combine and cause closed loops which exhibit particular forms of behaviour that can be categorised as Reinforcing (also known as Positive) or Balancing (otherwise known as Negative) feedback loops.

Reinforcing (also known as Positive) feedback loops have an accelerating behaviour over times showing exponential growth (or decline). A simple example is compound interest in a bank account where accrued interest is added to the account balance and so leads to an increased interest payment in the next period. However, not all reinforcing feedback is good, hyper-inflation or the collapse in reputation (and profits) of a business or bank are also example of reinforcing feedback loops.

Reinforcing loops can be identified as a closed loop with no negative/opposite relationships in the loop or an even number of negative/opposite relationships. Some diagrams highlight these loops using an "R" (for Reinforcing) or a "+" inside a clockwise or anticlockwise arrow circle, while others show a snowball rolling downhill.

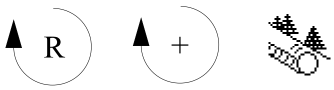


Figure 77: Common symbologies for identifying reinforcing feedback loops

Balancing (also known as Negative) feedback loops tend to have a decelerating behaviour that tends towards an equilibrium or a limit. These may be goals set by policy or management targets, or limits due to capacity constraints. For example, the speed at which fibre cable can be laid may be constrained by available skilled labour to do the work, which may create a limit to expansion of the network even if finance and demand is available. Note that other actions in the system may be targeted at shifting limits, for example training programs to increase the amount of skilled labour.

Sterman (2000)[102] provides a simple (and slightly tongue in cheek) example of a reinforcing feedback loop involving chickens and eggs. Without any other limiting factors, more chickens will lead to more eggs being laid, and more eggs lead to more chickens. A similar, and more realistic example is the growth of a bacterial culture. A high level CLD for the chicken and egg example is shown below along with time charts of possible behaviour.

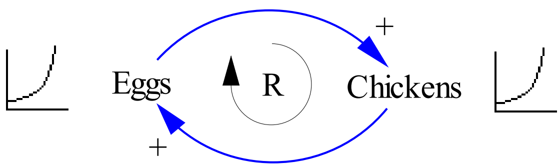


Figure 78: Simple reinforcing loop based on Sterman's Chicken and Egg example

Balancing loops can be identified as a closed loop with an odd number of negative/opposite relationships. Some diagrams highlight these loops using a "B" (for Balancing) or a "-" inside a clockwise or anticlockwise arrow circle, while others show a balanced set of scales.

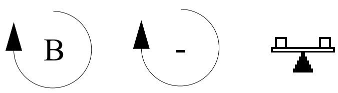


Figure 79: Common symbologies for identifying balancing feedback loops

[102] Sterman, J.D. (2000). Business dynamics. McGraw-Hill Higher Education.

Sterman (2000) expands on the chicken and egg theme by introducing a limit on the chicken population due to them having to cross the road. In this case, chickens crossing the road may lead to their deaths and so reduce the number of chickens. The more chickens there are, the more road crossings there will be. With no other influences, this will lead to a reduction in the number of chickens to zero, but the rate of chicken deaths will decline as we have fewer chickens and therefore fewer road crossings.

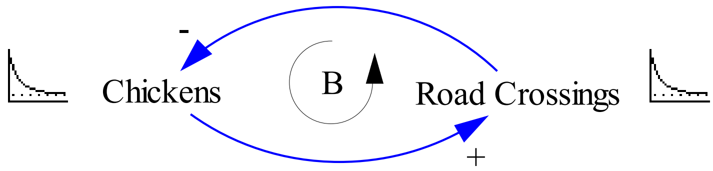


Figure 80: Simple balancing loop based on Sterman's Chicken and Road Crossings example

Most CLDs will contains multiple feedback loops which will be competing or complementary with each other and producing complex dynamic behaviour. Sterman's chicken, egg and road crossings example combines to produce a system where the chicken population growth is limited by road crossings.

