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Study for Stokab

Neutral fibre and the European Green Deal

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0 Executive summary

0.1 Stockholm: a model for the European Green Deal

In 2019, the European Commission adopted a Communication on the European Green Deal.[1] The Communication sets out the Commission's commitment to tackling climate and environmental challenges. At its heart is a target to reduce the EU's greenhouse gas emissions by at least 50% compared to the levels of 1990. To achieve this aim, significant reductions in transport emissions will be needed, alongside a dramatic shift in energy consumption in buildings, which account for 40% of the energy consumed today.

As the capital of Sweden, one of Europe's leaders in energy efficiency, Stockholm has set its own target to become climate positive by 2040.[2]

A key element of this strategy is to leverage the City's dark fibre network to support smart transport and building solutions as well as the re-use of waste energy. The fibre network has also played a critical role in enabling homeworking and remote healthcare provision during the Coronavirus epidemic, which reduced congestion and pollution in the City as well as providing support to the local economy during a time of crisis.

In this study, with the aid of interviews and case studies, we explore how Stockholm City's fibre network, AB Stokab has helped Stockholm to become amongst the world's greenest cities, and evaluate the environmental benefits that could be achieved across Europe if other communities follow Stockholm's example.

0.2 Fibre as a platform for innovation in environmental solutions

Transport has been one of the main contributors to CO2 emissions in Sweden (and elsewhere) since the 1980s.[3] Energy consumption in buildings was also traditionally a key source of Green House Gas emissions. Stockholm's fibre network has however played an important role in limiting these effects, as well as supporting initiatives which reduce the carbon footprint of the ICT sector itself.

Stockholm's fibre network supports extensive use of **homeworking** as well as remote healthcare and learning by the City's businesses and residents. During the first wave of the Coronavirus epidemic, congestion levels fell to 50% of their usual values as an estimated 30-50% of the population used their broadband connection to work or study from home. During this time, 12,500 students from 29 schools/gymnasia across the region of Stockholm were reliant on remote education, and doctors' appointments were

1 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX:52019DC0640
2 https://international.stockholm.se/city-development/the-eco-smart-city/
3 See https://www.worldometers.info/co2-emissions/sweden-co2-emissions/

routinely made via eHealth applications, many of them supported by Stockholm's vibrant innovation centres.[4]

Stokab's network is also supporting solutions which reduce journey times or eliminate unnecessary journeys (**smart transport**). For example, Smart Waste Handling, which involves using sensors to identify different types of waste and facilitate their separation, underground transportation and recycling,[5] has reduced traffic from waste vehicles by 90% with an accompanying reduction in CO2 emissions, noise and pollution. Buses experienced 25% faster driving times in a trial of dynamic traffic light controls. More generally, plans to extend fibre within the road network and enable access at traffic lights and other street furniture should provide an infrastructure platform for the development of other smart services which could support environmental goals, such as sensor-based systems to monitor congestion and air quality, as well as traffic management systems[6] for trucks and passenger vehicles. Fibre access points in the street could also support the deployment of 5G small cells, which in turn could facilitate other digital applications in the Internet of Things (IoT) space.

Fibre-connected sensors can also be used to optimise energy use in buildings, by controlling the use of heating, lighting and air conditioning to precisely reflect ambient conditions. Sisab, which is responsible for maintaining Stockholm's schools, was able to save 35% of energy, equaling 18,500 tons of CO2 or 4 million Euros per year between 2012 and 2019, through using "smart building" solutions, supported by fibre. Further efficiencies have been achieved through AI solutions.

Stockholm is also a leader in the re-use of energy from data centres. Through the Stockholm Data Parks initiative, excess power from data centres has been recycled to support Stockholm's district heating system. The data centres are able to support the heating and hot water needs of around 34,000 apartments.

Stokab itself has also used the heat from its largest core node to supply a school with heating and hot water, and Stokab estimates that heat generated by its other core nodes, area nodes and access nodes could have the potential to supply heating for around 2,000 apartments if the same solution were used.

0.3 Estimating the impact of fibre networks and digitisation on emissions

The highest proportion of energy is consumed in the operational phase (around 90% for fixed networks).

4 The region has the most unicorns per capita in the world after Silicon Valley and is home to innovation centres such as the H2 Health Hub https://www.investstockholm.com/globalassets/invest/reports/healthtech_170602.pdf

5 https://grow-smarter.eu/fileadmin/editor-upload/12Solutions/Factsheets/Stockholm/Solution_7_Smart_waste_collection_Stockholm.pdf

6 For example, sensors could be used to control a congestion charging scheme, or limit heavy good vehicles to certain times of day or routes

Various studies show that FTTH is considerably more energy efficient than technologies involving legacy infrastructure.

According to our estimations, a complete migration from the current fixed broadband technology mix in the EU to all fibre would result in emissions from the use of broadband access falling from 15.5 Mio t CO2 to 3.2 Mio t (fibre technology mix) and to 1.1 Mio t of CO2 (only point to point (PtP) connections) per year, if the existing power sources remained unchanged. This represents a reduction in emissions of more than 90% if all broadband connections in the EU moved to PtP FTTH. Moreover, PtP-FTTH can readily offer symmetrical Gigabit speeds with the capacity to further extend bandwidths over time, and can thus be seen as a future-proof technology.

PtP fibre is also an important supporting element for 5G, which is predicted to be significantly more energy efficient than previous generations of mobile technology, as well as enabling other sectors to become more energy efficient.[7]

Estimates of the potential impact on greenhouse gas emissions of adopting smart building and smart transport solutions vary widely. Estimates of the savings achievable from the application of smart building technologies range from 15-50%. As regards transport, a 2019 study estimates that initiatives to support driverless electric freight vehicles could reduce the impact of transport on the climate by 60%, while reductions of up to 90% could be achieved for countries with a low-carbon electricity mix, like Sweden.

0.4 The role of neutral networks in the European Green Deal

The Commission has acknowledged that digital solutions can advance the circular economy, support the decarbonisation of all sectors and reduce the environmental and social footprint of products placed on the EU market. However, in order to achieve positive effects, data centres and telecommunications will need to become more energy efficient, reuse waste energy, and use more renewable energy sources.

The experience of Stockholm, and Sweden more generally, shows that efficiencies in the operation of broadband networks and climate neutral data centres can be achieved. At the heart of these efficiencies has been a passive fibre network, which has been operated as a utility for the benefit of the City, its businesses, workers and inhabitants. A key benefit of a neutral dark fibre infrastructure is that service and application providers have been free to innovate, in the fields of data warehousing, monitoring of air and water pollution, smart buildings, eHealth, AI-driven learning applications and beyond.

7 Public and industrial applications provided over 5G, could reduce pollution, limit the use of toxic materials and foster energy savings in other sectors e.g. by supporting the development of autonomous vehicles, and targeting the use of herbicides in farmingSee Chapter 5.4 WIK (2019) Analysis of the Danish Telecommunication Market in 2030 (https://www.wik.org/fileadmin/Studien/2020/Analysis_of_the_Danish_TK_Market_in_2030.pdf)

Policies aimed at fostering the deployment and take-up of very high capacity broadband connections have typically focused on the economic and social benefits associated with high speed broadband, alongside the economic costs of deploying these networks. However, in view of the vital role that broadband has to play in achieving the European Green Deal (and in reducing existing emission levels), greater attention could also be paid to the environmental costs and benefits. For example:

- Energy efficiency could be taken into account in the context of public funding or other public support given to telecom network deployment. Consumers could also be made aware of the energy efficiency of broadband connections in the context of any broadband labelling schemes.
- Facilitating the transition from legacy copper and cable infrastructure to full fibre could contribute to significant energy savings in the operation of telecoms networks. Efforts to support this transition coupled with the switch-off of legacy infrastructure could contribute to stablising or reducing the carbon footprint of the telecom sector while supporting increased bandwidths.
- Examples such as Sweden illustrate how the participation of municipalities in the provision of neutral dark fibre infrastructure can contribute to innovation in the fields of environmental monitoring and smart transport and building solutions, as well as contributing to reduced requirements for digging. When pursuing strategies to support VHC broadband, Governments and local authorities should consider the role that could be played by municipal networks in supporting deployment and take-up, as well as in promoting wider societal and environmental goals.

More generally, in view of its essential role in the Coronavirus pandemic and its importance in supporting environmentally sustainable broadband and digital services for the future, there may be a case to consider fibre as an essential infrastructure for the digital revolution, in much the same way as roads, railways, and the exploitation of fossil fuels powered the industrial revolution.

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1 Introduction

In 2019, the European Commission adopted a Communication on the European Green Deal.[8] The Communication sets out the Commission's commitment to tackling climate and environmental challenges. At its heart is a target to reduce the EU's greenhouse gas emissions by at least 50% compared to the levels of 1990. To achieve this aim, significant reductions in transport emissions will be needed, alongside a dramatic shift in energy consumption in buildings, which account for 40% of the energy consumed today.

As the capital of Sweden, one of Europe's leaders in energy efficiency, Stockholm has set its own target to become climate positive by 2040.[9]

A key element of this strategy is to leverage the City's dark fibre network to support smart transport and building solutions as well as the re-use of waste energy. The fibre network also played a critical role in enabling homeworking and remote healthcare provision during the Coronavirus epidemic, which reduced congestion and pollution in the City as well as providing support to the local economy during a time of crisis.

In this study, with the aid of interviews and case studies, we explore how Stockholm City's fibre network, AB Stokab has helped Stockholm to become amongst the world's greenest cities, and evaluate the environmental benefits that could be achieved across Europe if other communities follow Stockholm's example.

- In chapter 2, we describe Stokab's business model and its role in supporting the local environment and combatting climate change
- In chapter 3, we illustrate through case studies how Stokab's network has been used to reduce pollution from transport and heating, as well as supporting efficient management of water supplies
- In chapter 4, we estimate how moving to all-fibre infrastructure would impact energy emissions from broadband across Europe, as well as considering the potential energy and CO2 savings that could be made if other cities and countries pursued smart building and transport strategies
- In chapter 5, we discuss the role that neutral fibre networks could play in supporting the European Green Deal
- We conclude in chapter 6 with recommendations on how communications sector policies could be adapted to take account of Europe's overarching climate goals

8 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX:52019DC0640
9 https://international.stockholm.se/city-development/the-eco-smart-city/

2 Stockholm: a showcase for sustainable broadband

KEY FINDINGS

The City of Stockholm has established a Climate Action Plan with the aim of achieving a fossil free and climate positive Stockholm by 2040.

The City's passive fibre network Stokab provides one of the key mechanisms through which the city can achieve its climate goals.

Stokab operates a point to point fibre network which connects nearly all the public buildings, offices and apartment buildings in Stockholm.

Stokab has been set an objective to "ensure the conditions for the digitization work of the city and the business community, thereby enabling climate-smart solutions".

Stokab has contributed to the City's environmental goals by reducing the need for digging in the city and by enabling the migration to modern energy-efficient fibre broadband connections. Stokab's neutral network has also been used to support a variety of digital applications and facilitate the re-use of waste energy to heat the City.

In this chapter, we describe the overarching environmental aims of the City of Stockholm and discuss the role played by Stokab in supporting the City's environmental goals.

2.1 The City of Stockholm: a green city

The Stockholm region is responsible for all publicly funded healthcare and public transport in Stockholm County. The Region Stockholm Assembly is also responsible for other activities, such as regional planning and cultural grants.

