IN CONFIDENCE

# Assessing the emissions footprint of the fibre networks relative to other fixed broadband options in New Zealand

A report for Chorus, Northpower Fibre Limited, Tuatahi First Fibre and Enable Networks Limited

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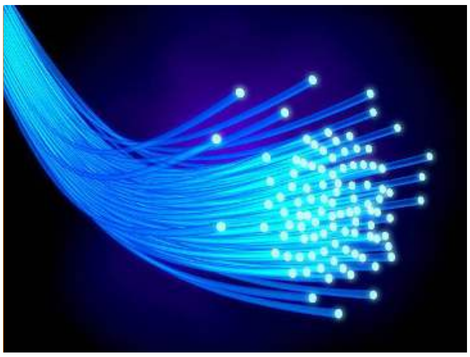

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# Glossary

| Abbreviation | Stands for |
|---|---|
| CPE | Customer premises equipment |
| DSL | Digital subscriber line |
| DSLAM | DSL access multiplexer |
| EoLT | End-of-life treatment |
| FTTH | Fibre to the home |
| FWA | Fixed wireless access |
| Gbps | Gigabits per second |
| GHG | Greenhouse gases |
| GPON | Gigabit-capable passive optical network |
| HFC | Hybrid fibre coaxial network |
| ICT | Information and communication technology |
| LCA | Life-cycle assessment |
| OLT | Optical line terminal |
| ONU | Optical network unit |
| Mbps | Megabits per second |
| PON | Passive optical network |
| RSP | Retail service provider |
| VDSL | Very High Bitrate (high-speed) DSL |
| WEEE | Waste electrical and electronic equipment |

# Executive summary

International studies show that the fibre network has a lower carbon footprint than other broadband options, primarily due to energy savings. This paper provides a first assessment of the emissions footprint of the current New Zealand fibre network, with a focus on internet provision to households and small to medium-sized businesses. Fibre (GPON and XGS-PON) is compared to Copper (VDSL), Hybrid fibre-coaxial (HFC) and 4G/5G fixed wireless (FWA 4G/5G).

The focus is on emissions generated during the use of the access network, as well as from the shipping and disposal of customer premises equipment (CPE). Emissions from network use are due to electricity consumption by the various equipment in the network, including CPE. To determine these emissions for the NZ fibre network, we use actual data on power use and network configuration from Chorus, Northpower Fibre Limited, Tuatahi First Fibre, and Enable Networks Limited. For the alternative technologies, we use a mix of actual and theoretical data, as available.

For average access rates[1] higher than ~50 Mbps, we find that fibre has a lower per-user emissions footprint than all the other fixed broadband alternatives in New Zealand (Figure 2 and Figure 1). Compared to VDSL and HFC, GPON can deliver 28-41 per cent and 12-29 per cent emissions reductions respectively, noting that in these networks per-user emissions footprint is exacerbated by the current low network utilisations.

Relative to fixed wireless, the emissions reduction potential of GPON increases with average access speeds. This is because the available bandwidth provided by the given radio channel and base station in the fixed wireless network is exhausted as the access rate increases, and additional resources must be deployed to deliver the improved service. Compared to FWA 4G, GPON's per-user emissions footprint is 46-56 per cent lower at 50 Mbps, and 96 per cent lower at 1 Gbps. Compared to FWA 5G, per-user emissions are 4-22 per cent lower at 50 Mbps, and 91 per cent lower at 1 Gbps. At high average access rates (e.g. over 600 Mbps),[2] XGS-PON provides an even greater emissions advantage than GPON due to more power-efficient equipment (Watts per user) outside customer premises. For GPON and XGS-PON networks providing similar minimum per-user speeds at peak, the per-user emissions footprint of XGS-PON can be 17 per cent lower than that of GPON.

For all broadband options, total emissions are predominantly driven by power consumption in the access network, with the power use by customer equipment having a major influence (except for fixed wireless at high access speeds where emissions are mostly driven by additional resources to increase bandwidth). The contribution of CPE power use to total power consumption is particularly high for GPON and XGS-PON, indicating significant opportunities for emissions reductions in the fibre network through a switch to more energy-efficient customer premises equipment.

[1] Average download speed sold in a network, and assuming a constant oversubscription rate for a given technology.

[2] In reality, XGS-PON technology would be used to provide individual access rates higher than 1 Gbps.. The 600 Mbps figure here refers to the *average* speed across the PONs at which a backhaul capacity of 100 Gbps would be required to provide service at the same quality, given a constant number of users and oversubscription rate..

Figure 1 – Per-user emissions by average access rate[3]

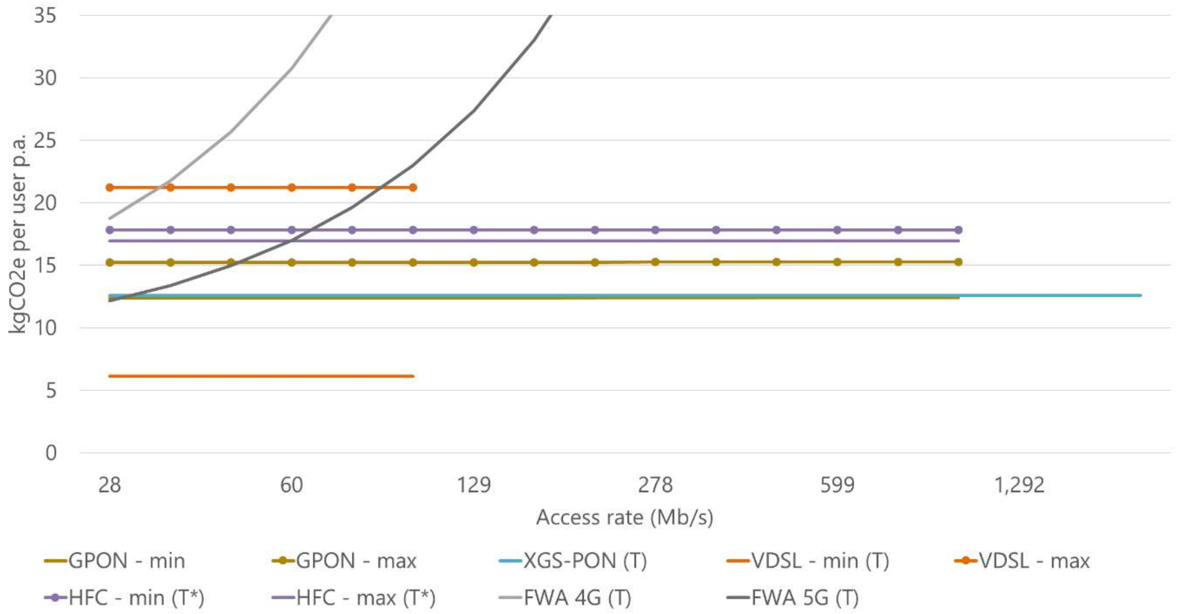
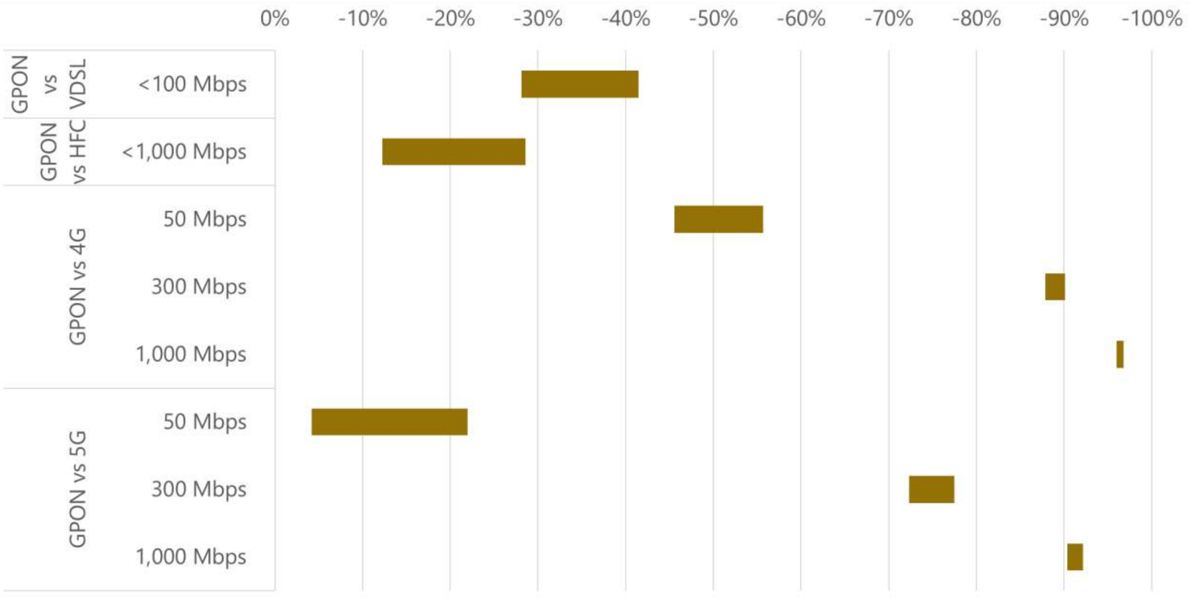



Figure 2 – Emissions reductions in the GPON network compared to VDSL, HFC and fixed wireless technologies[4]

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[3] T = theoretical values of power consumption and number of subscribers , T* = theoretical values of power consumption, expected current number of subscribers.

[4] The bars show a range for minimum and maximum emissions estimated for the GPON networks.