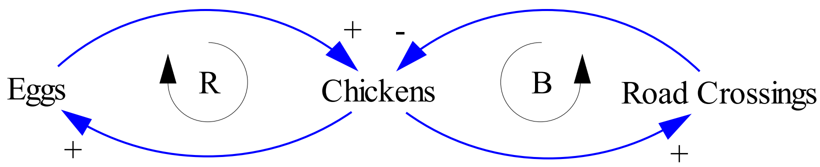


Figure 81: Combining feedback loops for Chickens, Eggs and Road Crossings

It is worth noting that the chicken, egg, road crossings example shows the use of the CLDs in a form represented by the very top of Coyle's cone of detail. It conveys concepts at a very high level in a simple format, but hides a number of important details on other factors that impact the rate of egg production, successful hatching rates, delays between egg production and hatching, and the reasons for (or at least rates of) chickens crossing the road. As described by Richardson (1986), these extra details are required to properly understand the drivers of the relative strengths of loops in CLDs. It is possible, and common, to expand Causal Loop Diagrams to include more details in order to better understand the drivers of the strengths of the feedback loops and to more explicitly show physical rates changes and information controls, but there is still a limitation in the + and – notation for understanding relative strengths of feedback loops.

Despite the limitations of high level CLDs, they have been used as the basis for developing generic archetypes that explain commonly seen dynamic behaviours. In his book "The Fifth Discipline", Senge (1990)[103] introduced a number of high-level CLD structures, or "archetypes" describing commonly observed dynamic structures, which were subsequently expanded in a follow-on fieldbook (Senge et al., 1994)[104]. In each case the CLDs provide a map to show dynamics but are always accompanied with narratives to describe how those dynamics play out in a specific example. An example is the "Fixes that Fail" archetype where a short-term fix creates unintended long-term consequences, which require even more use of the same fix.

---

[103] Senge, P. (1990). The Fifth Discipline: The art and practice of the learning organization. Doubleday/Currency.
[104] Senge, P., Kleiner, A., Roberts, C., Ross, R.B., & Smith, B.J. (1994). The Fifth Discipline fieldbook: strategies and tools for building a learning organization. Doubleday/Currency.

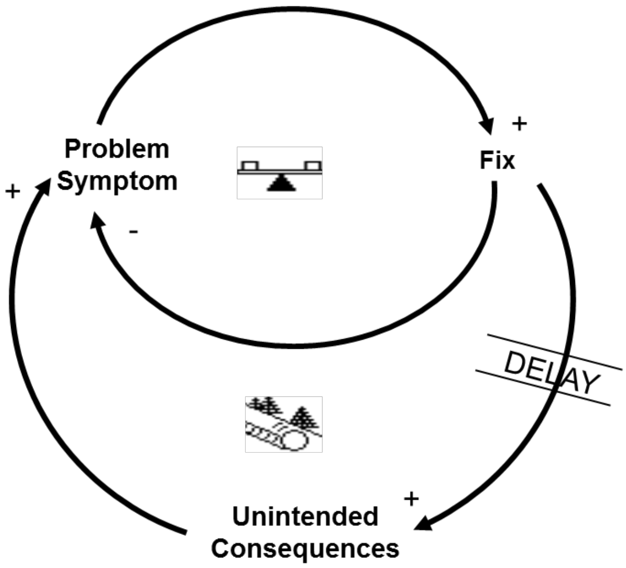


Figure 82: Fixes that Fail, based on Senge (with addition of polarity signs on arrows)

Senge uses the example of a manufacturing company that introduces a new high-performance part that was initially widely successful. The CEO, wishing to maximise ROI, delays introducing expensive new equipment that would make production more efficient. Production quality suffers, leading to a reputation for poor quality, leading to a reduction in sales and profits which makes the CEO even more unwilling to invest in new production equipment.

As part of the literature review, causal links (i.e. parts of CLDs) are used to capture some of the relationships expressed in the papers being reviewed. Some of these papers show closed loop behaviours that can be expressed as positive and negative feedback loops. The literature review also includes some papers that specifically use System Dynamics and CLDs to address telecommunications infrastructure studies, with examples ranging from small CLDs with a dozen causal links and a few feedback loops to large CLDs with a great many feedback loops.

A.3. Stock Flow Diagrams (SFDs)

Stock Flow Diagrams are an alternative way of representing dynamics in systems, being analogous in many ways to Causal Loop Diagrams. Many of the same concepts are present in both CLDs and SFDs but different symbology is used and flows are represented differently and more explicitly. SFDs can be used for qualitative System Dynamics models (pros and cons compared with CLDs are discussed later) and are generally the default mechanism for building quantitative System Dynamics models since they contain the structure and degree of rigour required to associate the diagrams with numerical measures and equations.

