Excellence in Business

Development of the Danish LRAIC model for fixed networks

Model Descriptive Document

[Version for 1st consultation]

Axon Partners Group

3 February 2020

Contents

1. Introduction

Since 2003, the DBA has annually regulated the wholesale prices for several fixed-network services through a Long Run Average Incremental Cost (LRAIC) model. As presented in the Model Reference Paper (hereinafter, 'the MRP') from October 2019[1], the relevant changes that occurred in the fixed Danish market since the last major update of the model in 2013, merited a new update of the fixed LRAIC model (hereinafter, 'the model') to make sure it is representative of the current situation and can fulfil DBA's regulatory needs.

The draft model submitted to consultation has been developed following the methodological principles laid out in the MRP from October 2019, which was subject to consultation with the industry between 1st July to 30th August 2019.

This Model Description Document aims to describe the modelling approach, structure and calculation process followed in the development of the model.

[1] Link: https://erhvervsstyrelsen.dk/sites/default/files/2019-10/Final%20MRP.pdf

2. Model architecture

The model developed follows a classical Bottom-Up LRAIC architecture. The architecture of the model is divided into blocks, to ease its conceptualisation. A high-level diagram of the blocks considered in the model and their relationship is presented in the figure below.

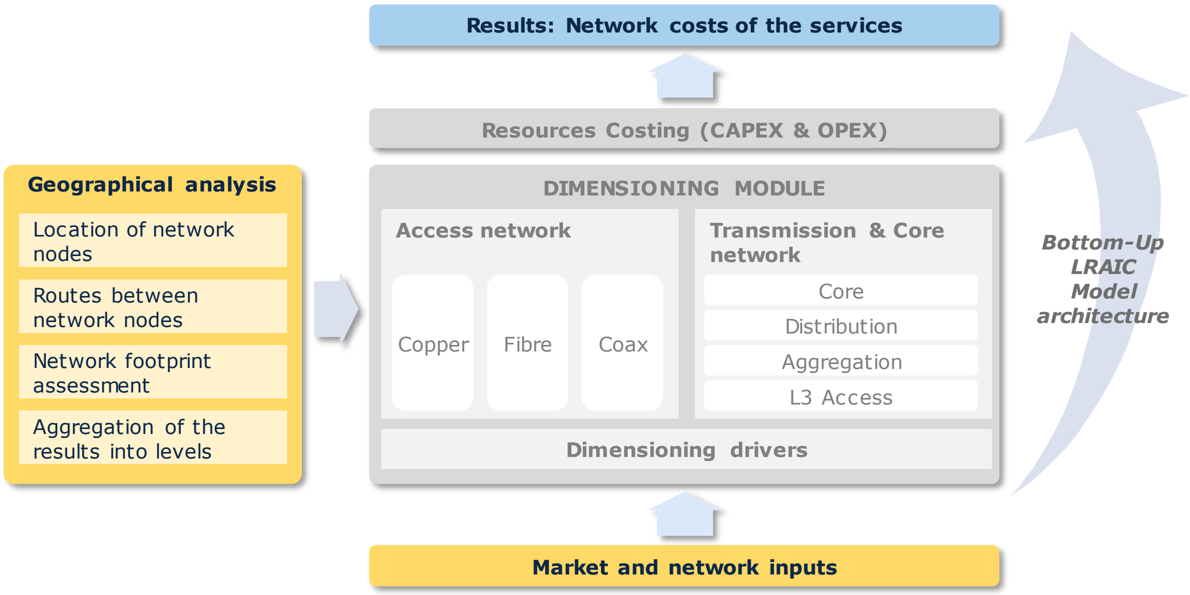

Exhibit 2.1: Structure of the model [Source: Axon Consulting]

As seen in this figure, several main function blocks are relevant to the model. These are:

- **Market and network inputs**. These inputs represent basic data from the market (e.g. demand) and network (e.g. traffic statistics) that the model uses in to perform its calculations (section '3 - Market and network inputs').
- **Geographical analysis performed in the R model**. Analysis of the geographical characteristics of Denmark, based on the road network, the existing building and access nodes of the operator (section '4 - Geographical analysis performed in the R model').
- **Dimensioning module.** Calculation of the number of resources needed for the network to supply the services provided by the reference operator (section 5 - Dimensioning module').
- **Resources costing.** Assessment of the annualized costs of the network, in terms of operational (OpEx) and capital (CapEx) costs (section '6 - Resources costing').

- **Network costs of the services:** Allocation of the costs of the resources to services and calculation of the final unit costs of the services considered in the model (section '7 - Network costs of the services').

Each of these modules is presented with a high level of detail in the sections below.

3. Market and network inputs

The cost model developed is data-intensive and has been populated with the information requested from the operators (through the data-gathering processes that ran from 14 June 2019 to 29 July 2019 and from 27 September 2019 to 1 November 2019), as well as additional publicly available information and other data available to DBA.

The model's inputs are included under the "Market and network inputs" and the "geographical analysis" blocks illustrated in Exhibit 2.1. The former is described in this section, while the latter is presented in section '4 - Geographical analysis performed in the R model' below.

The "Market and network inputs" block includes the following inputs:

- Demand
- Asset costs
- Adjustment for fully depreciated assets
- Coverage
- Broadband traffic
- Ancillary services inputs
- Other network and costing inputs

The following sections describe how each of these inputs has been defined in the model.

3.1. Demand

The demand of the modelled services is one of the primary inputs of the cost model and is crucial to determine the required elements in some parts of the network, as well as to calculate the unit costs of the services. This input is introduced in worksheet '1A INP DEMAND' for each of the modelled services and for the whole modelling period (i.e. from 2005 to 2038).

As per the MRP, the demand inputs shall represent the realities of the SMP operator in markets 3a) and 3b) which, at the time being, means that it should reflect TDC's demand.

In particular, we have adopted the approach described below to populate the demand inputs in the model:

- Whenever information was provided by the modelled operator (for past, current and future years), we mapped it to the relevant modelled services and inputted it to the model. Information from the modelled operator was used for 69% of all demand data points.
- In the absence of such information, we extracted it from the previous DBA's model, provided it was available. The information from DBA's previous model allowed us to fill in an additional 14% of the demand data points.
- Finally, when no information was available from any of the two previous sources, it was estimated based on a regression of the information available for other years[2]. The information from these regression analyses allowed us to populate the remaining 17% of the demand data points.

3.1.1 Copper switch-off

Beyond the demand inputs themselves, the model includes a feature to produce sensitivity analyses based on the selected year of shutdown of the copper access network.

As a base case, the model considers that the switch-off of the copper network will take place in 2030, but this can be easily modified by the user through a drop-down list included in the control panel as shown below:

[2] It should be noted that data was found for all the services for at least 4 consecutive years.

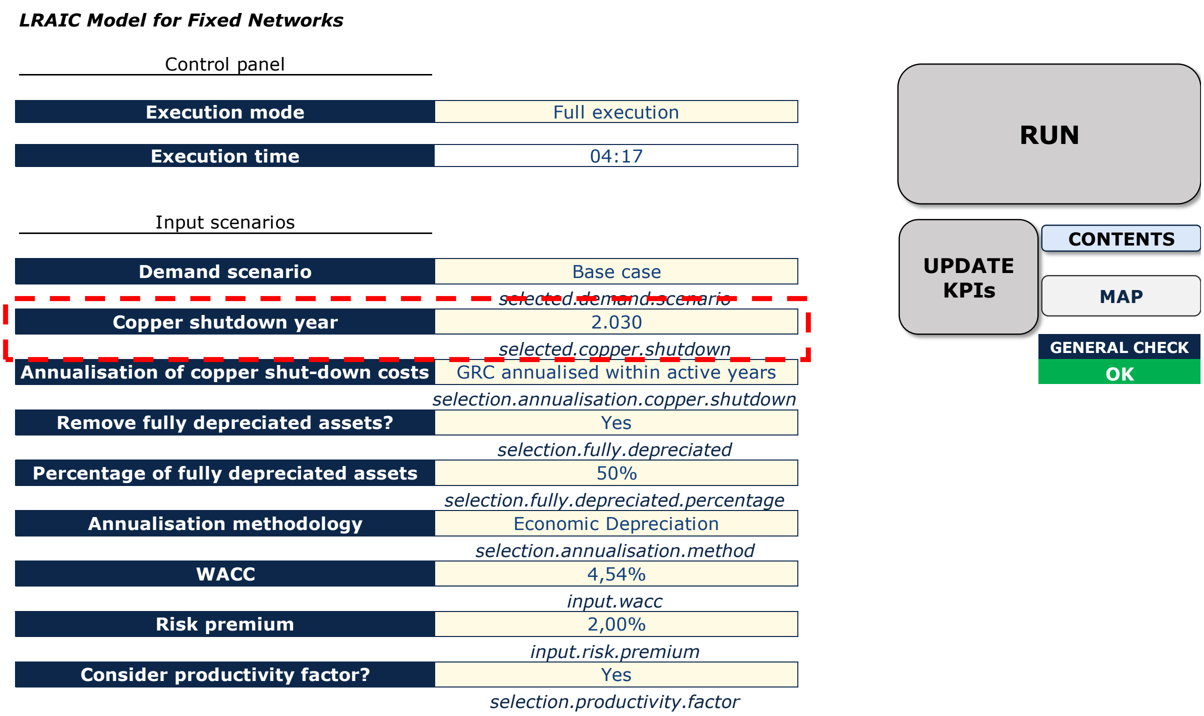

Exhibit 3.1: Selection of the year for the copper switch-off [Source: Axon Consulting]

Whichever year is selected, the model always ensures that:

1. The number of lines that are switched off is migrated to the FTTH network (i.e. they are not "lost").
2. There are no more copper access assets in the network after the year of the shutdown.
3. The recovery of copper access costs takes place only as long as the copper access network is active.

3.2. Asset costs

The assets' costs and associated information are included in worksheet '1B INP UNIT COSTS' of the model for each of the network elements defined. These inputs are used to calculate the annualised operational and capital costs which are to be later allocated to services.

For each of the assets defined in the model, this worksheet includes:

- Inputs relevant to **capital expenditures**.
  - **Unit CapEx**. Includes the costs associated with the purchase and installation of the network element.
  - **CapEx trend**. Cost trends for CapEx are defined in the cost model to assess the evolution of prices over the years.
  - **Useful live**. Useful lives are introduced in the model for the annualisation of the assets' CapEx.
- Inputs relevant to **operational expenditures**.
  - **Unit OpEx**. Includes the annual cost of maintenance and operation of the network element. It also includes rental expenses.
  - **Percentage of labour work**. Percentage of OpEx that is coming from staff costs.

As per the MRP, the prices used in the model should reflect those that an efficient operator would face, considering the scale of the modelled operator.

To populate these inputs, we have followed the approach illustrated below:

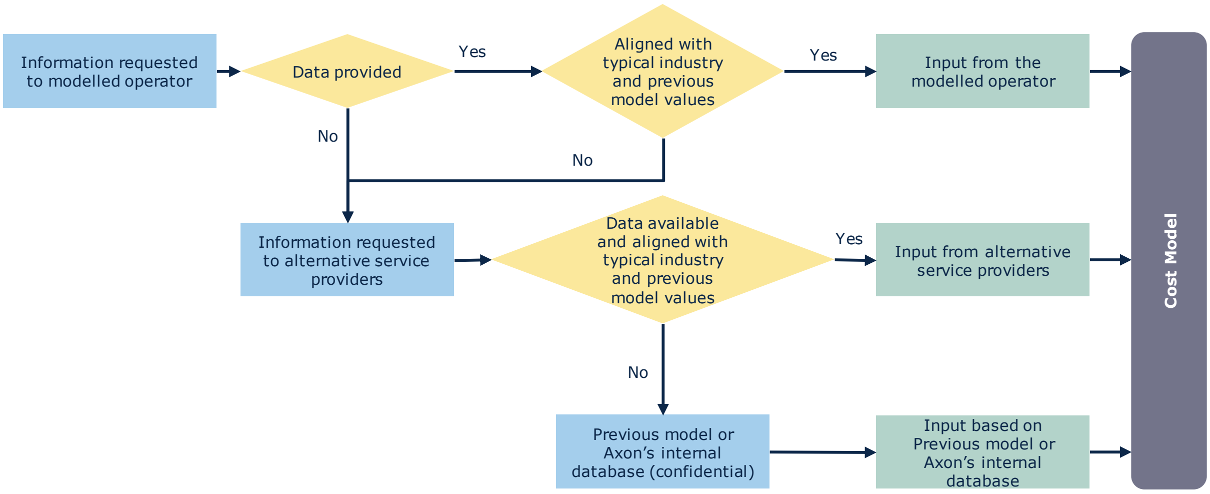

Exhibit 3.2: Decision tree adopted to define the assets' costs inputs [Source: Axon Consulting]

The paragraphs below provide a brief description of the decision tree adopted:

- Whenever information was provided by the reference operator, it was cross-checked and mapped to the relevant modelled resource and inputted in the model. Validated/accepted information from the modelled operator was used to populate 52% of the data points.
- Information from alternative operators proved to be helpful in the review and validation of the figures reported by the modelled operator.
- In the absence of information from the modelled operator (or in those cases where the figures were not aligned with the international practice, considering the inputs from alternative operators), we extracted it from the previous DBA's model provided it was available. This applied to an additional 16% data points.
- Finally, Axon's internal database was used to fill in the remaining 32% of the data points.

3.3. Adjustment for fully depreciated assets

As presented in the MRP, the model adjusts the cost base of the assets belonging to the copper and coax access networks[3] to avoid over-recovering the costs of the fully depreciated assets. Particularly, the adjustment applies to the following assets:

- **Copper networks**: Copper cable, including civil infrastructure used to install these cables (trenches, ducts, etc.).
- **Coax networks**: Coax cable, including civil infrastructure used to install these cables (trenches, ducts, etc.).

In order to apply this adjustment, we had to calculate the percentage of fully depreciated assets from the modelled operator's financial statements. However, multiple limitations in the data availability precluded us from reaching an accurate conclusion on this percentage.

Based on the information available, however, we have been able to conclude that this percentage is most likely to range between 30% and 50%, which is also in line with the BEREC's report on Regulatory Accounting in Practice for 2018[4].

[3] No adjustment is applied in the case of fibre networks

[4] Source: BEREC. Link: https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/8310-berec-report-regulatory-accounting-in-practice-2018

Consequently, and in order to provide maximum flexibility to the user when assessing the model's outcomes, the control panel includes a drop-down list with four different options (30%, 40%, 50% and 60%) to select from, as illustrated below:

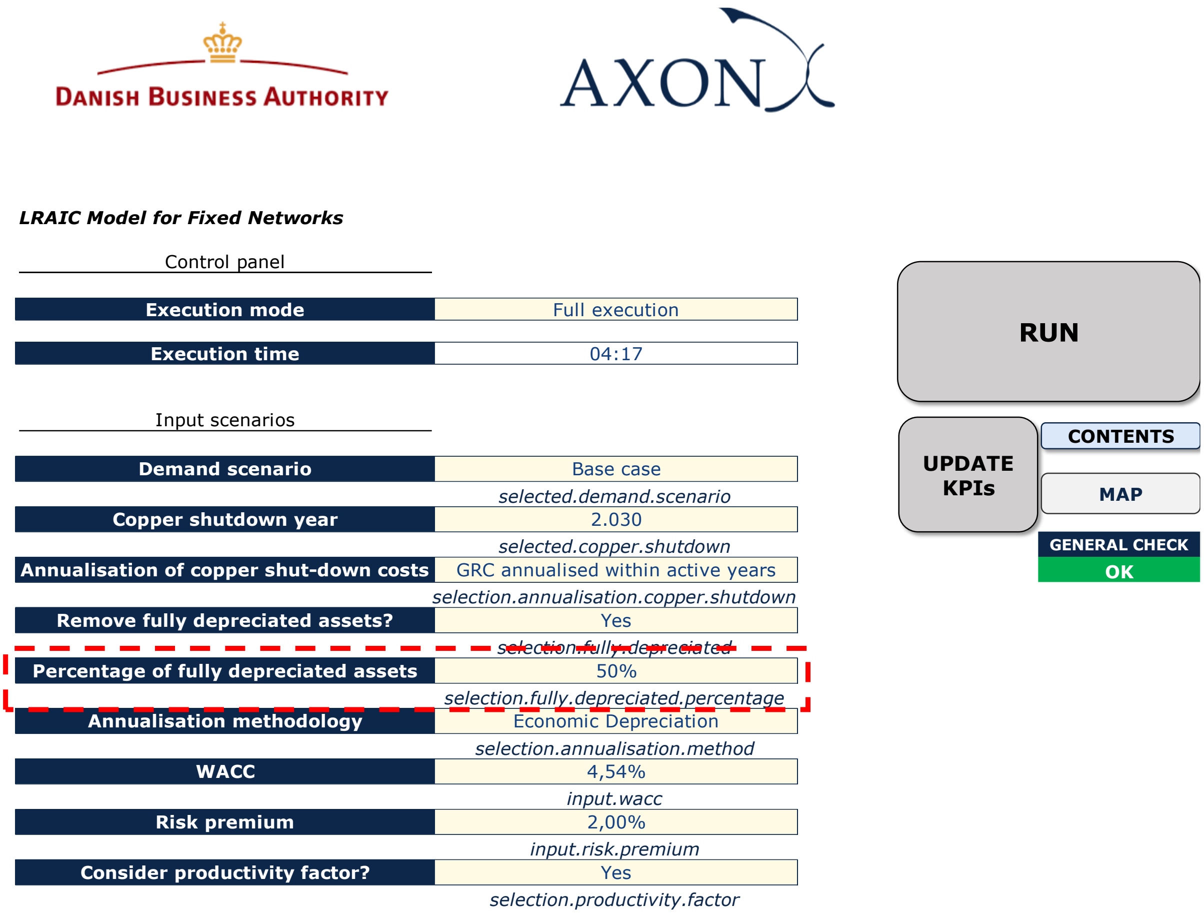

Exhibit 3.3: Selection of the percentage of fully depreciated assets [Source: Axon Consulting]

3.4. Coverage

Coverage inputs refer to the volume of homes passed by each access network per geotype and year.

These inputs were defined following different approaches for the copper and coax networks on one hand, and for the fibre access network on the other, as shown below:

- **Copper and coax coverage**: The 2018 coverage levels were extracted from the data available within DBA (see section '4.1.3 - Coverage database' for further information about this database). Coverage levels for the other years (before and after 2018) were set at the same level as for 2018 based on the indications received from the modelled operator.

- **Fibre coverage**. The 2018 coverage levels were also extracted from the data available within DBA. In this case, the evolution of the fibre footprint is based on the data reported by the modelled operator.

3.5. Broadband traffic

One of the critical inputs in the dimensioning of the transmission network is the broadband traffic. The model includes a series of inputs to calculate the broadband traffic that goes through the transmission network in the busy hour (in Mbps) based on the number of subscribers included in the demand section. These inputs include:

- **Average download traffic for a representative line of each network:** Which represents the traffic, in GB per year, consumed on average by a typical user in each access network.
- **Peak to mean ratio:** which represents the ratio between peak and average traffic to calculate the traffic in the busy hour.

These inputs have been populated as described below:

- Recent historical figures (2016, 2017 and 2018) are based on the data reported by the modelled operator.
- Older historical figures (2005-2015) are calculated based on a regression analysis, considering the interannual growth of these figures under each technology.
- Forecast figures (2019-2038) are determined based on a regression analysis of the interannual growth under each technology, taking into account that growth rates are expected to slow down over time.

3.6. Ancillary services inputs

The inputs to calculate the costs of ancillary (non-recurring) services are introduced in worksheet '1E INP ANCILLARY SERV' of the model. The main inputs required to calculate the costs of these services are:

- Wages per employee category (technician and administrative) in DKK per minute of work.

- For each ancillary service, the number of minutes required to perform each one of the following activities:
  - For administrative employees:
    - Processing of order
    - Customer service
    - Annulment fee
  - For technicians
    - Processing of order
    - Testing and monitoring/supervision
    - Installation
    - Projecting and planning
    - Customer service
    - Transport
- For each ancillary service the yearly capital costs associated with the provision of the service, along with an annual cost trend.

The information used to populate these inputs were provided by the modelled operator and were cross-checked against different references, such as:

- The information included in the previous model for 2018.
- Information provided by alternative operators.

3.7. Other network and costing inputs

Finally, the model includes other network and costing inputs that are also relevant to either dimension the network or calculate the costs of the services. These are described below, grouped between year-independent and year-dependent inputs.

Year-independent inputs (included in worksheet '1C INP NW'):

- **Access network inputs**: Includes information concerning the assets available in each access network, such as the number of pairs per copper cable. This information has been extracted from the data reported by the modelled operator.

- **Transmission and core network inputs:** Includes inputs such as the capacity of the transmission ports, redundancy of routers and number of landing stations. This information has been extracted from the data reported by the modelled operator.
- **Constants**, as the number of bits per byte or the number of seconds in a year. These constants are industry standards.
- **Non-network mark-ups** (G&A, IT, Wholesale and Working Capital): These mark-ups are included to reflect the additional costs incurred by the modelled operator to provide its wholesale services, but which are not directly related to the network. This information has been extracted from the data reported by the modelled operator. The treatment of these mark-ups in the model is further described in section '6.2 - Calculation of non-network costs'.
- **Churn**, the percentage of lines that are inactive but have a drop installed. This information has been extracted from the data provided by the modelled operator.

Year-dependent inputs (included in worksheet '1D INP NW EVO'):

- **Coax spectrum dedicated to each service**: Allocation of the spectrum to the different services provided over the coax network (broadband, TV, VoD). This information has been extracted from the data provided by the modelled operator.
- **Traffic per Leased Line:** Average traffic in the busy-hour reserved for uncontended traffic (in Mbps) for each type of leased line (Legacy and IP Fibre). This information has been extracted from the data provided by the modelled operator.
- **Inflation:** Evolution of prices in the country, used to estimate the OpEx trends. Extracted from OECD and European Commission databases.
- **Productivity:** Evolution of the efficiency of staff operations. This has been extracted from OECD databases.

When applicable, these figures have been cross-checked against different references, such as:

- Axon's internal databases.
- Information from the previous DBA's model for the year 2018.

4. Geographical analysis performed in the R model

The design of fixed access networks requires an extensive analysis of the geographical zones to be covered, as it will have a direct impact on the dimensioning of networks resources that are dependent on the underlying geography, like cables, trenches, etc.

The main purpose of this analysis is the definition of the network characteristics, mainly the location of network nodes and the definition of the routes to connect them, characterising the zones covered under each disaggregation level. This approach is aligned with the scorched node assumption described in the final MRP.

For the development of geographical analysis, several databases have been used. The main files used for the geographical analysis are:

Data	Description	Source	Link
Address database	CSV file collecting all the addresses in Denmark	Agency for Data Supply and Efficiency	https://eng.sdfe.dk/product-and-services/the-danish-address-register/
Road database	GIS file containing all the information related to the national road network	Agency for Data Supply and Efficiency	https://eng.sdfe.dk/about-us/organisation/geodata/
Coverage database	A file containing the coverage of each address.	Danish Business Authority	Not publicly available
Demand database	A file containing the type of access line used in each address	Danish Business Authority	Not publicly available
Node location	Location of the main nodes of the access and transmission network	TDC	Not publicly available

Exhibit 4.1 Databases and sources used in the geographical analysis [Source: Axon Consulting]

The steps followed in order to carry out the geographical analysis have been split according to their nature between:

1. Data cleaning
2. Location of network nodes
3. Definition of the routes between the nodes
4. Calculation of network elements from the geographical analysis
5. Definition of the disaggregation levels

Exhibit 4.2 Steps of the geographical analysis performed to obtain geographical inputs [Source: Axon Consulting]

The geographical analysis is performed in the R[5] Model and the results are loaded in the Excel model. For further information regarding the operation of the geographical analysis model, please see the User Manual of the model.

The detail of the activities carried out in each step is explained below.

4.1. Data cleaning

The starting databases available represent the main inputs of the geographical analysis and, thus their content will have a direct impact on the network's characterisation and model results.

Hence, the first step of the geographical analysis is related to the verification of the legitimacy and robustness of the source databases. For this, a data cleaning process has been set in order to:

- Adjust inaccurate information

[5] Link: https://www.r-project.org/about.html

- Remove unnecessary information
- Aggregate or disaggregate data depending on the needs of the analysis

The presented procedure to clean the databases has been applied to the following five databases:

- Address database
- Road database
- Coverage database
- Location of nodes

The following sections further develop the activities performed in each of the databases considered in the analysis.

4.1.1 Address database

The address database contains a list of all the Danish households, giving mainly the detail of:

- Address (including Street, Street number and Zipcode)
- Coordinates (in ETRS89/UTM zone 32N format)
- AAID (the unique identifier of the address access/Building)

This information is essential to extract relevant information about the buildings in Denmark, which is used to evaluate the footprint of the modelled operator.

First, in order to ensure the robustness of the database, several checks were performed to test the data. These checks included a visual analysis of the projection of the data on a map to verify that a sample of those addresses was consistent with the location of buildings according to satellite imagery and ensuring that all addresses fell inside Denmark borders.

Based on these checks, we observed that the database provided was clean and ready to be used for analysis purposes. Thus, no adjustments were required.

As a final step, given that the database is presented at the household level, the information is aggregated at building level (this is, households within the same building are aggregated together). This aggregation is done based on the AAID field of the database. It should be noted that information regarding the number of households in each building is stored in this process.

4.1.2 Road database

The road database contains a list of all the roads in Denmark. This information is relevant as often fixed telecom networks are deployed along with road networks.

The roads are disaggregated in sections, which represent the roads between two intersections.

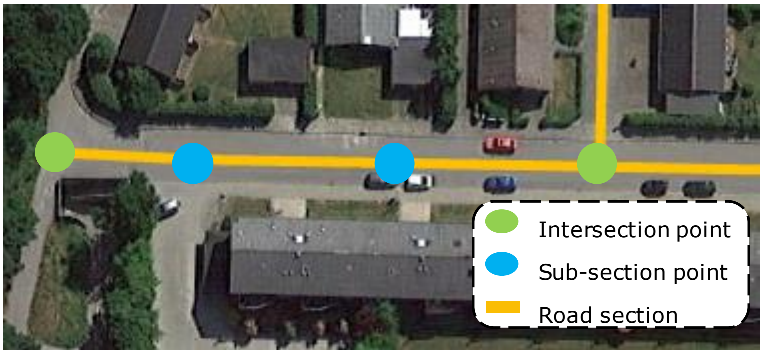

Exhibit 4.3: Extract of the sections available in the roads database [Source: Axon Consulting]

The distance between two intersections is calculated as the sum of the distances of all subsections between them.

In order to validate this database, we performed a number of checks, including:

- Visual analysis of the projection of the data on a map, to verify that a sample of the roads included was consistent with the roads and patch observed in satellite imagery and ensuring that all the database was comprehensive of all of the relevant roads in Denmark.
- Quantitative analysis of the distance between a sample of points between intersections within the country, in order to evaluate potential missing roads.