# 1. Objectives of the study

## 1.1 This paper provides a first assessment of the emissions footprint of the New Zealand fibre network

International studies show that the fibre network has a lower carbon footprint than other broadband options, primarily due to energy savings.

There is no New Zealand-specific study on the emissions savings benefits of fibre. This paper aims to fill in the gap, with a focus on internet provision to households and small to medium-sized businesses.

The focus is on emissions from power consumption within the access network, using actual data on power use in the fibre network from Chorus, Northpower Fibre Limited, Tuatahi First Fibre, and Enable Networks Limited. The analysis is focused on the near-term horizon (i.e. the next 5 years). There may be additional emissions savings as a result of changes in user behaviour supported by the improved internet service that fibre offers (e.g. working from home), although the incremental benefit compared to other broadband options requires further investigation. This long-term effect is excluded from the analysis.

# 2. Technology description

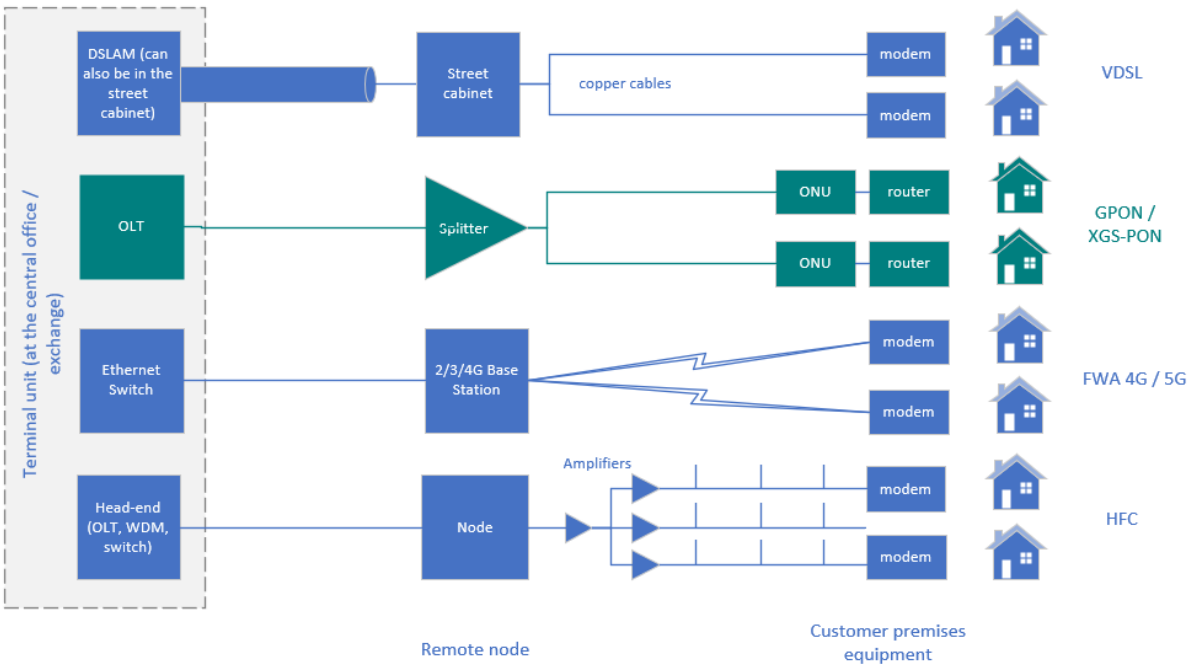
In the analysis, the baseline technology is ultrafast fibre GPON (Gigabit-capable Passive Optical Networks) and XGS-PON, the latter providing 10G GPON transmission. In New Zealand, GPON broadband is offered by Chorus, Northpower Fibre Limited, Tuatahi First Fibre , and Enable Networks Limited. XGS-PON is offered by Chorus, Tuatahi First Fibre and Enable Networks Limited.

Fibre is then compared to the following broadband alternatives: copper network (Chorus VDSL), hybrid fibre-coaxial (Vodafone HFC), and fixed wireless (FWA 4G, 5G – multiple vendors). Due to lack of detailed data, we have not been able to estimate the emissions profile of satellite broadband, however we include a summary of power consumption of a satellite dish in section 4.3.

The figure below illustrates the high-level architecture of the broadband technologies investigated, showing the key sources of energy consumption in the access network.[5] The key input parameters used in the modelling are provided in Table 3 in section 5.9.

Figure 3 – Key sources of energy consumption in access networks, by technology

Notes *DSLAM = DSL access multiplexer; OLT = optical line terminal; ONU = optical network unit; GPON = Gigabit Ethernet passive optical network; HFC = hybrid fibre coaxial network*




Source: adapted from (Baliga, et al., 2011)

## 2.1 GPON and XGS-PON

GPON stands for Gigabit-capable passive optical network (PON), in which a single optical fibre feeds one or more clusters of customers through a passive splitter (which does not consumer power). GPON

[5] The access network connects each subscriber to their immediate service provider. See section 3.1.

enables access speeds of up to 2.4 Gbps, though the maximum speed is typically limited by the maximum speed of the 1 Gbps copper port on the optical network unit (ONU), with the average download speeds in New Zealand being 858 Mbps (Sam Knows, 2021).

A laser installed into the optical line terminal (OLT) injects the photons from the central office (where the OLT is located) to a fibre-optic cable made of glass and plastic that ends at the passive optical splitter. The splitter breaks the single signal from the central office into numerous signals that are distributed to a number of customers. In this way, an OLT serves a number of optical network units (ONU) located at the customer premises. The number of customers served by one laser in the downlink direction is a result of the network configuration, and can be up to 128 (in a GPON network).[6] The Chorus network uses a default split ratio of 16:1 to provide a congestion-free network, supporting an average bandwidth of 150 Mbps (download) / 75 Mbps (upload) per ONU (Chorus, 2016).[7]

XGS-PON provides higher bandwidth than GPON (10 Gbps in both directions), but is otherwise functionally equivalent to GPON, and can co-exist on the same fibre with GPON. In its GPON network, Chorus offers 50 Mbps, 100 Mbps, 200 Mbps and 1 Gbps wholesale packages,[8] with plans to upgrade the 100 Mbps fibre service to 300 Mbps by end of 2021.[9] Chorus also offers 2Gbps, 4Gbps and 8Gbps XGS-PON packages that are symmetric (download and upload speeds are equal),[10] with XGS-PON currently being integrated in the GPON network.[11]

## 2.2 VDSL

A digital subscriber line (DSL) is provided through copper pairs. A DSL modem at each customer premises connects via a dedicated copper pair to a DSL access multiplexer (DSLAM) at the nearest central office or street cabinet. VDSL stands for Very High Bitrate (high-speed) DSL, offering average download speeds of 42 Mbps (Commerce Commission, 2021).

The DSL copper access is rate-adaptive, meaning that the available bandwidth per customer varies depending on distance, line quality and external conditions such as electromagnetic interference or house-wiring (Chorus, 2016). Consequently, the DSLAM power consumption can vary depending on broadband capacity, distance to the customer, and quality of the copper wire.

The current VDSL network is underutilised, with customers increasingly switching to newer broadband technologies, including fibre. In 2020, VDSL copper broadband connections (including VDSL) in New Zealand dropped by 20%, continuing a previous trend.[12]

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[6] In an XGS-PON network, the split can be up to 1/256.
[7] This assumes that all 16 customers are using their broadband 100 per cent of the time, which is not a real-world scenario.
[8] These are download speeds.
[9] https://company.chorus.co.nz/600000-kiwi-homes-and-businesses-able-benefit-chorus-300mbps-fibre-upgrade
[10] https://www.chorus.co.nz/broadband
[11] This paragraph notes Chorus products rather than industry.
[12] In 2019, there were 257,000 VDSL connections (Commerce Commission, 2020), and in 2020 – 207,000 connections (Commerce Commission, 2021).

## 2.3 HFC

HFC is a hybrid fibre coaxial network that uses fibre cabling to the local area and coaxial cabling to the home. Such networks were initially deployed to provide television services, and today can also deliver broadband. In New Zealand, UltraFast HFC Broadband is Vodafone's hybrid fibre coaxial network that uses DOCSIS 3.1 technology for high-speed data (Vodafone, 2021).

The high-level architecture of an HFC network outside customer premises includes (Baliga, et al., 2011):

- A "head-end," where video radio frequency (RF) carriers are combined in a broadband network platform (BNP) with data-supporting RF carriers onto transmission fibres. The material from the head-end is distributed through an optical fibre to local nodes, where the optical signal is converted into an electrical signal. We assume energy consumption related to data transmission is 80 per cent of total.[13]
- Optical node equipment that converts the optical signals into electrical signals suitable for cable distribution. This electrical signal is distributed to customers through a tree network of coaxial cables.
- A network of electrical RF amplifiers and splitters, so that each node can support a number of customers spread over many streets. The electrical amplifiers help maintain signal quality. We assume a highly distributed network of 625 nodes per terminal unit.

Vodafone offers two HFC packages: HFC Max and HFC 200. In good conditions, download speeds can reach 700-900 Mbps,[14] and up to 200 Mbps respectively (Vodafone, 2021). HFC has limited coverage in New Zealand (Sam Knows, 2021), and is offered in parts of Wellington, Kapiti and Christchurch.[15] We understand that the HFC network is also underutilised, with the current number of users being about a third of what the network had been provisioned for.