The key building blocks for SFDs are “Stocks” (also known as “Levels” or “Resources”), “Flows” or “Rates”, “Variables” (also known as “Auxiliaries”) and “Constants” (also known as “Inputs”). The figure below shows the building blocks of an SFD.

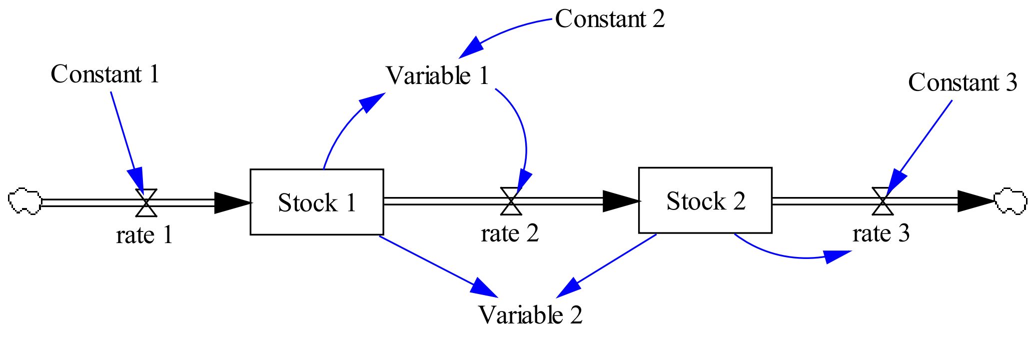


Figure 83: A Stock Flow Diagram showing all the main building blocks

Stocks represent an accumulation or a measure that characterises the state of a system at a point in time. They are often important quantities for a managed system and can represent something tangible such as “Customers”, “Employees”, “Money in Bank”, “Finished Goods” or intangibles such as “Morale”, “Brand Awareness”.

A key feature of stocks is that their quantity can only be changed as a result of flows that fill (inflow) or deplete (outflow) a stock. These are shown as double-lined arrows with valve symbols. Rates define the speed at which a stock is filled through an inflow or depleted by an outflow. Rates are always expressed in terms of a quantity per time period. For example, a stock might be “Employees” measured as the number of people with an inflow rate of “hires” measured as people/month and an outflow of “leavers” also measures as people/month. In order to keep the number of Employees at a steady state the number of hires must equal the number of leavers.

Figure 84: Stock of Employees is increased by hiring and depleted by leavers

Clouds symbols represent stocks that are outside of the scope of interest and which are not measured. In the employees example, we are not interested in the stock of people we are hiring from (although this might be of interest if there is a very limited pool of people with the appropriate skills), or the stock of ex-employees.

Variables represent a measure that can be calculated at any point in time from other elements in the diagram. These are the “effected” elements from the causal (cause and effect) links in a Stock Flow Diagram, which are shown by the single arrows. Constants only have causal links coming from them and represent exogenous fixed quantities or exogenous impacts. Despite commonly called “Constants”, these might change over time (e.g. a policy is changed at a particular point in time, or we might have demand for a service that is applied as an exogenous time-series), but this change is not explained by anything included inside the SFD. Causal link arrows shown in SFDs often do not have “+”/”S” or “-“/”O” polarity symbols by convention, but there is no reason why they cannot be used and may be observed in some studies. Variables that only have arrows in (i.e. no arrows out) usually represent key performance measure for the system of interest.

Like CLDs, an SFD will usually contain a number of feedback loops, but even if the SFD uses polarity symbols these feedback loops may not be so readily apparent if an outflow is included in the loop. The diagrams below show part of an SFD and the equivalent in CLD format, both incorporating a balancing feedback loop. This loop is readily apparent in the CLD but not in the SFD unless the reader is used to interpreting these in the SFD formulation.