Based on these checks, we identified that a set of additional roads had to be included in the dataset. This aspect is key to ensure the connectivity of the road network. With this objective, we added "virtual" sections to the database. This has been ensured through the development of an algorithm that verifies the connectivity of all the sections. Additionally, a check has been performed to ensure the reasonability of the added virtual sections.

2.642 virtual sections have been included in the database as a part of the data cleaning process (these represent 0,19% of the total sections in the database).

In addition, we added to the road database the sections related to submarine cables that were not initially included in the database. We added 31 new sections as a result of this adjustment.

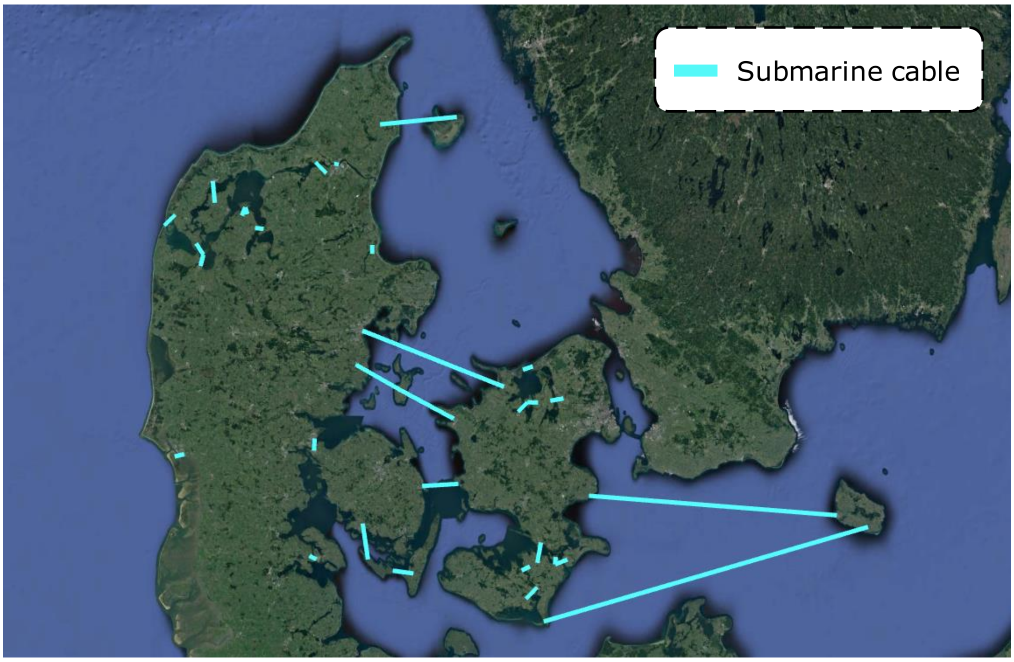

Exhibit 4.4: Addition of the submarine cables [Source: Axon Consulting]

Once we ensured the robustness and completeness of the database, we proceeded to consolidate the database, summarising for each section the coordinates of the corresponding intersections and the total distance.

4.1.3 Coverage database

The coverage database incorporates information about the coverage at household level. Especially for each household/address is specifies if it is covered by copper and/or coaxial.

This information is important for the dimensioning of the network as it is one of the main inputs with the demand, as outlined in section '5 - Dimensioning module'.

Knowing the importance of this database, we proceeded to evaluate its robustness performing a number of preliminary checks:

- Ascertain that all the addresses included in this database were included in the addresses database
- Identification of duplicated addresses
- Calculation of coverage percentages at a national level in order to check if those percentages match with the public data

These checks allowed to verify that the coverage database included robust data ready for analysis purposes. No adjustments were performed to the database as a result of these checks.

4.1.4 Location of nodes

As presented in the MRP, the model follows a scorched-node architecture, based on the actual network of the modelled operator. Thus, one of the most important datasets for the definition of the geographical analysis is the location of the network nodes.

During the data request process, we received a database containing a TDC's network nodes. The database has information about some of the main nodes of the access network for each technology. The detail of the information provided for each technology is presented below:

- For the Copper Access Network, TDC's database included the location of:
  - The Central Offices (COs)
  - The Main Distribution Frames (MDFs)
  - The Primary Distribution Points (PDPs)
- For the Fibre Access Network, based on the information provided by the modelled operator we observed that the OLTs and Fibre MSAN were deployed in the same locations as the copper MDF. Thus, a consistent architecture to the one used for copper networks has been considered.
- For the Coax Access Network, TDC's database included the location of:
  - The locations of the coax OLTs, equivalent to those of the Central Offices of the copper network.
  - The locations of the CMCs.

In addition, TDC reported GIS files regarding the areas covered by each of the Central Offices in the network. A sample of these areas are presented in the exhibit below:

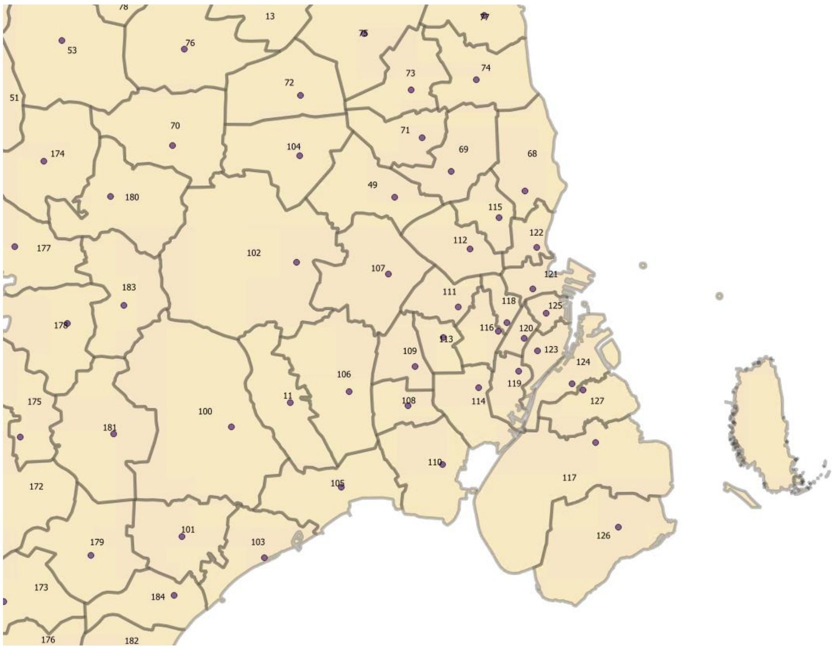

Exhibit 4.5: Snapshot of Central Office areas in Denmark [Source: Axon Consulting]

This information will be used during the determination of the routes in section '4.3 - Definition of the routes between the nodes'. To ensure the robustness of this data, we also proceeded to verify that there was no overlapping between the different areas. We identified 2 cases where we found an overlap. In these cases, we reassigned the nodes in the overlapping area to the area of its closest CO.

Finally, the database provided the location of the following transmission network nodes:

- L3 Access nodes
- Aggregation nodes
- Distribution nodes
- Core nodes

To ensure the robustness of the database, we performed a visual analysis of the projection of the data on a map, to verify that the nodes included were inside the boundaries of the Danish Territory. This check revealed that the information of all the nodes was correct.

4.2. Determination of the location of network nodes

The objective of the second step of the geographical analysis is the determination of network nodes locations. This information is relevant for the calculation of the routes using a "shortest path algorithm" between the nodes explained in section '4.3 - Definition of the routes between the nodes'.

As presented above, the locations of the network nodes are primarily based on data from the modelled operator, following a scorched node approach.

Each access network element is defined to have its own network nodes. A high-level overview of the hierarchy of the access nodes for each network is presented in the exhibit below:

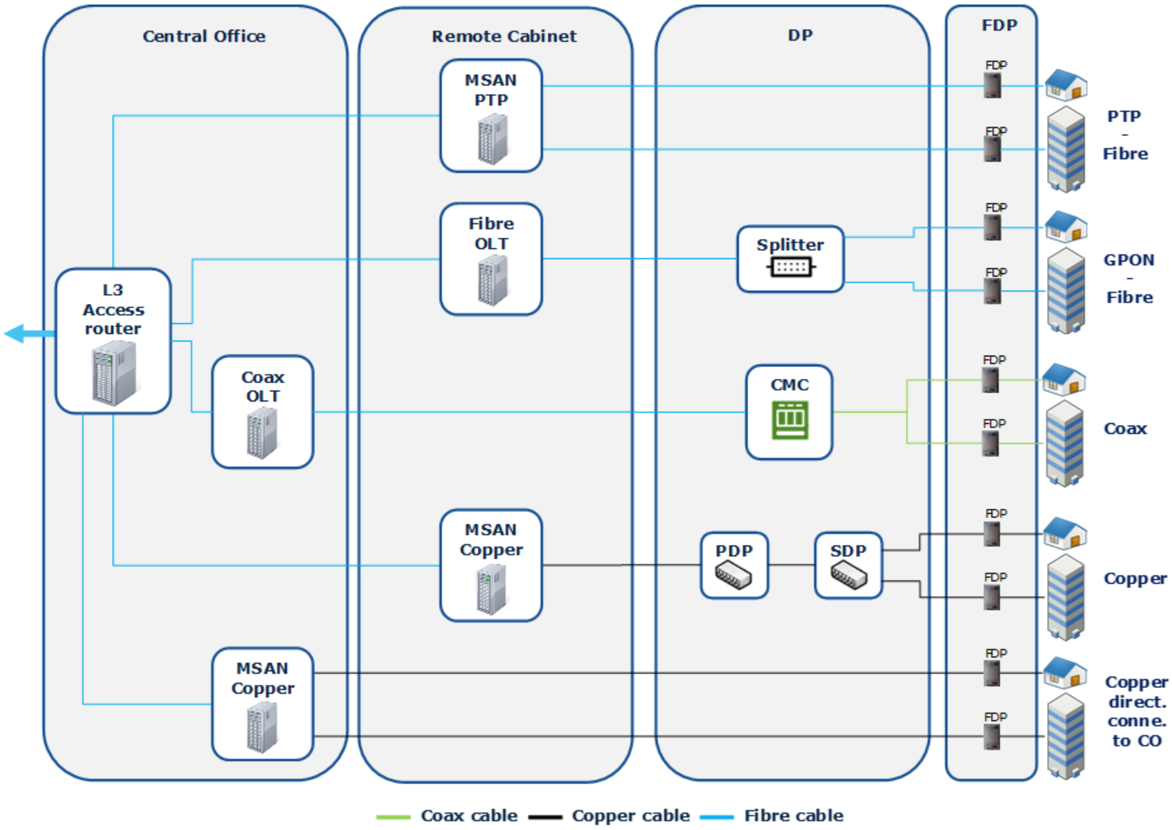

Exhibit 4.6: Architecture of the Danish Network [Source: Axon Consulting]

The particular description of the network nodes considered under each access network is detailed in the sections below.

4.2.1 Copper Access Network

The copper network is mainly composed of the following nodes:

- **Central Office** (CO), which represents the last concentration node of the copper access network, establishing the boundaries between the access and the transmission
- **Main Distribution Frame** (MDF), which can be in CO nodes or remote.
- **Primary Distribution Point** (PDP), aggregating
- **Secondary Distribution Point** (SDP), that represent the first aggregation node of premises in the copper network
- **Final Distribution Point** (FDP), located just outside the end user's premises

The exhibit below shows the architecture of the copper access network in Denmark.

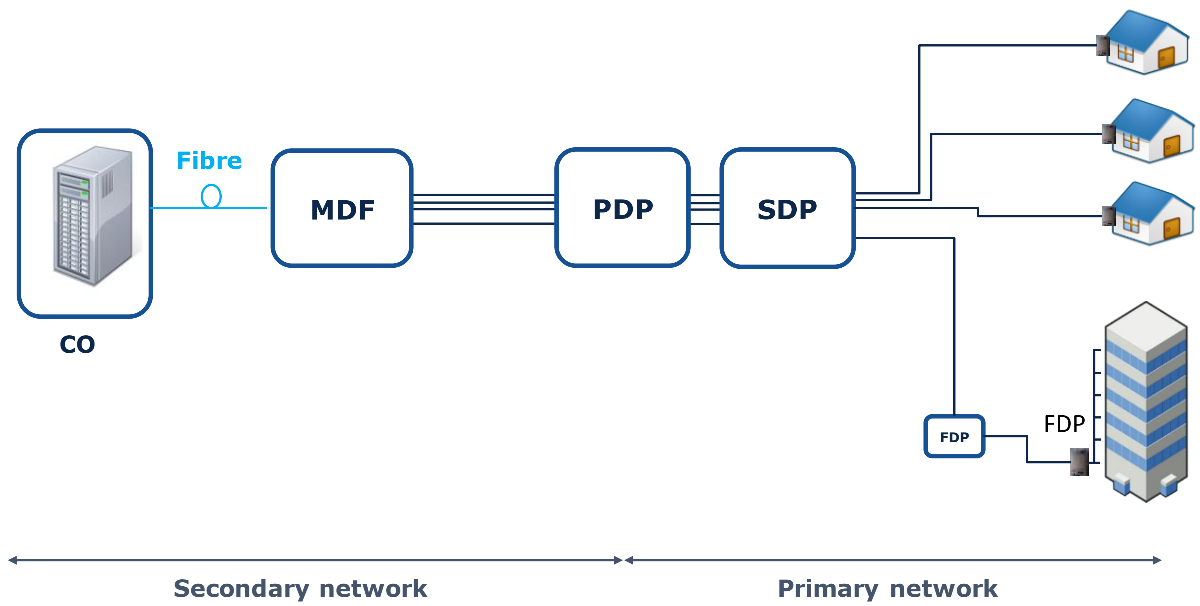

Exhibit 4.7: Architecture of the access copper network [Source: Axon Consulting]

The database available outlined the information regarding the location of MDFs and PDPs. However, the location of the FDPs and SDPs is calculated on a bottom-up basis, as presented in the MRP.

Thus, there are a number of tasks to complete in order to fully characterize the copper access network:

- Definition of the locations of the FDPs
- Association of the homes to the corresponding PDPs
- Definition of the locations of the SDPs

Each of these tasks is presented below.

Definition of the locations of the FDPs

FDPs represent the final point of the network, located just outside the end user's premises.

Exhibit 4.8: Location of FDPs [Source: Axon]

For the calculation of FDP's locations, two main steps were followed.

- Step 1: Identification of the closest section
- Step2: Calculation of FDP locations

Each of these steps is described below

Step 1. Identification of the closest section

First, all the sections close to the building are identified as a combination of two intersections. Then, we proceed to the calculation of the distance between the building and the intersections points of each section, selecting the section with the minimum distance, which is chosen as the closest section.

Step 2. Calculation of FDP locations

Finally, it is assumed that the FDP will be located in the same road section as the buildings it connects (as an orthogonal projection of the building towards the section). As a consequence, the "FDP-building" path does not require the shortest path calculation to be performed but rather an assumption on the distance of this link.

Exhibit 4.9: Projections of the buildings on the road sections [Source: Axon]

The length of the drop line is used for the calculation of the costs associated to the installation of a connected home that can be recovered from the monthly recurring payment. Therefore, the model considers a maximum of 30 meters in the length from the home to the FDP, considering that any additional distance should be recovered through additional one-off services, in line with the existing Price decision.

Finally, it should be noted that the model considers an "efficiency factor" to account for the fact that the drop line installed will not be a perfectly straight line.

Association of the homes to the corresponding PDPs

One of the key areas to characterize the copper access network is to determine the area covered by each primary distribution point (PDP).

To do so, the following steps have been applied:

1. Identification of all the buildings and PDP inside the same CO coverage areas. This is based on the boundaries provided by the reference operator.
2. Each building inside a CO area is associated to its closest PDP through the implementation of the shortest algorithm, applied over the roads of Denmark (please see section '4.3.1 - Access Networks' for more details in this matter). As shown in the exhibit below, this allowed us to identify the buildings covered by each PDP, defining a coverage area for the PDPs.

Exhibit 4.10: Example of PDP areas, where each colour represents a different PDP area [Source: Axon Consulting]

The output of this process has been mainly used in the definition of the routes between the nodes, facilitating the determination of optimal routes.

Definition of the locations of the SDPs

Once FDPs locations are known we proceeded to the determination of SDP locations. These SDPs aggregate access lines together in order to minimise the costs of deployment.

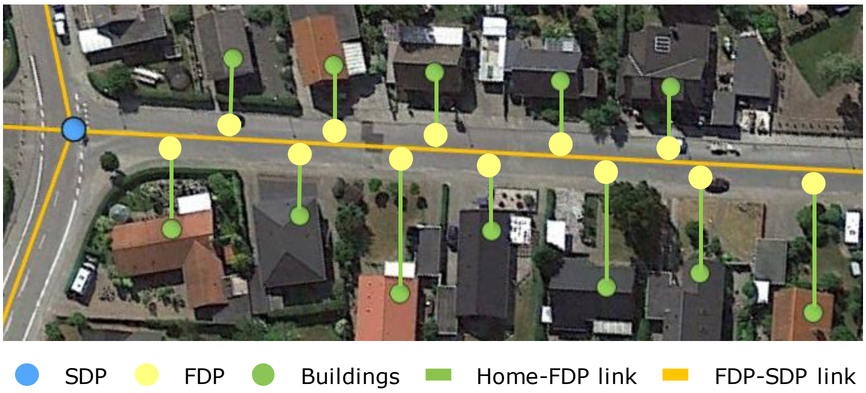

Exhibit 4.11: Example of SDP location [Source: Axon Consulting]

In order to determine the location of the SDP, we consider that all SDPs are located in road intersection. Therefore, the aim of this section is to present the hypothesis and calculations performed in order to determine which intersections need to have an SDP.

- Step 1: Calculation of the number of homes that require crossing each intersection to reach the corresponding PDP.
- Step 2: For each intersection, we observe if more than 7 homes require it to reach the PDP. Then, for one of these intersections with more than 7 homes associated, an SDP is placed.
- Step 3. We recalculate the number of homes that require crossing each intersection, removing those that are already aggregated by the SDP set in Step 2. This process is repeated until there are no more intersections with more routes than the threshold of 7 homes.
- Step 4. Finally, we identify the routes that have not been assigned to an SDP during this process, and we install an SDP in the COs managing those routes.

As shown in the exhibit below, the result is a list of intersections that include an SDP. Those intersections represent the SDP locations.

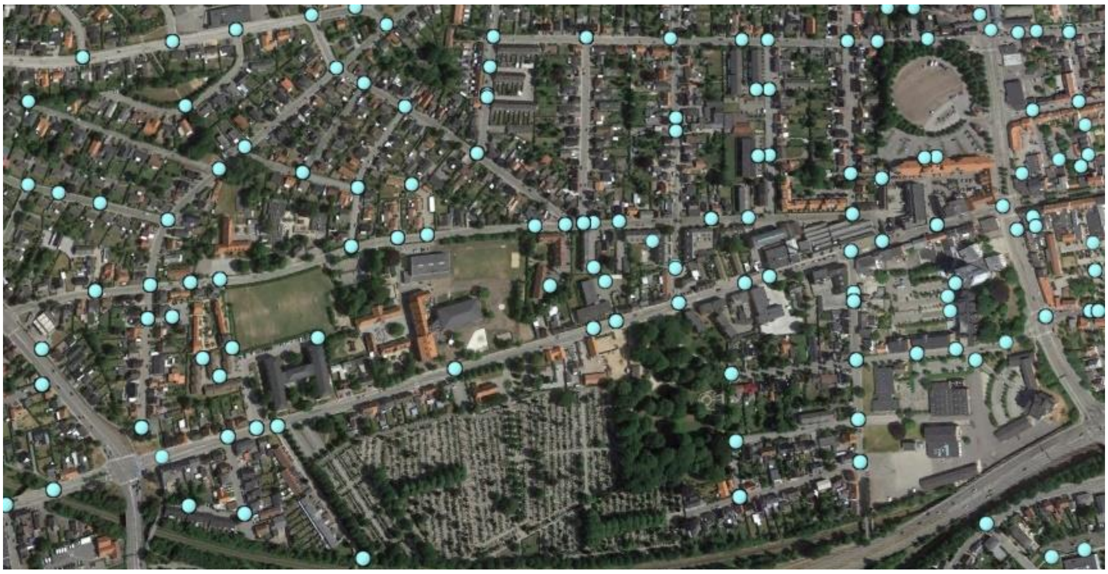

Exhibit 4.12: Illustrative example of SDP locations over a given area [Source: Axon Consulting]

4.2.2 Coax Access Network

The coax access network is made of three main nodes:

- Coaxial OLT, which are installed in CO nodes
- CMC, Aggregation node of the coaxial network
- TAP, as for the FDP in the copper, it is located just outside the end user's premises

The exhibit below shows the architecture of the coax access network in Denmark.

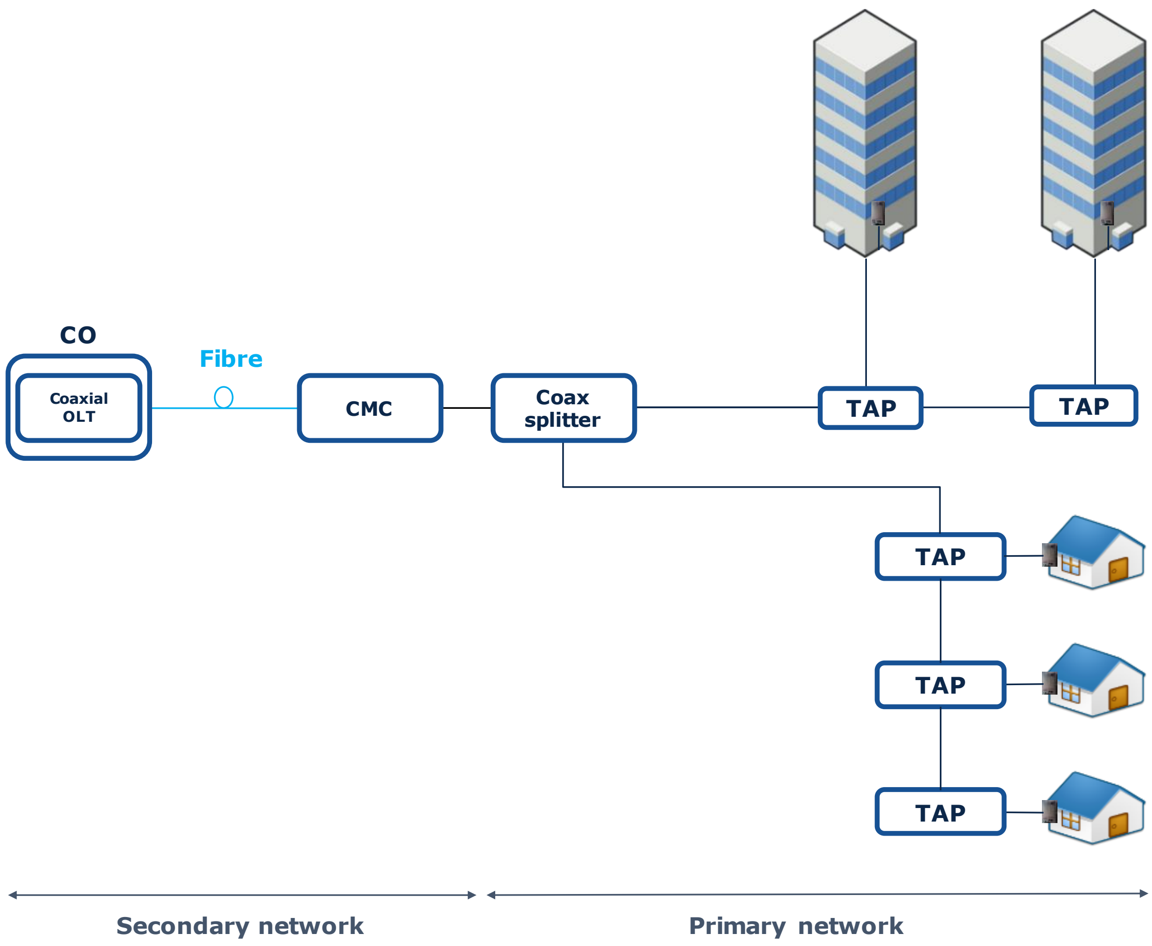

Exhibit 4.13: Architecture of the access coax network [Source: Axon Consulting]

The database available outlined the information regarding the location of CMCs and COs. However, during the assessment of the CMC database, we observed some inconsistencies in the number of existing CMCs. Thus, we completed the CMC database based on a Bottom-up approach by adding additional CMCs that would result from splitting the node due to a high capacity constraint.

It should be noted, that in the coax network we consider that there is no PDP, with the fibre cables going directly from the OLT placed in the Central Office to the CMC. Thus, in the case of coax, we calculated the associated CMC for each home in a similar manner as explained in section '4.2.1 - Copper Access Network' for the association between PDPs and homes.

On the other hand, the location of the TAPs is calculated on a bottom-up basis, as presented in the MRP. Notably, the locations of the TAPs are calculated following the same approach used for FDP in the copper access network, using the database of the buildings covered by the coax network.

4.2.3 Fibre Access Network

The FTTC network is following the same architecture as the copper network, the only difference being a fibre cable is rolled out on the part between the ODF and the FDP of the network instead of a copper cable.

Therefore, the fibre network is composed of the following nodes:

- **Central Office** (CO), which represents the last concentration node of the copper access network, establishing the boundaries between the access and the transmission
- **Optical Distribution Frame** (ODF), main aggregation point in the fibre access networks
- **Splitters**, for PON Architecture, which are used to aggregate cables and are located in a location equivalent to those of SDP nodes of the copper network
- **Final distribution Point** (FDP), located just outside the end user's premises

The exhibit below shows the overall architecture of the fibre access network.

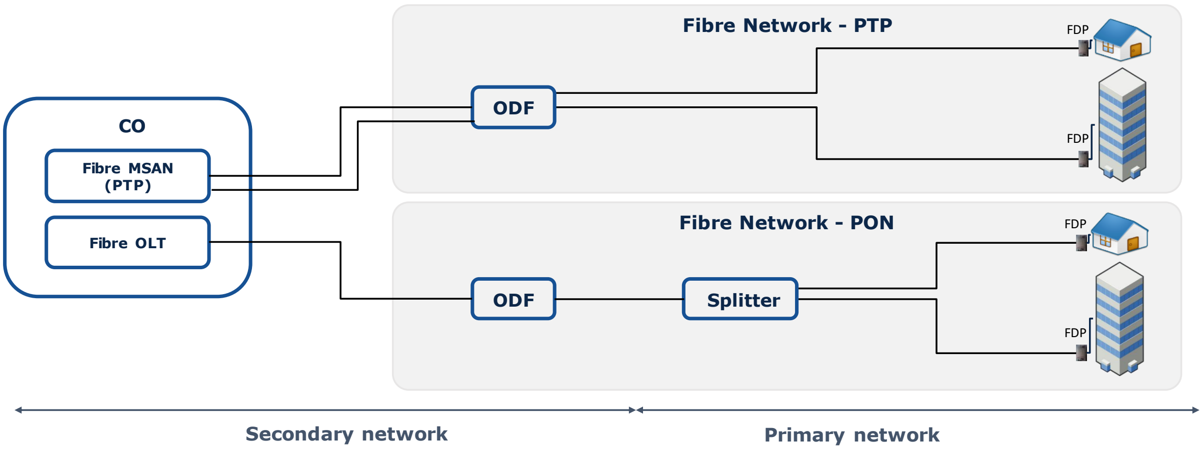

Exhibit 4.14: Architecture of the access fibre network [Source: Axon Consulting]

Based on the data reported by the modelled operator, we have considered the location of the nodes of the fibre network to be equivalent to those used in the copper network. The only differences in terms of locations are related to the differences in coverage between networks. The treatment of coverage in fibre networks is described in section '3.4 - Coverage' of this document.