## 2.4 Fixed wireless access

Fixed wireless access (FWA) is a way of providing wireless internet access to homes or businesses without laying fibre and cables for last-mile connectivity. The approach involves connecting existing fibre, cable, or DSL internet between two fixed locations via a radio and a receiver.

Each customer has an indoor modem that connects to a base station at a remote antenna site. The base station then connects to an upstream Ethernet switch. The area covered by a base station is

[13] In the (Baliga, et al., 2011) paper, 40% of energy consumption is allocated to Internet access. We assume a higher percentage, expecting data consumption to dominate broadcast television services in the HFC network currently.
[14] With an average download speed of 717 Mbps (Sam Knows, 2021).
[15] https://www.vodafone.co.nz/broadband/ultra-fast-hfc/

referred to as a cell, and users in a cell share the total available bandwidth. Per-user bandwidth can be significantly increased by creating multiple sectors in a cell through the use of directional antennas.[16]

We assume an Ethernet switch serves a single site,[17] and that the number of connections per 4G and 5G base station are 900 and 750 respectively.[18]

FWA 4G delivers lower download/upload speeds than fibre, with average speeds of 33 Mbps. FWA 5G offers higher bandwidth than existing 4G plans, but is currently available only in limited areas (Sam Knows, 2021). Featuring New Radio in the millimetre wavelength, 5G FWA can provide a competitive alternative to wired broadband with a level of service bandwidth capacity comparable to fibre (Metaswitch Networks, 2021). 5G technology is also more efficient in terms of watts per Mbps of bandwidth, but because users will consume more with greater bandwidth available, the per-user power consumption can be similar or higher.

[16] Multi-sector antennas can be used at the base station to densify coverage area, i.e. share bandwidth over a more constrained area, and therefore when combined at a site provide greater overall bandwidth per cell. In 5G networks, spatial multiplexing can also be utilised with Massive MIMO (multiple-input, multiple-output), which allows adding a much higher number of antennas on the base station. Additionally, 5G provides improved spectral efficiency of modulation.

[17] In reality, it is unlikely that a single 5G cell would use a single dedicated ethernet switch for front/X Haul; fibre backhaul using eCPRI is more likely. In our model, because FWA 4G and 5G can coexist, we assume it is less costly to install a switch rather than use separate fibers to connect each cell to the network. In other words, our model makes some allowance that some of the power consumption is shared between 4G and 5G.

[18] This is based on vendor-supplied data. In the (Baliga, et al., 2011) paper, a more centralised approach is used, with the switch serving multiple sites and a total of 24,400 connections. Therefore, in our model the power consumption by the switch is lower, but shared amongst fewer connections so higher on a per-user basis.

# 3. Emission boundaries

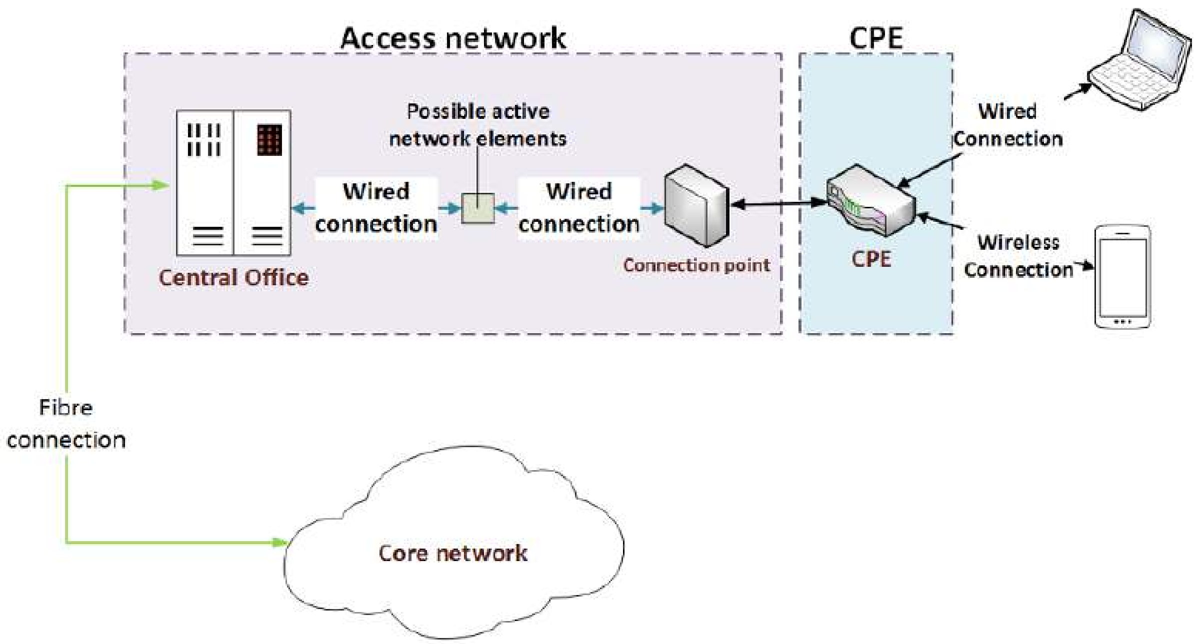
## 3.1 Emissions boundaries are those of the access network

A traditional network used by Internet Service Providers can be split into three main domains (Baliga, et al., 2009):

- the access network, including the CPE
- the metro and edge (or "regional") network, and
- the core network.

The **access network** connects each subscriber to their immediate service provider. It includes the passive connection point on the subscriber's premises (Figure 4), the active network termination including the connection into the core network on the service provider's side, and all active components in between (Prysmian Group, 2021)

Figure 4 – High-level description of an access network




Source: (Prysmian Group, 2021)

The **metro and edge network** serves as the interface between the access network and the core network. The metro and edge network includes edge Ethernet switches, broadband network gateway (BNG) or broadband remote access server (BRAS) routers, and provider edge routers. The switches concentrate traffic from a large number of access nodes. The BNG or BRAS routers perform access rate control, authentication and security services and connect to multiple provider edge routers to increase reliability. The provider edge routers connect to the core network (Baliga, et al., 2009).

The **core network** comprises a small number of large routers in major population centres. These core routers perform all the necessary routing, and also serve as the gateway to neighbouring core nodes (Baliga, et al., 2009).

The edge networks and the core network are needed for all broadband technologies, and their energy consumption across various technologies can be considered equal (Baliga, et al., 2009). The focus of the paper is on access networks, where energy consumption in the network varies with the technology used.

## 3.2 The focus is on emissions from the use of the access network, and the disposal of customer equipment

### 3.2.1 Stages in a life-cycle analysis

Typical stages in a life-cycle analysis (LCA) of emissions from ICT equipment, network and services include (ETSI, 2016):

- **Raw material acquisition**, which includes raw material extraction and processing
- **Manufacturing**, which includes production of ICT goods and supporting goods
- **Use**, which includes use of ICT and supporting goods, operator support activities, service provider support activities
- **End-of-life treatment (EoLT),** which includes re-use, ICT-specific EoLT and other EoLT.

For broadband networks, emissions also arise in the process of **deploying the networks** (e.g. installing cables), and from network **maintenance and repairs**.

### 3.2.2 Emissions from pre-use stages are excluded

**Pre-use stages.** In this paper, the emissions boundaries investigated are emissions arising from the use of the networks being compared, assuming that the physical deployment of network equipment is almost complete. The latter is premised on the fact that the coverage of the fibre network in New Zealand is already significant (a target of 87 per cent of the population by end of 2022).

Once full coverage is achieved, emissions from life-cycle stages before the actual use of the network ("pre-use" stages, such as from materials mining, network construction, equipment production, transport and installation[19]) are considered as sunk. This means that, from a customer perspective, the emissions contribution arises from the incremental usage of the network, rather than from expanding the network to accommodate new demand. The approach in this paper focuses on these *incremental* emissions, i.e. per-user emissions resulting from the use of electrical equipment after the network has already been deployed.

**Network deployment.** Notwithstanding the approach above, it is worth noting that there have been significant advances in the way the fibre network is built, so that environmental damages are minimised. Fibre-to-the-home (FTTH) construction can be intrusive, but the trench can also be dug "smart." For example, compared to a conventional trench, a micro trench[20] can be dug six times faster with less waste, less backfill material, 70 per cent less labour and up to 45 per cent less energy

[19] The equipment used to connect the network to the customer premises is covered separately further below.
[20] See https://www.ppc-online.com/blog/best-practice-for-installing-fiber-through-micro-trenching

consumption (Nokia, 2020a). Nokia estimates that $CO_2$ emissions from FTTH build are compensated after 4-7 years when compared to FWA emissions associated with the deployment of macro towers (Nokia, 2020a).

### 3.2.3 Emissions from network use and disposal of customer equipment are included

**Use of access network.** Emissions from the use of the access network are predominantly those arising from the use of electricity to power the equipment within the access network, including customer premises equipment (CPE). The method for estimating these emissions is described in section 5.

We also include emissions from international shipping of CPE from overseas manufacturing plants to New Zealand, reflecting the different locations of equipment manufacturers that we have assumed. The method is described in section 6.1. Transport emissions from distributing CPEs within New Zealand are excluded due to absence of granular data on CPE supply chains across different networks.

**End-of-life treatment (EoLT) of customer equipment.** End-of-life emissions for customer premises equipment (e.g. modem, optical network terminals) will depend on how the equipment is disposed of: at landfill or recycled. We assume the equipment is recycled through an open-loop system, whereby equipment materials are recycled into other products.[21] In New Zealand, there are a number of companies providing recycling services for end-of-life electronic products.[22] The method for estimating EoLT emissions is described in section 6.2.