In 2012, the Swedish Capital set out an ambitious goal of becoming fossil fuel-free by 2050. The City subsequently strengthened this goal and today, Stockholm has the ambitious target to run exclusively on renewable energy by 2040.[10]

Digitisation provides one of the cornerstones through which the City of Stockholm plans to achieve its objectives. Indeed, the Deputy CEO of the City of Stockholm Staffan Ingvarsson observed in an interview conducted for this study that:

10 Interview with Mika Hakosalo – City of Stockholm, Environmental Department. See also the City of Stockholm's Strategy for a fossil-fuel free Stockholm by 2040

> ***"The City Council of Stockholm has adopted the strategy to become the world's smartest city." (Deputy CEO Staffan Ingvarsson, City of Stockholm)***

One of the mechanisms through which the City achieves its digitization goals is the operation, through its subsidiary AB Stokab, of a dense dark fibre network in the City of Stockholm as well as backbone infrastructure covering the wider region.

2.2 Stokab's ownership model and objectives

AB Stokab is a wholly owned subsidiary of the City of Stockholm. It was established in 1994, initially to provide connectivity to public institutions, universities and businesses in the knowledge-intensive Stockholm region. Stokab's fibre network was later expanded to cover smaller business and households within "multi-dwelling units" (MDUs) and in addition nearly all commercial buildings.

From its inception, the City Council considered Stokab as a public infrastructure company, much like a public organisation responsible for roads.[11]

As befits a publicly-owned organisation, Stokab's aims go beyond an interest in achieving a return on its substantial investments to provide "a competitive neutral IT infrastructure in the Stockholm region to create competition, diversity, freedom of choice and minimize the digging in the city."[12]

More specifically, the City of Stockholm has directed Stokab, via its extended fibre network to "provide the conditions to support the digitization of the city and the business community, thereby enabling climate-smart solutions".[13]

2.3 Architecture of the Stokab network

The Stokab network serves a population of around 3m in the Greater Stockholm area, including 1m in the City of Stockholm itself. Stokab's network is very dense in the City of Stockholm, and provides backbone connectivity, connecting other city networks, schools and hospitals in the Greater Stockholm area. Stokab's business model is based on the provision of unbundled dark fibre. Stokab does not provide active equipment or offer telecommunications services itself, but supplies fibre as a "basic utility" to a range of customers for any purpose.

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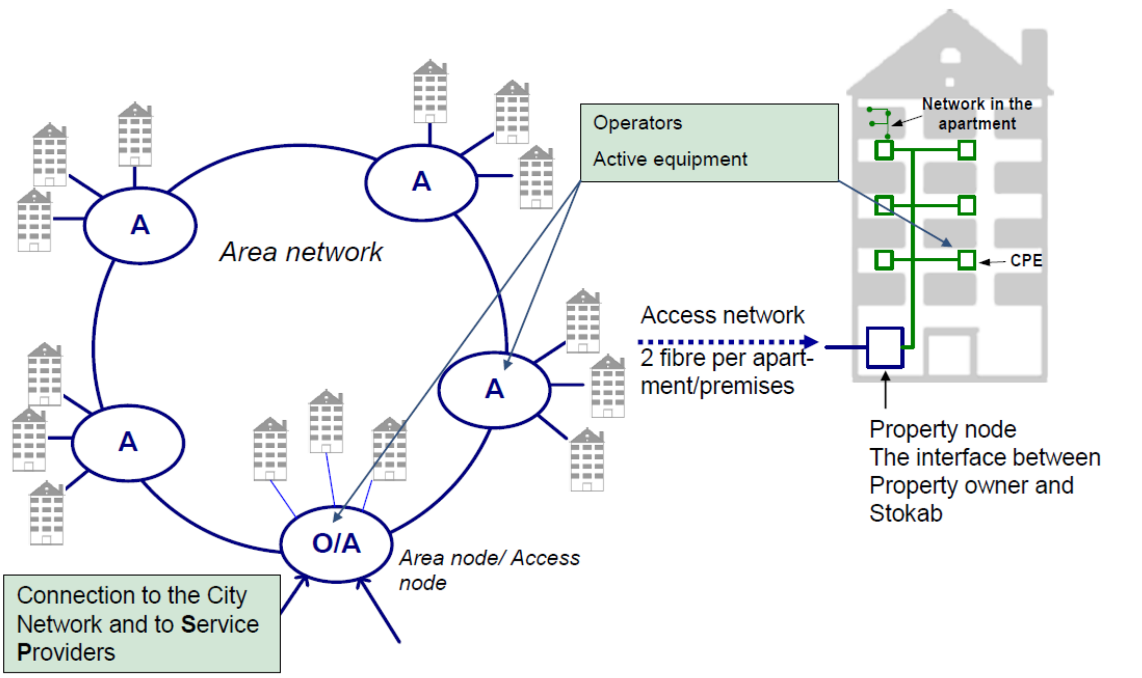
11 https://www.ftthcouncil.eu/documents/CaseStudies/STOKAB.pdf
12 https://www.stokab.se/Om-oss/
13 https://www.stokab.se/Om-oss/Foretagsfakta/

Stokab has installed 9,500km of fibre optic cables which can be accessed via 350 access nodes (see diagram below). On average, 5 different service providers are present at each node.

Figure 2-1: Stokab network



Stokab focuses on deployment to offices, public buildings and MDU's. Its network terminates in 23,000 buildings including 11,500 apartment buildings serving 400,000 households. The in-building wiring is controlled by the owners of the buildings.

Nearly all buildings have been served with multi-fibres (2 per company/dwelling with extra fibre capacity for future use). This structure provides resilience and flexibility for future use, as well as the opportunity for customers to take services from different service providers.

Connecting to an access node enables service providers to reach between 35-40 buildings and 1,500-2,000 households. Because Stokab has installed point to point connections with multiple fibers to every premise, there is no need to deploy a PON solution when connecting customers, even for the mass-market. Service providers prefer point to point connections when they are available, as these offer a more future-proof solution, which can be readily upgraded to meet customer needs.[14] Stokab's dense node-based network architecture is capable of being adapted to future needs, and is currently being expanded to support the provision of 5G mobile services. Trials are being conducted in conjunction with Ericsson to support driverless buses.[15] In addition, the network is also being extended to support smart city infrastructure, by connecting the network to street traffic lights and other street furniture such as bus-stops.

2.4 Network performance and competition on the Stokab network

Stokab competes at the infrastructure level with the incumbent Telia and cable operator Comhem, whose DOCSIS 3 network covers more than 75% of premises in the Stockholm area. According to data gathered by the Swedish regulatory authority PTS, in October 2019, based on the combined coverage of the three network operators, Stockholm benefited from fibre coverage of more than 97%, and nearly 100% of premises in the Stockholm area could access Gigabit broadband.

Retail competition is intense, as the passive wholesale only nature of Stokab's business means that there are a wide range of services available from different suppliers over its network (in addition to providers offering services over the Telia network and Comhem).

Stokab's network hosts 900 customers and more than 100 operators and service providers. The customers of Stokab's network include public sector organisations, including the City of Stockholm and Stockholm County Council, which operates the region's hospitals, as well as colleges and universities. Stokab's fibre is also widly used by private companies including banks, and companies in the fields of construction, manufacturuing, pharmaceutical and retail services. A diagram of the role that Stokab's network plays in supporting different types of customers is shown below.

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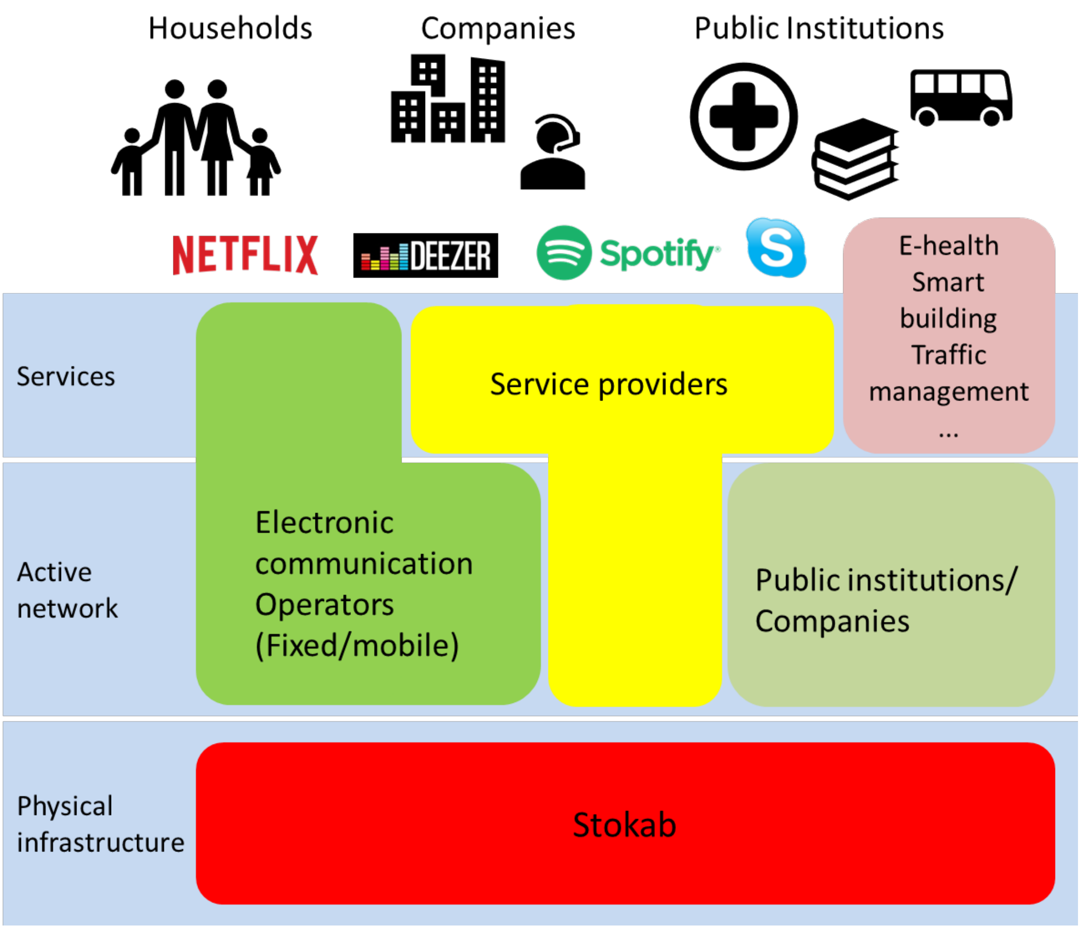
14 The benefits of point to point connections from a technical and service perspective are discussed in more detail in the WIK (2020) study on Future electronic communications product and service markets subject to ex-ante regulation https://ec.europa.eu/digital-single-market/en/news/study-future-electronic-communications-product-and-service-markets-subject-ex-ante-regulation

15 http://www.stokab.se/Nyheter-Press/Nyheter/Stokabs-fiber-skapar-testmojligheter-med-5G-natet/

Figure 2-2: Business model of Stokab's fibre network



Source: WIK-Consult

The separate sale of dark fibre to large public and commercial organisations allows Stokab's customers to activate the fibre themselves or procure communication and other digital services, including data warehousing, secure communications, and over-the-top services and applications in the open market.

This has enabled the authorities to achieve significant cost savings as well as enabling innovation in public service offerings. For example, according to Stockholm's former financial county councillor Ms Elmsäter-Svärd:

> "***In the mid-90s, we were able, thanks to the operator-neutral fibre network Stokab, to connect all our hospitals and then procure telecommunications and data communications among all the operators who were active in the region. Already in the first year, we reduced costs by 6 Million Euro***." (Stokab 20 year anniversary book)

Further savings were made to the City of Stockholm´s annual costs for telephone communication. By linking together the city's different administrational offices, companies, schools and elderly care units with leased fibre from Stokab and procuring telephony through a separate competitive tender, costs where reduced from €15m in the 1990s by 40% to around €9m million Euro/year.[16]

In addition to hosting international and national broadband service providers, Stokab's network is also used by local and regional operators and specialist business providers, as well as mobile operators, which use dark fibre to provide backhaul connectivity for their mobile network.