4.3. Definition of the routes between the nodes

Once the nodes' locations are determined, the next phase is related to the calculation of the routes connecting each node of the network. As the routes of the network are mainly used to determine the total distance needed for cables, trenches, etc, the results extracted from this analysis are very relevant for network dimensioning.

The steps to calculate the routes between the network nodes are similar for the access technologies, however, the process is slightly different in the case of transmission networks. Hence, the next sections introduce the calculations for each set of networks separately:

- Access Networks
- Transmission and Core Networks

4.3.1 Access Networks

The routes that are calculated for the access networks allow to connect the homes to the Central Offices, considering all intermediate levels between both. The process to calculate the routes is based on the calculation of the shortest path (based on Dijkstra's algorithm) between the nodes, considering the different possible paths through the roads in Denmark.

This process is followed for every segment for each access network. For example, in the exhibit below, we present the routes calculated connecting the PDP to MDFs in the copper network.

Exhibit 4.15: Illustrative example of the calculation of routes between network nodes [Source: Axon Consulting]

4.3.2 Transmission and Core Networks

Similarly, to the access network, the different nodes from the transmission network need to be interconnected to one another. As previously discussed, the model disaggregates the transmission network into four different layers:

- L3 Access network
- Aggregation network
- Distribution network
- Core network

A summary of the topology considered is presented in the exhibit below:

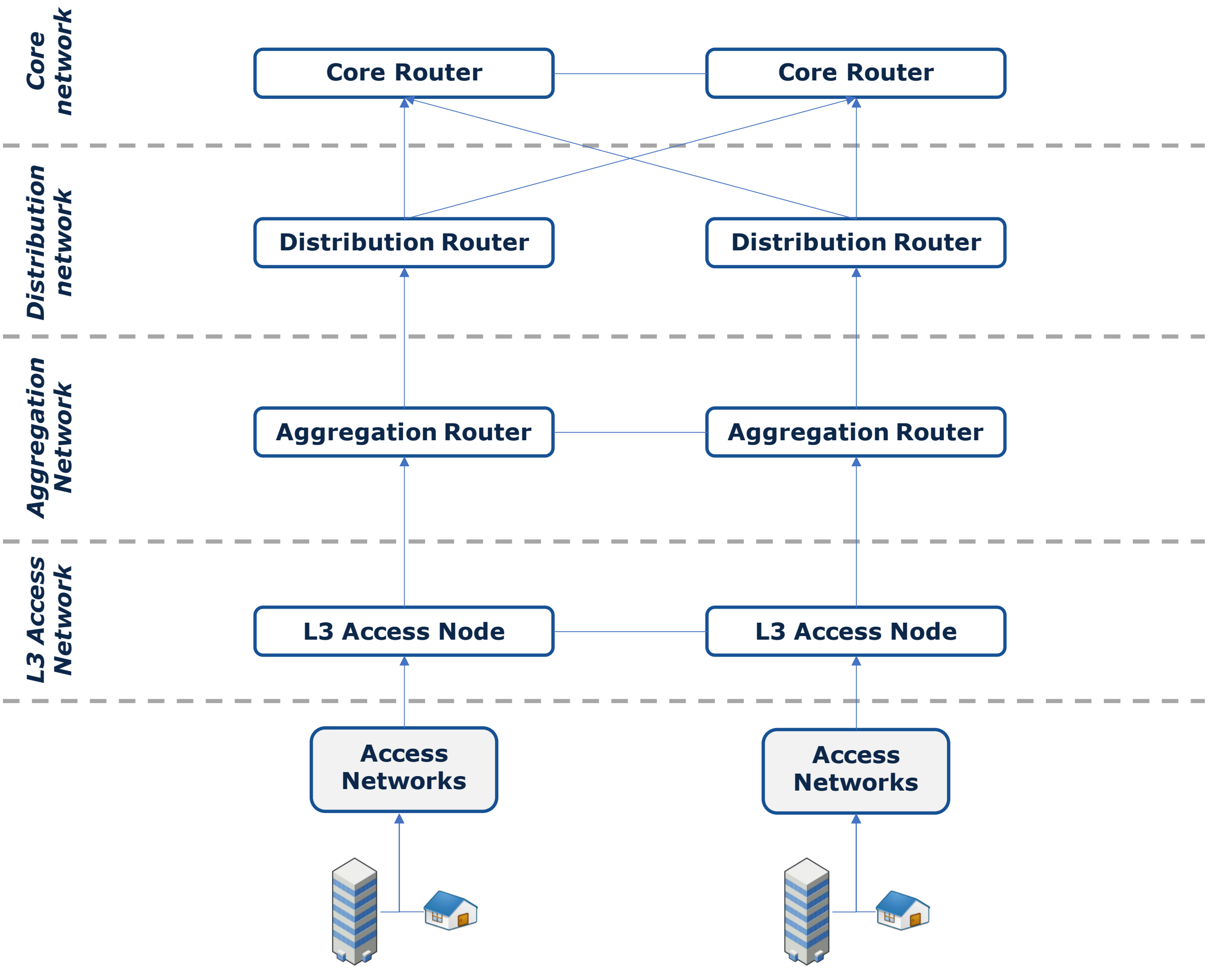

Exhibit 4.16: Architecture of the transmission networks [Source: DBA]

The locations of the transmission nodes, as well as the distribution of the nodes into chains/rings are, for the most part, known based on data reported by the modelled operator. For clarification purposes, a chain/ring is defined as a set of nodes of the same layer interconnected to one another, and which ends are connected to nodes from a higher hierarchy.

However, in some instances (especially with regards to the L3 access network), the actual links within each chain are unknown. Then, to determine the links and routes needed to connect all the nodes with their corresponding higher hierarchy node, we applied a TSP[6]

[6] Travelling Salesman Problem.

algorithm for each chain. This algorithm outputs how should the nodes be interconnected between themselves in order to minimise the total distance of the chain.

Based on this information, we finalised the logical interconnection between each node in the different layers of the transmission network:

- **L3 Access nodes**: This network allows the connection of the COs and aggregation nodes in Denmark. It is composed of 1.105 nodes, distributed across 156 chains.

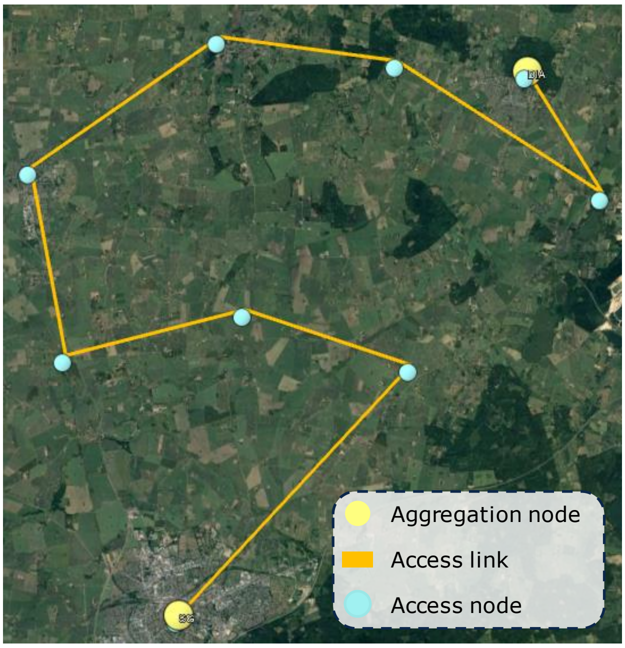

Exhibit 4.17: Illustrative example of the nodes and links in the L3 Access network [Source: Axon Consulting]

- **Aggregation nodes**: The aggregation network represents the interconnection of the L3 Access network with the distribution and core nodes. This layer has 88 nodes, distributed over 21 chains.

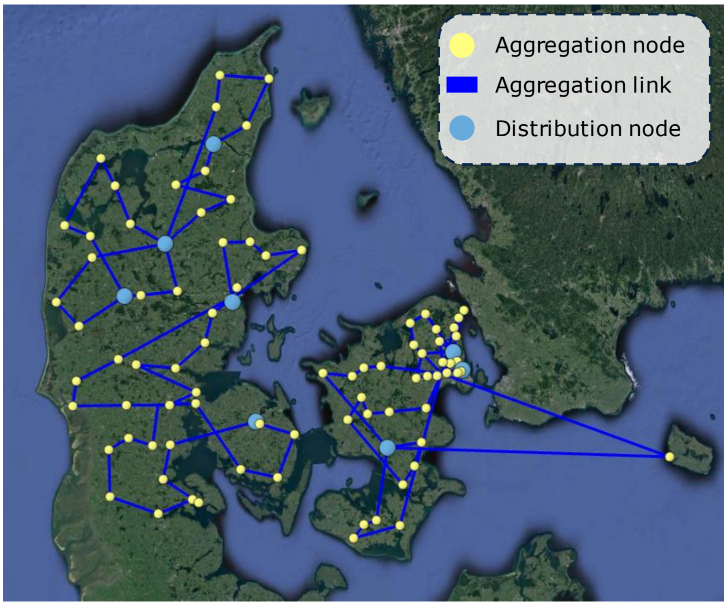

Exhibit 4.18: Illustration of the nodes and links in the aggregation network [Source: Axon Consulting]

- **Distribution nodes**: The distribution network has 8 nodes, responsible to connect the aggregation network with the core network. Each of these nodes is connected to two separate core nodes (dual-homing solution).

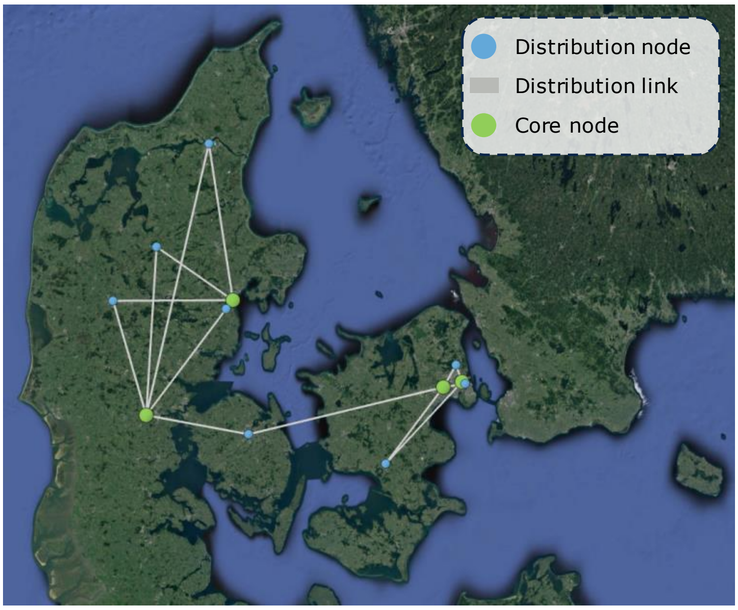

Exhibit 4.19: Illustration of the nodes and links in the distribution network [Source: Axon Consulting]

- Core nodes: The core network has 4 nodes, all interconnected to each other in a ring topology.

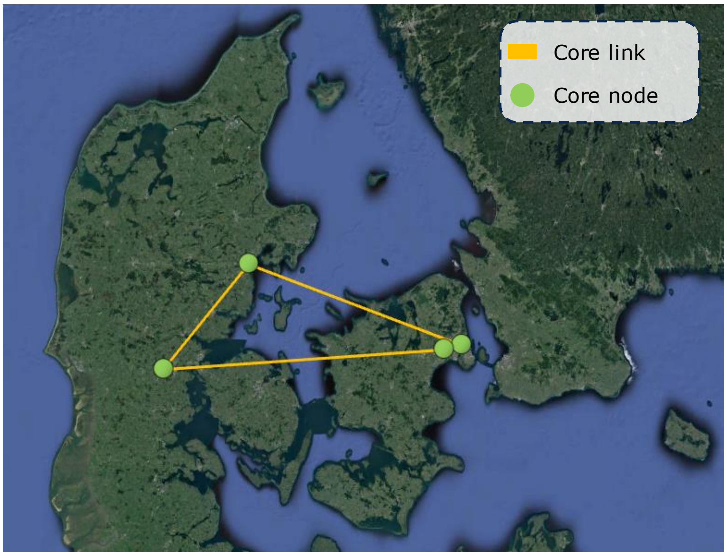

Exhibit 4.20: Illustration of the nodes and links in the distribution network [Source: Axon Consulting]

Once, all the chains/rings have been determined we proceed to the calculation of the road distance between the nodes, which is applied based on the same algorithm presented in section '4.3.1 - Access Networks', by means of the road graph calculating the minimum distance.

4.4. Calculation of network elements from the geographical analysis

The aim of the geographical analysis is to calculate the number of passive network elements (e.g. cables, trenches, etc.) required to meet the coverage levels defined for each network element and for each year (for further indications on the calculation of the coverage levels defined for each network, please see section '3.4 - Coverage).

As the modelled operator manages different access and transmission networks that involve passive civil infrastructure element, the calculation is divided as follows:

- Copper Access Network
- Fibre Access Network

- Coax Access
- Other common civil infrastructure elements
- Core and Transmission networks

Each of these blocks is presented separately below.

4.4.1 Copper Access Network

The algorithm for copper access networks is organised into five steps, as shown in the chart below:

Step 1. Calculation of Percentage of homes connected directly to COs

Step 2. Calculation of km of pairs of copper cable

Step 3. Calculation of fibre cable for copper networks

Step 4. Calculation of equipment for copper networks

Step 5. Calculation of joints

Exhibit 4.21: Steps followed for the calculation of copper network elements [Source: Axon Consulting]

The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of homes connected directly to a Central Office

The objective of this step is to disaggregate the homes that are directly connected to an MDF located in the Central Office (instead of a remote MDF). This step is relevant to ensure that the calculation of fibre elements is done only for those homes that are connected to the CO through a remote MDF.

Therefore, in this step, we proceed to the calculation of the percentage of homes that are directly connected to a CO, outputting the number of homes connected in each Central Office that do not pass through a remote MDF.

Step 2. Calculation of km pairs of copper cable

This step focuses on the calculation of the length and typology of the copper cables used in the access copper network.

Copper cables are used in the network to connect the segments from the FDP to MDFs (FDP-SDP, SDP-PDP, PDP-MDF). The final drop of copper that connects the homes to the FDP is calculated in the Excel model (see section '5.3.1 - Copper Access Network Dimensioning') as it depends on the demand.

We consider that a 2-pair cable is deployed for each home passed. Notably, a catalogue of cables with a variable number of pairs per cable is available in the model based on typologies handled by the modelled operator. Therefore, the calculations of the model have to ensure that the typology of the cables used in the network as the cables aggregate represents the most efficient alternative, with the constraints posed by the levels of coverage in the network and the available cable sizes from the catalogue.

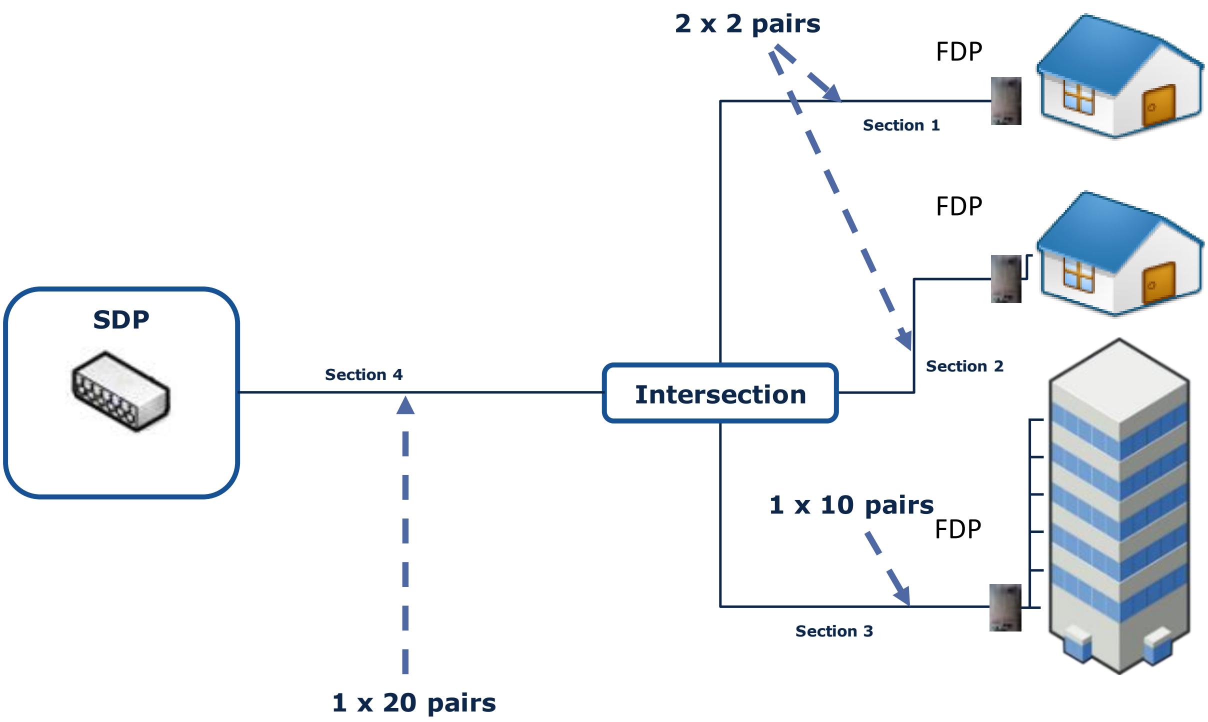

Exhibit 4.22: Illustrative example of the aggregation of copper cables in FDP-SDP segments [Source: Axon Consulting]

In order to accomplish this task, the model carries out the following algorithm for each section where a copper cable should be installed:

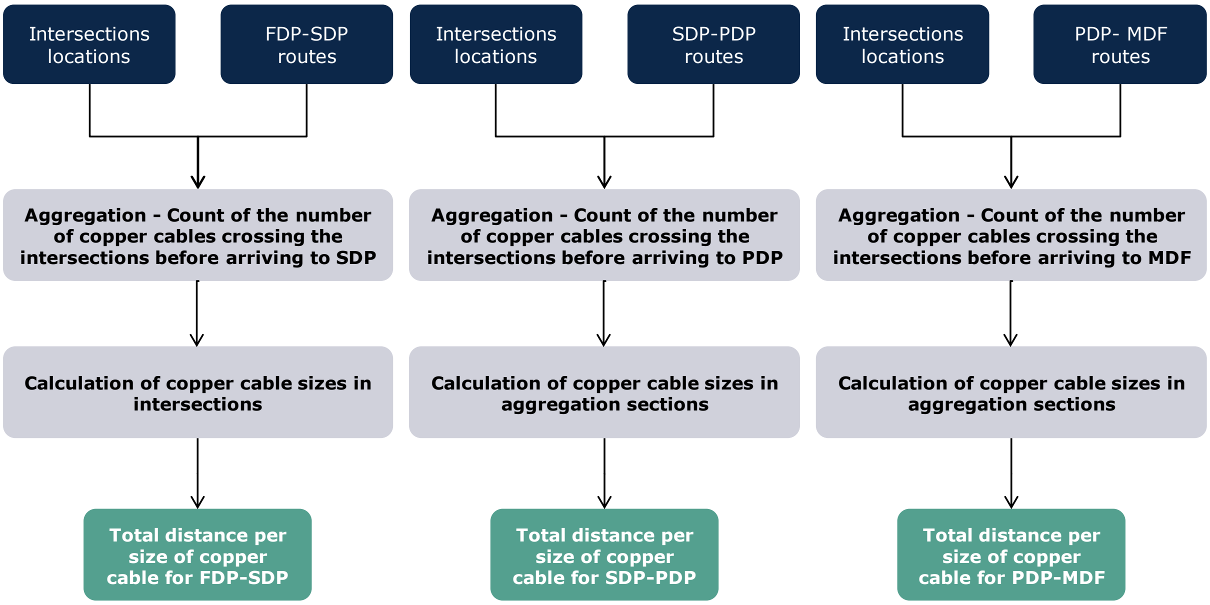

Exhibit 4.23: Algorithm used for the calculation of the km of copper cables per network layer in copper networks[Source: Axon Consulting]

This algorithm allows the calculation of the length of copper cable to install in each section as well as the efficient size of the cable.

The output of this algorithm is the length of the copper cable per size required to reach the next higher level in the network.

Step 3. Calculation of km of fibre cable for copper networks

Fibre cables are used to interconnect the remote MDFs to the Central Offices. The model considers that all remote MDFs are connected through optic fibre. We consider that there is a single fibre cable connecting the MDF to the Central office, which is equivalent to the one used in higher-layer transmission networks (12 strands).

To calculate the km of fibre needed for this segment of the network, the following algorithm is performed:

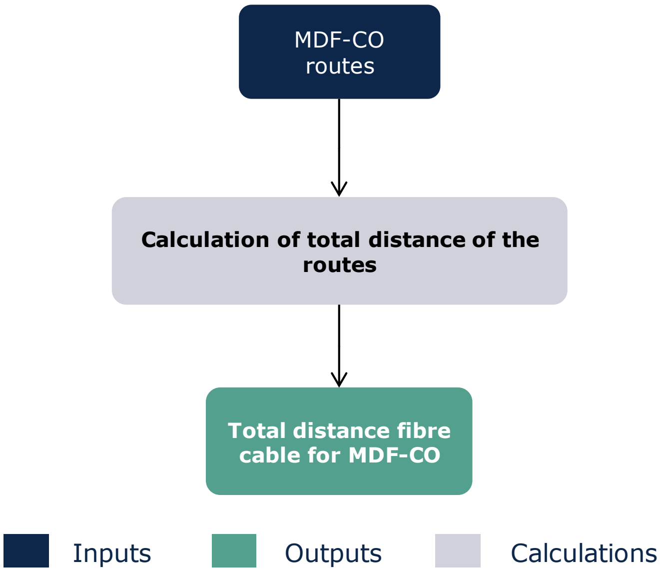

Exhibit 4.24: Algorithm used for the calculation of the fibre cable distance used in the copper network [Source: Axon Consulting]

The output of this algorithm is, for each remote MDF, the length of the fibre required to reach the Central Office.

Step 4. Calculation of SCs, DPs and MDFs

The third step involved the calculation of the number of street cabinets (SC), Distribution Points (DP) and Main Distribution Frame (MDF) needed for each scenario of the copper access network. Each of these is detailed below separately.

Calculation of the number of street Cabinets

The street cabinets are installed to hold remote MDFs nodes. The model defines different sizes of cabinets, based on the number of homes passed it can hold.

Hence, in order to determine the number of street cabinets needed the following algorithm has been applied to each MDF location:

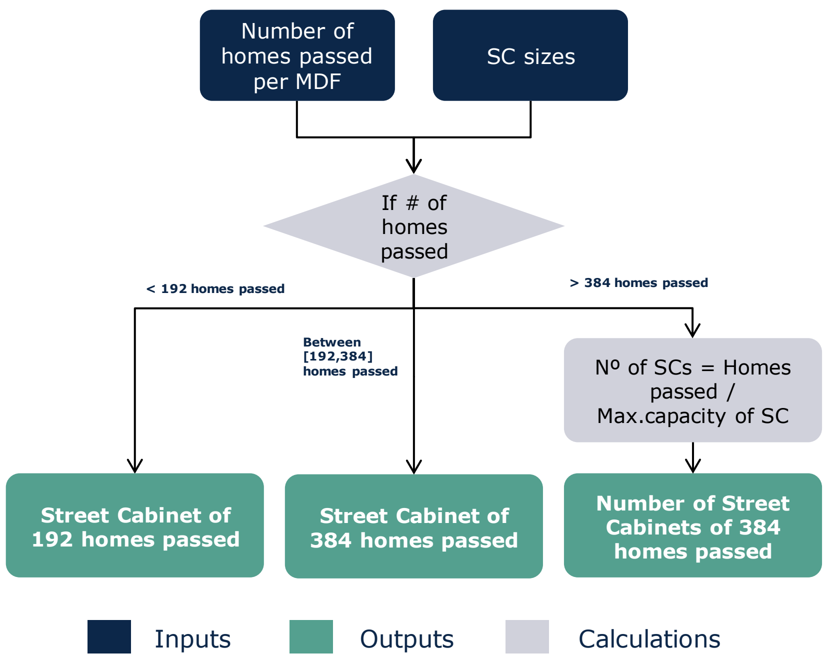

Exhibit 4.25: Number of street cabinets algorithm [Source: Axon Consulting]

The output of the algorithm is the final number of street cabinets and its typology.

Calculation of number of DPs

The distribution points aggregate the cables coming from the homes and are installed in SDP and/or PDP nodes. Similarly, to other network elements, the model includes different DPs depending on the number of homes passed. Hence, in order to determine the number of DPs needed the following algorithm has been applied to each SDP/PDP location:

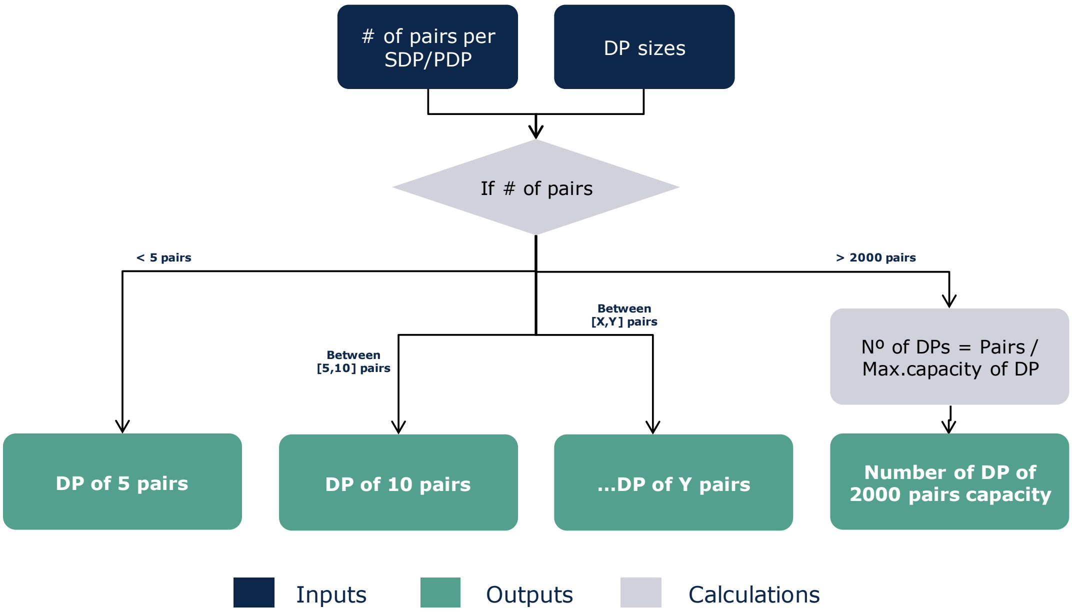

Exhibit 4.26: Number of DPs algorithm [Source: Axon Consulting]

The output of the algorithm is the final number of distribution points in the copper network and its typology.