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[21] By contrast, in closed-loop systems materials are recycled back into the same product.
[22] For example, https://www.e-cycle.co.nz/, https://techcollect.nz/, https://www.computerrecycling.co.nz/recycle/modems/

# 4. Key findings from existing literature

## 4.1 There is evidence that fibre networks are more energy efficient than copper networks

International studies indicate that fibre networks are much more energy efficient than copper networks. Fibre networks were shown to use 12x times less energy than copper by transmitting data using light sources of emissions (Otelco, 2019), and deliver emissions reductions and energy improvements up to 80 per cent compared to copper-based infrastructure (TalkTalk, 2021). In Europe, fibre was estimated to deliver 88 per cent reduction in GHG emissions per Mbit compared to a combination of copper and coax (Aleksic & Lovric, 2014).

These energy and environmental benefits of fibre are largely due to:

- **Rationalisation of infrastructure required to deliver services**. Whereas fibre networks use light to transmit signals, in copper networks power is required to 'push' the signal. Even when the network is not in use, it must be powered to prevent the copper from corrosion due to a redox reaction. Because copper cables can reliably carry signals for only seven miles before significant degradation, copper infrastructure requires many exchanges and street cabinets to ensure good quality of broadband to users (TalkTalk, 2021).
- **Utilisation of more energy efficient technology.** There have been significant advances in switching technology at exchanges, potentially delivering 10-15 per cent energy efficiency improvements (TalkTalk, 2021). Nokia estimates that between 2017 and 2020, power reduction per GPON and XGS-PON port was 35 and 50 per cent respectively (Nokia, 2020a). Newer fibre optic technology also has a smaller physical footprint, generating less heat and therefore requiring less energy for cooling.
- **Improved reliability of fibre optic networks**. Fibre cables are connected to premisses directly and are less susceptible to water. By contrast, copper-based networks are highly vulnerable to water ingress, and the wires are shared in broadband cabinets where they may be damaged (TalkTalk, 2021). Furthermore, with the shift to fibre and passive power splitting, fewer ports/electronics are needed to serve end users (Nokia, 2020). Fewer faults mean fewer field engineer visits, and therefore reduced emissions from transport.

## 4.2 ...and can be more energy efficient than other broadband alternatives

**Fixed wireless.** A study by (Baliga, et al., 2011) investigated the per-user power consumption for different broadband technologies, as a function of the access rate.[23] They found that for higher access rates (e.g. greater than 10 Mbps), PON technologies used in fibre-to-premises installations are more energy efficient than fixed wireless (WiMAX technology at the time).

[23] Access rates in this document refer to the headline rate sold to customers.

The lower emissions footprint of fibre compared to fixed wireless has also been demonstrated in a recent study undertaken by the German Environment Agency. The study found that high-definition video streaming over the fibre optic connection generates 2 gCO2 per hour of video streaming for the data centre and data transmission, whereas emissions over the 5G network are more than double that - 5 gCO2 per hour (German Environment Agency, 2020).

It is worth noting that the 5G Radio Access Network has been found to be significantly more energy efficient than legacy fixed wireless technologies – about 90 per cent more energy efficient per traffic unit than legacy 4G networks. This is due to 5G power-saving features, small cell deployments and new 5G architecture and protocols, among other (Nokia, 2020b).[24] Nevertheless, it is expected that the exponential increase in traffic would increase the carbon footprint of 5G. and a combination of energy-saving solutions would be required to improve the energy efficiency of wireless networks (Nokia, 2020b).

In fixed wireless networks, power consumption increases with higher speeds due to the inherent limitation of available radio capacity. At lower speeds, fixed wireless can flexibly share capacity among a very large population, achieving high efficiency and utilisation. However, as the speed increases, fewer customers can use a given radio channel or base station, and more resources must be provisioned to deliver the service. Additional cell sites are required to meet the same number of users to ensure that the additional bandwidth does not result in service degradation.

**HFC.** The same study also found that PON technologies are more energy efficient than HFC technologies at all access rates, and that for access rates greater than 20 Mbps, power consumption by HFC services increases at a slower rate than fixed wireless (Baliga, et al., 2011). Consistent with this, (Aleksic & Lovric, 2014) find that, compared to HFC, GPON could achieve 93% GHG emissions reductions (per user Gbit) if it were the technology of choice in Europe.

**Satellite.** We are not aware of studies that have directly compared power consumption in fibre networks with those of satellite broadband networks. However, evidence suggests that a Starlink dish can consume over 100W in normal mode (ISP Review, 2021), which is significantly higher (in the order of 10x) than the power consumption of customer premises equipment (CPE) for the other broadband options (see Table 3). This is important because CPE power usage has been shown to have a major contribution to total per-user power consumption in a network (see next section).

Nevertheless, it is also worth noting that in the future, the technology may be able to offer deeper power-savings mode, reducing power consumption while still connected to the network (Brodkin, 2020).

## 4.3 Evidence also suggests that energy consumption at customer premises is the largest source of energy use

In copper-based networks (ADSL), fibre (PON) and HFC, customer modem or ONU was shown to consume 65 per cent of total power in the access network (Baliga, et al., 2011), although automated

[24] In our model, we assume that that the power-saving features would have been accounted for in the typical power consumption figures provided by vendors for FWA 4G/5G equipment.

sleep modes could significantly reduce this power use (by 40 per cent). On a life-cycle basis,[25] Nokia estimates that 89 per cent of GHG emissions from fixed networks are in product use at customer premises (Nokia, 2020a).

[25] Installation, transport and end-of-life treatment.

# 5. Estimating emissions from power consumption in the access network

## 5.1 The access network can be split into three major sources of power consumption

Power consumption can be broadly split into energy consumption at:

- The customer premises equipment (e.g. modem/router/ONU)
- Remote note or base station (cabinet)
- The terminal unit (located in the local exchange / central office).

The key sources of energy consumption across different broadband networks are shown in Figure 3 above.

The table below summarises the terminology for the different components in the access networks as illustrated in Figure 3.

Table 1 – Summary of key component names in the access network, by technology

| Technology | Terminal unit | Remote node / base station | Customer premises equipment |
|---|---|---|---|
| **GPON / XGS-PON** | Optical Line Terminal (OLT) | NA (the splitter does not consume power) | Optical Network Terminal (ONU) + router, or Gateway |
| **VDSL** | DSLAM | NA | Modem |
| **HFC** | Head-end: WDM, switch, OLTs | Remote node | Modem |
| **FWA 4G/5G** | Ethernet switch | Base transceiver station | Modem (gateway / receiver) |

## 5.2 Per-user power consumption is a function of average access rate

Our model reflects a fixed network configuration, where the number of users and the oversubscription rate (see section 5.4) is held constant, and the power consumption outside customer premises scales as a function of the total network capacity required to support increases in speed.

We compare power consumption amongst different technologies using a power-per-user metric estimated for different average access rates (average download speed sold in a network). This metric is the sum of the per-user power consumption by the different sources of power use in a broadband network, as illustrated in Figure 3.

At the terminal unit, in addition to the power used by the electrical equipment, power is also required for cooling, to compensate distribution losses, or for external power supplies. Given these overheads, the per-user power consumption at the terminal unit is multiplied by a factor of 1.5 as per (Baliga, et al., 2011). We note that the choice of the multiplier value does not affect our results, which we find to be most sensitive to the power consumed at the customer premises (section 7.2).

For the remote node and at the customer premises, it is assumed that the electrical equipment is cooled naturally by the surrounding environment.

The general formula for the power-per-user metric is as per (Baliga, et al., 2011):

$$P_a = P_{CPE} + \frac{P_{RN}}{N_{RN}} + 1.5 * \frac{P_{TU}}{N_{TU}}$$

where:

- $P_{CPE}$, $P_{RN}$ and $P_{TU}$ are the power consumed by the customer premises equipment, remote node or base station (where this exists), and the terminal unit respectively.
- $N_{RN}$ and $N_{TU}$ are the number of customers or subscribers that share a remote node, and the number of customers that share a terminal unit respectively.
- The factor of 1.5 on the right-hand side of the equation reflects additional overheads, e.g. external power supplies, electricity distribution losses, and cooling requirements in the buildings housing the terminal equipment.

The formula from (Baliga, et al., 2011) is generic and can be easily adapted to the New Zealand context. The authors of the paper assume full network utilisation, whereas we apply the formula using current estimates of power consumption and network utilisation (in terms of number of subscribers).

A key insight from the (Baliga, et al., 2011) paper is that per-user power consumption can vary with the access rate offered. In our model, power at the terminal unit and power at the remote node are estimated as a function of the backhaul capacity installed (GPON, VDSL, HFC), or of the average traffic (FWA) for a given access rate (see more in sections 5.5 and 5.6). Average power use by customer equipment (accounting for power use in idle and active times) does not change with the access rate.[26]

## 5.3 Actual and theoretical scenarios have been modelled

Depending on data, power consumption was estimated to reflect (i) actual power consumption and number of active users, and/or (ii) theoretical power consumption and number of users. Whereas the latter case generally reflects full, or close to full, utilisation of network capacity, the former reflects current subscription rates and data traffic. Generally, lower utilisation would correspond to higher per-user power consumption.

[26] For fibre, CPE power consumption for WiFi functionality, whether provided by the 3rd Gen ONT or a separate RGW/WiFi device, could increase with higher traffic, but the increase is unlikely to be significant based on real-world observations. We assume this to also be the case for CPE in the other networks, as the functionality of switching / routing traffic is comparable across all devices.