In an interview for a study conducted by WIK in 2018,[17] Peter Bryne, an independent consultant who was previously Head of Core and Transmission for Net4mobility, the joint venture between the mobile operators Telenor and Tele2 in Sweden, noted that

> "***The availability of fibre city networks which have already been used to provide backhaul for 4G may enable a more rapid evolution towards 5G. Such networks will in particular provide an advantage for the second and third player in 5G compared with countries in which wholesale dark fibre is not available to the same degree***".

This has been borne out by recent developments as, in addition to the incumbent Telia, two other operators – Tele2 and Three - have already established 5G networks in parts of the City of Stockholm with plans to cover most of the city with 5G in the near future,[18] and at least one other player is planning to start 5G operations in Stockholm in the near future. The requirement for fibre to support 5G is likely to increase as demand grows and the number of cell sites increases.

2.5 Stokab's contributions to environmental goals

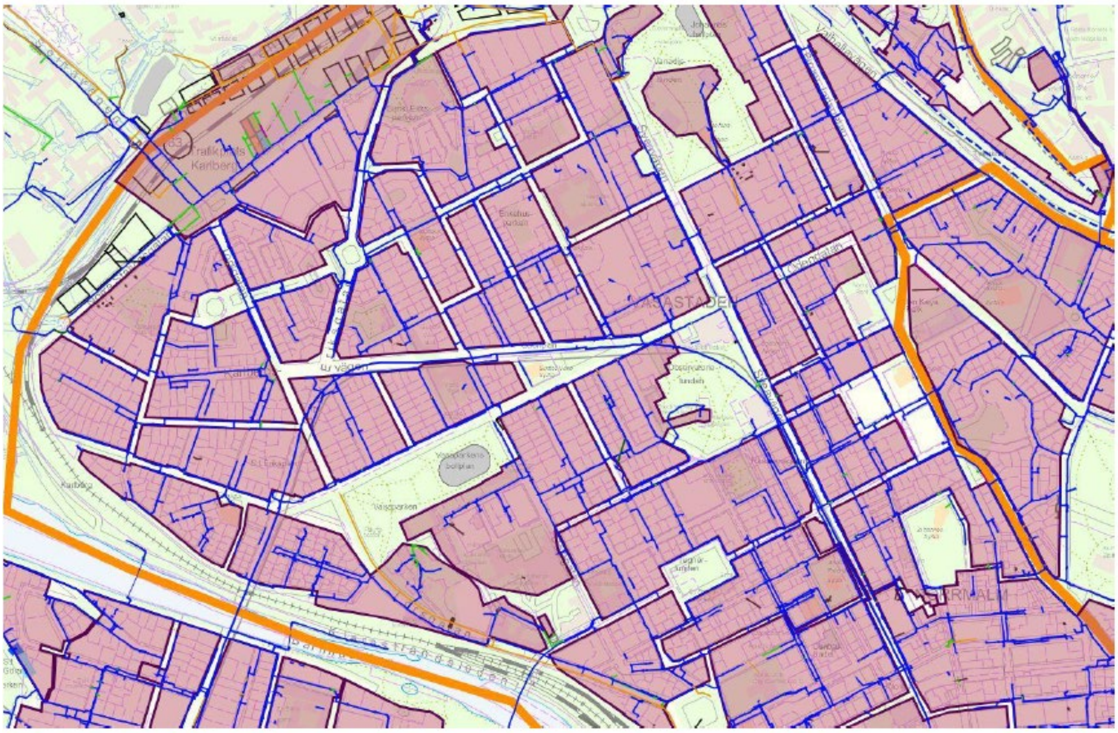
Stokab's business model contributes to Stockholm's environmental goals by both reducing the carbon footprint of broadband networks in the city and by facilitating the provision of digital services. Some examples follow.

Future-proofing infrastructure, reducing digging

Stokab has installed ducts across Stockholm with sufficient capacity to hold fibre to serve the population for the years to come. In each 110mm duct there is space for 4 sub ducts, each of which is capable of holding up to 1,000 fibre cables. Stokab's extensive duct network (illustrated in the figure below) has meant that, when Stokab connected nearly all MDUs in the city in 2012, it could do so to a large extent through its existing duct network, avoiding digging up the streets.

16 Analysis conducted by the City of Stockholm Executive Office 1996
17 WIK (2018) The role of wholesale only models in future networks and applications
18 https:/www.mobileeurope.co.uk/press-wire/14809-swedish-operators-announce-5g-launches

Figure 2-3: Stokab's duct network (shown in blue)



Source: Stokab

Through its status as a municipally owned utility, Stokab was also able to readily gain permission from building owners to connect buildings from basement to basement, which also increased the speed of deployment and reduced the need for digging between buildings

The adoption of a passive only wholesale only model has also reduced the need for other operators to access or deploy their own ducts, as dark fibre is readily available on equal terms for all needs. Moreover, where new ducting is needed, Stokab ensures there is sufficient space for future needs, and co-ordinates its digging with other utilities, where possible, in line with its commit to "support the traffic committee's task of co-ordinating street work with other leading companies in the city as well as the Swedish Transport Administration".[19]

Reduced digging limits the disruption to local households and businesses as well as limiting the pollution and energy consumption associated with installing duplicate infrastructure.

19 https://www.stokab.se/Om-oss/Foretagsfakta/

Enabling optimal energy use by broadband providers

Stokab's node system means that a number of operators can co-locate their active equipment in the same location and optimise the use of this active equipment across multiple buildings and customers instead of having the active equipment in the basement of each building, as each access node can serve up to 2,000 premises. This should enable more efficient use of capacity, and save energy. Sharing of facilities such as uninterrupted power supplies (UPS) is also possible amongst the co-locating operators.

Re-use of energy for district heating

The concentration of heat-generating equipment in one location can also facilitate the re-use of waste energy, for example through district heating. Stokab has used the heat from its largest core node to provide the heating and hot water needs for a school (see section 3.2.2)

Supporting the migration to energy-efficient fibre

As discussed in section 2.4, the deployment of dark fibre by Stokab has contributed to the widespread availability of competitive fibre-based services within the Stockholm region and enabled customers to migrate from copper and cable to fibre technology. As the carbon footprint of fibre is significantly lower than that of copper and cable for a given bandwidth consumption, Stokab's primary business has made a substantial contribution towards reducing energy needs for broadband in the area covered by its network.

Providing a platform for digitisation

In addition to facilitating more energy-efficient forms of broadband, Stokab's infrastructure has been used to provide a platform for remote working, and the wider digitisation of transport, public services and buildings across the Stockholm area. These applications are likely to provide significant benefits for the environment, as well as sustaining the economy and contacts amongst vulnerable populations during the Coronavirus pandemic. More detailed use cases of Stokab's infrastructure are provided in the chapters that follow.

3 Case studies in digitisation

The primary sources of greenhouse gas emissions in Sweden and other advanced economies stem from transportion in fossil-fuel powered vehicles. Energy consumption (including heating) in buildings has also historically contributed to greenhouse gas emissions.

In this chapter, we explain through case studies and interviews how Stokab's network has been utilised to support digitisation and reduce energy consumption by enabling remote working and service provision, increasing efficiency in transportation, supporting "smart building" applications and improving efficiency in the delivery of essential services such as water and sewerage.

KEY FINDINGS

Sweden provides one of the few examples of a country in which greenhouse gas emissions have fallen while economic prosperity has increased. In 2014, Sweden's CO2 emissions had fallen to 40% of the levels seen 50 years before.

CO2 emissions in Stockholm have fallen from 7.45 to 6.23 tonnes per capita in the last 10 years. Reductions in emissions from buildings have been substantial, but pollution from transport remains a challenge for Stockholm's climate goals.

Stockholm's fibre network supports extensive use of homeworking and remote healthcare and learning by the City's businesses and residents. During the peak of the Coronavirus epidemic, congestion levels fell to 50% of their usual values as an estimated 30-50% of the population used their broadband connection to work or study from home.

Stokab's network is also supporting smart transport solutions. Smart Waste Handling, which involves using sensors to identify different types of waste and facilitate their separation, underground transportation and recycling, has reduced traffic from waste vehicles by 90% with an accompanying reduction in CO2 emissions, noise and pollution. Buses experienced 25% faster driving times under a trial of dynamic traffic light controls and plans to fibre street furniture should provide further opportunities for traffic monitoring as well as enabling the implementation of control systems such as congestion charging and measures to exclude or control the most polluting vehicles.

By using fibre to connectt sensors to control heating, lighting and air conditioning, Sisab was able to save 35% of energy, equivalent to 18,500 tons of CO2 and save €4m per year in Stockholm's schools between 2012 and 2019. Further efficiencies have been achieved through AI solutions.

Stockholm is a leader in the use of cloud computing. Extensive fibre capacity allows data to be centrally processed rather than distributed amongst many offices and server rooms. According to Layer Mesh, one virtual machine cluster can support 300-500 companies, using the same energy as one company with 3-4 traditional servers.

Through the Stockholm Data Parks initiative, excess power from data centres has also been recycled to support Stockholm's district heating system. The data centres are able to support the heating and hot water needs of around 34,000 apartments. Stokab itself has also used the heat from its largest core node to supply a school with heating and hot water, and Stokab estimates that heat generated by its other core nodes, area nodes and access nodes could have the potential to supply heating for around 2,000 apartments if the same solution were used.

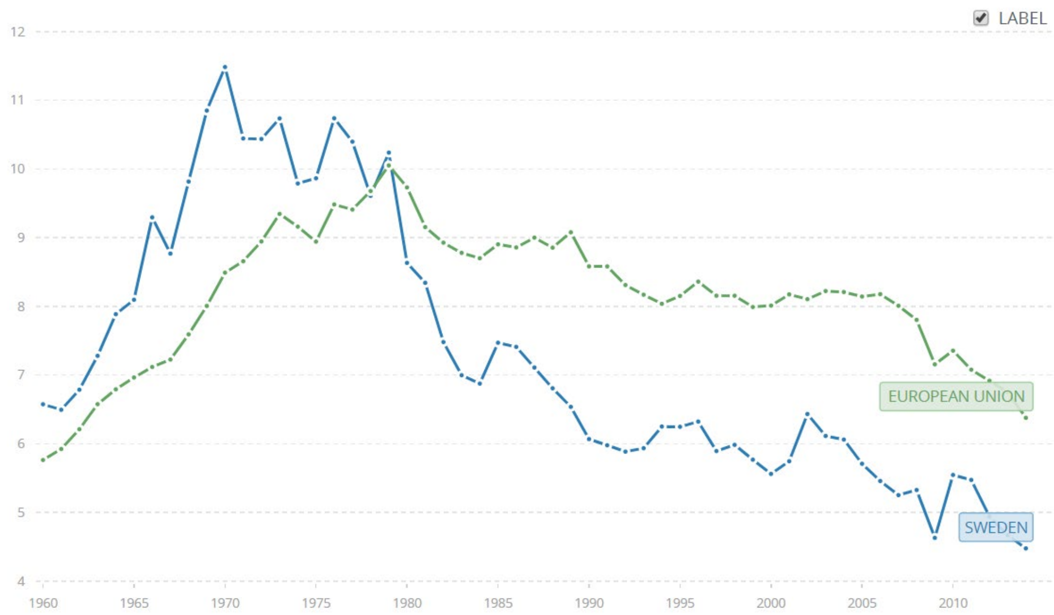
Fibre connectivity is also being used to reduce water wastage through monitoring and predictive maintenance.

3.1 Sweden's carbon footprint

Sweden has achieved considerable success in reducing CO2 emissions, and has been seen as a leader in Europe at a time when many countries have struggled to reduce their reliance on fossil fuels and other contributors to climate change.