Calculation of number of MDFs

The MDF is an equipment that is installed the points of the network where copper cables end. This is, can be in remote locations (cabinet) or in the Central Office. Hence, in order to determine the number of MDFs needed and its size the model considers for each potential location the number of homes passed.

Step 5. Calculation of copper joints

The joints are used in the copper network to merge cables, facilitate the management of their direction as well as to reduce costs in its installation and operation. Therefore, it is assumed that the joints are needed in every intersection where there are copper cables.

Therefore, the total number of copper joints are calculated as the sum of the installed joints in each intersection of the country.

However, similarly to other network elements, the model considers different sizes for the joints depending on the number of lines aggregated. Therefore, in order to calculate the number of joints per intersection per size, the following algorithm is followed:

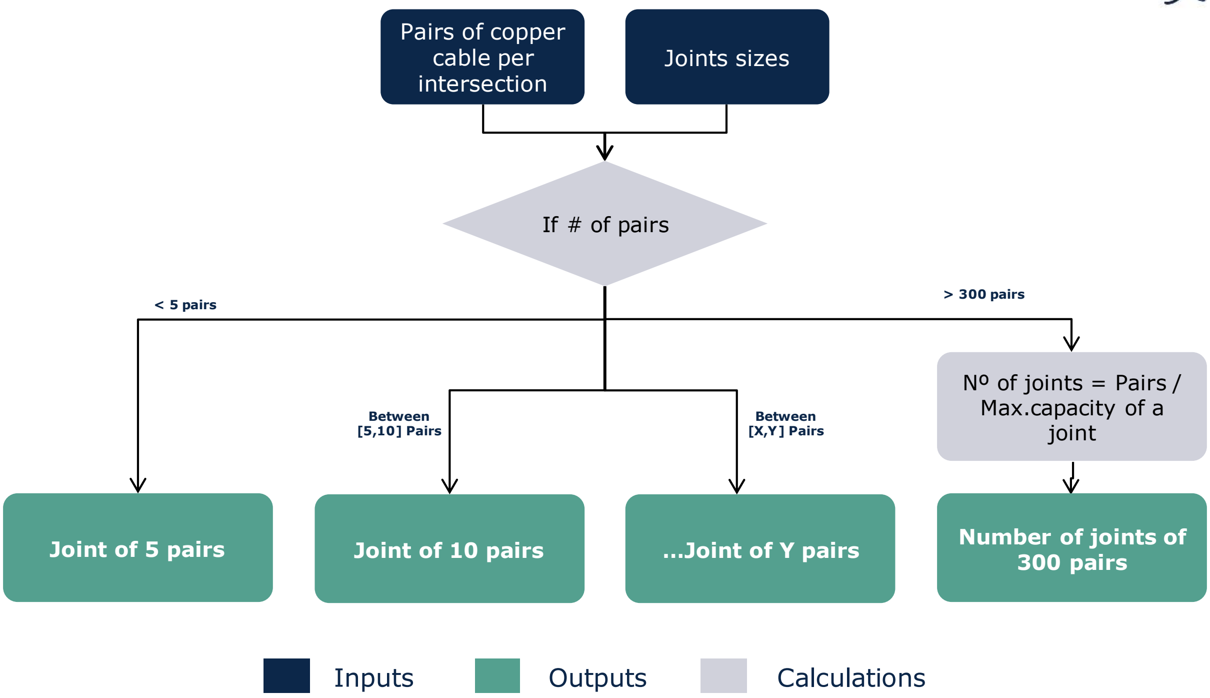

Exhibit 4.27: Algorithm for copper joints [Source: Axon Consulting]

The output of the algorithm is the final number of joints in the copper network and its typology.

4.4.2 Fibre Access Network

The algorithm for fibre access networks is organised into three steps, as shown in the chart below:

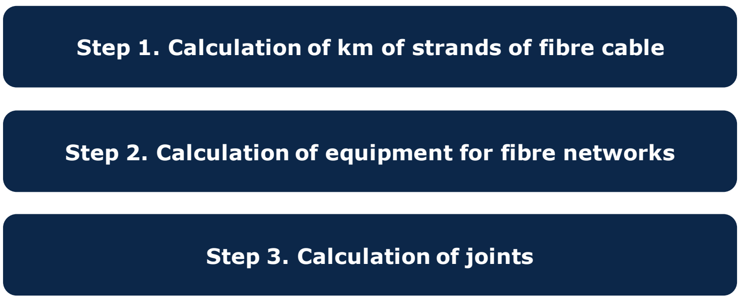

Exhibit 4.28: Steps followed for the calculation of fibre network elements [Source: Axon Consulting]

The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of km of fibre cable

The first step focuses on the calculation of the total kilometres of fibre cable used in the access fibre network.

Fibre cables are used in the network to connect the home to the Central Offices (FTTH). The final drop of fibre that connects the homes to the FDP is calculated in the Excel model using the average final drop distance calculated in the R model (see sections '4.4.4 - Other common civil infrastructure elements' and '5.3.2 - Fibre Access Network Dimensioning') as it depends on the demand.

We consider that a 2-strand cable is deployed for each home passed. Notably, a catalogue of cables with a variable number of strands per cable is available in the model based on typologies handled by the modelled operator. Therefore, the calculations of the model have to ensure that, as cables start to aggregate, the typology of the cables used in the network represent the most efficient alternative, with the constraints posed by the levels of coverage in the network and the available cable sizes from the catalogue.

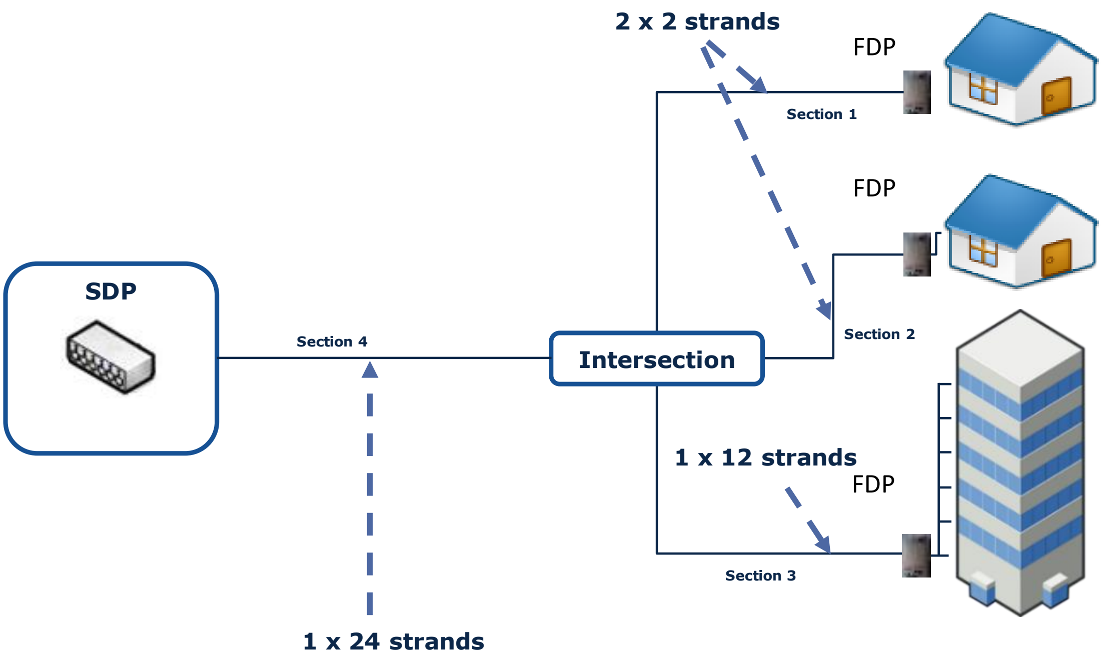

Exhibit 4.29: Aggregation of fibre cables in FDP-SDP segments [Source: Axon Consulting]

In order to accomplish this task, the model carries out the following algorithm for each section where a fibre cable should be installed:

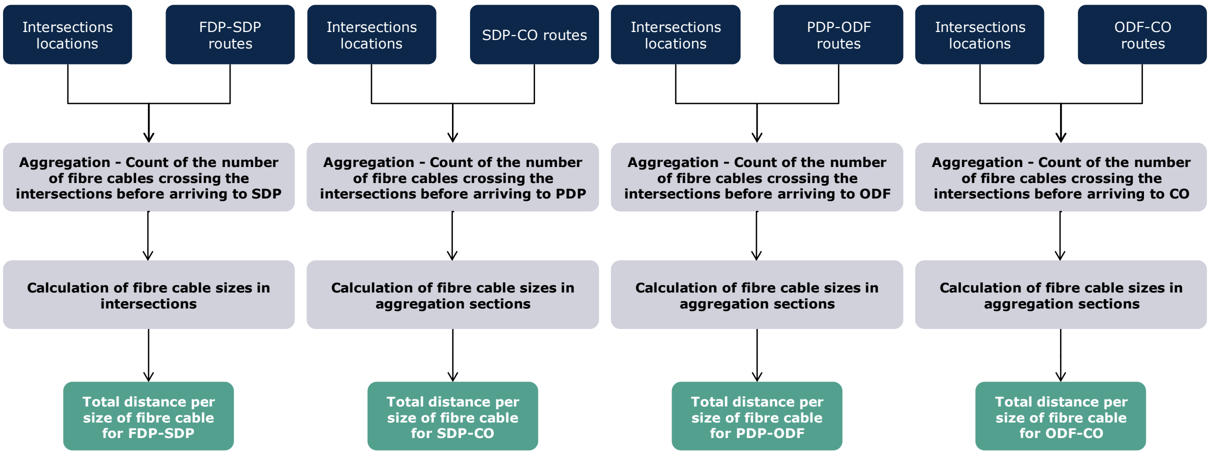

Exhibit 4.30: Algorithm used for the calculation of the km of fibre cables per network layer in fibre networks [Source: Axon Consulting]

It is important to note that links may be sequentially aggregated to save digging, ducting, and cabling costs. Therefore, the algorithm allows the calculation of the length of fibre cable to install in each section as well as the efficient size of the cable. The output of this algorithm is the length of the fibre cable per size required to reach the next higher level in the network.

In addition, this process is performed independently for both fibre architectures (PON and PTP), as PON architecture includes splitters (1:32). This reduces the number of strands of fibre cables required at higher levels. Notably, the algorithm returns the same results from the FDP up to the splitter (located in the SDP) for both, PON and PTP architectures.

The output of this algorithm is the length of the fibre cable per size required to reach the next higher level in the network.

Step 2. Calculation of equipment configurations for fibre networks

The following step is related to the calculation of the number of equipment needed for each scenario of the fibre access network. The main equipment is:

- Calculation of number of splitters
- Calculation of number of DPs
- Calculation of number of ODF

Calculation of number of splitters

The splitters are used in GPON architecture to split the fibre for its distribution towards the households. In order to calculate the number of splitters needed in the network the following algorithm has been applied:

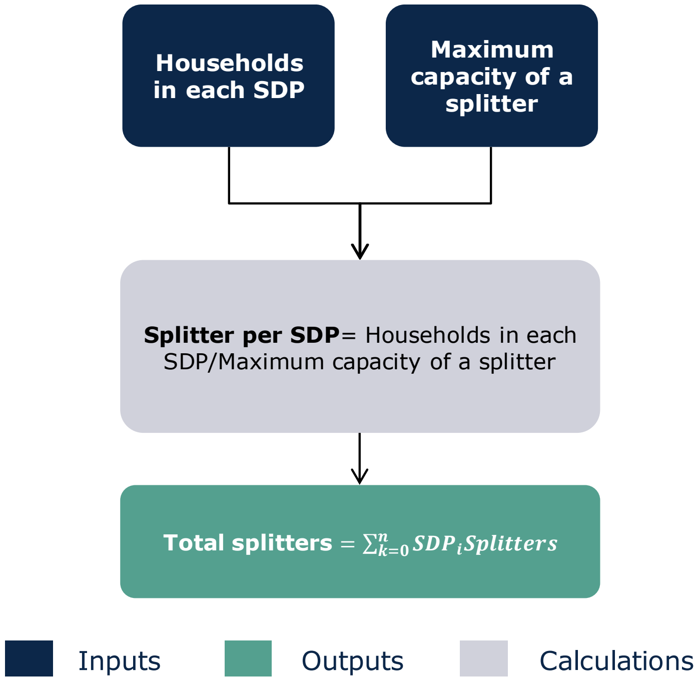

Exhibit 4.31: Algorithm for the calculation of the number of splitters [Source: Axon Consulting]

Calculation of number of DPs

The distribution points are installed in SDPs nodes. Hence, in order to determine the number of DPs needed the following algorithm has been applied to each SDP and PDP location:

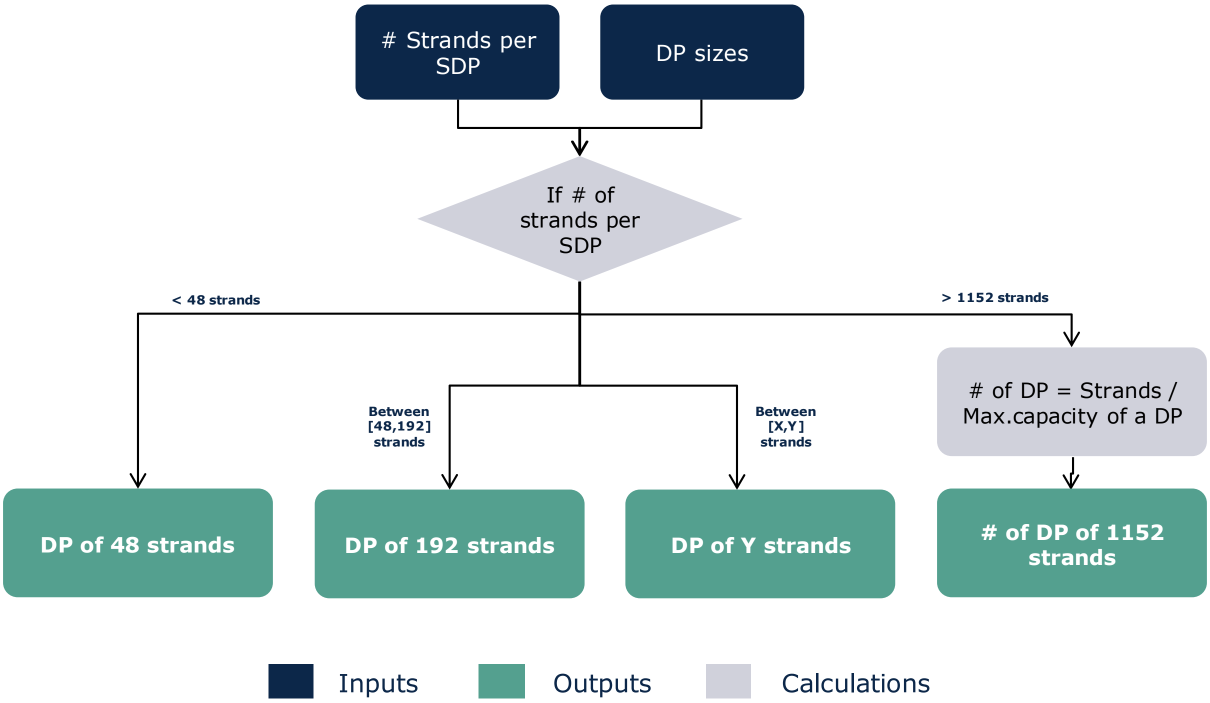

Exhibit 4.32: Algorithm used for the calculation of the number of DPs [Source: Axon Consulting]

The output of the algorithm is the final number of distribution points in the fibre network and its typology.

Calculation of number of ODF

The ODFs are installed in ODFs nodes. Hence, in order to determine the number of ODFs needed the following calculation flow is applied:

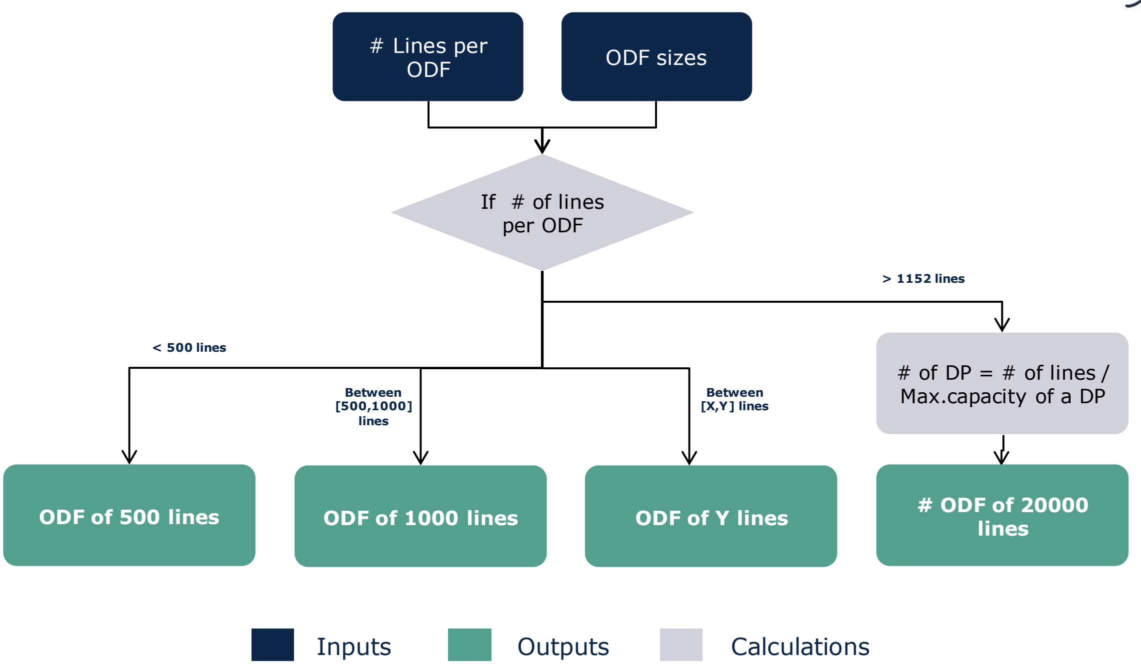

Exhibit 4.33: Algorithm used for the calculation of the number of ODFs [Source: Axon Consulting]

The output of the algorithm is the final number of optical distribution frames in the fibre network and its typology.

Step 3. Calculation of fibre joints

The joints are used in the fibre network to merge cables and facilitate the management of their direction. Therefore, it is assumed that the joints are needed in every intersection with fibre cables. In the case of the fibre network, the calculations are done separately for PON and PTP architecture considering the total amount of cables in each type of architecture.

Therefore, the total number of fibre joints are calculated as the sum of the installed joints in each intersection of the country.

In order to calculate the number of joints per intersection and size, the following algorithm is followed:

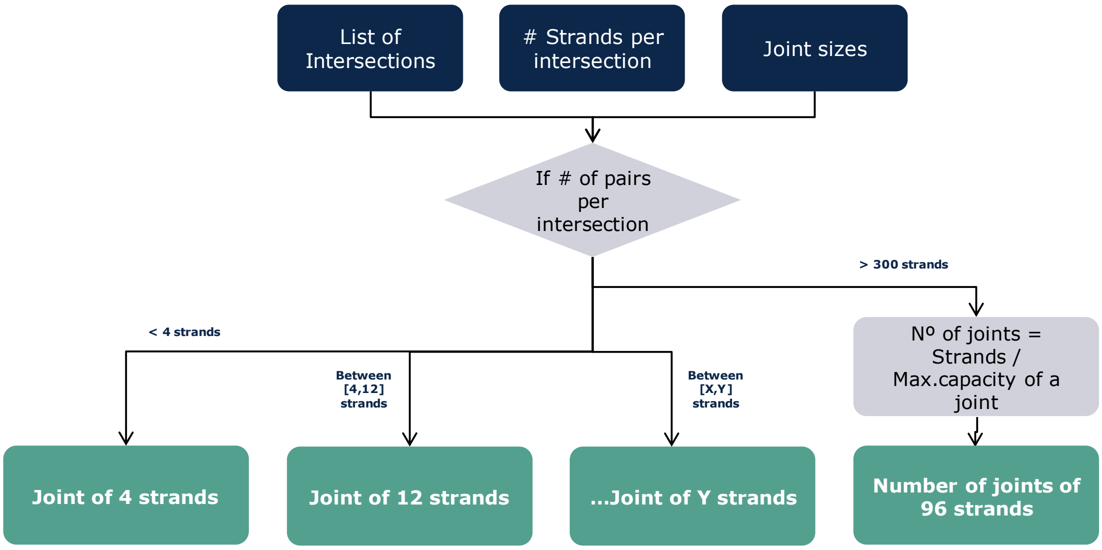

Exhibit 4.34: Algorithm used for the calculation of fibre joints [Source: Axon Consulting]

After the total number of joints per size is determined as the sum of all the joints in each intersection.

4.4.3 Coax Access Network

The algorithm for coax access networks is organised into three steps, as shown in the chart below:

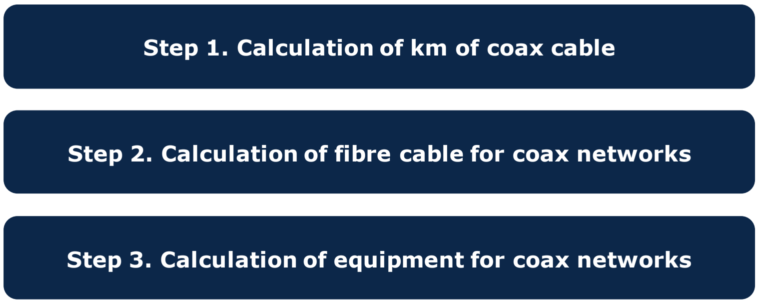

Exhibit 4.35: Steps followed for the calculation of coax network elements [Source: Axon Consulting]

The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of km of coax cable

The first step focuses on the calculation of the total kilometres of coax cable used in the access coax network. Coax cables are used in the network to connect the segments from the TAPs to CMCs. The final drop of fibre that connects the homes to the FDP is calculated in the Excel model using the average final drop distance calculated in the R model (see sections '4.4.4 - Other common civil infrastructure elements' and '5.3.2 - Fibre Access Network Dimensioning') as it depends on the demand

For this calculation, the following algorithm is implemented:

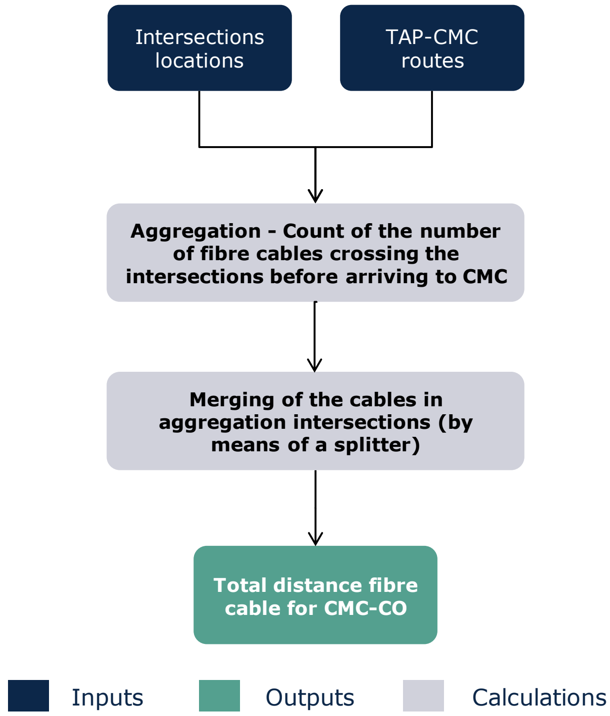

Exhibit 4.36: Algorithm used for the calculation of coaxial cable for coax networks [Source: Axon Consulting]

The output of this algorithm is the length of the coax cable required to reach the next higher level in the network.

Step 2. Calculation of km of fibre cable for coax networks

Fibre cables are used to interconnect the remote CMCs to the Central Offices. The model considers that all CMCs are connected through optic fibre. We consider that there is a single fibre cable connecting the CMC to the Central office, which is equivalent to the one used in higher-layer transmission networks (12 strands).

To calculate the km of fibre needed for this segment of the network, the following algorithm is performed:

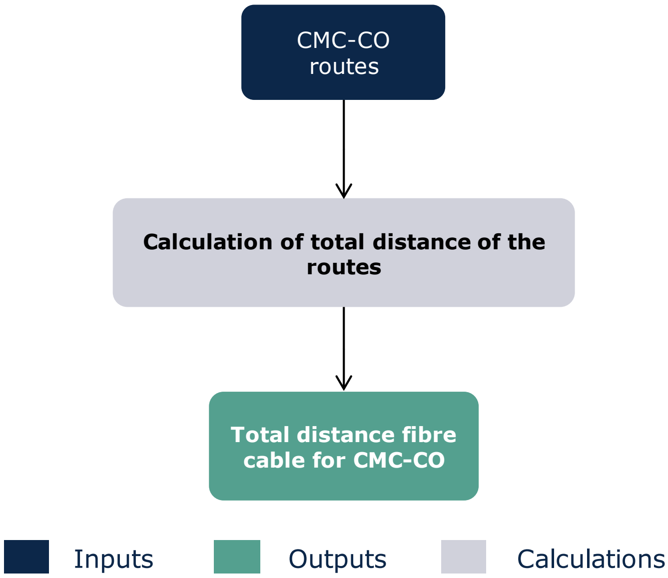

Exhibit 4.37: Algorithm used for the calculation of the fibre cable distance used in the coax network [Source: Axon Consulting]

The output of this algorithm is, for each CMC node, the length of the fibre required to reach the Central Office.

Step 3. Calculation of equipment for coax networks

The third step involved the:

- Calculation of number of CMCs, OLTs and TAPs
- Calculation of number of coaxial splitters

Calculation of number of CMCs, OLTs and TAPs

The TAPs, OLTs and CMCs represent the main equipment used in the coax network. The number of locations with this equipment is determined based on the coverage information provided. Hence:

- The number of TAPs is equal to the number of buildings covered.
- The number of CMCs is equivalent to the number of CMC nodes determined in section '4.2 - Determination of the location of network nodes'.
- The number of OLTs is equal to the number of Central Offices where there is coverage for coaxial network

Calculation of number of coaxial splitters

Finally, the splitters are used in the coax network in order to split high-level cables to cover households. Hence, knowing the routes of the coaxial cables, the geographical model identifies all the intersections that are crossed by a coaxial cable, then it assigns one splitter per intersection.

4.4.4 Other common civil infrastructure elements

This step is related to the calculation of the km of trenches in the access network. It is assumed that these trenches are shared by the different technologies (copper, fibre and coax).

The trenches are calculated considering all the routes calculated in section '4.3 - Definition of the routes between the nodes' for the three technologies. The process followed for every section is the following:

1. For every section, a trench is installed in the side with more buildings. As we can see in the figures below, the first trench is placed on the upper side of the section, for this reason. In the second exhibit, the trench is placed on the lower side, where there are more buildings.