The table below summarises the scenarios considered for the different technologies. The key parameters for the respective technologies are presented in Table 3.

Table 2 – Scenarios considered for different broadband technologies

| Technology | Scenario |
|---|---|
| **GPON** | Five actual and one theoretical scenario. The actual scenarios reflect different power usages, numbers of subscribers and oversubscription rates across New Zealand fibre networks. |
| **XGS-PON** | One theoretical scenario |
| **VDSL** | One actual and three theoretical scenarios. The theoretical scenarios reflect different possible values for DSLAM power consumption, assuming a constant (theoretical) number of users. |
| **HFC** | Two theoretical scenarios of power use, with current number of users reflecting expected current network utilisation |
| **FWA 4G** | One theoretical scenario of power consumption, number of users and backhaul capacity |
| **FWA 5G** | One theoretical scenario of power consumption, number of users and backhaul capacity |

## 5.4 The model makes assumptions about oversubscription rates

Backhaul networks connecting the access network to the metropolitan and edge networks are dimensioned by network operators such that they provide a minimum per-user speed (MPUS) to each user, taking advantage of the bursty nature of customer Internet traffic. The ratio of the advertised access rate to this minimum per-user rate is referred to as the oversubscription rate. We use theoretical values, actual values provided by the fibre companies, and estimated values.

In the New Zealand GPON networks, oversubscription rates are between 20 and 36, estimated based on the actual data provided by the NZ fibre companies.

In an underutilised network, the oversubscription rate is lower than what the network would have been dimensioned for. A lower oversubscription rate would trigger an earlier upgrade of equipment to support a higher access rate while maintaining the existing oversubscription rate. To describe a more realistic inflection point for equipment upgrade, we use a theoretical oversubscription rate of 20 for the underutilised networks in New Zealand (VDSL and HFC).[27] We use the same value of 20 for the remainder technologies.

[27] This is the lower value in the GPON networks, and also the assumption used in (Baliga, et al., 2011).

## 5.5 For all technologies except fixed wireless, power consumption reflects the maximum capacity a network has been dimensioned for

### GPON / XGS-PON

OLT power consumption is comprised of a fixed component (the baseload power use), and a variable component reflecting the number of interface cards added to the base. Data usage also drives some variability, as the equipment has to work harder to route traffic through it. On average, most of the power is used by the baseload (around 96 per cent).

For a given number of users, the model assumes that OLT power consumption is constant up until the increase in access rate implies a higher minimum per-user speed (MPUS) than what the network originally supported, where MPUS is the maximum speed that the network can support at peak if all active users were concurrent, assuming a constant oversubscription rate. In essence, MPUS is a proxy measure of the congestion levels that the network has been configured to avoid.

The assumption above reflects the fact that OLT power consumption does not flexibly adjust up or down with traffic. Instead, power use reflects the backhaul capacity that the network has been dimensioned for. Although there will be variability with the number of active interfaces (whether PONs or backhaul links), for a given network configuration, little variability is expected based on traffic actually carried.

We make similar assumptions for the power use at the terminal units in the VDSL and HFC networks, i.e. it is constant up until the increase in access rate implies a higher MPUS than what the network originally supported.

Once an increase in access rate results in a higher MPUS, the additional capacity requires a new uplink interface, which is provided by adding a new plug-in optical module. The interface card can support multiple plug-in modules of different types, depending on the capacity required and the distance being transmitted over. The additional power consumption from the new modules is approximately 10W.

### VDSL

DSLAM power consumption is also comprised of a fixed component (the baseload), and a variable component depending on the number of lines. Similar to GPON, the baseload accounts for most of the power use at the terminal unit (around 97 per cent).

The actual VDSL scenario reflects the current low network utilisation as a result of customers increasingly switching to fibre. Consequently, we assume no further investments in additional equipment for this scenario, which results in a flat line for per-user power consumption (Figure 5)

### HFC

Similar to VDSL and GPON, baseload power consumption at the HFC terminal unit (head-end) is a function of the backhaul capacity that the network was configured for (resulting in a specific MPUS given the number of users and oversubscription rate).

Because utilisation of the HFC network in New Zealand is low, similar to VDSL, we assume no further investments in additional equipment in the HFC scenarios, resulting in a flat line for per-user power consumption (Figure 5).

## 5.6 For fixed wireless, power consumption is assumed to be a function of average throughput per user

In the fixed wireless network, a base load is installed to provide coverage, and as demand grows, additional capacity can be added up to the limit of the available spectrum. In this way, fixed wireless provides more flexibility with which capacity is added. This means power consumption is more reflective of actual traffic, which can be measured by the average throughout per user metric (ATPU). Once the limit of the available spectrum is reached, additional cell sites are required to serve the same number of users, in order to ensure that congestion (or oversubscription rate) does not degrade.

Conceptually, the main difference between MPUS and ATPU is that the former is a design feature, whereas ATPU is actual traffic carried. ATPU can be seen as a floor value for MPUS, where the latter corresponds to full capacity utilisation. When all capacity is utilised, ATPU equals MPUS. In practice, ATPU understates the effective per-user design level.

Power consumption in a fixed wireless network is assumed to be a function of the ATPU corresponding to a given access rate. We assume a functional form determined based on the following coordinates:

- maximum power consumption when all backhaul capacity is utilised, and
- typical power consumption corresponding to average traffic (ATPU multiplied by the number of active users).

The relationship between ATPU and access rate is determined as follows:

$$ATPU = Network\ utilisation * \frac{Access\ rate}{Oversubscription\ rate}$$

where "network utilisation" is the ratio between total backhaul capacity and average traffic (ATPU multiplied by the number of active users). We assume network utilisation in the fixed wireless network to be 70 per cent.

With an increase in access rate, ATPU will also increase, assuming a constant number of users and a constant oversubscription rate. The ATPU increase will first lead to greater power consumption by the existing equipment, and after a certain point, new equipment is added to provide higher speeds.[28]

[28] Note that emissions from building a new site (in addition to energy consumption by electronics) to provide additional capacity in the fixed wireless network are not included. The advantage of fibre is that an increase in capacity only requires upgrades to the electronic equipment.

## 5.7 Power use by customer equipment reflects the power consumed during idle and active times

We assume that the modem/router at the customer premises goes on standby mode when not in use. For the main results, modems and routers (providing wifi functionality) are assumed to be used half a day on average (50% availability), with results being tested for sensitivity assuming a higher availability of 80 per cent. In the fibre network, the ONT equipment (without the wifi functionality) is always on.

The power consumed by modems and routers is then estimated as the average of equipment power use during idle and active times of the day, weighted by the availability factor above. We assume that modem/router power use in idle mode is 58 per cent of the typical power use in active mode.[29]

## 5.8 Emissions are estimated using the current grid electricity emissions factor

MfE's emission factor for current grid electricity is 0.101 kgCO2e/kWh (MfE, 2020),[30] and we assume that this does not materially change over the near-term horizon (~5 years) that this study focuses on. However, we note that over the long term, an increased penetration of renewable energy sources into the grid will reduce the carbon footprints of all broadband technologies in absolute terms, although not also in relative terms so long as grid electricity emissions are non-zero.[31]

Power consumption in Watts is converted to kWh assuming daily utilisation of broadband (8,760 hours p.a.). For the customer premises equipment, the conversion to kWh reflects total energy consumed by the equipment given assumptions on model/router idle time (section 5.7).

## 5.9 Summary of key network input parameters used

Estimates for GPON and VDSL power consumption reflect actual network usage today in New Zealand. Estimates for other technologies reflect vendor-supplied information and own assumptions. The key parameters are summarised below.

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[29] This is based on the assumptions that (i) power use in the idle mode is 50 per cent of the maximum power use by the equipment (based on specifications for Huawei VDSL Home Gateway HG659), and (ii) typical power use in the active mode is 86 per cent of the maximum power use by the equipment (based on specifications for FWA Nokia Fast Mile 5G Receiver 5G14-B).

[30] This emissions factor is location-based, meaning that it reflects an average value in the grid. In contrast, a market-based emissions factor would reflect the emissions impacts of differentiated electricity products that companies have purposefully chosen (SBTI, 2017).

[31] We note that even under a 100% renewable electricity, the emissions factor for grid electricity may still be non-zero due to emissions generated by geothermal (a renewable source of energy).

Table 3 – Key technology input parameters

*Notes* *TU = terminal unit; RN = remote node; CPE = customer premises equipment*

*T = theoretical value, if different from actual*

| | **GPON** | **XGS-PON** | **VDSL** | **HFC** | **FWA 4G** | **FWA 5G** |
|---|---|---|---|---|---|---|
| **Typical $P_{TU}$ (Watts)** | 884-1,300<br>515 (T) | 611 (T) | 516<br>247 – 1,378 (T) | 1,748 (T) | 170 (T) | 130 (T) |
| **Typical $P_{RN}$ (Watts)** | NA | NA | NA | 203 -<br>179 (T) | 4,259 (T) | 3,509 (T) |
| **$P_{CPE}$ (Watts)[32]** | 13.2 – 16.2<br>13.4 (T)[33] | 13.4 (T) | 6.32 | 11.84 (T) | 7.5 (T) | 7.5 (T) |
| **$N_{TU}$** | 748-3,592<br>2,048 (T) | 2,048 (T) | 44.14<br>768 (T) | 12,250 | 900 (T) | 750 (T) |
| **$N_{RN}$** | NA | NA | NA | 19.6 | 900 (T) | 750 (T) |
| **Backhaul capacity (Mbps)** | 10,000 –<br>20,000 | 100,000 (T) | 10,000 | 10,000 (T) | 504 (T) | 1,000 (T) |
| **Over-subscription rate** | 20-36<br>20 (T) | 20 (T) | 20 | 20 (T) | 20 (T) | 20 (T) |
| **Highest speed offered (Mbps)** | 1,000[34] | 8,000 | 100 | 1,000 (T) | 1,000 (T) | 1,000 (T) |

32 For modems and routers, we assume typical power consumption as indicated by manufacturers.

33 For GPON and XGS-PON, total power consumed by the customer premises equipment is the sum of power consumed separately by the ONU and router. For the other technologies, CPE power reflects that of the modem providing wifi functionality.