The following figure shows the development of per capita CO2 emissions in Sweden and the EU since 1970, and highlights that emissions have fallen from 11.5 tonnes CO2 per capita to approximately 4.5 tonnes over the last 50 years.[20]

Figure 3-1: Development of CO2 emissions per capita in Sweden and the European Union, 1960-2014

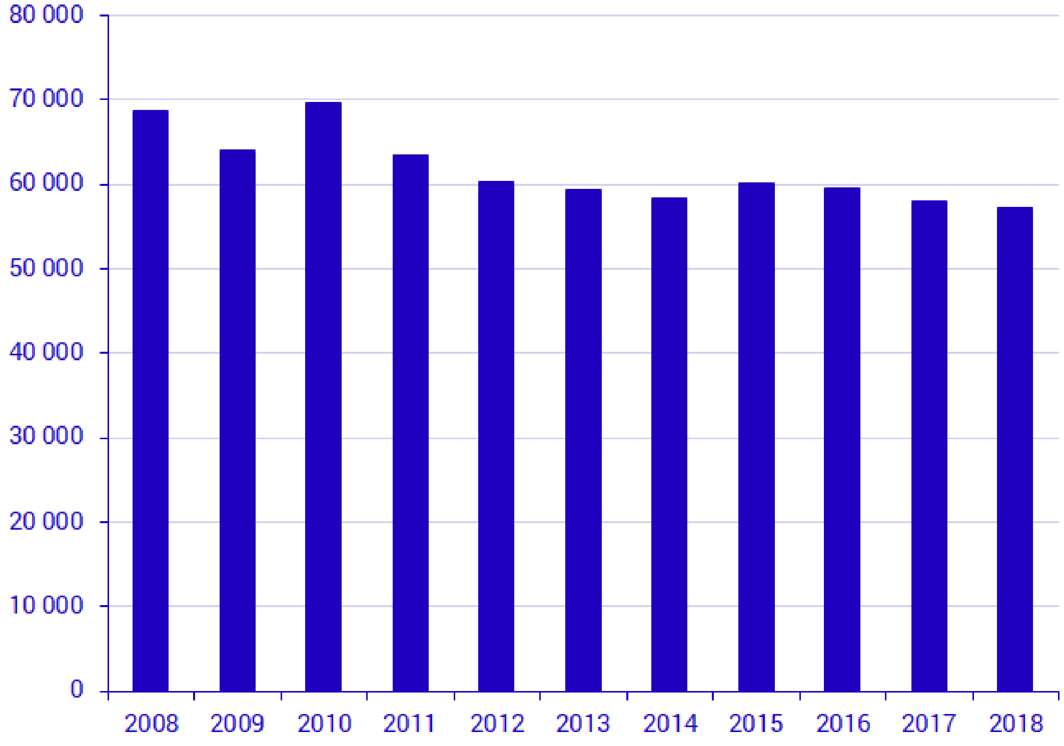


Source: https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?locations=SE-EU

Progress has continued in recent years, albeit at a more gradual pace, as can be seen from data gathered by Statistics Sweden, which shows a decline from 70m tonnes in 2010 to below 60m tonnes in the years to 2018.

20 https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?locations=SE-EU

Figure 3-2: Greenhouse gas emissions Sweden 2008-2018



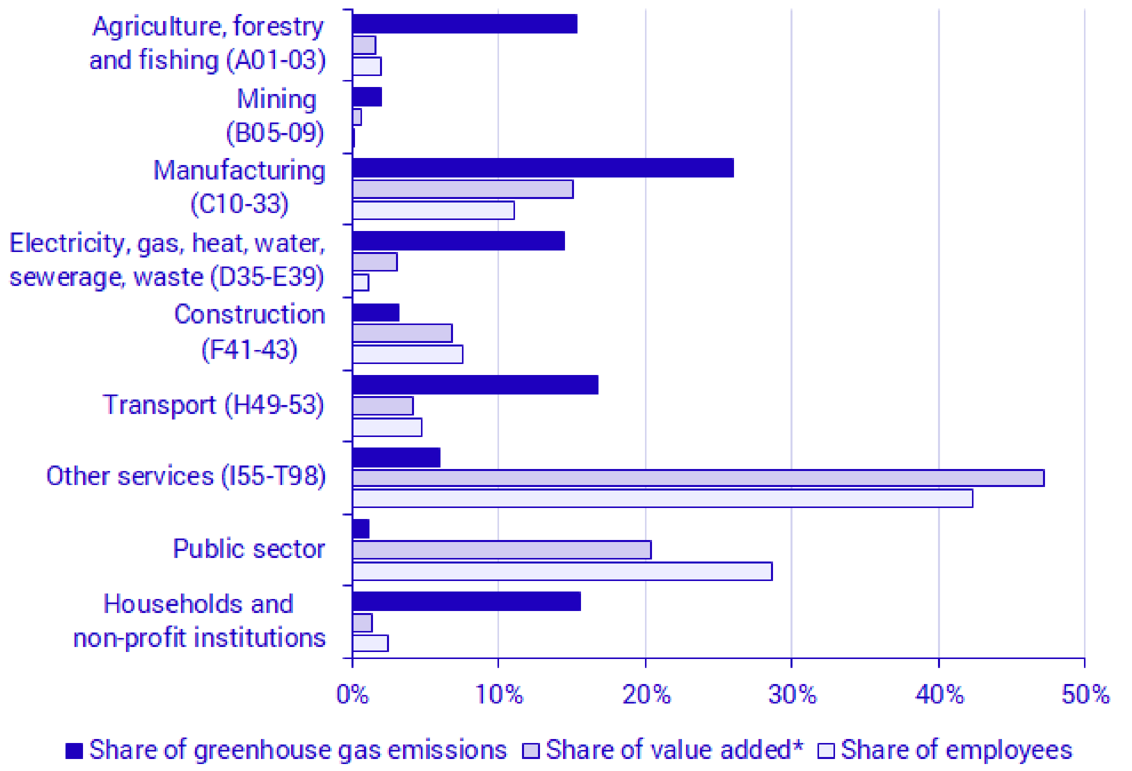
Source: Statistics Sweden[21]

Within the Stockholm area, emissions have fallen from 6m tonnes in 2008 to 5.9m tonnes in 2017, which is equivalent to a decline in per capita emissions from 7.45 tonnes to 6.23 tonnes.[22]

In 2018, Statistics Sweden reports that the highest proportion of greenhouse gas emissions were associated with the manufacturing industry. However, emissions from transport, households and energy, water and waste came not far behind.

21 https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/environmental-accounts-and-sustainable-development/system-of-environmental-and-economic-accounts/#_Tablesandgraphs
22 Statistics Sweden

Figure 3-3: Environmental and economic profiles by industry in Sweden 2018



Source: Statistics Sweden[23]

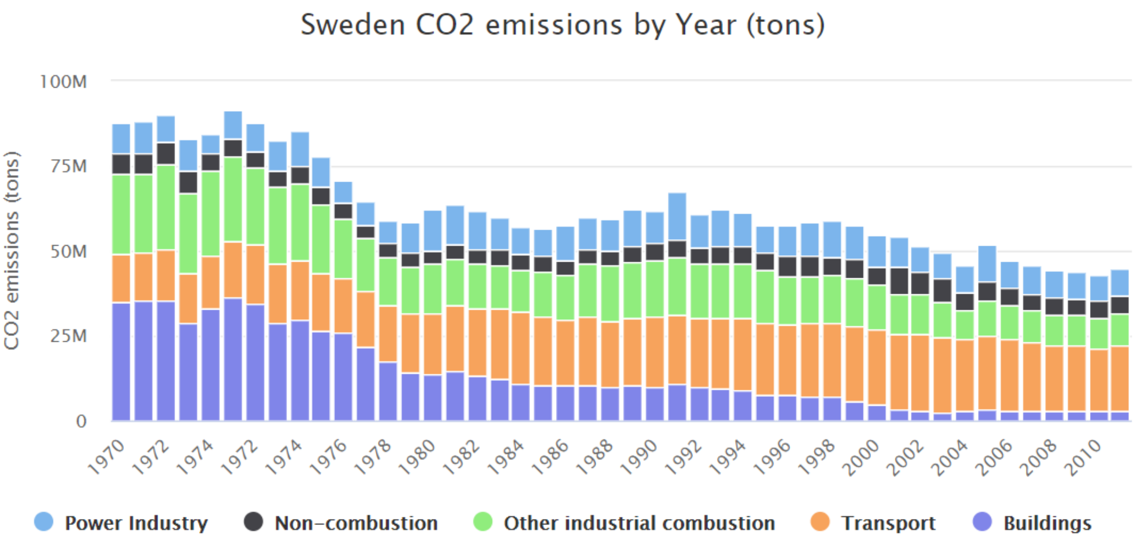
3.2 Digitisation as a driver of traffic management and reductions

As the following figure illustrates, transport has been one of the main contributors to CO2 emissions in Sweden (and elsewhere) since the 1980s. While Sweden has been successful overall in reducing emissions, transport remains a particular challenge, as observed in Stockholm's strategy for a fossil-fuel free Stockholm, and confimred by the Deputy CEO of the City of Stockholm,Staffan Ingvarsson.

> ***"Heating and traffic are today the main challenges for CO2 emissions in Stockholm." (Deputy CEOStaffan Ingvarsson, The City of Stockholm)***

23 https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/environmental-accounts-and-sustainable-development/system-of-environmental-and-economic-accounts/pong/tables-and-graphs/emissions-to-air/environmental-economic-profiles-by-industry/

Figure 3-4: Development of CO2 emissions in Sweden, 1970-2011



Source: https://www.worldometers.info/co2-emissions/sweden-co2-emissions/

While the City has limited powers over fossil-fuel pollution from aviation and shipping, and energy generation also lie outside its purview, actions taken by the City can contribute to limiting congestion.

As discussed below, digitisation can in particular reduce the need for journeys by supporting remote working and service provision and improve the efficiency of traffic flows by limiting reliance on public vehicles, encouraging use of public transport and alternative transport mechanisms, as well as facilitating the collection of congestion charges or other charges designed to limit poolution.

3.2.1 Reducing traffic through efficient traffic management and support for alternative mobility solutions

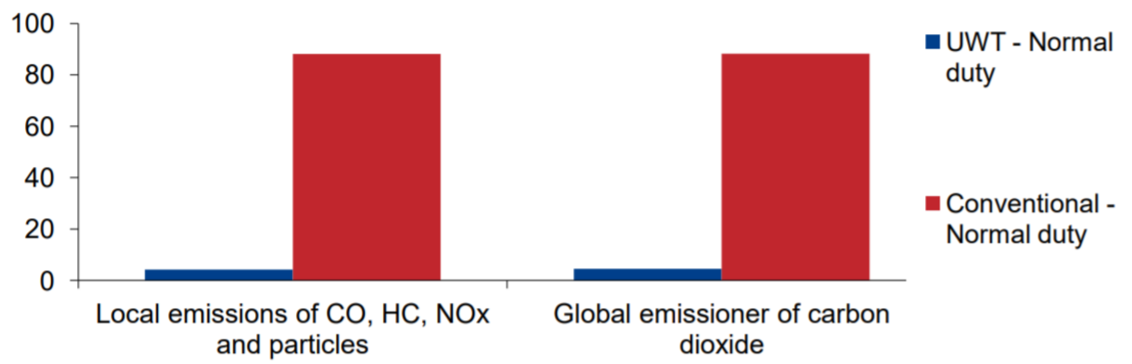
The City of Stockholm is currently engaged in a number of digital initiatives which should have the effect of limiting congestion and pollution in the city.

One initiative which has limited the use of polluting public vehicles is Stockholm's Smart Waste Handling System. Under this system, residents put their waste into coloured bags, which are then identified by sensors, separated and partly transported via underground empty pipes.[24] One of the environmental benefits from this programme is that it supports recycling rates by giving residents feedback on their waste habits. However, another important benefit is that it has enabled savings in CO2 due to a reduction in waste transportation. As Mika Hakosalo from the City of Stockholm's environmental Department noted:

> "***With the introduction of the Smart Waste Handling System, waste collection traffic was reduced by 90% with an accompanying reduction in CO2 emissions, noise and pollution".***

The savings are also apparent from the following figure, which compares emissions from underground waste transportation compared with onventional waste management.