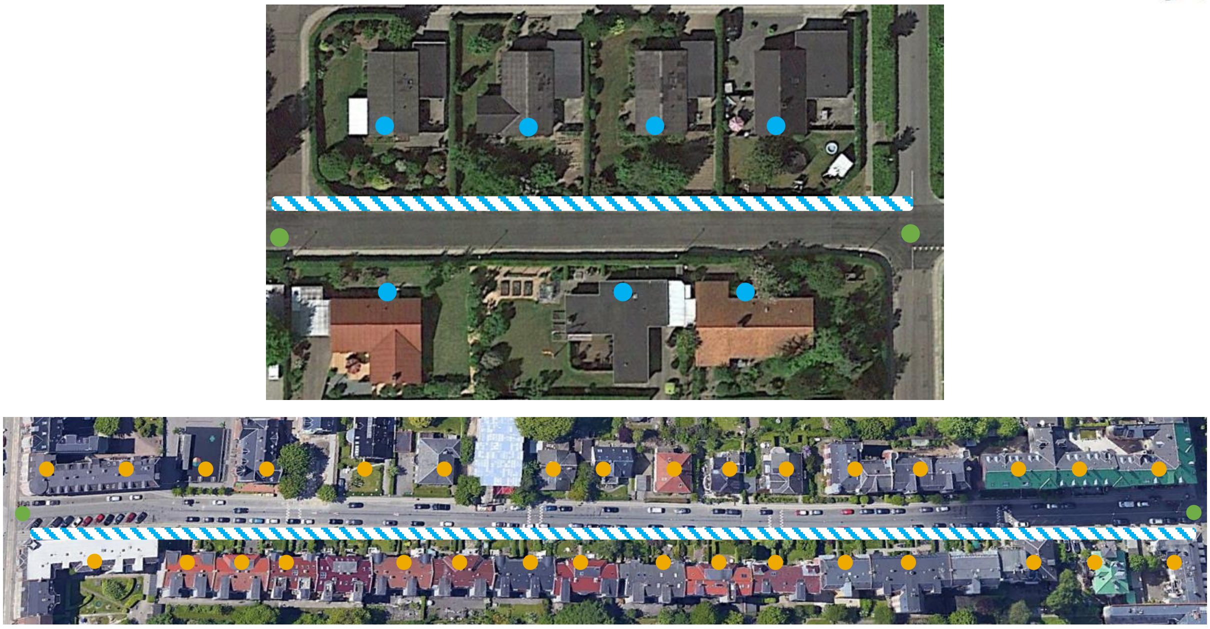

Exhibit 4.38: Identification of the side to install the main trench in each section [Source: Axon Consulting]

2. The next step considers that the building on the other side of the road must be able to either have their own trench or to have a road crossing to reach the existing trench. For this, in each section two main options have been considered:

    a. If the average distance between buildings higher than 10 meters, we consider that it is more cost-efficient to cross the road separately for each building.

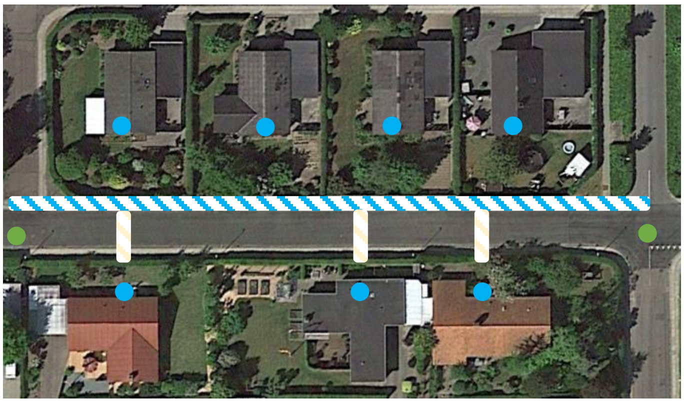

Exhibit 4.39: First option for the second trench in each section [Source: Axon Consulting]

In this case, the total length of the trenches to be dug out for each section would be:

$$d = Length\ of\ the\ section + \#\ of\ buildings\ in\ the\ side\ with\ less\ buildings \cdot width\ of\ the\ road$$

b. If the average distance between buildings lower than 10 meters, we consider that it is more cost-efficient to dig out an additional trench on the other side of the road.

Exhibit 4.40: Second option for the second trench in each section [Source: Axon Consulting]

In this case, the total length of the trenches to be dug out for each section would be:

$$d = 2 \cdot Length\ of\ the\ section$$

Additional KPIs

In addition to trenches, some general KPIs are calculated:

- The total number of buildings per geotype
- The average number of houses per building per geotype
- The average drop length per geotype. The average drop length is the average of all the distances between the building and the FDP considering the characterisation presented in section '4.2 - Determination of the location of network nodes'.

4.4.5 Core and Transmission networks

The algorithm for core and transmission networks is organised into two steps, as shown in the chart below:

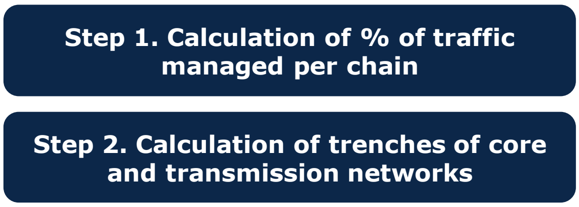

Exhibit 4.41: Steps followed for the calculation of core and transmission network elements [Source: Axon Consulting]

The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of % of traffic managed per chain

The first step focused on the calculation of the percentage of traffic that is being managed for each of the chains of each of and core networks.

In order to do that, the following formula has been applied for each chain:

$$\%\ of\ traffic\ = \frac{\sum Homes\ managed\ by\ the\ nodes\ of\ the\ chain}{Total\ homes}$$

This traffic is used in section '5.2 - Transmission network dimensioning' in order to characterize the equipment of the core and transmission network.

Step 2. Calculation of trenches of core and transmission networks

In this step, we proceeded to the calculation of the trenches required for the transmission network. This step is divided into two different substeps:

- The total transmission trench distance is calculated using the shortest path distance (already explained in previous sections) between each node of the transmission links.
- Using the sections where a trench of the transmission should be used and the sections where a trench of the access network should be used two KPIs are calculated:
  - The percentage of transmission network not shared with access network nationwide
  - The percentage of the access network that is shared with the core network at geotype level

Each one of the results of the substeps is extracted as a KPI for the excel model.

4.5. Aggregation of the results into geotypes

The model provides results at "geotype" levels. The geotypes are defined based on four different sets of classifications:

- **Region**: One of the five administrative regions in Denmark ("Hovedstaden", "Midtjylland", "Nordjylland", "Sjælland" and "Syddanmark").
- **Degree of urbanisation**: Depending on the building density, the geotypes are divided into "Urban", "Suburban" or "Rural".
- **Type of dwelling**: Depending on the type of building considered ("Single-dwelling" or "Multi-dwelling")
- **Regulatory status**: Depending on the regulatory status of the buildings, geotypes are divided in to "Regulated or "Not-regulated".

The characterisation of each of the aforementioned classifications is further detailed below.

4.5.1 Region

The first geotype classification used is related to the administrative regions in Denmark. There are 5 regions in Denmark:

- Hovedstaden
- Midtjylland
- Nordjylland
- Sjælland
- Syddanmark

In this case, each home is assigned to its corresponding region based on its location. In the event that there is a home where that is located in a given region but the Central Office to which it is assigned is located in a different region, the home adopts the region from the associated Central Office.

4.5.2 Degree of urbanisation

Based on the available information at sector level across the country, we have proceeded to classify all CO coverage areas into geotypes. The number of geotypes has been set to 3 in order to represent three different types of areas: Urban, Suburban and Rural.

The geotype definition has been performed through cluster analysis. This cluster exercise is carried out using a "k-means" algorithm, considering two main variables that have been selected to characterize the geotypes:

- Number of buildings per CO (buildings/per CO).
- Area per CO coverage area (km^2).

Based on this, we observed the following characterisation of the different existing Central Offices:

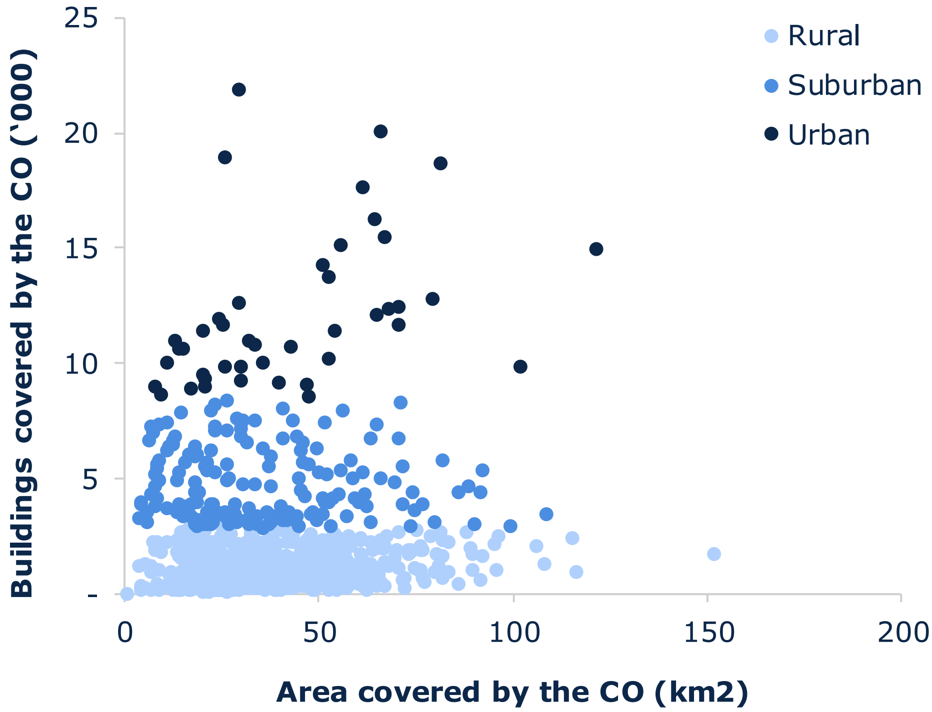

Exhibit 4.42: Characterisation of the central offices into geotypes [Source: Axon Consulting]

Based on this characterisation, we obtained the following distribution of geotypes across Denmark:

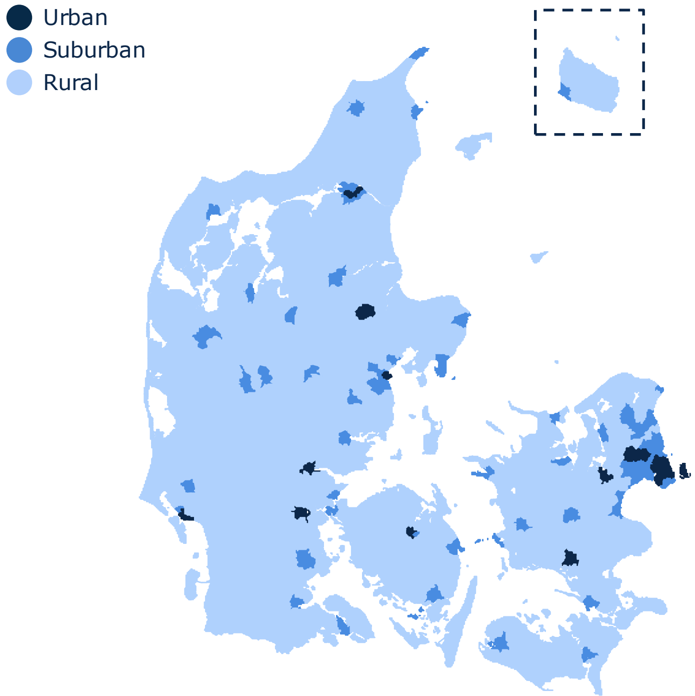

Exhibit 4.43: Classification into geotypes of CO areas for the geographical analysis [Source: Axon Consulting]

As it can be extracted from the exhibit, more dense areas in the country are classified as urban geotype whereas less populated sectors are identified as rural.

4.5.3 Type of dwelling

An additional disaggregation performed is the definition of whether a building is single dwelling (only one home in the building) or multi-dwelling (two-or-more homes per building). This information is extracted from each building based on the data available from the address database presented in section '4.1.1 - Address database'.

4.5.4 Regulatory status

Finally, disaggregation between regulated and non-regulated areas is also considered.

This disaggregation is based on the latest analysis of markets 3a and 3b, where DBA lifted the price regulation obligations applicable to TDC for fibre-related services in some specific areas (at zip code level) of Denmark, introducing a geographical disaggregation of the regulatory obligations imposed. This information is introduced in the model at building level.

Therefore, the model is able to calculate the costs stemming from regulated and non-regulated areas separately. It should be noted that results based on this disaggregation are only applicable to fibre services.

4.5.5 Disaggregation of the results into the detailed geotypes

The last step is related to the allocation of the results of the geographical analysis into the different geotypes.

Considering that the region and degree of urbanisation are defined at CO level, all the KPIs can be easily assigned to the region and degree of urbanisation without further adjustments.

In order to disaggregate the results in all the different geotypes we used two methodologies to further split the KPIs based on the regulatory status and the type of dwelling:

- **Number of houses**: The first methodology, mainly used to disaggregate KPIs not related to distance (DP, joints, MDF, ODF, etc), is based on the number of houses per each geotype in the CO. The final KPIs per geotype are calculated multiplying the KPIs per CO by the percentage obtained dividing the number of houses per geotype and the total number of houses
- **Number of houses weighted by the house-CO distance:** The second methodology is used for KPIs related to distance (trenches and cables). In order to account for the distance cost factor on these KPIs, we calculated a weight which is the result of multiplying the number of houses per building by the distance house-CO. The final KPIs per geotype are calculated multiplying the KPIS per CO by the percentage obtained dividing the sum of the weights of the buildings per each geotype and sum of the weight of all the buildings of the CO.

5. Dimensioning module

The Dimensioning Module aims at designing the network and dimensioning the network resources required to serve the demand of the modelled operator. This dimensioning is performed in the Excel model and focuses on the calculation of the network elements that depend on the demand (number of active lines), traffic (Mbps) and Spectrum.

Therefore, the main inputs to this module are:

- Drivers, representing the overall traffic, demand and spectrum
- Geographical inputs, the results obtained from the geographical analysis performed in section '4 - Geographical analysis performed in the R model'.

This section presents all the calculations followed for the purpose of the dimensioning of all the network elements. For that, this section has been divided into three different network sections which are described in detail below:

- **Dimensioning Drivers**, presenting the process for the definition of the drivers
- **Core and Transmission Network Dimensioning,** introducing the algorithms used for the calculation of Core and Transmission network elements
- **Access Network Dimensioning**, introducing the algorithms used for the calculation of access network elements

5.1. Dimensioning drivers

The rationale of the dimensioning drivers is to express traffic and demand (at service level) in a way that facilitates the dimensioning of network resources that are dependent on demand volumes (e.g. active equipment).

This section presents the following aspects of dimensioning drivers:

- Dimensioning drivers' concept
- Mapping services to drivers
- Conversion from services to drivers

5.1.1 Dimensioning drivers' concept

The explicit recognition of a dimensioning "Driver" in the model aims at simplifying and increasing the transparency of the network dimensioning process.

Dimensioning drivers represent, among others, the following requirements:

- Number of connections (copper, fibre and coax) for the dimensioning of the access network.
- Mbps for transmission through the different layers of the transmission network.

The following list contains the drivers used in the LRAIC costing model for fixed networks:

VARIABLE
DRIV.Access copper.Connections.Total Active connection
DRIV.Access coaxial.Connections.Total Active connection
DRIV.Access fibre.Connections.Total Active connection
DRIV.Broadband.Traffic.Copper broadband - Access
DRIV.Broadband.Traffic.Fibre broadband - Access
DRIV.Broadband.Traffic.Coax broadband - Access
DRIV.Broadband.Traffic.Copper broadband - Aggregation
DRIV.Broadband.Traffic.Fibre broadband - Aggregation
DRIV.Broadband.Traffic.Coax broadband - Aggregation
DRIV.Broadband.Traffic.Copper broadband - Distribution/Core
DRIV.Broadband.Traffic.Fibre broadband - Distribution/Core
DRIV.Broadband.Traffic.Coax broadband - Distribution/Core
DRIV.Leased lines.Traffic.Leased Lines - Legacy
DRIV.Leased lines.Traffic.Leased Lines - IP Fibre
DRIV.Video.Traffic.Retail TV - Access
DRIV.Video.Traffic.Retail TV - Aggregation
DRIV.Video.Traffic.Retail TV - Distribution
DRIV.Video.Traffic.Retail TV - Core
DRIV.Video.Traffic.Retail VoD
DRIV.Video.Traffic.Wholesale multicast - Access
DRIV.Video.Traffic.Wholesale multicast - Aggregation
DRIV.Video.Traffic.Wholesale multicast - Distribution/Core
DRIV.Video.Traffic.Wholesale VoD - Access
DRIV.Video.Traffic.Wholesale VoD - Aggregation
DRIV.Video.Traffic.Wholesale VoD - Distribution/Core

Exhibit 5.1: List of Drivers used in the model (Sheet '0D PAR DRIVERS'). [Source: Axon Consulting]

Two steps are required to calculate the drivers:

1. Mapping services to drivers
2. Converting traffic units into the corresponding driver units

Each of these two steps is discussed below in more detail.

5.1.2 Mapping services to drivers

To obtain drivers it is necessary to indicate which services are related to them. It should be noted that each service is generally assigned to more than one driver as drivers represent traffic in a particular point of the network.

For example, broadband copper services should be contained in both the drivers used to dimension the access network (in order to properly dimension the number of MSANs required) as well as the core networks.

The following exhibit shows an excerpt of the mapping of services into drivers:

DRIVER (Variable Name)	SERVICE (Variable Name)
DRIV.ACCESS COPPER.Connections.Total Active connection	Access.Copper.Retail.Access
DRIV.ACCESS COPPER.Connections.Total Active connection	Access.Copper.Retail.Access with bonding
DRIV.ACCESS COPPER.Connections.Total Active connection	Access.Copper.Wholesale.VULA (POI0)
DRIV.ACCESS COPPER.Connections.Total Active connection	Access.Copper.Wholesale.VULA (POI1)
DRIV.BROADBAND.Traffic.Fibre broadband - Aggregation	Broadband.Fibre.Retail.broadband
DRIV.BROADBAND.Traffic.Fibre broadband - Aggregation	Broadband.Fibre.Wholesale.BSA broadband - POI2
DRIV.BROADBAND.Traffic.Fibre broadband - Aggregation	Broadband.Fibre.Wholesale.BSA broadband - POI3
…	…

Exhibit 5.2: Excerpt from the mapping of Services into Drivers (Sheet '3A MAP DRIVERS') [source: Axon Consulting]

5.1.3 Conversion from services to drivers

Once services have been mapped to drivers, volumes need to be converted to obtain drivers in proper units.

For that purpose, a conversion has been worked out representing the number of driver units generated by each demand service unit. In general, conversion calculation consists of two subfactors, in compliance with the following structure:

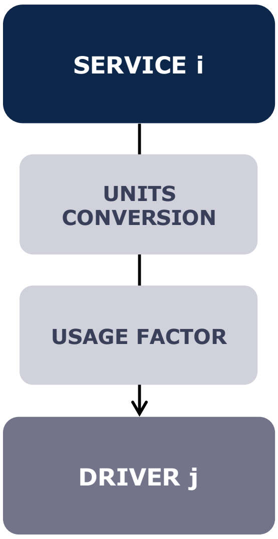

Exhibit 5.3: Conversion Process from Services to Drivers [Source: Axon Consulting]

The conversion factor thus includes the following items:

1. Usage Factor (UF)
2. Conversion Factor (CF)

Finally, the relationship between a given service and a driver is obtained by following the formula outlined below:

$$FC = UF * CF$$

Usage factor represents the number of times a service makes use of a specific resource.

Conversion Factor represents the need to adapt services' units (e.g. lines) to those used by the driver (e.g. Mbps). The application of the conversion factors from services to drivers is performed using "weights" (Average traffic per line). These weights are calculated in the worksheet '3A MAP WEIGHTS'.

5.2. Transmission network dimensioning

The objective of the dimensioning of the transmission network is the calculation of the number of network elements required to meet the demand and coverage levels present from the networks of the modelled operator. These network elements include active elements (Routers, ports, etc.) and passive elements (trenches, landing stations, fibre cable, etc.).

As a first instance, the dimensioning of the transmission network is performed at a national level, this is, geotypes are not considered in the calculation of the results. The dimensioning approach is performed separately for each of the layers in the transmission network:

- L3 Access Network
- Aggregation Network
- Distribution Network
- Core Network

However, it should be noted that the algorithms considered for each layer are equivalent. Thus, below we present the algorithms followed once, capturing any small differences identified.

Router equipment

The number of routers installed in each network layer is determined based on the number of nodes and their associated traffic.

As a starting point, the model considers a single router in each network node. This figure can be increased if the traffic that the router needs to hold is greater than its capacity. In addition, the model considers router redundancy for core and distribution router nodes. Hence, in these cases, two routers are installed in each node.

Once the number of routers has been determined, we proceed to the calculation of each one of its elements. The details of the dimensioning of each element are outlined below:

SPF (100G, 10G, 1G[7])

The SPFs correspond to the ports of the routers in the transmission network. Their number and capacity are calculated depending on the traffic managed by each of the nodes in the network.

The calculation of the number of SPF per capacity is performed in four steps in order to ensure that the algorithm chooses the most cost-efficient solution. The following steps are repeated for each transmission network (Core, Distribution, Aggregation and L3 Access) and type of SPF port:

- Step 1: It is calculated the maximum number of ports of each capacity that where it is more cost-efficient to have before using a higher capacity port. This is done considering the capacities of each port and the cost of each type of port. For example, if the cost of a 1G port is 300 DKK and the cost of a 10G port is 1.000 DKK. The value calculated in this step will be 3 ports, because the cost of 3 low capacity ports is lower than the cost of a high capacity port.
- Step 2: For the port with the highest capacity, we calculate a preliminary number of ports as the traffic that has to be handled, divided by the capacity of the port. This figure is rounded down.
- Step 3: The remaining traffic per node not assigned in the previous step is checked:
  - In case that the necessary number of lower capacity ports is higher than the number calculated in Step 1 then 1 port is added to the result of Step 2.
  - In any other case, nothing is added. The remaining capacity will be the one used for calculating the number of ports in the lower capacity ports (repeating Step 2 and Step 3 with the ports with lower capacity).
- Step 4: Finally, the number of ports per router calculated in previous steps is multiplied by the number of routers.

The output of this process is the number of SPFs required in the core and transmission network.

---

[7] The 1G SPFs are not used in the core transmission layer (backbone), as at this aggregation level the traffic handled by the equipment is higher.

Number of subracks

The number of subracks, which are cards of ports (SPFs) installed in the transmission routers, depends on the number of ports that the subrack installed in each transmission layer can manage. The calculation of this figure is performed as follows:

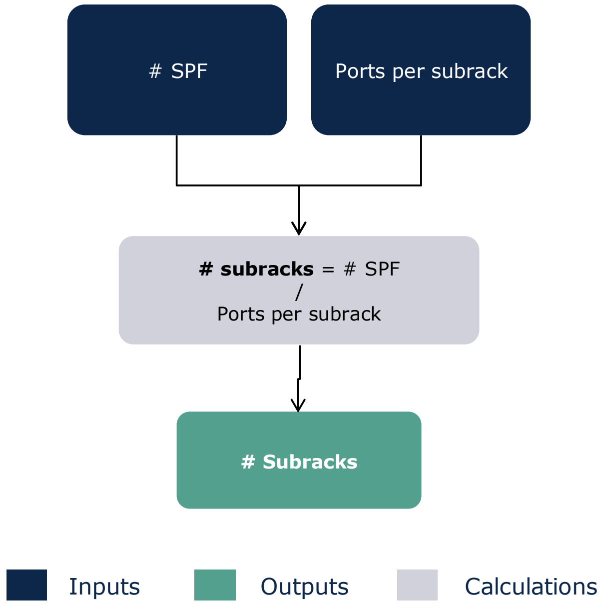

Exhibit 5.4: Calculation of number of subracks [Source: Axon Consulting]

Number of racks

The number of racks, which aggregate the subracks installed in the transmission routers, depends on the number of subracks that the rack installed in each transmission layer can manage. The calculation of this figure is performed as follows:

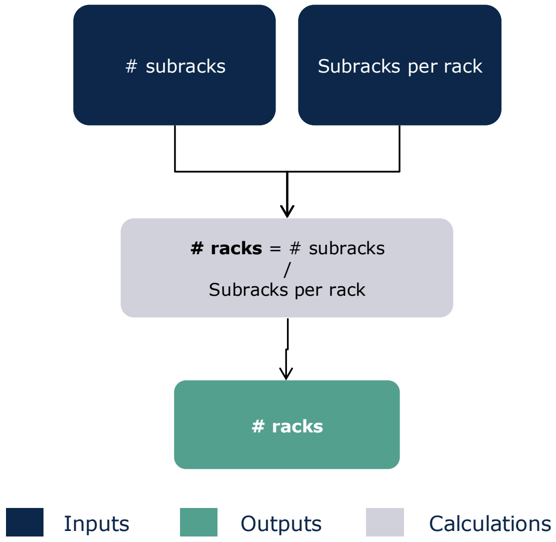

Exhibit 5.5: Calculation of number of racks [Source: Axon Consulting]

Number of chassis

The number of chassis, which are the main body of the transmission routers themselves, depends on the number of racks that each router in each transmission layer can manage. The calculation of this figure is performed as follows:

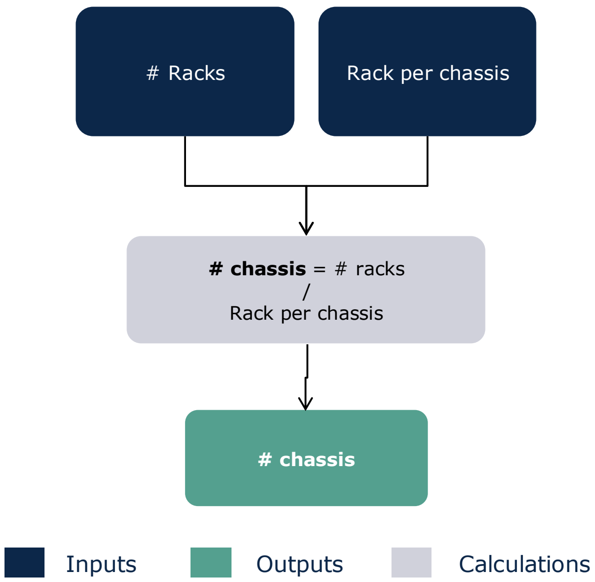

Exhibit 5.6: Calculation of number of chassis [Source: Axon Consulting]

Sites

The number of sites, which represent the physical location where the routers are installed, determined in the model is simply calculated as the total number of node locations of each network.

Submarine cables and Landing stations

The list of submarine cables and their distance used in this network are known (please see section '4.3.2 - Transmission and Core Networks' for further details on this aspect). Therefore, the total distance of submarine cables is equivalent to the sum of the distance of each of the submarine cables dedicated to each one of the transmission networks.