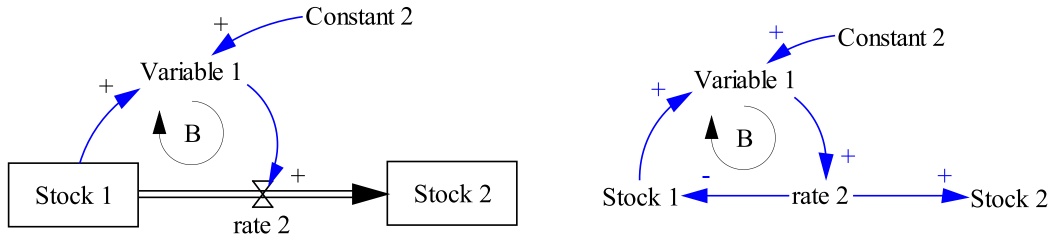


Figure 85: Comparative SFD (left) and CLD (right) formulations with a Balancing Loop

In the SFD formulation the outflow from "Stock 1" controlled by "rate 2" is the equivalent to a CLD causal arrow from "rate 2" into "Stock 1" with a -ve (opposite) polarity (the higher rate 2, the more Stock 1 will be reduced). In the SFD the outflow must be interpreted as a -ve polarity arrow from the rate in order to recognise the feedback loop. The CLD has the advantage of making the feedback loops more apparent while the SFD has the advantage of making the stocks and flows more explicit and apparent.

A.4. Quantitative System Dynamics Models

Quantitative System Dynamics models are simulation models that combine quantities, equations and functional relationships with the visual structure of Stock Flow Diagrams to allow numerical analysis of systems over time. The simulation model steps through time in fixed increments and calculates the change in stock values for each time increment.

Although simulation in general, and SD in particular, may initially seem technically complex, they merely combine known causal relationships and convert them into time-based quantified models. Each element in the model can be thought of as a spreadsheet column, with the item's name in the top cell and each period's values in the cells below. The link arrows are like cell-references. The models, provided they are properly constructed, reflect universal principles of how the real world works. Complexity comes from combining relatively simple equations with the structure of the SFD.

Calculations for each relationship in the model will take the form of mathematical equations, like those in a cell in a spreadsheet, or in terms of graphical functions relating input and output values. Inputs to the models represents exogenous variables and may be a fixed value for the duration of the time represented in the simulation, a value that varies at particular points in time (e.g. a change in policy) or a time-series that can change over the course of the simulation period.

The action of a System Dynamics simulation engine is to use the calculations in each time step to perform numerical integration to calculate the stock values, and numerical differentiation to determine rate values for a particular step in time. This simplifies the actual equations that are entered for each part of the model.

The degree of precision in the outputs of System Dynamics simulation models, like most other quantitative methods, is dependent on the degree of certainty in the relationships (equations and functions) in the model and, similarly, for any input data. Tightly bounded models based on well-known physical attributes can have very precise outputs. However, most models used for assessing policy involve a broad scope for the system being studied (requiring a level of abstraction in their representation) and some degree of uncertainty in the numerical representation of the relationship and in input parameters. This uncertainty means that most models designed to test policy formulation cannot be treated as highly precise forecasting tools. By considering the appropriate level of precision of the model, they will provide an understanding of the direction of travel for key outcomes based on a mix of policy levels and potential unintended consequences. Combined with appropriate sensitivity analysis around uncertainties and assumptions, they can be used to assess the robustness of policies against uncertainties that are present in the system.

A.5. Use of Causal Loop Diagrams (CLD) vs Stock Flow Diagrams (SFD)

Causal Loop Diagrams and Stock Flow Diagrams both embody fundamental aspects of System Dynamics but demand different levels of representational rigour in their formulation and differ in the ease of identifying feedback loops and stock/flow elements. It is almost essential that the SFD formulation is used for quantitative simulation models since the explicit representation of stocks and flows is essential to the calculation process used in simulations.

SFDs require explicit representation of stocks and rates, which implies a certain degree of detail that might obscure some high-level relationships and dynamics that we wish to communicate towards the top of Coyle's cone of diagrams. In these circumstances the use of CLDs might be preferable, particularly since it is easier to identify feedback loops in CLDs than in SFDs.