Figure 3-5: Emissions savings through smart waste management



The graph above shows the difference in emissions of CO, HC (hydrocarbons), NOx, particles and SO2in another residential area in Stockholm (Stora Ursvik). UWT stands for underground waste transportation and Conventional stands for bin collection with rear loading lorry.

Source: https://grow-smarter.eu/fileadmin/editor-upload/12Solutions/Factsheets/Stockholm/Solution_7_Smart_waste_collection_Stockholm.pdf

Such systems and the communication between many thousands of sensors have been facilitated by Stockholm's comprehensive fibre infrastructure, and according to Mika Hakosalo, this infrastructure also provides a platform to test other new technologies that could contribute to reduced traffic and emissions on the roads.

Wifi-based sensors, which communicate between buildings via existing infrastructures, can already be used today to determine how much traffic there is in a given area. As a

24 https://grow-smarter.eu/fileadmin/editor-upload/12Solutions/Factsheets/Stockholm/Solution_7_Smart_waste_collection_Stockholm.pdf

next step, this information could be passed on to users so that they can avoid possible traffic jams.

Connecting and digitising the traffic light system itself could generate additional fuel savings. For example, with current low levels of connectivity (linked to existing copper-based connections), schedules for traffic lights are set for specific time periods and settled in advance, whereas if lights were connected via fibre, traffic patterns could be analysed and changes could be made in real time. Dynamic capacity in traffic lights could be used to prevent traffic jams in urban areas, and could have a positive impact on the environment and energy consumption by reducing waiting times for cars and making buses comparatively more attractive compared with private vehicles. It was observed that in the first week of trials of dynamic traffic light controls in the Stockholm area, buses experienced 25% faster driving times. In a simulation conducted for the city as a whole – buses were able to drive as if there were no rush hour.

Digital data capture should also support the modernization of traffic measurements. At the moment, metal plates and cables are used to assess the number of cars crossing intersections at a cost of €300,000 every year. This mechanical measurement is conducted only one month every year and the data is then extrapolated. If this system were replaced with sensors connected via fibre, there would be a one-time investment, but it could be used permanently. Moreover, cameras could be installed to assess which kind of traffic is using the road such as buses, trucks, bicycles or pedestrians, rather than just assessing the numbers of road users. The technology should thus both save money and support better quality data, providing support for the development of new applications e.g. to better manage interactions between different road-users and favour more environmentally friendly mobility solutions. Connectivity can also provide the infrastructure to support and manage car sharing schemes, which can have significant positive impacts on the environment. For example, Mika Hakosalo notes that an existing electric car sharing pool in Stockholm was able to reduce CO_2 emissions by 60-70% in a specific area.

Smart solutions involving cameras could also in the near future help to enforce congestion charges or enforce restrictions on traffic, for example by limiting certain kinds of vehicles e.g. transport of goods to certain times of the day or to limit their speed.

In order to provide the infrastructure for these mobility applications, the city of Stockholm plans to connect 500 city cabinets at all major street crossings with fibre within the next two years, upgrading existing streetside connectivity, which is currently based on analogue copper connections, which do not allow sufficient capacity to transmit data from the street corners to the central processing unit for analysis.

This infrastructure could become a platform on which further innovative fixed and wireless applications could be developed by a range of actors.

According to Deputy CIO of the City Ms Kristina Lundevall and Director of Innovation Mr Gunnar Björkman there is a need for closer cooperation between the traffic department and other involved departments in the City to support Stockholm's aim to become fossil-free by 2040. Moreover, closer co-operation with universities and scientists (Digital Stockholm) is planned to find additional, innovative mobility and communications solutions.

3.2.2 Reducing traffic through teleworking, remote education and healthcare solutions

Alongside making travel more efficient, measures to reduce the need for travel can also have an important role in reducing pollution and greenhouse gas emissions.

Commuting to work or school is recognised to be one of the major sources of traffic-based emissions in Europe.[25] A 2010 study[26] of the sources of greenhouse gas emissions in Sweden found that a person commuting 5 times per week by car with a 20km return trip would generate between 0.3-1 tonnes in CO2 emissions per year, depending on the efficiency of the vehicle.

Sweden has benefited from CO2 reductions as a result of its relatively high levels of teleworking. Data from Eurostat shows that as of 2019, at 37% of working-age adults, the incidence of teleworking either for part or most of the time was higher in Sweden than in any other country in the EU. Various studies have found that access to effective broadband in the home is one of the drivers of teleworking,[27] and thus it seems likely that the prevalence of fibre in Sweden may have contributed to enabling a high proportion of the workforce to work flexibly, for at least part of the time.

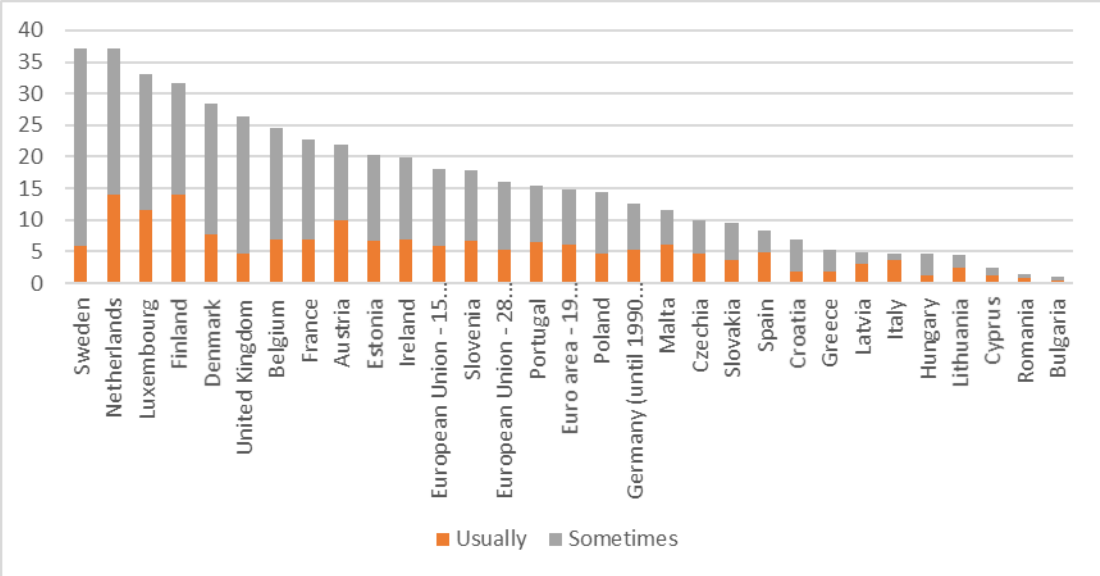
However, it is notable that despite its high ranking overall, relatively few workers are reported to have "usually" worked from home in Sweden, with higher proportions in neighbouring Denmark and Finland.

25 An estimate of the impact of commuting and effects of teleworking on CO2 emissions in the case of Switzerland is made in the study by Giovanis (2017) https://www.researchgate.net/publication/317565238_The_relationship_between_teleworking_traffic_and_air_pollution

26 The Climate Impact of Swedish Consumption Table 8 https://www.naturvardsverket.se/Documents/publikationer/978-91-620-5992-7.pdf

27 The study "working anytime, anywhere" notes that the difference in the incidence of teleworking can be partly explained by the spread of ICT and Internet connectivity: see table 3 https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_544138.pdf

Figure 3-6: Proportion of the working age population working usually or sometimes from home: EU 2019



Source: Eurostat

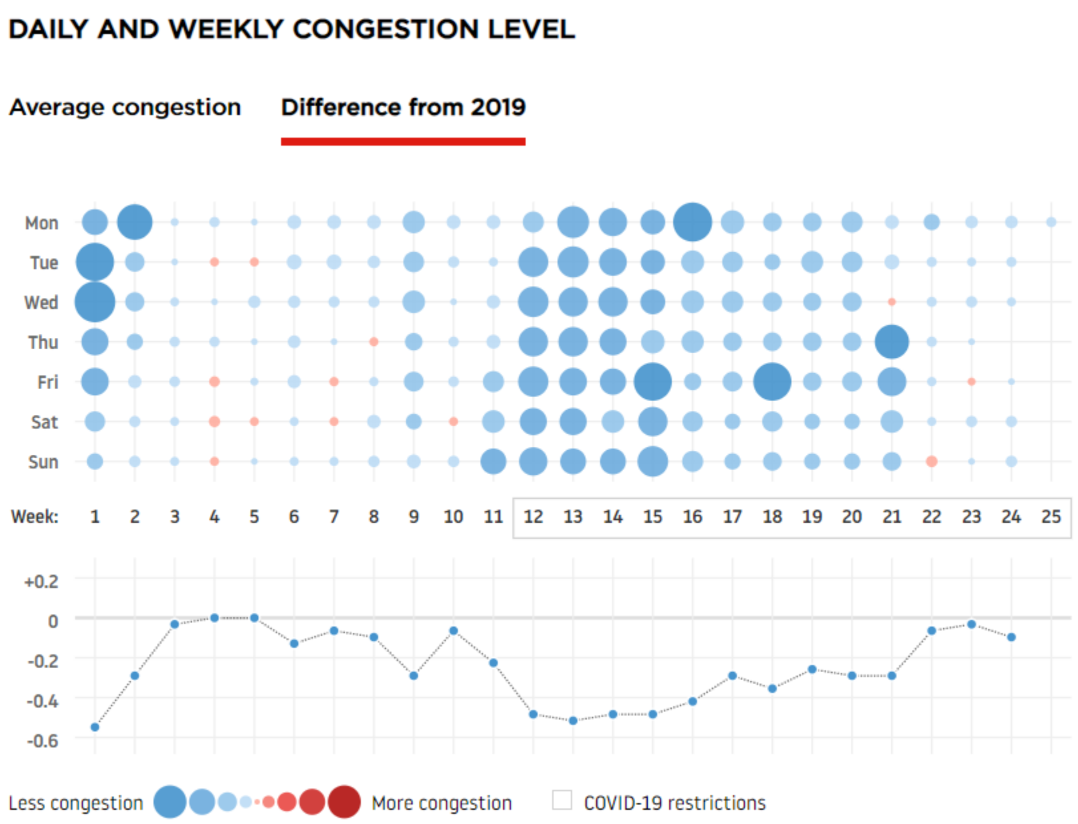
Analysis of data during the period of the Coronavirus outbreak shows that further reductions in traffic could be achieved with greater reliance on homeworking. For example, data from Tomtom[28] shows that congestion levels in Stockholm fell to 50% of the usual values during the period following the introduction of COVID-related guidelines. Representatives of the City Hall noted that demand for transport had reduced significantly during this period as an estimated 30 to 50% of the population was working or learning from home due to the pandemic,[29] including a significant proportion of employees of the City itself.[30]

Various studies have shown that COVID-related reductions in transport were linked to reduced CO2 emissions. A decline of around 15% in traffic-related emissions globally in the period Jan-April 2020 was identified in a 2020 study, conducted at the height of the epidemic.[31]

28 https://www.tomtom.com/en_gb/traffic-index/stockholm-traffic
29 Interview with City Hall referring to data based estimates by Google.
30 According to the interview with City Hall, prior to the epidemic, only 500 of the staff worked from home on a typical working day and use of Skype (typical for remote working) was limited to around 2,000 weekly users from a total workforce of around 40,000, but there are 15.700 PC:s, due to the fact that a majority of the personnel works in sectors like elderly care, child care and schools, where they don´t have an PC of their own. Weekly Skype use increased to 7,000 employees following the epidemic and 6 500 persons work from home, compared with 500 before the epidemic.
31 Liu et al (2020) https://arxiv.org/ftp/arxiv/papers/2004/2004.13614.pdf

Congestion levels in Stockholm have since recovered to near-normal levels, potentially due to increased use of private vehicles rather than public transport. This hypothesis is supported by the findings of the COVID-19 Community Mobility Report by Google, which suggests that for Sweden, mobility trends for public transport hubs, such as subway, bus, and train stations decreased by 21% compared to a baseline scenario (Google 2020). In turn, reduced use of public transport may have counteracted the positive effects from homeworking on transport-related emissions. However, sustained reductions in congestion could in principle be achieved in a post-COVID era where increased homeworking is combined with increased use of public transport and other green transport methods. In an interview conducted for this study, Deputy CIO of the City Ms Kristina Lundevall and Director of Innovation Mr Gunnar Björkman noted in particular that the Covid-19 Pandemic has shown that unnecessary travel can be avoided through digital meetings or the use of working hubs, which would allow for a more decentralised working without people needing to commute to the city.