34 Although GPON can offer speeds up to 2.4 Gbps, current customer equipment only supports speeds of up to 1Gbps.

# 6. Estimating emissions from non-energy use of customer equipment

## 6.1 Emissions from international shipping reflect different locations of equipment manufacturers

Using assumptions on the location of manufacturer plant for customer premises equipment as shown in Table 7 (Appendix A), we determined the distance for international shipping travel as the average distance between the overseas plant and Ports of Auckland or Lyttelton port.[35] An average emissions factor of 0.02 kgCO2e/tkm for container ships (MfE, 2020) was then used to estimate emissions from the international shipping of CPE, using CPE weights as per Table 7.

The table below presents average emissions[36] from CPE shipping across the different technologies.

Table 4 – Emissions from international shipping of customer premises equipment

| Technology | Device | Emissions from international shipment (gCO2e) |
|---|---|---|
| Fibre | ONU + router | 323.4 |
| VDSL | Modem | 107 |
| HFC | Modem | 84 |
| FWA | Receiver | 126.1 |

## 6.2 Emissions from equipment disposal assume open-loop recycling

As mentioned previously, we assume customer equipment is recycled through an open-loop cycle. This gives us a conservative estimate of end-of-life emissions, as the emissions factors for open-loop cycle recycling (21.3 kgCO2e/ton) is higher than from landfill disposal (8.9 kgCO2e/ton), as per (UK DBEIS, 2021). We note that the choice of the equipment disposal method does not affect our results (see section 7.1).

Using the equipment weights from Table 4, emissions CPE disposal are as follows:

Table 5 – Emissions from disposal of customer premises equipment

| Technology | Device | Emissions from open-loop recycling (gCO2e) |
|---|---|---|
| Fibre | ONU + router | 15.4 |
| VDSL | Modem | 9.2 |

[35] The shipping routes were determined using http://ports.com/.
[36] For a given technology, an average is used to account for the different device models and weights.

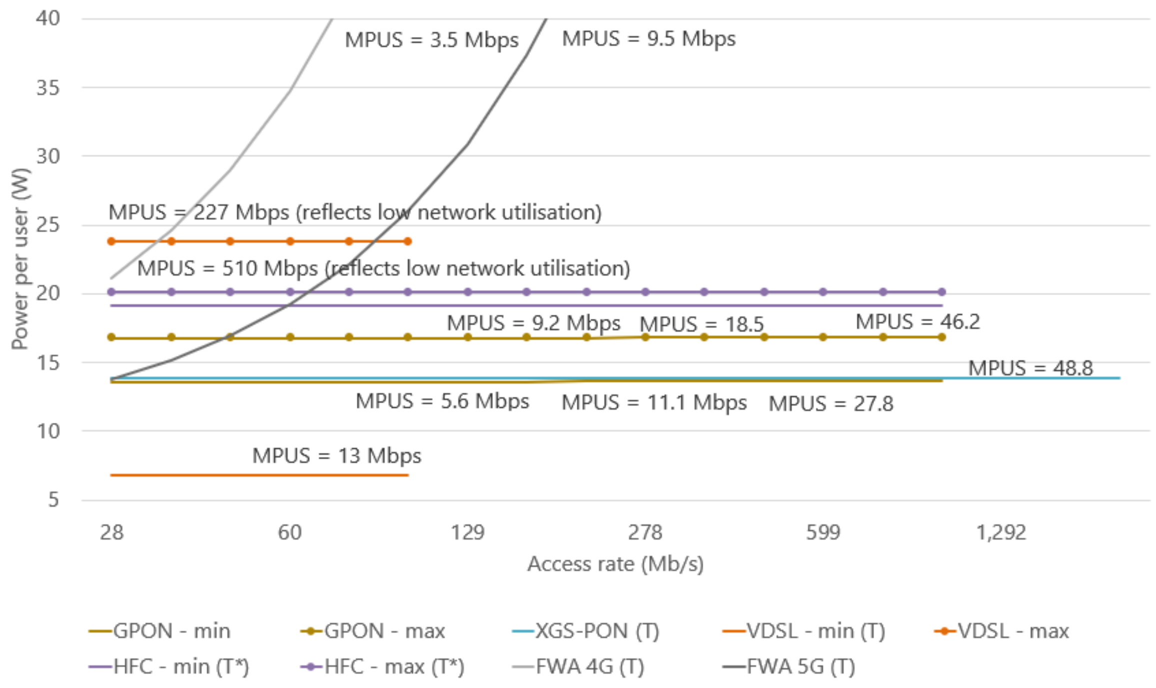
| Technology | Device | Emissions from open-loop recycling (gCO2e) |
|---|---|---|
| HFC | Modem | 12.3 |
| FWA | Receiver | 9.6 |

# 7. Key findings

For increasing access rates, the following two charts present the estimates for per-user power consumption and emissions across the different broadband technologies investigated. The estimates for GPON reflect the range of per-user power use and emissions across the four networks providing fibre in New Zealand. For HFC, two estimates are provided to show two possible values of power consumption at the node. For VDSL, the lower bound reflects a theoretical estimate where network utilisation is high; the upper bound reflects current utilisation and power use in Chorus' VDSL access network.

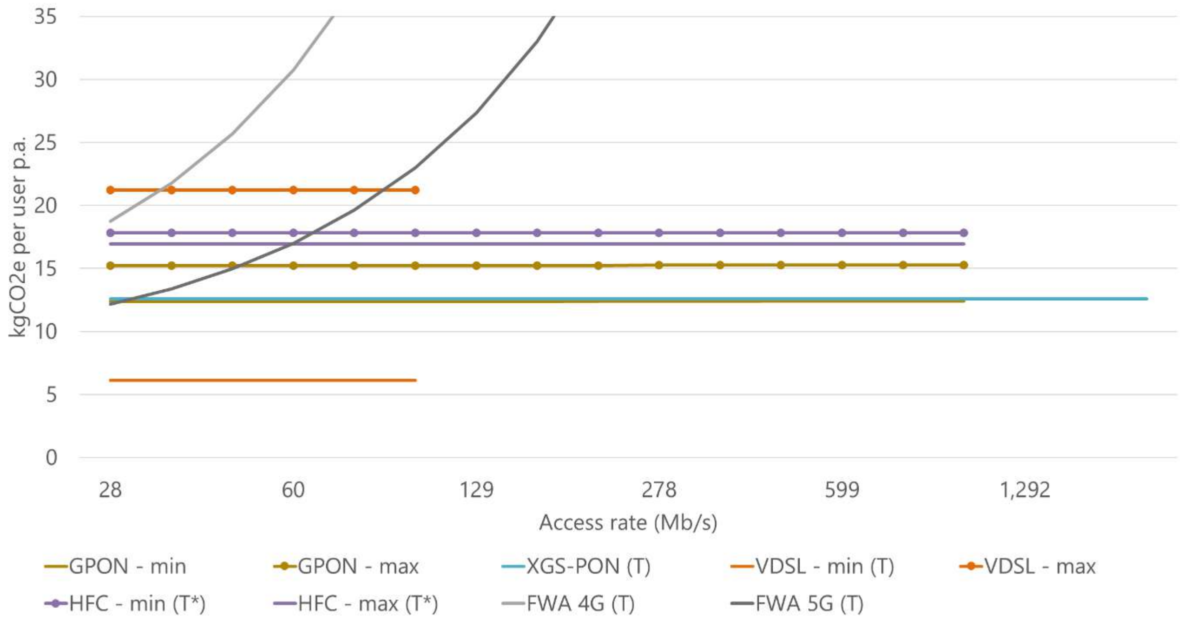
Figure 5 – Per-user power consumption by average access rate[37]

*Note: MPUS = minimum per-user speed supported by the network (at peak); T = theoretical values of power consumption and number of subscribers; T* = theoretical values of power consumption, expected current number of subscribers.*




[37] For the VDSL and HFC networks, the MPUS available – calculated as the ratio of backhaul capacity and number of users – reflects low utilisation of network (lower number of users than the network was configured for).

Figure 6 – Per-user emissions by average access rate




## 7.1 Emissions are mainly generated by the power consumption in the access network

Non-energy use emissions from international shipping and end-of-life disposal of customer equipment account for under 0.5% of annual per-user emissions from equipment power consumption.[38]

## 7.2 Customer equipment is a major source of power use, with significant efficiency improvement opportunities for fibre

Before significant equipment upgrades are made to support an increase in capacity demanded, power consumption by customer premises equipment account for most of the power use in the network. After the upgrades, the share of CPE power use across the network declines. This can be seen in Figure 7 below.