On the other side, the number of Landing stations is calculated supposing that each submarine cable needs 2 landing stations.

Fibre cable

The total length of fibre cable used in each one of the transmission network layers is calculated as follows:

$$\sum_{1}^{N} Distance\ route\ of\ ring/chain(i)$$

Where i represents each of the ring/chains of the layer of the transmission network.

Trenches

Trenches represent the civil infrastructure required to deploy the fibre transmission cables.

As presented in section '4.4.5 - Core and Transmission networks', the model takes into consideration that some of the routes followed by the layers of the transmission network are shared with the civil infrastructure of the access networks.

Based on this, the following algorithm has been used to calculate the trenches of the transmission network:

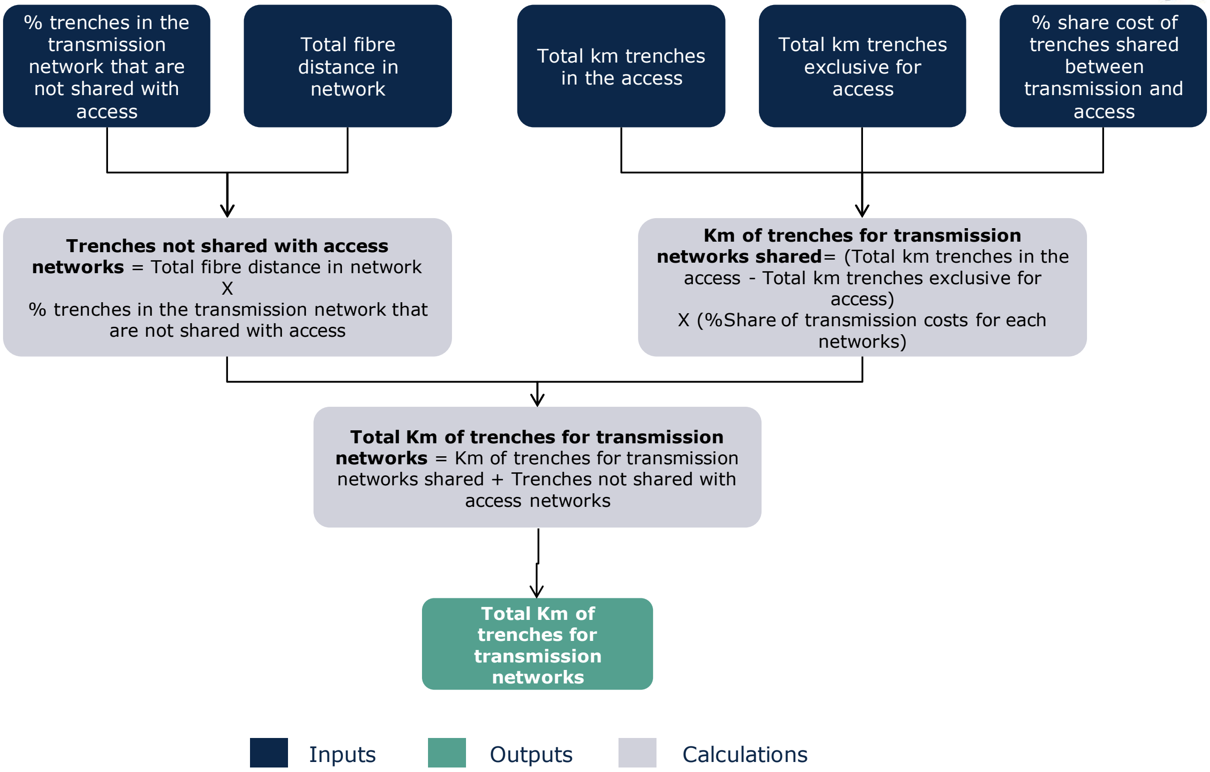

Exhibit 5.7: Algorithm for the transmission trenches calculation [Source: Axon Consulting]

Allocation of transmission elements into geotypes

The dimensioning of the core and transmission networks is performed independently from the geotype. Nevertheless, to obtain disaggregated costs, the results of the dimensioning must be distributed to the geotypes presented in section '4.5 - Aggregation of the results into geotypes'. In order to do so, two drivers[8] have been calculated for each network (L3 Access, Aggregation, Distribution and Core):

- **Traffic share per geotype**: allowing the allocation of the resources depending on the traffic as routers, cards, ports, etc.
- **Distance share per geotype**, to distribute the resources depending on distance as cables and trenches.

[8] These drivers have been extracted from the geographical analysis.

Therefore, the results are multiplied by those drivers in order to distribute the transmission resources in geotypes.

5.3. Access Network Dimensioning

The dimensioning of the access network is performed separately for each of the geotypes defined, to accurately reflect the impact of the geographical characteristics of Denmark in the deployment of access network elements. The dimensioning approach employed has been divided into three different blocks, namely:

- Copper Access Network Dimensioning
- Fibre Access Network Dimensioning
- Coax Access Network Dimensioning

5.3.1 Copper Access Network Dimensioning

The dimensioning algorithm for copper access networks is organized into four steps, as shown in the chart below:

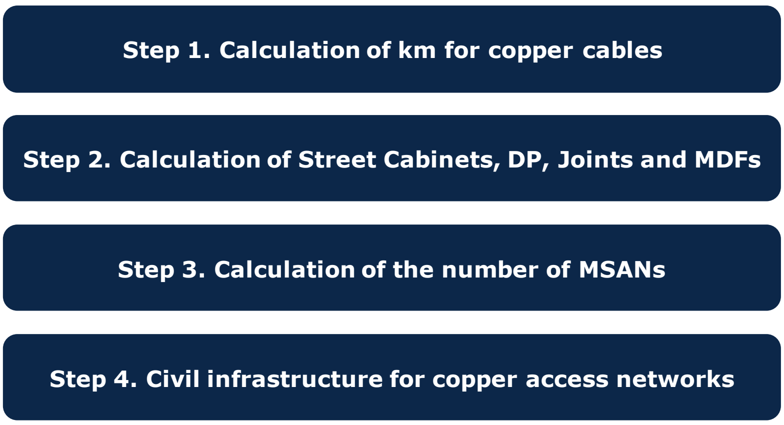

Exhibit 5.8: Steps followed for the dimensioning of copper network elements [Source: Axon Consulting]

The dimensioning algorithm for the copper access network is implemented in worksheet '5B DIM GEO' of the model for each one of the geotypes. The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of km for copper cables

The first step in the dimensioning of the Copper Access Network consists of the calculation of the number of cables required. As we mentioned in previous sections the Copper Access network is composed of three main types of cables:

- Final Drop Copper Cables
- Copper cables used between the FDP and MDF
- Fibre cables used between the MDF and CO

The number of such elements is calculated according to the algorithms outlined below:

Final Drop Copper Cables

The final drop cables are used in the copper network to connect the households to their assigned FDP. Therefore, the total length of drop cables is calculated following the algorithm below:

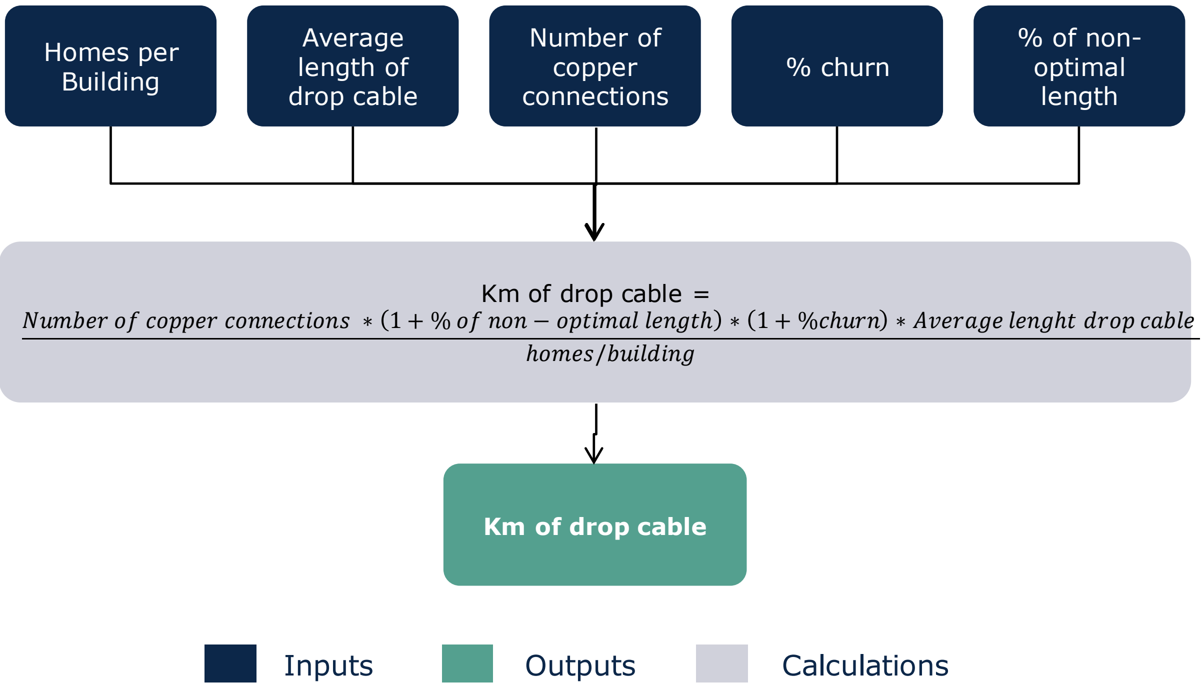

Exhibit 5.9: Algorithm for the calculation of the copper drop cables [Source: Axon Consulting]

Copper cables used between the FDP and MDF

The total copper cables used to connect from nodes FDP to MDF nodes and the percentage of each type of cable deployed have been calculated in section '4.4.1 - Copper Access Network'. Therefore, considering this information as input, the kilometres per type of cable have been determined as follows:

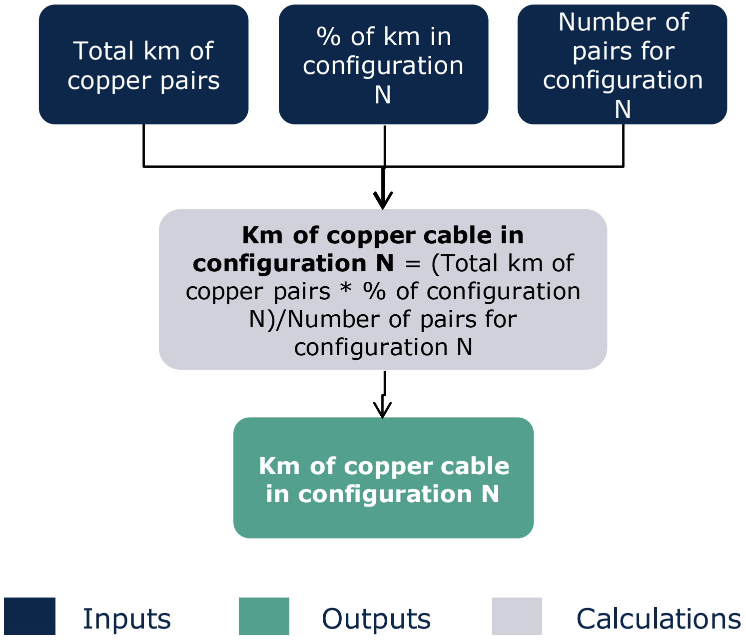

Exhibit 5.10: Algorithm for the calculation of the length of copper cables per configuration [Source: Axon Consulting]

The N configurations introduced in the model for copper cables are 4, 10, 20, 50, 100, 200, 400, 600, 800 pairs.

Fibre cables used between the MDF and CO

The total distance of fibre cable used to connect the MDFs to the COs in the Copper Access network have been determined in the geographical analysis. This cable has only one possible configuration (12 strands), and therefore the result from the geographical analysis is directly entered for this resource.

Step 2. Calculation of Street Cabinets, DPs, Joints and MDFs

The second step focuses on the calculation of the Street Cabinets, DPs, Joints and MDFs. The total number of these elements and the percentage of each of their configuration are known (extracted from the outputs of section '4.4.1 - Copper Access Network') and introduced in the Excel model.

The calculation flow is similar for all the elements modelized in this step. The following, exhibits present the algorithm implemented for the DPs:

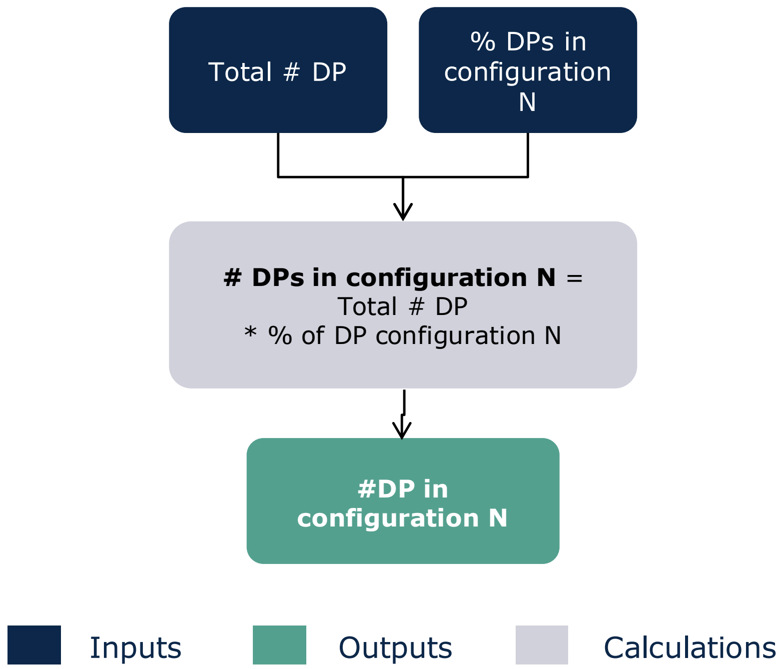

Exhibit 5.11: Algorithm to determine the number of copper DPs [Source: Axon Consulting]

The modelling of the MDFs, joints and Street Cabinets is equivalent to that of Distribution Points but considering their configurations. The available configurations for each element are presented in the table below:

DP configurations	SC configurations	Joints configurations	MDF configurations
Copper DP - 5 pairs	Copper SC - 192 subs.	Copper joint - 10 pairs	MDF - 250 subs.
Copper DP - 10 pairs	Copper SC - 384 subs.	Copper joint - 50 pairs	MDF - 500 subs.
Copper DP - 20 pairs		Copper joint - 100 pairs	MDF - 2000 subs.
Copper DP - 50 pairs		Copper joint - 300 pairs	MDF - 12000 subs.
Copper DP - 100 pairs			MDF - 48000 subs.
Copper DP - 500 pairs			
Copper DP - 1000 pairs			
Copper DP - 2000 pairs			

Exhibit 5.12: Configurations of Street Cabinets, DPs, Joints and MDFs [Source: Axon Consulting]

Step 3. Calculation of the number of MSANs

Once the previous elements are determined we proceed to calculate the number of MSANs required for the network. The model considers to main types of MSAN depending on their location:

- Local MSAN: located in the CO
- Remote MSAN: located in the street cabinets

Local MSANs

The local MSANs are placed in the CO to serve those home that is directly connected to the COs. The algorithm followed to calculate the number of local MSANs is outlined below:

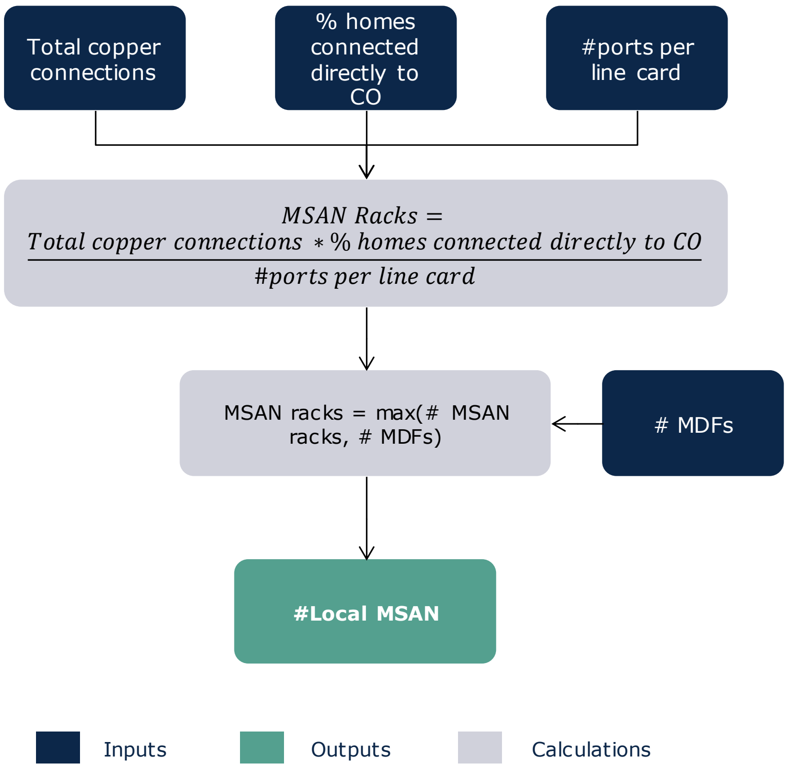

Exhibit 5.13: Algorithm for copper Local MSANs [Source: Axon Consulting]

Remote MSANs

The Remote MSANs are considered as the MSANs that are located in the Street Cabinets and are placed to serve all the homes that are not directly connected to COs. Therefore, the calculation performed to determine their number is the same as for local MSAN considering the number of homes not connected directly to the COs.

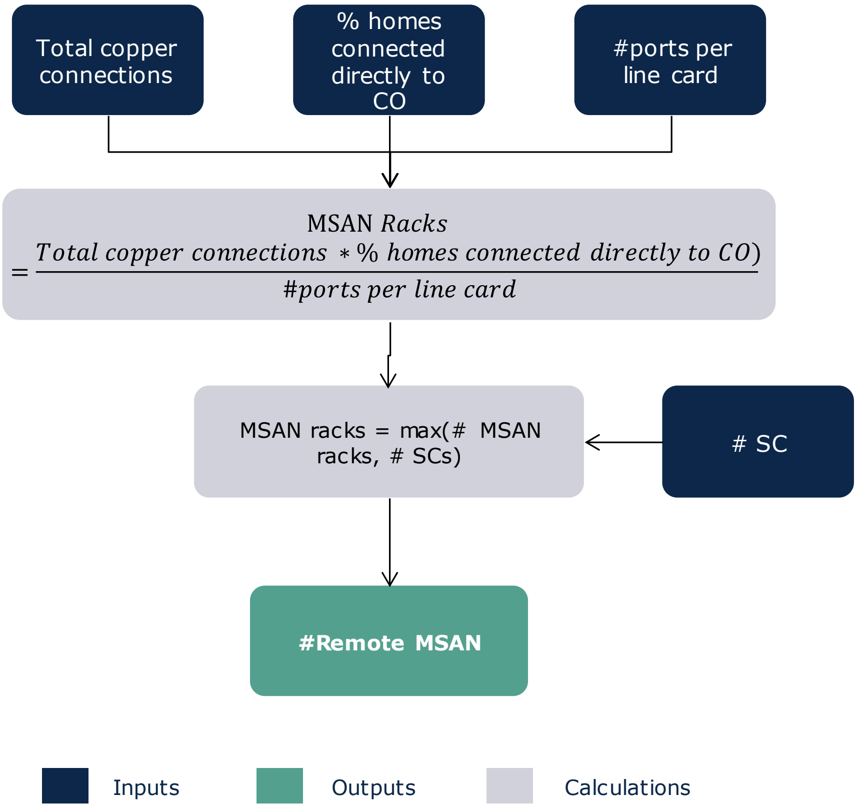

Exhibit 5.14: Algorithm for copper Local MSANs [Source: Axon Consulting]

Step 4. Civil infrastructure for copper access networks

The last step is related to the dimensioning of the civil infrastructure required for the copper access network. The civil infrastructure required for this technology consists of:

- Home-FDP trenches: these are the trenches dug for final drop cables
- FDP-MDF trenches: required for the buried copper cables used in this part of the network
- MDF-CO trenches: required for the buried fibre cables used in this part of the network
- Ducts
- Joint holes and Manholes

In the following sections, the calculations done in order to determine these elements are presented.

Home-FDP Trenches

The total km of trenches for the final drop cables are calculated using the following algorithm:

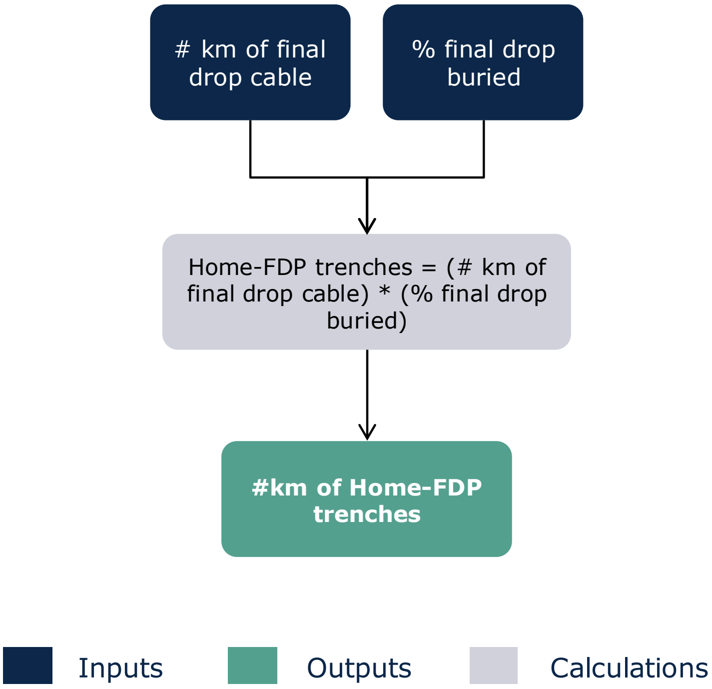

Exhibit 5.15: Calculation of Home-FDP trenches [Source: Axon Consulting]

FDP-MDF trenches

The geographical analysis allowed the calculation of the total trenches required for the copper access network. However, this total distance contemplates the hypothetical case where there was no sharing of these trenches, while the trenches are could be shared with other access technologies, the core network or even utility companies.

In this section we present the adjustments done in order to settle the number of km that are used exclusively for access networks, distinguishing the part that is shared with transmission and core networks.

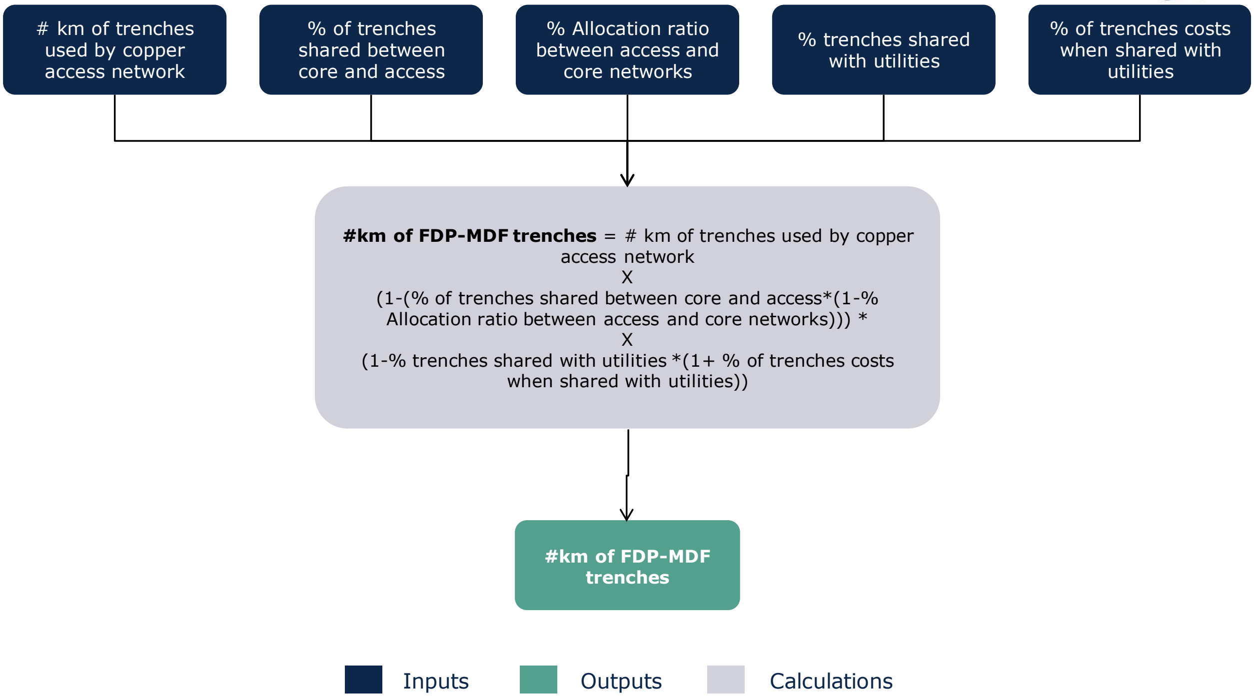

Exhibit 5.16: Calculation of FDP-MDF trenches [Source: Axon Consulting]

MDF-CO trenches

The geographical analysis allowed the calculation of the total trenches required for the MDF-CO connections for the copper access network. As for the FDP-MDF trenches, this part of the network can also be shared. In order to consider this sharing, the same algorithm as for FDP-MDF trenches has been followed.