Figure 3-7: Congestion levels in Stockholm before and after the COVID pandemic



Source: Tomtom

Sweden is also a leader in the use of eHealth solutions, which can also serve to reduce the need for transport while improving the effectiveness of healthcare interventions. A 2018 survey conducted on behalf of the European Commission placed Sweden in fourth place within the EU on eHealth adoption, behind only Denmark, Estonia and Finland.[32]

Healthcare is organised on a regional basis, and the Region of Stockholm is responsible for organising healthcare for its 2.4m inhabitants. According to Daniel Forslund, Commissioner for Innovation and eHealth for the Region of Stockholm, increased investments in and usage of eHealth solutions began 5-6 years ago and the usage of eHealth has since doubled year on year. A major focus has been to replace physical visits to the doctor with online consultations, to reduce travelling for patients and increase the efficiency of consultations. In 2018, an online platform was introduced which allowed hospitals to contact patients via video conferencing. The platform was initially introduced in smaller, privately run clinics, but later expanded to include large hospitals.

Stockholm's investments in remote healthcare solutions proved invaluable in the context of the pandemic. Due to Covid-19, the number of video meetings between January 2020 and April 2020 increased by 1000%, from 3.300 video meetings in January to 40.000 video meetings in April.The installation of e-health facilities also meant that medical staff were able to work from home, during the pandemic, reducing their exposure to the virus. VPN connections were installed in order for medical staff to be able to safely work from home, access medical records, conduct administrative task as well as conducting online consultations.

> Forslund notes that "***Due to COVID-19, it was possible to observe that many things in healthcare are possible online – more than one might think. E-health is cost-effective for society as patients do not have to travel and can continue to work from home. Online meetings also had a positive impact on the working environment of medical personnel, as it meant they could optimise their appointments between physical and virtual meetings***".

Stockholm has now made it mandatory for healthcare providers to offer basic digital services, and Forslund observes that online consultations have become the norm. Future developments may include the expansion of online services to other patient groups, and the ability to monitor patients with chronic disease such as heart disease or diabetes, from home. Whereas today, diabetes patients visit the doctor on a regular basis, with the support of eHealth monitoring systems, doctors will be able to better determine when visits are necessary. Forslund also sees a greater role for data analytics in healthcare going forwards, improving diagnostics and treatment.

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32 See Figure 33 Composite index of adoption https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=60210

Remote learning has also played an important role in maintaining educational opportunities for older school children and university students in Stockholm during the pandemic. Stockholm University moved exclusively to distance learning in March 2020. The offering has involved web-based teaching, and digital exams supported by online platforms such as Athena and Zoom video-conferencing.[33] In an interview conducted for this study, Microsoft noted that they had seen a dramic increase in the usage of tools for home working and for schools in connection with the pandemic. Microsoft representatives noted that:

> "***Municipalities have already implemented technological solutions and the advanced network infrastructure in many Swedish cities made it easy to move from physical to virtual meetings***". ***(Microsoft)***

Ann-Marie Taylor, CIO of the Department of Education at the City of Stockholm, confirms that connectivity in schools has played a vital role in supporting remote learning for older schoolchildren during the Coronavirus crisis. During the epidemic, 12,500 students from 29 schools/gymnasia across the region of Stockholm were reliant on remote education.

Taylor notes that there were different experiences for different schools and students and that while it was difficult for students without Internet access at home to participate, most students had fibre to their home and were able to join in every day. Taylor observed that:

> ***"An interesting finding was that students that previously hadn't come to school participated more. More students joined in when the classroom turned digital turned up than before. Schools found the positive results a real eye-opener." (Ann-Marie Taylor, CIO at Department of Education, City of Stockholm)***

Taylor expects that the experience will lead to lasting change as teachers could see the benefits of undergoing a digital transformation. Moreover, digital learning might prove to be a more permanent solution for students which previously had not come in to school.

The role of advanced broadband infrastructure in supporting remote learning and healthcare has also been confirmed in studies[34], which highlight the importance of connectivity not only in cities, but also in more rural areas, where remote service

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33 https://www.su.se/corona/studera-hemifr%C3%A5n-1.489914

34 For example Forzati, M. and C. Mattson (2014), FTTH-enabled digital home care – A study of economic gains, Department for Networking and Transmission, Acreo AB. The study finds that if just 10% of home care service recipients use digital services, the annual net cost reductions are estimated to be USD 0.6 million for a rural municipality with 8 000 residents by 2020; a medium-sized city with 90,000 residents can lower the cost with USD 3.6 million; and a large city with 500,000 residents can lower the cost with USD 9.2 million.119 The authors conclude that a widespread introduction of digital services could stabilise the cost of home care or even decrease it by up to 50% for sparsely populated municipalities, but this outcome is dependent on end-users having access to high quality, reliable broadband connections.

provision may play a critical role. A recent study by Ecorys and WIK-Consult[35] also confirms the importance of point to point fibre connectivity for healthcare practioners and educational establishments of all sizes to enable them to exploit the future potential of eHealth solutions.

EHealth and remote educational provision in Stockholm is also boosted by the prevalence of tech communities and startups in the region. The region has the most unicorns per capita in the world after Silicon Valley and is home to innovation centres such as the H2 Health Hub,[36] as well as eHealth application developers such as Kry (a virtual consultation service provider), Doktor.se and Doctrin.[37] The AI-based personalised learning solutions provided by Stockholm-based Sana Labs[38] have been rolled out to 75% of schools in Sweden,[39] and the technology was used to upskill furlougherd flight attendants to assist healthcare workers in Swedish hospitals during the Coronavirus pandemic.[40] Ready access to dark fibre for start-up businesses as well as their potential customers has been considered an important enabling factor for these initiatives.[41]

3.3 Reducing energy consumption in buildings

According to the World Green Building Council building and construction activities account for 39% of CO2 emissions in the world.[42] Figure 3-4 shows that in Sweden buildings also account for a large part of CO2 emissions, alongside traffic and industrial combustion.

Heating and systems to support air circulation can be a significant source of energy consumption and emissions in buildings. IT equipment including servers can also contribute to high levels of energy consumption in public institutions and offices.

3.3.1 Efficient heating in school buildings

A good example of energy savings in buildings in Sweden based on the existing fibre infrastructure is provided by Sisab, the Stockholm School Property Company. Sisab was founded in 1991 and is owned by the City of Stockholm.[43] Sisab is in charge of 600 schools (400 pre-schools and 200 secondary schools) in Stockholm. Sisab manages a

35 Ecorys, WIK et al (2020) Implementing CEF2 Digital https://op.europa.eu/en/publication-detail/-/publication/8947e9db-4eda-11ea-aece-01aa75ed71a1/language-en
36 https://www.investstockholm.com/globalassets/invest/reports/healthtech_170602.pdf
37 https://www.eu-startups.com/2019/07/10-stockholm-based-startups-to-look-out-for-in-2019-and-beyond/
38 https://www.sanalabs.com/
39 https://medium.com/@sanalabs/bringing-the-sana-technology-to-sweden-with-ne-86532ac90f6c
40 http://www.ourtownny.com/news/using-ai-learning-for-covid-care-LK1185638
41 https://www.fastcompany.com/3061052/how-stockholm-is-creating-a-second-silicon-valley-in-scandinavia
42 https://www.worldgbc.org/news-media/WorldGBC-embodied-carbon-report-published#_ftn1
43 https://sisab.se/sv/in-english/

total of 1,800,000 square meters in over 3,000 buildings. Almost all buildings are connected to the fibre network of Stokab. Less than 5% of the buidlings in remote areas are connected via wireless connections (4G). According to Niklas Dalgrip (Chief Operations Department at Sisab) Sisab has managed to save 35% in energy consumption, equalling savings of 18,500 tons of CO_2 between 2012 and 2019. In monetary terms, these are savings of about 4 million euros per year.

While in the past, each building was managed independently and the heating of the buildings was usually based on measured outside temperatures, today, there are around 200,000 sensors installed, which enable highly efficient heating in all Sisab buildings. The communication between the sensors and the energy savings are only possible because the buildings are connected via a common single network. With the help of sensors, Sisab has also established 6 weather stations located at different schools in the city, that not only collect weather data for their own use, but also collect information useful to third parties.

> ***"Between 2012 and 2019 Sisab was able to save 35% of energy, equaling 18,500 tons of CO_2 or 4 million Euros per year" (Niklas Dalgrip, Chief Operations Department at Sisab)***

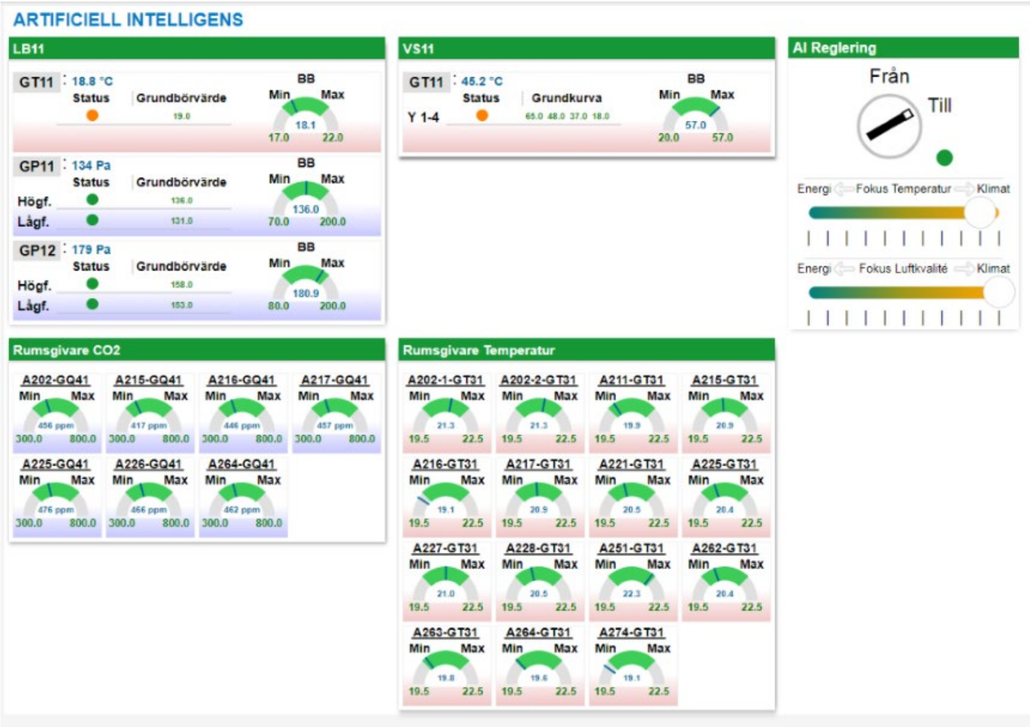
Today, each building has its own property server, which converts the instructions from the central system into the respective local system and vice versa. The intelligence of the buildings are in these servers and these servers are able to steer and control all the equipment within the buildings including heating, electricity, kitchen equipment, etc.. Savings are possible because maintenance work can now be carried out much more efficiently. Previously, technicians had to visit each location to maintain the systems. However, today, most of the maintenance can be organized and controlled via the centralized control room. Technicians only visit specific locations in case of need as indicated by the control room. Each school has a graphical interface, via which it is possible to identify the need for maintenance work.