As we move into the middle area of the cone of diagrams between the very high-level representation and the quantitative simulation level of representation, the use of CLDs vs SFDs is less clear-cut and depends on the need to clearly communicate the feedback loops and the wish to communicate the important stocks (resources) and flows in the system, as well as the perspective of the system stakeholders during joint construction of the diagrams. The decision on which format to use often depends on analyst preferences for methods of knowledge elicitation and perspectives of the importance of the relative strengths and weaknesses of the diagramming approaches, and key messages to be communicated.

If feedback loop identification is the pre-dominant aim then CLDs will tend to be used, while if the emphasis is on understanding the role and development of the key resources (and the drivers on build-up and depletion of those resources) then SFDs will tend to be used. Warren (2007)[105], for example, argues that performance outcomes of concern are driven by easily-identified 'asset-stocks' and any change in performance over time must then reflect changes to the quantities of those stocks so that gains and losses of asset-stocks are therefore the critical levers determining system performance.

It is also worth noting that there are many examples of System Dynamics diagrams that are neither pure CLD nor pure SFD but instead exhibit a mixture of the two. Casey & Töyli (2012)[106] present System Dynamics models for mobile telecoms competition as pure high-level CLDs and then with more detail in a format that is essentially a CLD but with aspects of SFDs to highlight key stocks in the system. Ghaffarzadegan *et al.* (2011)[107] present several small System Dynamics models for analysing public policy that are essentially SFDs in nature but make use of polarity signs on causal links and highlight the presence of feedback loops. These examples are most aligned to the approach adopted in the current study.

Warren (2002)[108] moves qualitative SFDs further into the quantitative dimension with the Strategy Dynamics approach that emphasises numerical time-path traces by displaying time-series graphs on what is otherwise essentially a qualitative SFD. The graphs are derived from sketching numerical evidence onto stocks and rates into the SFD (along with other inputs and variable in the diagram as required) to provide evidence-based relationships beyond the standard polarity symbols. The representation then extends directly into the quantitative model realm by the addition of equations and functions to the model to calculate the numerical values, which can then be compared against the sketches for historical data and for evaluating future trends based on policy settings.

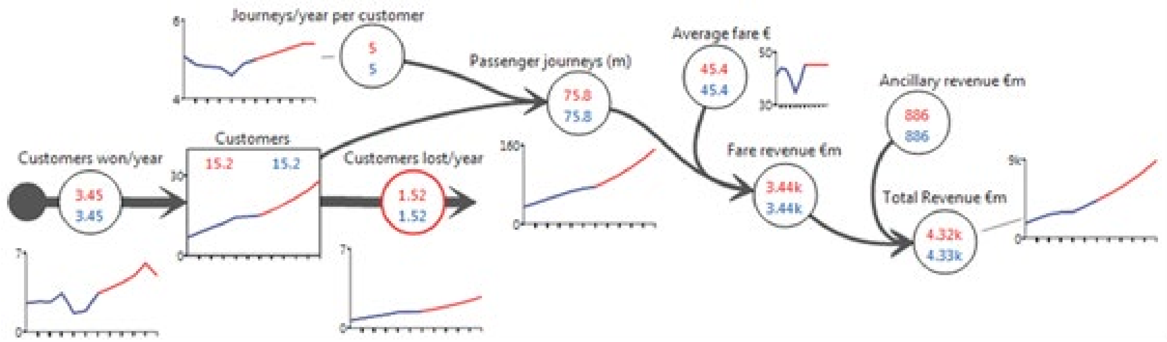
---

[105] Warren, K. (2007). Strategic management dynamics. John Wiley & Sons.

[106] Casey, T. R., & Töyli, J. (2012). Mobile voice diffusion and service competition: A system dynamic analysis of regulatory policy. Telecommunications Policy, 36(3), 162-174.

[107] Ghaffarzadegan, N., Lyneis, J., & Richardson, G.P. (2011) How small system dynamics models can help the public policy process. System Dynamics Review, 27(1), 22–44.

[108] Warren, K. (2002). Competitive strategy dynamics. John Wiley & Sons.



(Warren 2008)

Figure 86: Part of a Strategy Dynamics model showing customer growth and revenue at Ryanair

Annex B. Example interview questionnaire – operators

This annex provides an example of the interview guides used for interviews. These provided a structured approach common across interviewees but allowing for broad discussion.