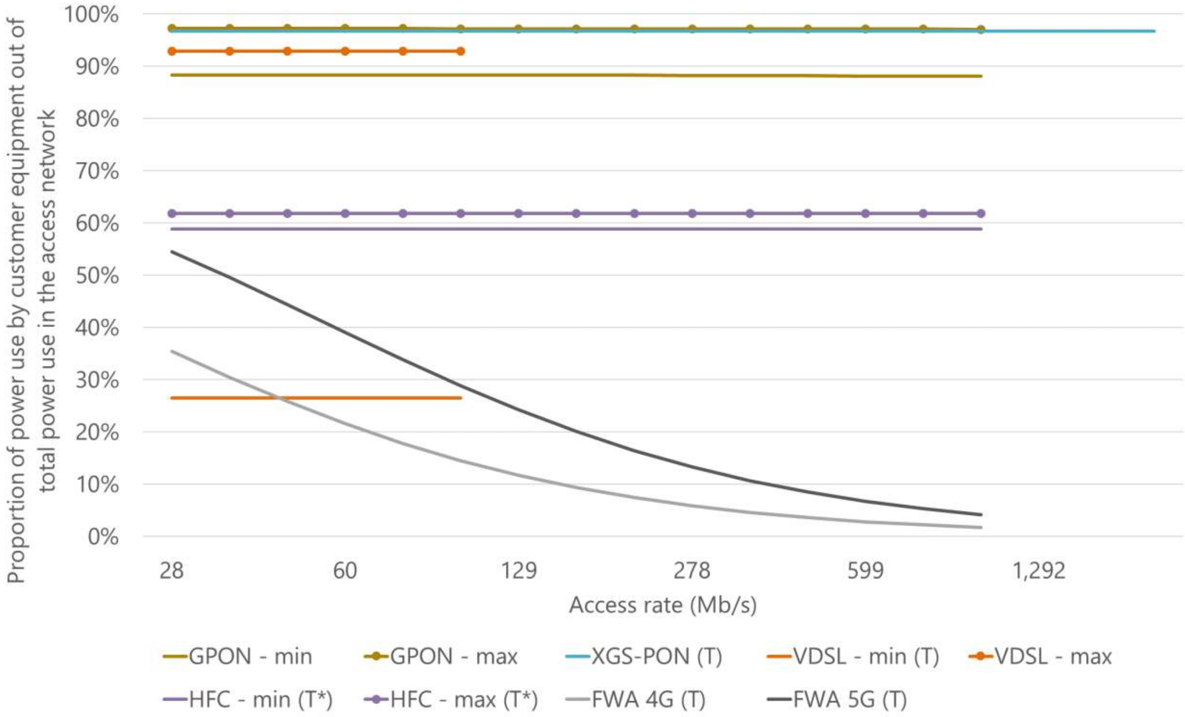
The figure also shows that CPE power use, as a proportion of total power consumption, is particularly high for fibre. This provides significant opportunities for emissions reductions in the fibre network through switching to more energy-efficient CPE.

For example, a third-generation GPON Gateway,[39] which integrates the ONU and modem functionality into a single box, can halve the total power consumed by separate ONU and modem boxes. An important consideration in the roll-out of such equipment is the extent to which it enables retail

[38] Assuming equipment useful lifetime of 5 years.
[39] https://sp.chorus.co.nz/product/rgw-ont-residential-gateway-ont/overview

service provides (RSP) to continue to provide differentiated customer services in a competitive market. An integrated modem functionality in an off-the-shelf gateway equipment can take away some of the RSP flexibility. There is an opportunity to review the roles that fibre network owners and RSPs have with regards to CPE offerings, in an aim to promote the use of more energy-efficient equipment.

Figure 7 – Proportion of power use by customer equipment out of total power use in the access network




## 7.3 For average access rates higher than ~50 Mbps, GPON has a lower per-user emissions footprint than all other non-fibre technologies in New Zealand

**VDSL.** For VDSL, higher per-user emissions are due to low network utilisation, with the number of users being approximately 20 times lower than in a fully-utilised network. This explains the large gap in per-user emissions estimates between the actual and theoretical scenarios (Figure 5)

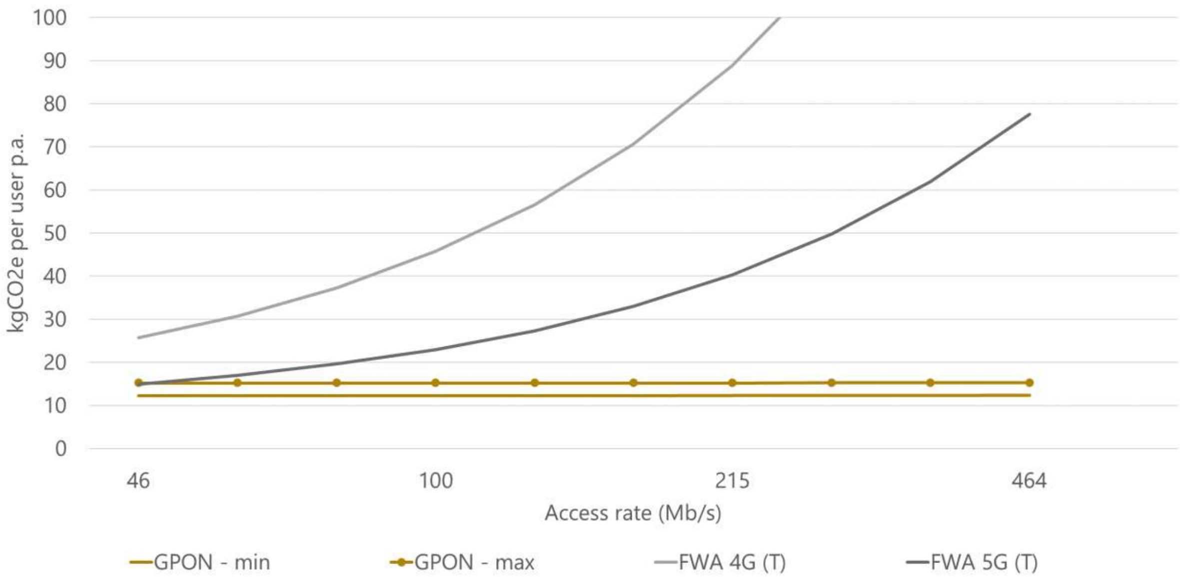
We note that, in contrast to the findings in (Baliga, et al., 2011), our estimates of power consumption in the VDSL theoretical scenario are lower than that in the GPON theoretical scenario. This is because CPE power consumption in the former case is almost half that of that in the latter case. By contrast, CPE power consumption in (Baliga, et al., 2011) is equal for ADSL and PON technologies.

**HFC.** High emissions per user for the HFC technology also reflect low utilisation of the network in New Zealand. However, even under high utilisation, HFC has been shown to be more energy intensive than GPON ( (Baliga, et al., 2011), (Prysmian Group, 2021)).

**Fixed wireless.** At lower rates, fixed wireless can share capacity among a large number of users, and therefore can achieve high efficiency and utilisation, resulting in a lower emissions profile. As the access rate increases, the available bandwidth provided by the given radio channel and base station is exhausted, and additional resources must be deployed to deliver the improved service.

The figure below compares GPON with 4G and 5G fixed wireless over a range of advertised broadband speeds in New Zealand.[40] It can be seen that GPON has a much lower per-user emissions footprint for access rates over 50 Mbps. At 50 Mbps, per-user emissions for FWA 4G are about twice as high as those of GPON. At 300 Mbps, per-user emissions of FWA 5G are about four to five times higher than those of GPON.

Figure 8 – Emissions in GPON and FWA 4G/5G networks for average access rates between 50 and 500 Mbps

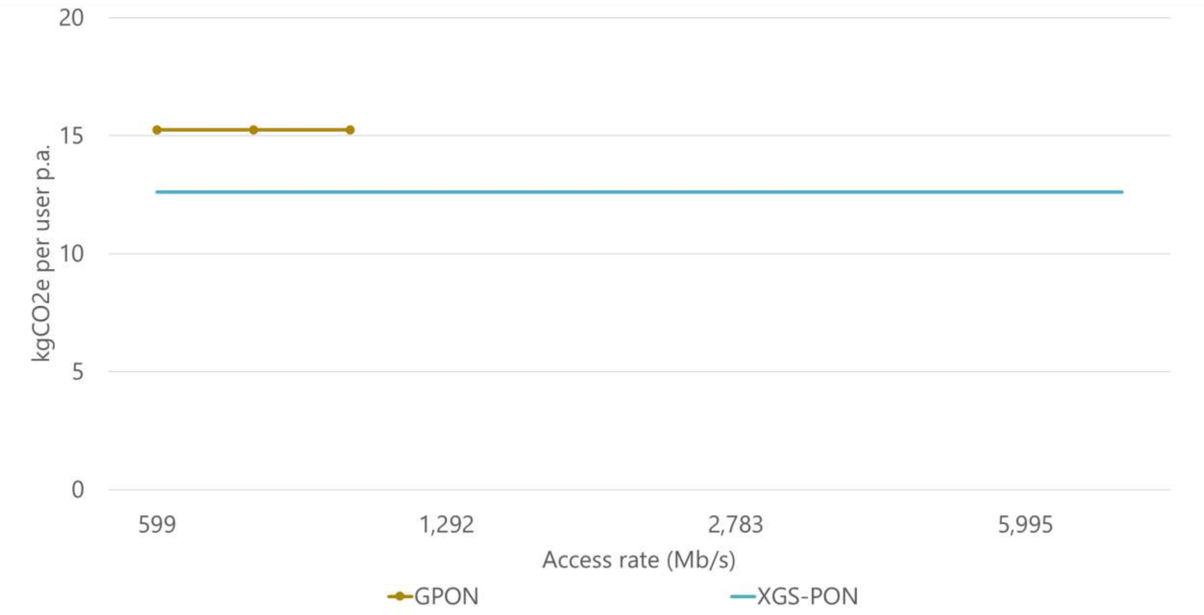



## 7.4 For fibre networks with comparable minimum speeds that can be supported, the emissions footprint of XGS-PON can be lower than that of GPON

In the model, comparable minimum speeds that can be supported (MPUS) in the GPON and XGS-PON networks occur at average access speeds greater than 600 Mbps, where MPUS are between 46 and 49 Mbps (Figure 5). Figure 9 provides a snapshot of this segment. As can be seen from the figure, per-user emissions are lower for theoretical XGS-PON over that segment (by about 17 per cent), mainly due to lower CPE power consumption, and also due to lower power per-user consumption at the OLT.