The role of Artificial Intelligence (AI)

Sisab has provided additional services based on AI to 50 out of its 600 schools and notes that additional energy savings can be achieved through these measures.

While most schools are managed on demand and adjustments still need to be triggered manually, for these 50 schools each parameter is set in a preset range (see Figure 3-8). In case the temperature rises for example, the system will automatically adjust the temperature accordingly.

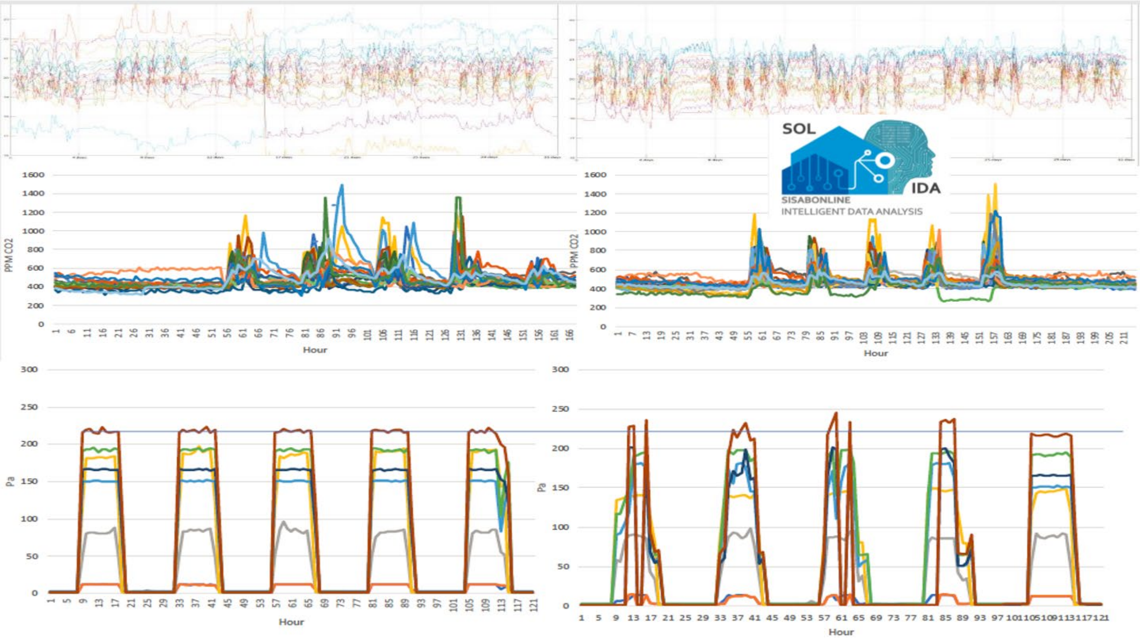
Figure 3-8: Increased energy efficiency due to Artificial Intelligence (AI) in buildings



Source: Sisab

Figure 3-9 shows which additional efficiencies can be achieved by AI in the area of building heating systems and air circulation. The figure shows the amount of carbon dioxide in the air, on the left for the conventional system and on the right for an AI-based system. AI works with temperatures in the ventilation and heating system while working with the air flows to achieve the best possible indoor climate. The graph shows lower CO2 levels and more even temperatures. With the support of AI, the air circulation is more efficient and room temperature adjustments can be made more quickly and with greater precision, creating a better indoor climate which ultimately leads to further energy savings.

Figure 3-9: Artificial Intelligence in buildings



Source: Sisab

With the help of AI it has been possible to further reduce energy consumption. Based on tests conducted in 2018, Sisab estimates that a further overall 4% energy savings could be achieved, with power savings on heating amounting to 15%. Today Sisab works together with a local energy company. If the energy company has a temporary shortage of power, they can call Sisab and Sisab can shut down individual systems in order to save energy. In total 35 MW can be reduced at short notice.

3.3.2 Clustering IT equipment

Further energy savings in buildings, especially office buildings, are possible by using centralised clouds and virtual servers, rather than distributing IT equipment across different sites. For example, Layer & Mesh (LM[44]), an ISP founded in 2006 by Daniel Persson (CEO, Layer & Mesh) in Sweden, offers combined business solutions based on Stokab's fibre infrastructure consisting of closed networks, virtualization and applications.[45]

44 Layer refers to ISO layers. Mesh refers to meshing communications to achieve advantage in communication and warfare

45 https://www.layermesh.se/?lang=en

Amongst other things, LM offers virtual machine clusters (VM clusters). VM clusters allow businesses to access multiple functionalities on the same server as well as providing a dynamic backup process, which is important to companies and organizations where data is of great value. VM clustering is an effective technique that ensures high availability of servers and the network. According to Daniel Persson, since the first VM clusters were set up in 2014 there has been no need for downtime for repairs or maintenance, since when a physical node fails, the virtual machine can access another node, with no time lag.

> ***"One virtual machine cluster can support 300-500 companies, using the same energy as one company with 3-4 traditional servers." (Daniel Persson, CEO Layer & Mesh)***

In addition to offering benefits in terms of cost and resilience, energy consumption can also significantly be reduced by using VM cluster. According to Persson, while a medium-size company would have energy requirements of more than 1kWatt per hour (based on 3 servers each with. 400 Watt power supply per hour), a cluster can run up to 1,000 virtual machines, with an overall consumption of 1.6 kWatt per hour. This means that with a VM cluster 300-500 companies can be supported consuming approximately the same energy as one company using 3 to 4 traditional servers.

Persson considers that there is a potential market for this technology amongst all companies and households, as when all the devices in one household are added together, the power consumption is similar to that of a company. Companies such as Nvidia, Microsoft, Intel AMD and Amazon could position themselves to offer the benefits of GPU clusters (Graphics Processing Units), enabling consumers to benefit from energy and other savings.

According to LM, the presence of a wholesale only dark fibre network in Stockholm has been a core enabler for their business. Persson notes that in cities such as Göteborg, London or Madrid it is possible to buy a layer 2 (Ethernet) product, but this does not allow the evolution in protocols that has enabled LM to innovate in the provision of VM services.

3.3.3 Data centres and district heating

Another important benefit associated with clustering servers is that the heat generated from the operation of the machines can potentially be re-used.

Stockholm Data Parks is a pioneer in this field. The initiative was launched in January 2017, supported by the City of Stockholm and a number of local utility companies. The initiative makes use of synergies between the extensive district heating system in Stockholm and the heat generated by data centres.

Overall, there are 2,800km of pipes for the heating system in Stockholm, reaching from the airport, to the other end of the city. Erik Rylander, Head of Stockholm Data Parks, notes that “The district heating system provides the ability to move energy from where it’s generated to where it’s used”.

Rylander explains that hyperscale data centres, such as those operated by Facebook and Google, are too large to site near a big city. However, Stockholm Data Parks is targeting smaller scale data centres with a capacity of 10-20MW. Stockholm Data Parks reports that a 10 MW data center load can meet the heating needs of around 20 000 modern residential apartments.[46] Stockholm’s 12 TWh/year district heating system aggregates demand for energy that could accommodate heat re-use from up to 150 data centers with a load of 10 MW.

In November 2019, the data centre operators IP-Only, Interxion and Advania Data Centres announced that they would be building new data centres in Stockholm’s Kista Data Park, which is situated in Stockholm’s technology hub. When operational, the data centres have the potential to heat more than 35,000 modern residential apartments in Stockholm.[47] Another Data Park is sited at Brista, with a third Data Park Skarpnäck planned for 2021.

Stockholm Data Parks reports that, during the Spring of 2020, Stockholm Exergi was able to close the last coal-fired heat generating plant in Sweden, in part as a result of measures which had enabled large-scale heat recovery.[48]

Rylander notes that Sweden has traditionally been an attractive place to host data centres due to its green energy mix, with a high proportion of hydroelectric power, and nuclear energy.[49] Whereas 1KWh in the EU produces on average 450grams of CO2, the Swedish grid produces just 20 grams. Re-using this energy to provide hot water and heating means that heating does not have to be provided through less climate-friendly sources, such as gas.

Although the opportunity was there for the taking in Stockholm, due to the existing district heating system and green energy sources, Rylander notes that there could be significant opportunities elsewhere as well:

46 https://stockholmdataparks.com/benefits-of-green-computing-in-stockholm/
47 https://stockholmdataparks.com/2019/11/12/three-new-data-centers-with-heat-recovery-in-stockholm-data-parks/
48 https://stockholmdataparks.com/benefits-of-green-computing-in-stockholm/
49 40% of Sweden’s electricity is generated via hydroelectricity, and 40% nuclear with the remainder largely based on wind and biomass

"There is huge potential from re-using energy from data centres. Every bigger city has data centres. Even if there is no district heating today, they can always start to recover heat by supplying the buildings nearby. Last year at Stockholm Data Parks, we recovered 124 GWh from data centres, enough to serve 34,000 modern residential flats" (Erik Rylander, Head of Stockholm data parks)

Rylander notes that there are opportunities from the district heating systems present in many German cities, and that there is interest in this approach in London, Amsterdam and Frankfurt, as these cities are host to significant data centres. "It's a matter of wanting to find solutions and someone to drive the agenda," says Rylander. "One way could be to make building permits dependent on the re-use of energy". Rylander notes the important role that Stokab's dark fibre network has also played in the process.

"All data centres need fibre as the service is exported through the fibre. If you don't have fibre infrastructure, an important piece of the puzzle is missing. Dark fibre is abundant in Stockholm due to Stokab, so customers do not face high costs when it comes to fibre connections" (Erik Rylander, Head of Stockholm data parks)

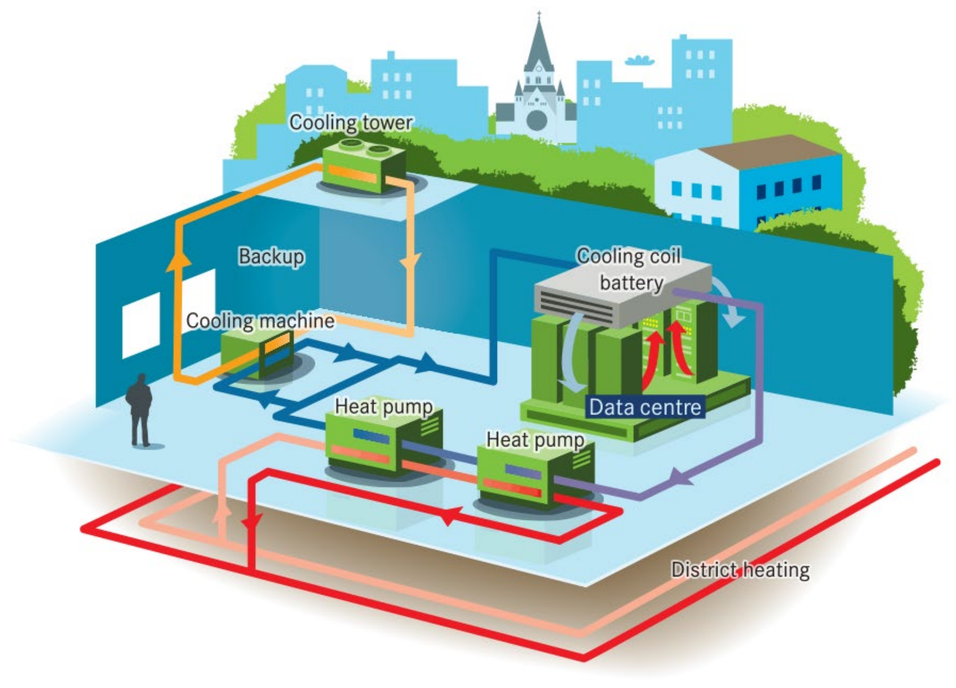
Broadband service providers such as Bahnhof are also taking advantage of the opportunity to re-use waste heat from their hardware in association with Open District Heating.[50] In the data centre Pionen in Södermalm in Stockholm, Bahnhof has installed a cooling plant for primary cooling of the data centre which delivers the excess heat to the district heating network.