Determinants of investment in VHCN

Operator Questionnaire

This project is being conducted in the light of the new requirement in the EECC for NRAs to promote investment in Very High Capacity Networks (VHCN). BEREC is seeking to understand the overall determinants of investment using a System Dynamics model. We will provide a brief overview of SD models at the start of our interview. At this stage of the project, we are seeking to understand the factors that operators take into consideration when considering an investment, to help develop a qualitative model. Once the qualitative model is developed, the project envisages the development of a quantitative model.

The answers to these questions will be used to develop our understanding of the drivers of investment. Individual answers will remain confidential.

1. Could you briefly describe your company's overall strategy for providing VHCNs to residential and business customers?
2. Overall, what are the main factors that determine the:
   a. Level,
   b. Timing and
   c. Location

   of investments in VHCN?
3. We'd like to understand what factors help you determine where you may make an investment in VHCN. To do this, we'd like to set out different conditions that may exist in two discreet geographic areas, e.g. cities or municipalities, where you are thinking about investing. For each factor please state whether that creates a preference towards one location or the other or is neutral. Each pair of factors is independent of the preceding and following ones.

<table>
<tr><th colspan="5">Location 1</th><th colspan="5">Location 2</th></tr>
<tr><td colspan="5">The regulated price of wholesale access to current generation network is tightly regulated</td><td colspan="5">The regulated price of wholesale access is weakly regulated.</td></tr>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">The market is dominated by ADSL and your ADSL product faces strong competition in the retail market from providers using wholesale access</td><td colspan="5">The market is dominated by ADSL and your ADSL product faces weak competition in the retail market from providers using wholesale access</td></tr>
</table>

<table>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">The market is dominated by NGA (e.g. FTTC) and your product faces strong competition from other operators in the same generation using the wholesale equivalent</td><td colspan="5">The market is dominated by NGA (e.g. FTTC) and your product faces weak competition from other operators in the same generation using the wholesale equivalent</td></tr>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">Another firm is building a VHCN in this location</td><td colspan="5">No other firm is building a VHCN in this location</td></tr>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">Duct access is available on a symmetric basis, i.e. from all network operators</td><td colspan="5">Only the SMP operator is required to offer duct access</td></tr>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">The regulator has made it clear that it will consider regulating any VHCN if it develops SMP in a discreet geographic area</td><td colspan="5">The regulator has made a commitment to allow any VHCN to earn a risk premium even if it is the only gigabit capable network in the location</td></tr>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">The NRA has said that it will not regulate fibre to the building but will regulate internal wiring on a symmetric basis</td><td colspan="5">The regulator's policy is to encourage multiple end-to-end fibre networks to the house/apartment.</td></tr>
<tr><td colspan="2">Strong preference</td><td colspan="2">Weak preference</td><td colspan="2">Neutral</td><td colspan="2">Weak preference</td><td colspan="2">Strong preference</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="5">The cable operator has announced upgrade to DOCSIS 3.1</td><td colspan="5">There is no competition from cable</td></tr>
</table>

Strong preference	Weak preference	Neutral		Weak preference	Strong preference
Your most upstream product (e.g. ducts and poles) is regulated on a cost-oriented basis with pricing freedom, subject to an ERT, on downstream wholesale prices			All levels of wholesale product are regulated on a cost orientated basis		
Strong preference	Weak preference	Neutral		Weak preference	Strong preference

4. Are there any other criteria that would make you favour one area over another?
5. Do you consider fixed wireless access could be a means to deliver Ultrafast Broadband in some areas?
6. Do you consider the need for fibre to the base station to support 5G MNOs to be a driver of investment?
7. Do you consider 5G microcells to be a means of delivering UFB within buildings at lower cost than wired access?
8. Is there anything else you would like to add?

Annex C. Generic Network Business Model

This annex presents the complete qualitative model representing a generic network operator business system. This is described in detail in section 8. It is included overleaf as an A3 sized page.

Glossary

NetOI = Network Operator of Interest

RetOI = Retailer Operators of Interest on Network of Interest

OtherOI = Competitor Network Operator of Interest - competing with NetOI

Legacy & Upgrade = Cable 2.x, 3.0, ADSL, VDSL, FTTC

VHCN = Cable DOCSIS3.1, FTTP