Ducts

Part of the cables of the copper network is introduced in ducts. Hence, the calculation of km of ducts follows the algorithm below:

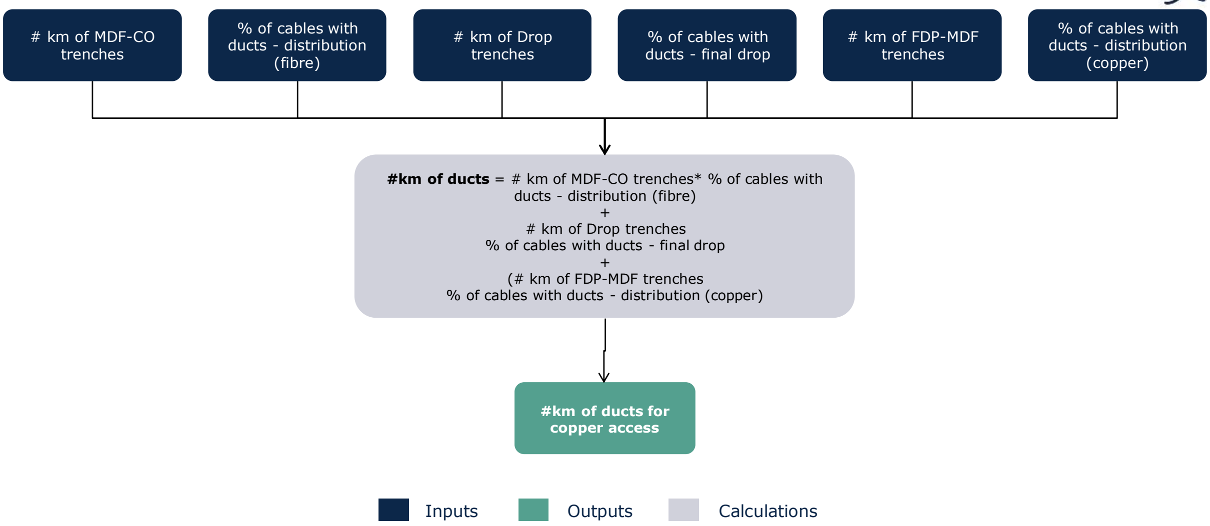

Exhibit 5.17: Calculation of km of ducts in the copper access network [Source: Axon Consulting]

Joint holes and Manholes

Finally, the number of Manholes and Joint holes is determined in the model. For that, the model considers the following:

- One manhole is installed in each DP
- One joint hole is installed in each joint

5.3.2 Fibre Access Network Dimensioning

The dimensioning algorithm for fibre access networks is organized into four steps, as shown in the chart below:

Step 1. Calculation of km for fibre cables

Step 2. Calculation of Splitter, DP, Joints and MDFs

Step 3. Calculation of the number of MSANs

Step 4. Civil infrastructure for fibre access networks

Exhibit 5.18: Steps followed for the dimensioning of fibre network elements [Source: Axon Consulting]

The dimensioning algorithm for the fibre access network is implemented in the worksheet '5B DIM GEO' of the model for each one of the geotype. The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of km for fibre cables

The first step in the dimensioning of the Fibre Access Network consists of the calculation of the number of cables required. As we mentioned in previous sections the Fibre Access network is composed of two main types of cables:

- Final Drop Fibre Cables
- Fibre cables used between the FDP and CO

The number of such elements is calculated according to the algorithms outlined below.

Final Drop Fibre Cables

The final drop cables are used in the fibre network to connect the households to their assigned FDP. Therefore, the total length of drop cables is calculated following the algorithm below:

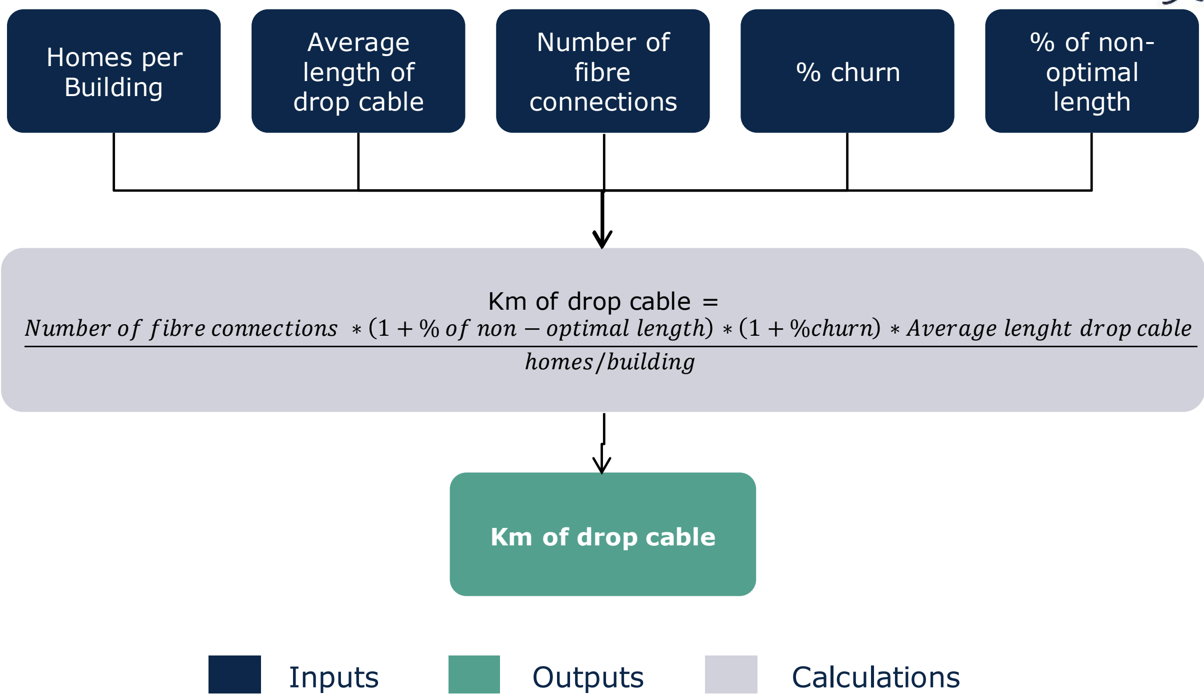

Exhibit 5.19: Calculation of km of fibre drop cable [Source: Axon Consulting]

Fibre cables used between the FDP and CO

The total fibre cables used to connect from nodes FDP to CO nodes have been calculated in section '4.4.2 - Fibre Access Network', along with the percentage of each configuration of cable deployed. Therefore, considering this information as input, the kilometres per type of cable have been determined as follows:

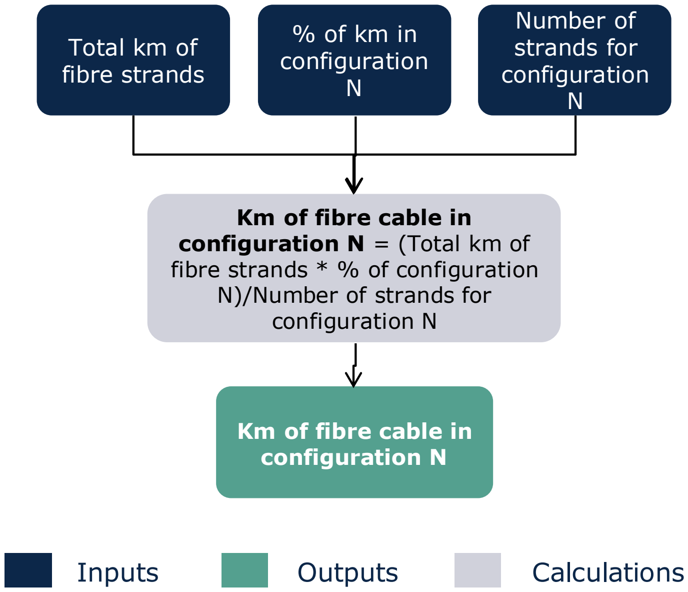

Exhibit 5.20: Calculation of km of fibre cable [Source: Axon Consulting]

The N configurations for fibre cables introduced in the model are: 2, 12, 24, 48, 96, 192 strands.

Step 2. Calculation of Fibre splitters, DPs, Joints, and ODFs

The second step focuses on the calculation of the Fibre splitters, DPs, Joints, and ODFs. The total number of these elements and the percentage of each of their configurations are known (extracted from the outputs of section '4.4.2 - Fibre Access Network') and introduced in the Excel model.

The calculation flow is similar for all the elements modelized in this step. The following, exhibits present the algorithm implemented for the DPs:

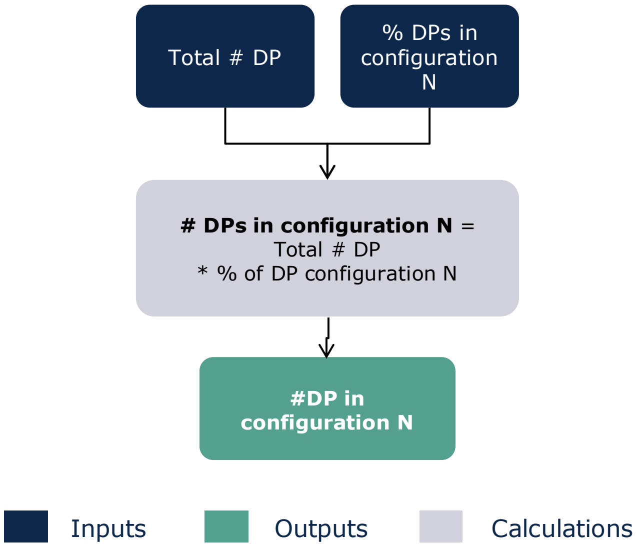

Exhibit 5.21: Calculation of fibre DPs [Source: Axon Consulting]

The modelling of the Fibre splitters, ODFs and joints is equivalent to Distribution Points but considering their configurations. The available configurations for each element are presented in the table below:

DP configurations	Fibre Splitters	Joints configurations	MDF configurations
Fibre PDP - out 48 strands	Fibre splitter (1:32)	Fibre joint - 4 strands	ODF - 500 lines
Fibre PDP - out 192 strands		Fibre joint - 12 strands	ODF - 1000 lines
Fibre PDP - out 576 strands		Fibre joint - 24 strands	ODF - 2000 lines
Fibre PDP - out 1152 strands		Fibre joint - 48 strands	ODF - 5000 lines
			ODF - 10000 lines
			ODF - 20000 lines

Exhibit 5.22: Configurations of Fibre splitters, DPs, Joints and ODFs [Source: Axon Consulting]

Step 3. Calculation of the number of MSANs and OLTs

Once the previous elements are determined we proceed to calculate the number of MSANs required for the network. The model considers to main types of MSAN depending on their location:

- OLT: Used for the PON architecture
- PTP MSAN: Used for the point-to-point architecture

PON OLT

The number of PON OLTs can be determined based on two factors:

- Coverage: The geographical analysis performed in section determines the number of OLTs required for the actual coverage of the network
- Demand: the number of OLTs required in order to attend the fibre services demand (active fibre connections). This number is calculated in the Excel model.

Once both numbers are calculated, the highest number of both will be chosen.

Therefore, to determine the final number of OLTs, two main steps have been followed:

1. The first step involved the calculation of the number of cards required in the network attending to the demand and to coverage. The algorithm used is presented below:

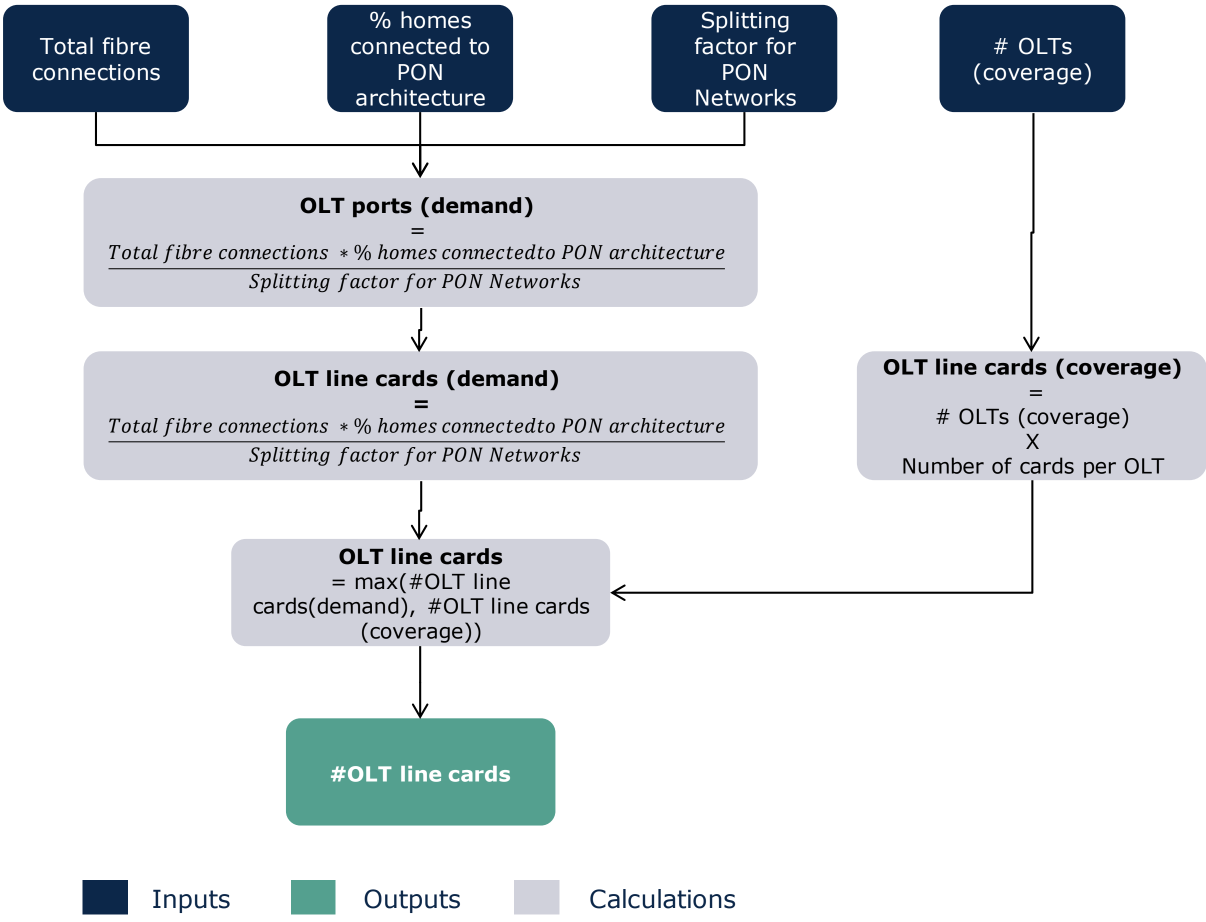

Exhibit 5.23: Calculation of OLT line cards [Source: Axon Consulting]

2. Given the number of OLT line cards required in the network, the second step proceeded to the calculation of the number of OLTs needed to handle these line cards.

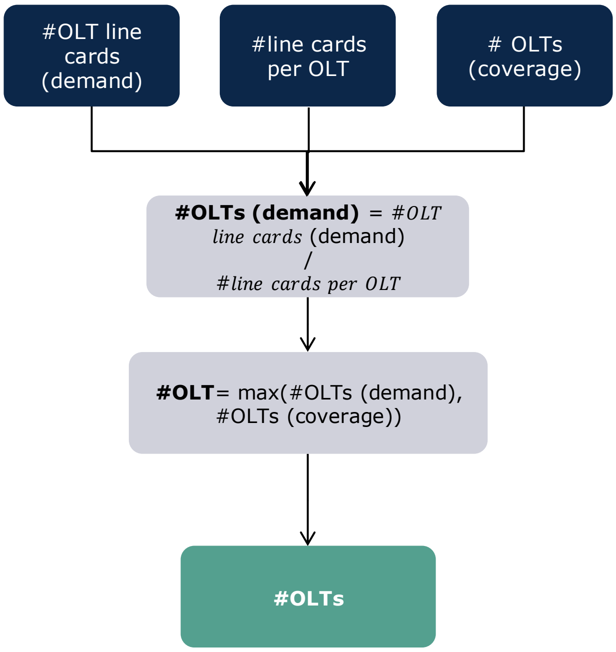

Exhibit 5.24: Calculation of number of OLTs [Source: Axon Consulting]

PTP MSANs

For the PTP MSAN the exact same calculation flow has been considered considering the percentage of fibre connections connected through PTP architecture.

Step 4. Civil infrastructure for fibre access networks

The last step is related to the dimensioning of the civil infrastructure required for the fibre access network. The civil infrastructure required for this technology consists of:

- Home-FDP Trenches: these are the trenches dug for final drop cables
- FDP-SDP trenches: required for the buried fibre cables used in this part of the network
- SDP-CO trenches: required for the buried fibre cables used in this part of the network
- Ducts
- Joint holes and Manholes

In the following sections, the calculations done in order to determine these elements are presented.

Home-FDP Trenches

The total km of trenches for the final drop cables are calculated using the following algorithm:

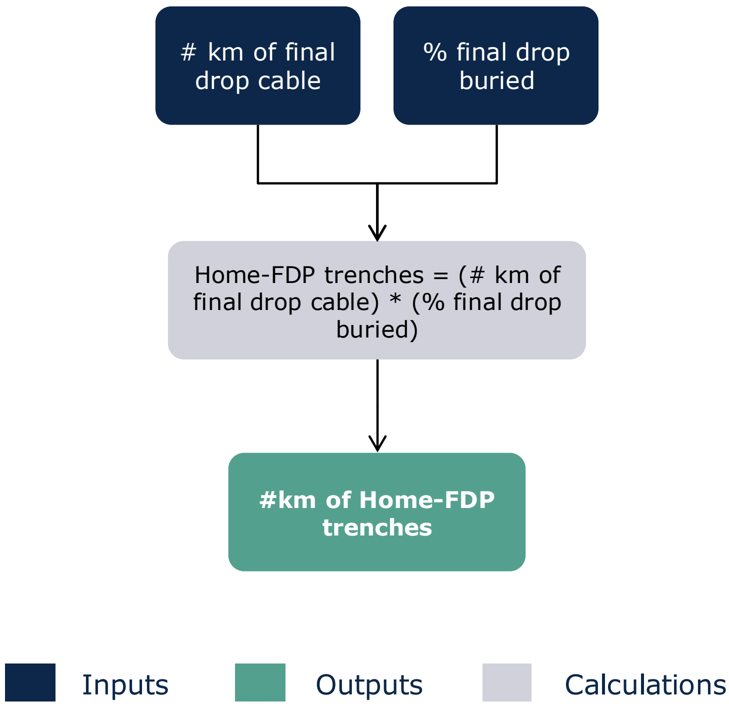

Exhibit 5.25: Calculation of Home-FDP Trenches [Source: Axon Consulting]

FDP-SDP trenches

The geographical analysis allowed the calculation of the total trenches required for the fibre access network. However, this total distance contemplates the hypothetical case where there was no sharing of these trenches, while the trenches are could be shared with other access technologies, the core network or even utility companies.

In this section we present the adjustments done in order to settle the number of km that are used exclusively for access networks, distinguishing the part that is shared with transmission and core networks.

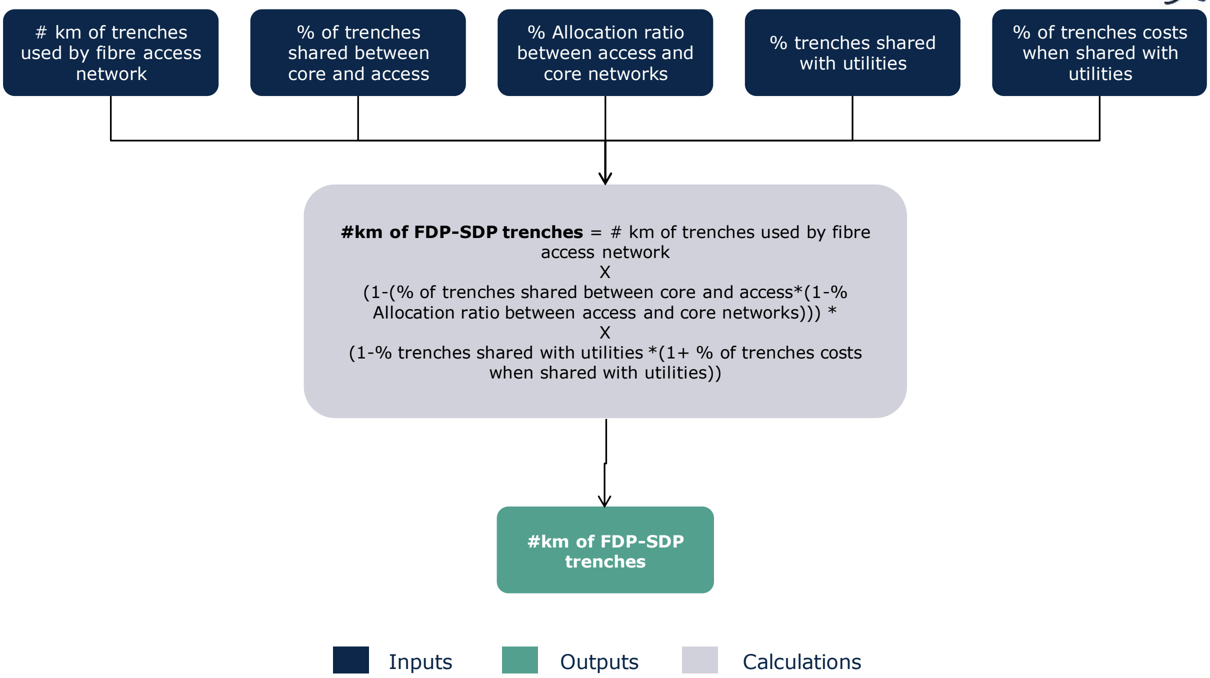

Exhibit 5.26: Calculation of FDP-SDP Trenches [Source: Axon Consulting]

SDP-CO trenches

The geographical analysis allowed the calculation of the total trenches required for the SDP-CO connections for the fibre access network. As for the FDP-SDP trenches, this part of the network can also be shared. In order to consider this sharing, the same algorithm as for FDP-SDP trenches has been followed.

Ducts

The calculation of km of ducts follows the algorithm below:

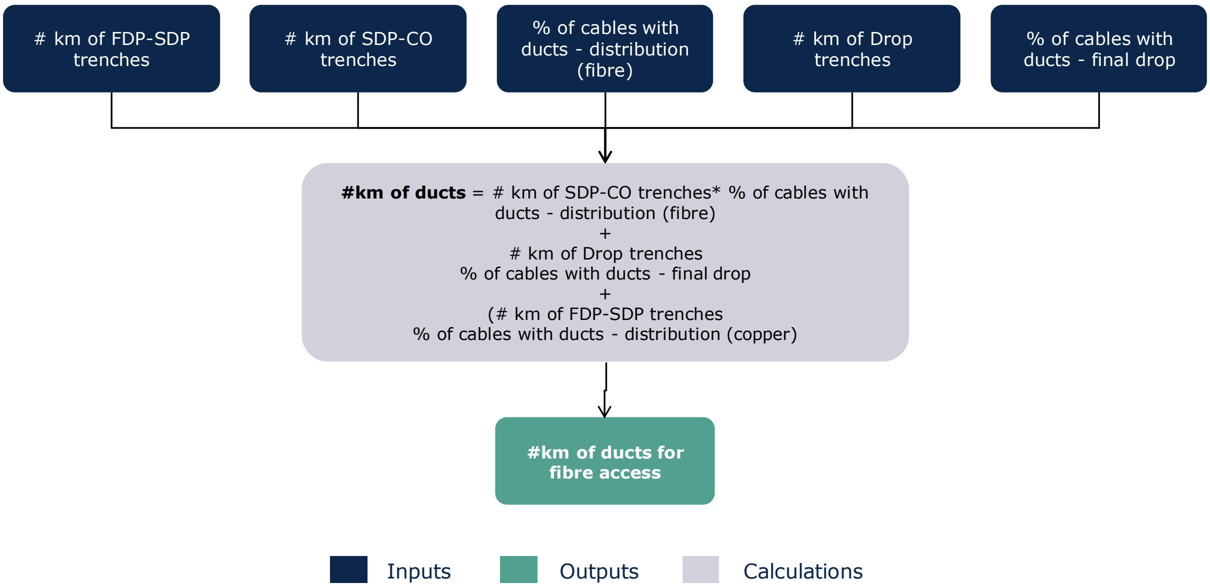

Exhibit 5.27: Calculation of Ducts [Source: Axon Consulting]

Joint holes and Manholes

Finally, the number of Manholes and Joint holes is determined in the model. For that, the model considers the following:

- One manhole is installed in each DP
- One joint hole is installed in each joint

5.3.3 Coax Access Network Dimensioning

The dimensioning algorithm for coax access networks is organized into four steps, as shown in the chart below:

Step 1. Calculation of km for coax cables

Step 2. Calculation of active equipment

Step 3. Civil infrastructure for coax access networks

Exhibit 5.28: Steps followed for the dimensioning of coax network elements [Source: Axon Consulting]

The dimensioning algorithm for the coax access network is implemented in the worksheet '5B DIM GEO' of the model for each one of the geotype. The following subsections provide further detail about each specific step of the algorithm.

Step 1. Calculation of km for coax cables

The first step in the dimensioning of the coax Access Network consists of the calculation of the number of cables required. As we mentioned in previous sections the Coax Access network is composed of three main types of cables:

- Final Drop Coax Cables
- Coax cables used for distribution (TAP-CMC)
- Fibre cables used between the CMC and CO

The number of such elements is calculated according to the algorithms outlined below:

Final Drop Coax Cables

The final drop cables are used in the coax network to connect the households to their assigned TAP. Therefore, the total length of drop cables is calculated following the algorithm below:

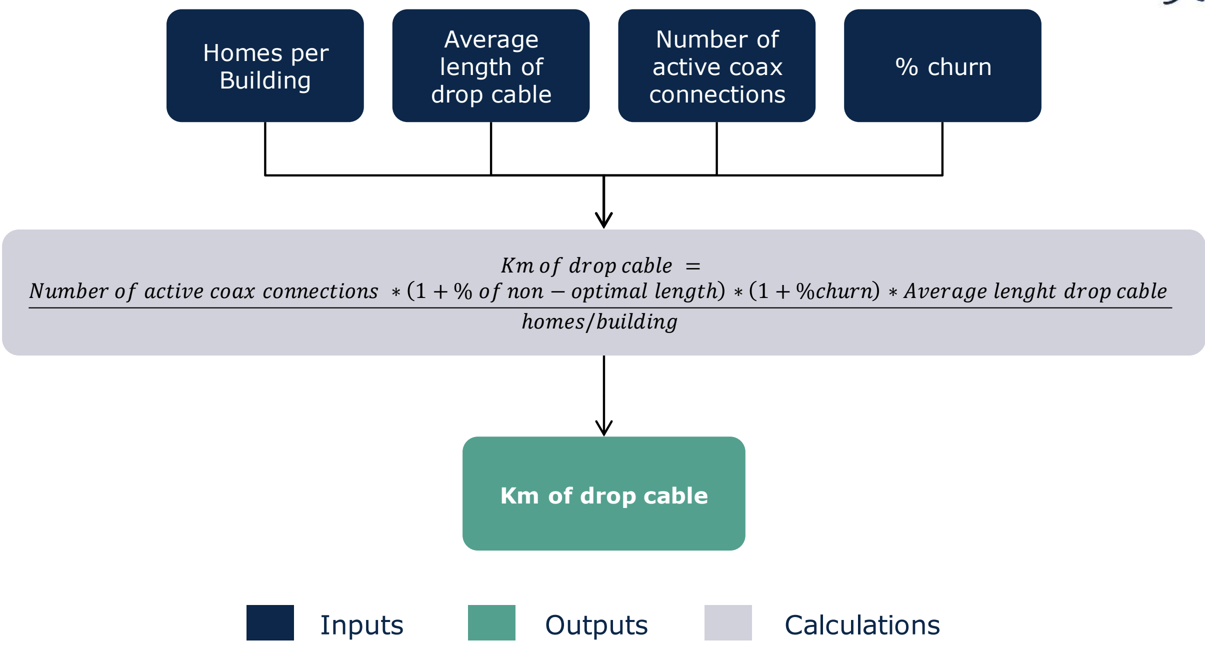

Exhibit 5.29: Calculation of km of coax final drop cable [Source: Axon Consulting]

Coax cables used for distribution (TAP-CMC)

The total coax cables used to connect TAP nodes to CMC nodes have been calculated in section '4.4.3 - Coax Access Network'. As there is only one type of coax cables used for this section of the network, this number has been attributed fully to the resource of "Coax cables used for distribution (TAP-CMC)".