[40] https://www.vodafone.co.nz/home-wireless-broadband/, https://www.chorus.co.nz/broadband

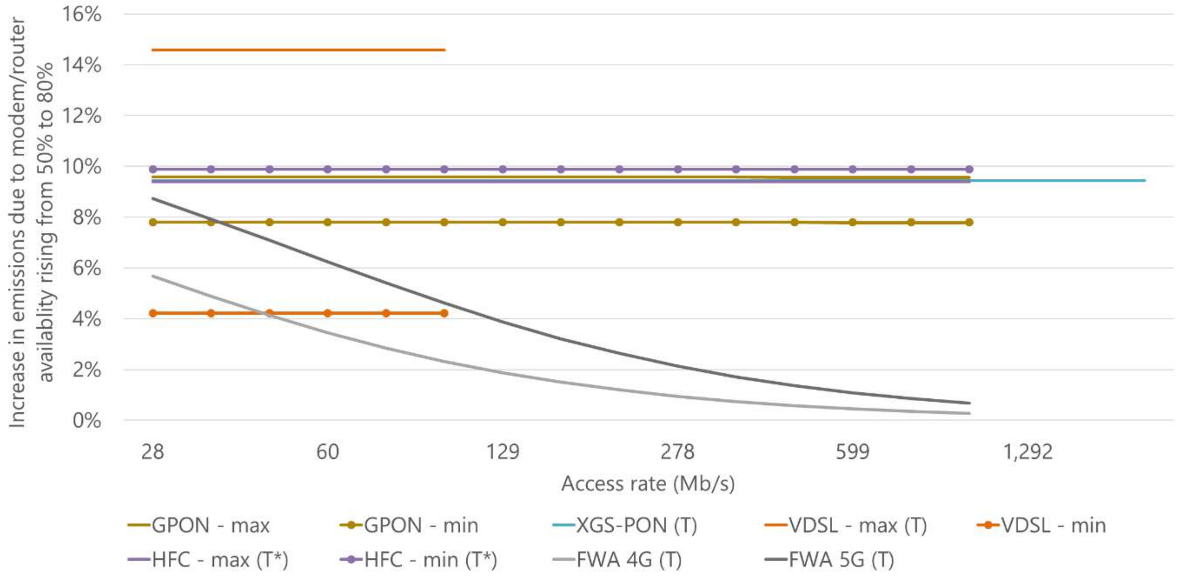
Figure 9 – Comparison of per-user emissions in GPON and XGS-PON networks with comparable minimum speeds that can be supported




## 7.5 Absolute emissions are sensitive to the active time assumed for modems and routers, whereas relative emissions are not

The results presented in Figure 6 assume that routers and modems are active half of the day (50% availability factor). If this factor increases to 80 per cent, absolute emissions across the networks also increase (Figure 10). For the fibre network, the range of increase is 8-10 per cent. For HFC the range is 9-10 per cent, and for VDSL it is 4-15 per cent. In fixed wireless networks, total emissions become less susceptible to changes in the availability factor of the modem at higher average access rates. This is because total power consumption becomes dominated by the power use of electronics outside the customer premises.

Figure 10 – Increase in absolute emissions due to an increase in modem/router active time from 50 to 80 per cent of the day




Notwithstanding the increase in absolute emissions, the figure below shows that a change in the availability factor of routers/modem does not significantly change the relative emissions footprint of networks. In the 80% scenario, at 50 Mbps the per-user emissions for 4G are twice as high as those for GPON (similar to the 50% scenario). At 300 Mbps, the per-user emissions for 5G are four times higher than for GPON (compared to four to five in the 50% scenario). Table 6 summarises the range of emissions reductions from GPON compared to other broadband options for two scenarios of modem/router availability.

Figure 11 – Per-user emissions assuming the modem/router is active 80 per cent of the day

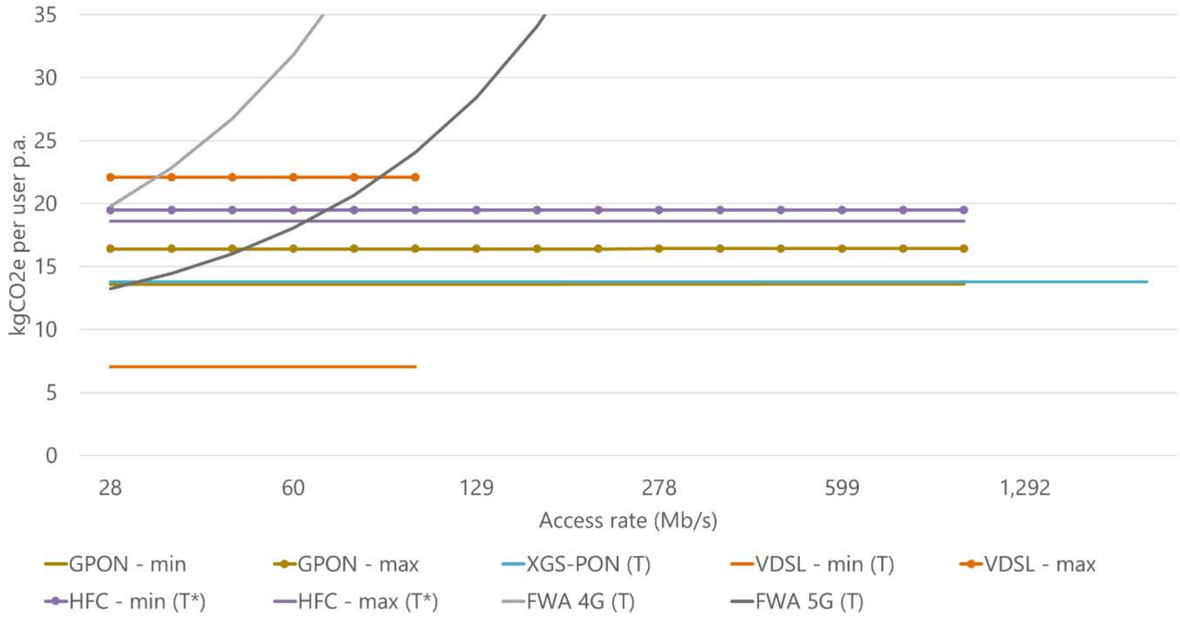


Table 6 – Comparison of emissions reductions in two scenarios of modem/router active time (50 and 80 per cent of the day)

| | Access rate | 50% scenario | 80% scenario[41] |
|---|---|---|---|
| **GPON vs VDSL** | <100 Mbps | 28%-41% | 26%-38% |
| **GPON vs HFC** | <1,000 Mbps | 12%-29% | 14%-29% |
| **GPON vs FWA 4G** | 50 Mbps | 46%-56% | 43%-53% |
| | 300 Mbps | 88%-90% | 87%-89% |
| | 1,000 Mbps | 96% | 96% |
| **GPON vs FWA 5G** | 50 Mbps | 4%-22% | 3%-20% |
| | 300 Mbps | 72%-77% | 71%-76% |
| | 1,000 Mbps | 91% | 91% |

[41] Assumes the modem/router is active 80 per cent of the day, and is idle 20 per cent of the day.

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# Appendix A Assumptions on customer premises equipment

Table 7 – Detailed information on customer premises equipment by broadband technology

| Technology | Type of device | Manu-facturer | Series | Weight (grams) | Plant location[42] | Average km travelled by sea |
|---|---|---|---|---|---|---|
| Fibre | ONU | Calix | T063G (II) | 310 | California, USA | 36,738.12 |
| Fibre | ONU | Calix | T072G | 280 | California, USA | 36,738.12 |
| Fibre | GigaHub | Calix | 812G & 813G | 400 | California, USA | 36,738.12 |
| Fibre/VDSL | modem | NetComm | NF8AC | 430 | Shenzhen, China | 12,404.70 |
| HFC | modem | Technicolor | TC4400 | 650 | Melbourne, Australia | 3,208.59 |
| Fibre/HFC/VDSL | modem | Vodafone UltraHub (manufacturer not known) | | 509 | Shenzhen, China | 12,404.70 |
| FWA | gateway | Nokia | 3.2 | 1,000 | Chenni, India | 14,008.53 |
| FWA | gateway | Nokia | 3 | 1,000 | Chenni, India | 14,008.53 |
| FWA | receiver | Nokia | 5G14-B | 450 | Chenni, India | 14,008.53 |

[42] We note that in some NZ fibre networks, the ONT is are shipped from Chinar or Vietnam, and in that case emissions from international shipping would be lower.

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