Fibre cables used between the CMC and CO

The total distance of fibre cable used to connect the CMCs to the COs in the Coax Access network have been determined in the geographical analysis. This cable has only one possible configuration (12 strands), and therefore the result from the geographical analysis is directly entered for this resource.

Step 2. Calculation of active equipment

The second step focused on the calculation of the active equipment required for the coax access network. The active equipment dimensioned is:

- Coaxial amplifier
- Splitters

- TAP, CMC, OLT
- Cabinets

Coaxial amplifier

The coaxial amplifiers are used to boost/amplify the coax signal in order to improve the quality of service for end-users.

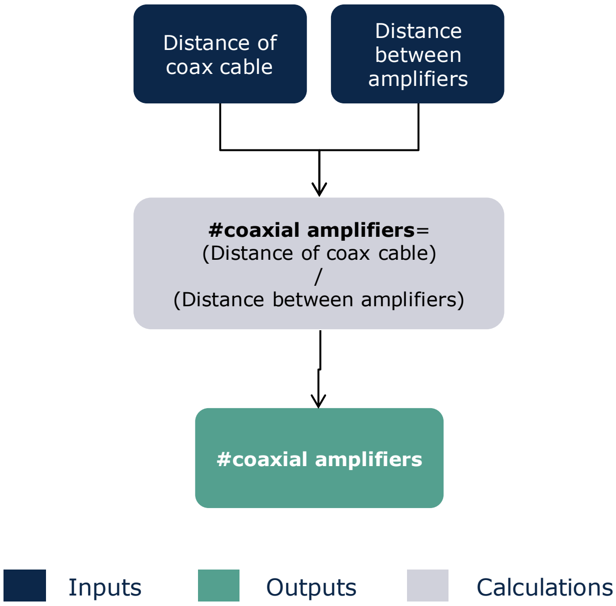

Exhibit 5.30: Calculation of number of Coaxial Amplifiers [Source: Axon Consulting]

Splitters, TAP, CMC and OLT

The number of splitters, TAPs, CMCs and OLTs has been determined in section '4.4.3 - Coax Access Network', and the results are introduced in the Excel model for the respective resources.

Cabinets

The model includes two types of cabinets (small and large). The small cabinets are used for the Coaxial amplifiers whilst the Large ones are installed for the CMC. Therefore, the calculation of these elements follows the algorithm below:

- A small cabinet is installed for each Coaxial Amplifier and Coaxial DP
- A large cabinet is installed for each CMC

Step 3. Civil infrastructure for coax access networks

The last step is related to the dimensioning of the civil infrastructure required for the coax access network. The civil infrastructure required for this technology consists of:

- Home-TAP trenches: these are the trenches dug for final drop cables
- TAP-CMC trenches: required for the buried coax cables used in this part of the network
- CMC-CO trenches: required for the buried fibre cables used in this part of the network
- Ducts
- Joint holes and Manholes

In the following sections, the calculations done in order to determine these elements are presented.

Home-TAP Trenches

The total km of trenches for the final drop cables are calculated using the following algorithm:

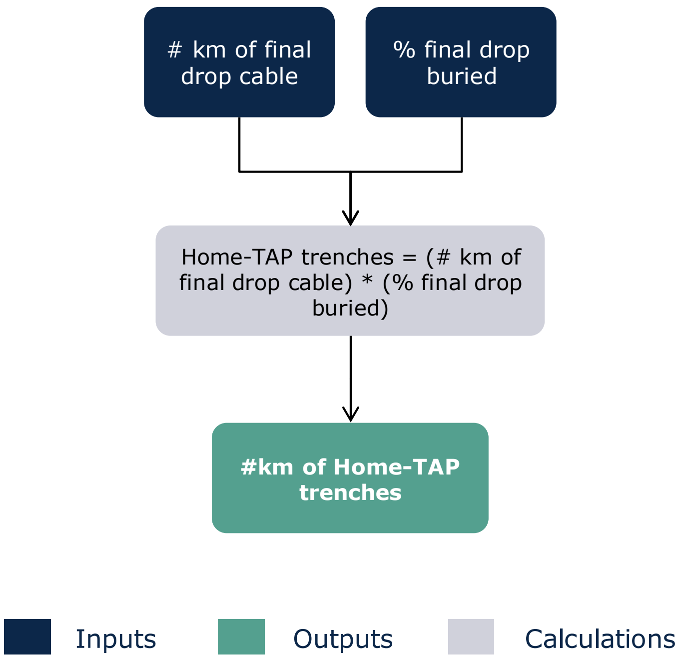

Exhibit 5.31: Calculation of Home-TAP Trenches [Source: Axon Consulting]

TAP-CMC trenches

The geographical analysis allowed the calculation of the total trenches required for the coax access network. However, this total distance contemplates the hypothetical case where there was no sharing of these trenches, while the trenches are could be shared with other access technologies, the core network or even utility companies.

In this section we present the adjustments done in order to settle the number of km that are used exclusively for access networks, distinguishing the part that is shared with transmission and core networks.

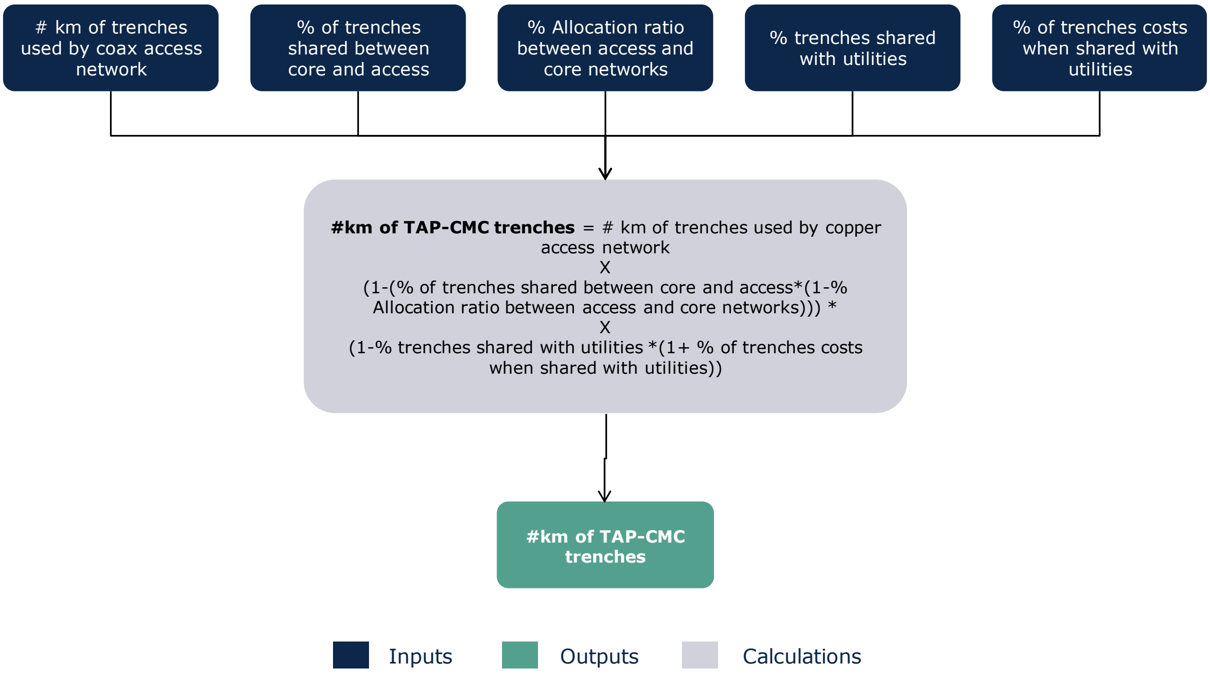

Exhibit 5.32: Calculation of TAP-CMC trenches [Source: Axon Consulting]

CMC-CO trenches

The geographical analysis allowed the calculation of the total trenches required for the CMC-CO connections for the coax access network. As for the TAP-CMC trenches, this part of the network can also be shared. In order to consider this sharing, the same process as for TAP-CMC trenches has been followed.

Ducts

Part of the cables of the coax network is introduced in ducts. Hence, the calculation of km of ducts follows the algorithm below:

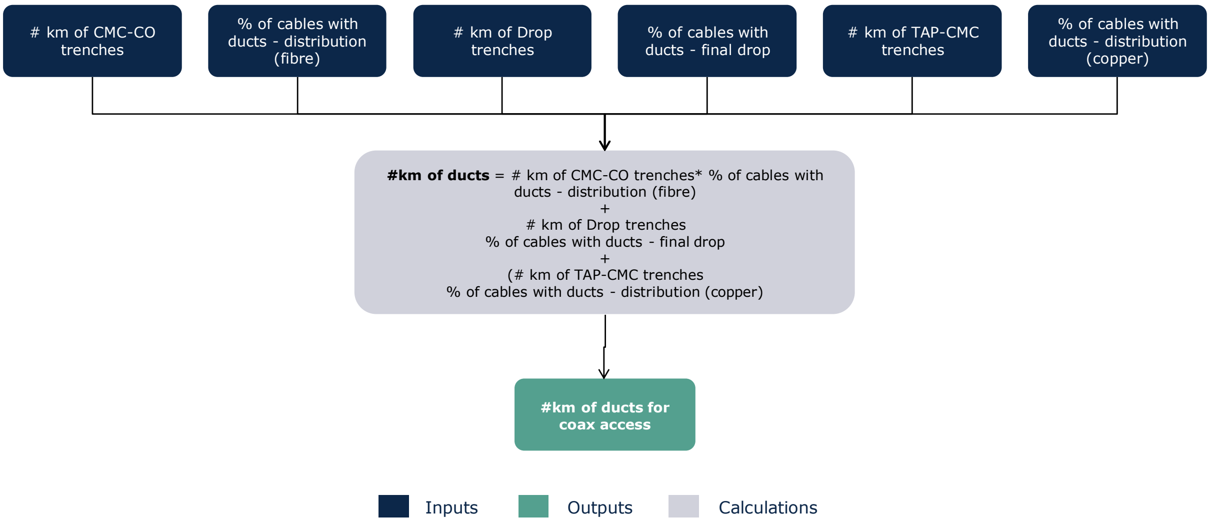

Exhibit 5.33: Calculation of ducts for the coax access network [Source: Axon Consulting]

Joint holes and Manholes

Finally, the number of Manholes and Joints holes is determined in the model. For that, the model considers the following:

- One manhole is installed in each Coaxial amplifier and Splitter
- One joint hole is installed in each TAP

6. Resources costing

Once the model has calculated the number of resources needed to accommodate the demand and coverage levels in the network, the next step is the calculation of the costs of the network. This calculation is performed separately for CapEx and OpEx on a nation-wide aggregated level.

The procedure to assess network costs is presented in the following sections

- Calculation of network costs
- Calculation of non-network costs

6.1. Calculation of network costs

Two main steps are followed to calculate total network annual costs (including both CapEx and OpEx):

Step 1. Determination of unit costs throughout the modelling period

Step 2. Calculation of annual network costs

Exhibit 6.1: Resources Costing [Source: Axon Consulting]

The following sections explain each step in detail.

Step 1: Determination of unit costs throughout the modelling period

The definition of the unit costs is performed separately for CapEx and OpEx components.

Notably, for the definition of the CapEx unit costs of the resources considered in the model, the following formula is considered:

$$Unit\ CapEx_i\ (n) = Unit\ CapEx_{2018}\ (n) * (1 + t\ (n))^{(i-2018)}$$

Where:

- **Unit ÇapEx$_i$ (n)**: Represents the cost of installing and acquiring a unit of network element “n” in the year “i”. The figure included for the reference year (2018) is input in the model based on the process

- **t (n)**: For each resource, a cost trend can be introduced, outlining the expected evolution of its prices in the future period.

Meanwhile, for the determination of the unit costs of the resources considered in the model the following formula is considered:

$$Unit\ OpEx_i\ (n) = Unit\ OpEx_{2018}(n) \cdot CPI_i \cdot\ ((1 - m\ (n)) + \frac{m\ (n)}{PI_i})$$

Where:

- **Unit OpEx$_i$ (n)**: Represents the cost of operating and maintaining a unit of network element "n" in year "i". The figure included for the reference year (2018) is input in the model based on the process
- **CPI$_i$:** Represents the index of inflation in Denmark for the year "i" referenced to 2018.
- **m (n):** Represents the percentage of unit OpEx that is related to man-work for network element "m".
- **PI$_i$:** Represents the productivity index, used to evaluate the improvement in the amount of man-work that can be done in the same time in year "i" compared to 2018.

The definition of each of these inputs is presented detailed in section '3.2 - Asset costs' of this document.

Step 2. Calculation of annual network costs

Once the unit costs for each resource and year are determined, the calculation of annual costs is calculated.

The calculation of annual costs relies on the use of a given methodology to depreciate capital costs. The model defines two alternatives:

- Tilted annuities
- Economic depreciation

The implementation followed in the model to calculate total annual costs (considering both, CapEx and OpEx) is presented below.

Tilted annuities

The tilted annuities approach aims to adapt the profile of cost recovery with the objective of recognizing fluctuations in asset prices. For example, in case prices of assets decrease, a new market entrant could have a great advantage over existing operators because it will benefit from better prices and therefore lower depreciation costs. Following this tilted annuity approach, when prices decrease, a higher proportion of the asset is recovered during the initial periods so the same cost will be recognized for both market participants, not taking into account the time when they entered the market.

The formula used in the model to obtain the annualized capital-related expenses is presented below:

$$A_t = I \times \frac{(\omega - p) \times (1 + p)^t}{1 - \left(\frac{1 + p}{1 + \omega}\right)^n}$$

Where ω is the cost of capital, I the investment, t the year considered, n the asset life, p the tilt (price trend of the asset in the long term) and A_t the annuity of year t[9].This formula is derived by the same equation as the one provided at the beginning of this section[10] but with the following relationship between each annuity:

$$A_t = A_{t-1} \times (1 + p)$$

Which means that annuities are evolving with asset prices.

In this case, annual OpEx is considered separately, following a P·Q approach based on the unit costs of the resources calculated in Step 1 and the number of resources outputted from the dimensioning algorithms.

---

[9] This annuity is calculated by assuming that the first annual cost recovery is occurring one year after the investment is made. If the time between the moment the first annuity happens, and the investment is paid is one year lower (respectively one year higher), then the annuity should be multiplied by a $(1 + \omega)^{-1}$ (respectively $((1 + \omega))$.

[10] $I = \sum_{i=1}^{n} \frac{A_i}{(1+\omega)^i}$

Economic depreciation

The objective of economic depreciation is to adjust the recovery of the asset value to the economic value it produces.

In particular, economic depreciation adjusts the annuities of the investment by means of a production factor, defined by the performance that is extracted from the asset. For instance, if an asset is expected to be used more exhaustively in the future (e. g. due to an increase in adoption), the application of the economic depreciation results in higher annuities in the future than in the present (and relatively constant unitary costs).

Particularly, the formula used in the calculation for the economic depreciation is as follows:

$$A_t = O_t \times p_t \times \frac{\sum_{j=1}^{n}(1+\omega)^{j} \times I_j}{\sum_{j=1}^{n}(1+\omega)^{j} \times O_j \times p_j}$$

Where,

- A_t represents the annual cost
- O_t is the production factor of the asset in year t
- p_t is the reference price of the asset in year t
- ω represents the cost of capital
- I_j represents the yearly investment, calculated as the number of assets purchased in year j multiplied by their unit price in that year. This figure shall accrue the OpEx that would be incurred in order to operate and maintain the asset throughout its lifetime.
- N represents the last year in which an asset is used in the network.

As extracted from above, in the case that economic depreciation is considered, OpEx is not treated separately.

6.2. Calculation of non-network costs

The model also considers the costs not related to the network. This type of cost is included in the model as a mark-up over total network costs (considering, both, CapEx and OpEx). The figures have been calculated based on data from the modelled operator. Notably, the total network costs have been extracted from the Accounting Separation results, as the sum of depreciation and OpEx of all products, excluding those related to voice and mobile and excluding support/overhead (non-network) expenditures.

There are 4 different mark-ups depending on the nature of the costs:

- **G&A mark-up**: this mark-up represents the costs of general and administrative activities. This mark-up has been calculated using the following formula:

$$\% \, G\&A \, mark-up = \frac{Support \, and \, overheads \, costs \, (relevant \, for \, LRAIC \, model)}{Total \, network \, costs (relevant \, for \, LRAIC \, model)}$$

  Where the total support and overhead costs have been extracted from the Accounting Separation results of the modelled operator for the products relevant for the LRAIC model.

- **IT mark-up**: additional costs incurred by operators due to IT platforms. This mark-up has been calculated using the following formula:

$$\% \, IT \, Platforms \;\; mark-up = \frac{IT \, platform \, costs \, (relevant \, for \, LRAIC \, model)}{Total \, network \, costs (relevant \, for \, LRAIC \, model)}$$

  Where the IT platform costs have been extracted from data reported by the modelled operator for the Columbus IT System that handles customers, orders, agreements, provisioning and pricing.

- **Wholesale and commercial mark-up**: additional costs incurred by operators due to specific wholesale and commercial costs. This mark-up has been calculated based on the cost accounts of the modelled operator using the following formula:

$$\% \, Wholesale \, mark-up = \frac{Wholesale \, and \, commercial \, costs \, (relevant \, for \, LRAIC \, model)}{Total \, network \, costs (relevant \, for \, LRAIC \, model)}$$

  Where the wholesale and commercial costs have been extracted from data reported by the modelled operator specifically for this purpose.

- **Working capital mark-up**: referring to the costs of maintaining daily operations at an organization.

$$\% \, Working \, capital \, mark-up = \frac{Working \, capital}{Total \, network \, costs (relevant \, for \, LRAIC \, model)}$$

  This figure is set as zero in the cost model as no information has been made available for its assessment.

7. Network costs of the services

This section presents the methodology followed to calculate the incremental and common costs of the resources, and how these costs will be allocated to the services in order to obtain unit costs under the LRAIC standard.

7.1. Incremental and common costs calculation

The incremental cost associated with each increment is the reduction in the costs calculated by the model due to ceasing the provision of the services included in that increment. This cost is expressed mathematically as the difference between the cost of total demand and the cost obtained when the level of demand for the services included in the increment is set to zero, leaving all others unchanged:

$$INCREMENTAL\ COST(increment1) = F(v1, v2, v3, vN, C) - F(0, v2, v3, vN, C)$$

Where F is the formula that represents the LRAIC model (which calculates the cost according to demand and coverage), vi represents the demand volume of increment *i*, and *C* represents the coverage.

To calculate the incremental costs, increments are defined as groups of services. Therefore, services have to be assigned to increments. In the model (sheet '0F PAR OTHER'), one increment has been defined, related to the Demand of all the services modelled.

Once incremental costs are calculated for this increment, as described previously, common costs by the resource are obtained as the difference between the total cost base obtained under Fully Allocated Costs standard (considering all the demand) and the incremental costs. The following formula shows this calculation:

$$\begin{aligned} COMMON\ COST = {} & TOTAL\ COSTS\ (Fully\ Allocated\ Costs) \\ & - INCREMENTAL\ COST(Demand\ increment) \end{aligned}$$

In the model, resources' incremental and common costs are calculated in sheet '6E RES INCR-COM COST'.

The following section presents the methodology employed for the allocation of resources' costs to services in the model.

7.2. Allocation of network costs to services

Incremental costs are allocated to services using Routing Factors. This methodology allocates costs to services based on the use made of each equipment. The Routing Factor is a measure of how many times a resource is used by a specific service during its provision. Once annual costs incurred per resource are available, these have to be distributed to the final services.

The allocation of network costs is performed at geotype level. This is done to ensure causality in the allocation of the costs, given that demand and costs for each geotype follow different patterns.

The steps followed in the allocation process are depicted below:

- Step 1: Mapping of services and resources
- Step 2. Calculation of demand for the three allocation criteria
- Step 3: Cost Allocation to Services

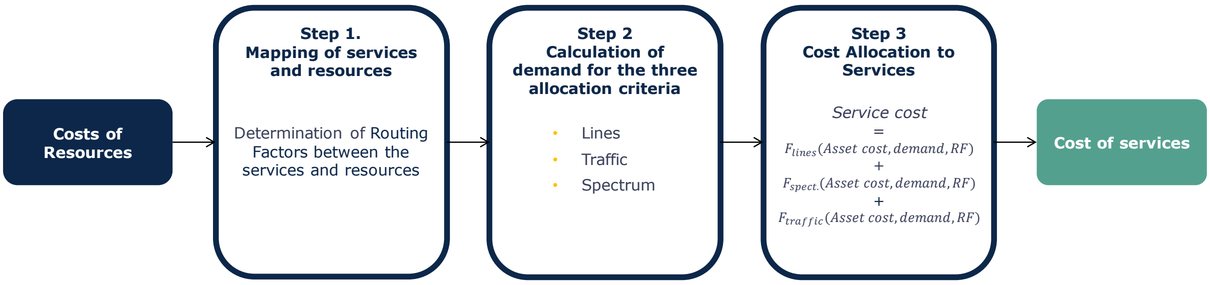

Exhibit 7.1: Cost imputation process using Routing Factors [Source: Axon Consulting]

As common costs are allocated to services based on an Effective Capacity approach, this approach is followed to allocate both incremental and common costs to services.

7.2.1 Step 1: Mapping of services and resources

Resources' costs have to be allocated to the services proportionally to the amount of lines/traffic/spectrum they generate/use and to a "factor of use", the Routing Factor. Hence, the more lines/traffic/spectrum a service generates/uses, the higher the cost will be allocated to it from the asset considered.

The excerpt below illustrates some relationships between resource and services, together with the applicable routing factor:

Service	Access fibre.Fibre drop cable.length	Access fibre.Fibre cable - 2 strands (SDP-User).length	Access fibre.Fibre cable - 12 strands (SDP-User).length	Access fibre.Fibre cable - 24 strands (SDP-User).length	Access fibre.Fibre cable - 48 strands (SDP-User).length	Access fibre.Fibre cable - 96 strands (SDP-User).length	Access fibre.Fibre cable - 192 strands (SDP-User).length
Access.Fibre.Retail.Access	1	1	1	1	1	1	1
Access.Fibre.Wholesale.Raw access (POI0)	1	1	1	1	1	1	1
Access.Fibre.Wholesale.Raw access (POI1)	1	1	1	1	1	1	1
Access.Fibre.Wholesale.VULA access (POI1)	1	1	1	1	1	1	1
Access.Fibre.Wholesale.BSA Access (POI2/POI3	1	1	1	1	1	1	1

Exhibit 7.2: Illustrative extract of the routing factors defined between services and resources (Sheet '3C MAT ROUTING FACTORS') [Source: Axon Consulting]

7.2.2 Step 2. Calculation of demand for the three allocation criteria

The cost imputation process is done depending on the resources' nature. Notably, the resources introduced in the model can be divided into three main groups based on the driver shaping the allocation of its cost:

- **Lines**, these are network elements that rely on the number of lines of the service to allocate the proper amount of costs. These include, for instance, all passive elements in the access network.
- **Traffic,** these are network elements that rely on the volume of traffic of the service to allocate the proper amount of costs. These include, for instance, the ports in the routers in the transmission network.
- **Spectrum**, these are network elements that rely on the spectrum (in MHz) used by the service to allocate the proper amount of costs. The elements needing this allocation methodology are in the coax access network, where some elements allocate the spectrum to TV or broadband services.

Based on these three criteria, to perform an accurate allocation of the services, the demand of the services has to be transformed into these three main groups. To perform this transformation, the demand of the services introduced in the model is multiplied by a series of factors or weights depending on the relevant allocation driver.

7.2.3 Step 3: Cost Allocation to Services

Once the relationship of each service to each resource has been performed (Step 1) and ensured that the demand allocation driver is properly analysed in the relevant unit (Step 2), it is possible to distribute all costs to all services.

This step is performed separately for each of the allocation criteria presented in Step 2 and for each geotype independently. The basic relation is the following:

$$\begin{aligned} Service\ cost(i, year) &= \sum_n \frac{Cost_{lines}(n, year) \cdot Demand_{lines}(i, year) \cdot RF(i,n)}{\sum_i Demand_{lines}(i, year) \cdot RF(i,n)} \\ &+ \sum_n \frac{Cost_{traffic}(n, year) \cdot Demand_{traffic}(i, year) \cdot RF(i,n)}{\sum_i Demand_{traffic}(i, year) \cdot RF(i,n)} \\ &+ \sum_n \frac{Cost_{spectrum}(n, year) \cdot Demand_{spectrum}(i, year) \cdot RF(i,n)}{\sum_i Demand_{spectrum}(i, year) \cdot RF(i,n)} + \end{aligned}$$

Where:

- Service cost (i, year) is the cost of service "i" in a given year
- Cost (n, year) is the cost of resource "n" in a given year. Assets are separated based on their specific rule for allocation (demand, traffic and spectrum).
- Demand (i, year) is the demand of the service "i" in the selected year. As for assets, the demand considered depends on the allocation rule of the associated asset.
- RF (i, n) is the Routing Factor that relates the resource "n" with service "i".

The allocation of resources' cost to services is presented in the sheet ` 7C GEO SERV COSTS ´ and where the formula used allows the implementation of steps described under this section.

It should be noted that common and joint network costs are also allocated to services based on this methodology, aligned with the "effective capacity" approach defined in the MRP. Meanwhile, non-network overheads are allocated to services based on an equi-proportional mark-up (EPMU) approach, on top of total network costs.

Annex A. List of acronyms

BEREC	Body of European Regulators for Electronic Communications
BSA	Bitstream Access
BU	Bottom-Up
BU-LRAIC	Bottom-up Long-run Average Incremental Costs
CAPEX	Capital expenditure
CMC	Coaxial Media Converter
CO	Central Office
CSV	Comma-separated values
DBA	Danish Business Authority
DKK	Danish Krone
DP	Distribution Point
DWDM	Dense wavelength division multiplexing
EC	European Commission
EPMU	Equal Proportionate Mark-Up
FDP	Final Distribution Point
FTTC	Fibre to The Cabinet
G&A	General and Administrative
GPON	Gigabyte Passive Optical Networks
IP	Internet Protocol
IT	Information and Technology
Kbps	Kilobit per second
LRAIC	Long-run average incremental cost
Mbps	Megabit per second
MDF	Main Distribution Frame
MRP	Model Reference Paper
MSAN	Multi-Service Access Nodes
ODF	Optical Distribution Frame
OECD	Organisation for Economic Co-operation and Development
OLT	Optical Line Terminal
OPEX	Operational expenditure
PDP	Primary Distribution Point
PON	Passive Optical Network
PTP	Point to Point

SC	Street Cabinet
SDP	Secondary Distribution Point
SMP	Significant Market Power
VoD	Video on Demand
VoIP	Voice over IP
WACC	Weighted Average Cost of Capital

MADRID (HQ)
Sagasta, 18, 3
28004, Madrid
Tel: +34 91 310 2894

ISTANBUL
Buyukdere Cad. No 255, Nurol
Plaza B 04 Maslak 34450
Tel: +90 212 277 70 47

MEXICO CITY
Torre Mayor Piso 41,Paseo de la
Reforma 505,Cuauhtémoc
Ciudad de México, 06500
Tel: +52 55 68438659