The cooling facility comprises two cooling machines/heat pumps (Carrier 30XWH 802-HT) connected in series, with a total cooling output of 694 kW and a heat output of 975 kW.

Stockholm Exergi has connected the property to the district heating network via a new, 67 meters long distribution pipeline (DN125). During normal operation the plant supplies heat of around 600 kW with a delivery temperature of 68 degrees Celsius. The system is illustrated in the figure below.

50 https://www.opendistrictheating.com/case/bahnhof-data-centre-pionen/#:~:text=Below%20the%20Vita%20Bergen%20park,the%20cabinets%20are%20heated%20up

Figure 3-10: Connecting data centres to district heating systems



Source: Open District Heating[51]

The conversion of power sources used for Stockholm's extensive district heating system, to make use of waste heat from data centres and other clean energy is a key plank in the City of Stockholm's strategy to further reduce reliance on fossil-fuels in buildings.

Stokab has also itself made use of waste heat from its core nodes to heat a local school and is in discussions with the district heating company.[52] Stokab's largest core node uses 1,000 MHWh of electricity per year and the school – covering an area of 11,000 square metres, receives the equivalent in heating capacity. This is sufficient to supply the school with all its heating and hot water needs. In addition, Stokab's other core nodes, area nodes and access nodes consume 9,750,000kWh of energy per year, with the potential for expansion as demand for digital services grows in the coming years. According to calculations made by Stokab,[53] if energy from the remaining core nodes,

51 https://www.opendistrictheating.com/case/bahnhof-data-centre-pionen/#:~:text=Below%20the%20Vita%20Bergen%20park,the%20cabinets%20are%20heated%20up
52 Stokab interview May 2020
53 The Swedish Energy Agency has calculated that on average 10 300 kWh is used per apartment for heating and hot water during the year

area nodes and acces nodes were re-used, with the same level of efficiency as offered to the school, heat generated from these facilities could provide around 1,000 apartments with heating and hot water, potentially expanding to 2,000 over time.

> ***"Stokab's largest core node uses 1,000 MHWh of electricity per year. This is used to supply a school covering an area of 11,000 square metres, with all its heating and hot water needs. Stokab estimates that if energy from the remaining core nodes, area nodes- and access nodes were re-used, with the same level of efficiency as offered to the school, heat generated from these facilities could provide around 1,000 apartments with heating and hot water, potentially expanding to 2,000 over time "***

3.4 Supporting efficient use of water and processing of sewage

Water distribution provides another opportunity to leverage broadband to reduce waste. Through process optimisation and resilience, digital technologies are generating direct savings for utilities and creating both internal and external value across utilities' supply chains.[54]

A current challenge is that 20% of water is lost on its way to customers through leaks in the system. Stockholm Vatten och Avfall (SVOA) is the supplier of water and waste water in and around Stockholm (10 cities). SVOA produces 360,000 m3 of drinking water every day distributing it to 1,000,000 people in Stockholm, to 1,500,000 in total (including Stockholm surroundings).[55]

SVOA has made use of fibre connections since the beginning of the 1990's, when Stokab first began to build out its fibre infrastructure network. SVOA operates 40 drinking water pump stations which are all connected to the Stokab fibre network. Next to the drinking water pump stations, there are around 1,000 waste water pump stations in and around Stockholm. Around 60-70% of the waste water pump stations are connected to the fibre network.[56] There are also waste water pump stations which are connected via wireless technologies (3G).

With regards to the waste water management, it must be noted that sewage pipes have always been leaking. In so called combined sewage systems, storm water is discharged to treatment plants using the same pipes as sewage. This means that besides domestic and industrial wastewater, storm water and other waters enter the wastewater treatment plant through leakages in the sewage systems. Combined sewage systems are found mainly in older urban areas and were constructed up until the mid-20th century. Storm

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https://www.energimyndigheten.se/globalassets/statistik/bostader/energistatistik-for-flerbostadshus-2016.pdf

54 https://iwa-network.org/wp-content/uploads/2019/06/IWA_2019_Digital_Water_Report.pdf

55 See also https://www.stockholmvattenochavfall.se/en/water-and-wastewater/

56 In case of the waste water pumps, there are many smaller ones operating single houses or buildings. 350 out of 1,000 are connected to large water pipes.

water and water from other sources dilutes the contaminated wastewater, which may risk causing overflows, meaning that wastewater is released to the recipient untreated or without having undergone full treatment. Another effect might be the reduction of the treatment level provided by the wastewater treatment plant due to lower water temperature, or shorter hydraulic retention time and dilution.[57]

According to Tommy Giertz (operator and developer of water and waste water services at SVOA) the main focus of the digitalization of the water system today lies in achieving operational efficiencies. A key aim is to detect failures immediately from the control centre and be able to repair them as quickly as possible. In the control centre, it is possible to see whether the electricity power in the water pump stations work, whether fuses are broken or whether water levels and pressures are in order. The fibre network supports the maintenance process and via the control center it is possible to start or stop the pumps or check data from the water towers.

The main challenge in the near future will be to reduce water leakages in the water systems, and SVOA is currently working on a maintenance plan to address this challenge. A prototype of the plan is already running, and SVOA expects that in 1-2 years a system can be implemented to reduce water leakages.

> ***"With the help of fibre connections and analytical software it will be possible to learn more about water consumption and to react faster in the event of faults or errors in the systems" (Tommy Giertz, Operator and Developer of water and waste water services at SVOA)***

Sensors and other visualisation tools are becoming key elements to managing water resources. Data from such technologies can better prepare water resource managers and utilities for incidences of heavy storm water flow (e.g., altering operations to prevent sewage overflow), indicate when conservation practices should be enacted during periods of drought, and ensure all treated water is delivered to customers.

Today already, sensors are being used to provide near real-time data on water quality, flows, pressures and water levels, among other parameters. Dispersing more sensors throughout the water systems could further support the daily operation of the water network by optimising resource use (e.g. chemical use for water treatment), detect, diagnose and proactively prevent detrimental events (e.g. pipe bursts, water discoloration events, sewer collapses/blockages, etc.), and provide useful information for preventative maintenance and improved longer term planning for water utilities (e.g. by helping to prioritise repairs and replacements for aging infrastructure). Moreover, sensors can provide evidence for pipe corrosion and alert home owners and utilities when water quality standards are not being met. In addition, smart meters record

57 See https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-8809-5.pdf?pid=22471 customer water usage, providing a clear picture of water consumption and conveying data to both consumer and utility, allowing for improved water management.[58]

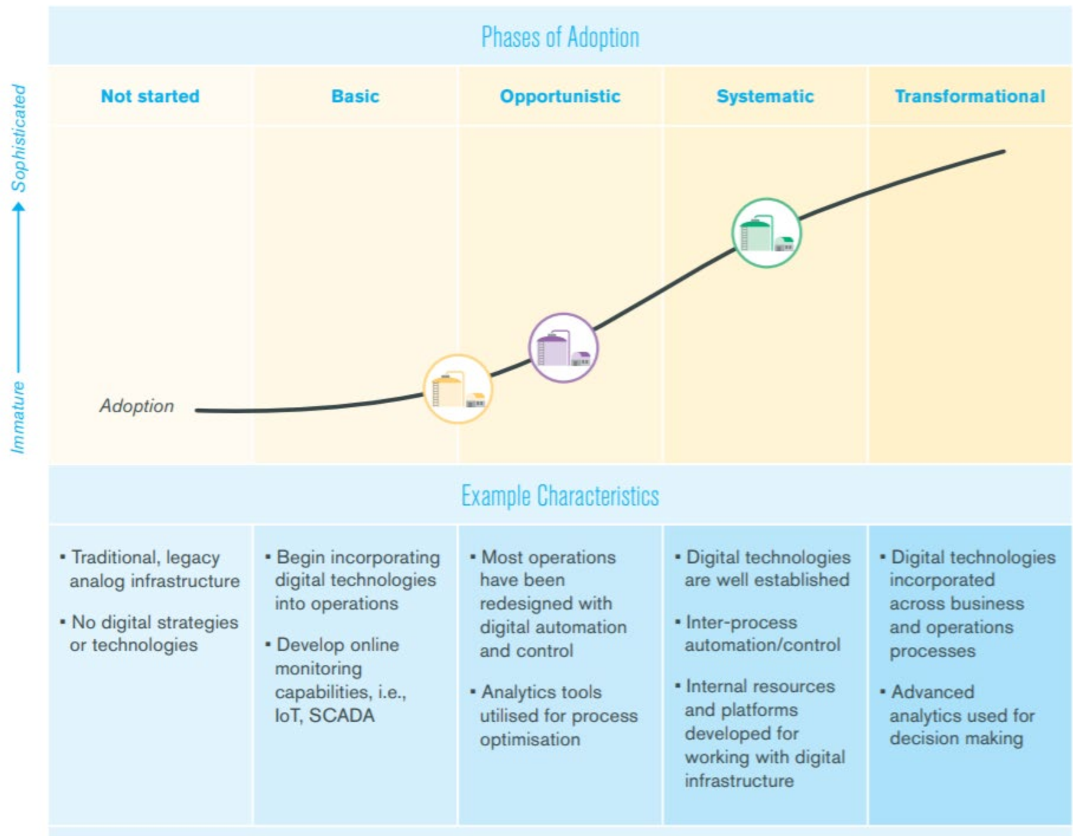
The biggest obstacle to the use of such systems are the costs and efforts involved in the civil engineering work (cost and time of digging when placing a sensor in the network). Water pipes are buried around 2 meters into the ground, and digging would be necessary every couple of meters to install sensors. However, Giertz considers that monitoring could be significantly improved if many more sensors were installed in the Stockholm area.

As an alternative today, SVOA is working on a cheaper sensor solution that can more readily be installed via manholes in the sewer network. Such sensors should already give a good understanding of the current situation and status of the sewer system.

Overall it can be said that much is already being done in Stockholm in the area of digitisation of water utilities. Nevertheless, there is still room for improvement and new applications are expected in the near future. In terms of the Digital Water Adoption Curve (see Figure 3-11), which has been adapted from Gartner 2017 and gives a synthesised view of how utilities are adopting digital technologies, SVOA can be considered a systematic user of digital technologies. The next step will be to use the data that is being collected for advanced analytics and decision making.

58 See also https://iwa-network.org/wp-content/uploads/2019/06/IWA_2019_Digital_Water_Report.pdf

Figure 3-11: Digital Water Adoption Curve



Source: IWA Digital Water Report 2019, p.25.

4 Estimating the impact of digital technologies on the environment

In the previous chapter, we illustrated through case studies how Stokab's dark fibre network has contributed to reducing carbon emissions through more efficient use and management of transport and climate control within buildings in the Stockholm area. In this chapter, based on a review of literature and our own analysis, we consider to what extent deploying dark fibre networks more widely as well as implementing digital solutions could help to reduce greenhouse emissions across Europe and beyond.

We start by considering the environmental impact of deploying point to point fibre networks similar to those deployed by Stokab, and continue with a review of available evidence around the savings on CO2 emissions that could be achieved through wider adoption of digitisation in the fields of transport and building management.

KEY FINDINGS

Energy is consumed in both the construction and operation of telecom networks. At the construction phase, creating the equivalent length of fibre optic cabling produces less than 0.01% of the emissions associated with copper.

The highest proportion of energy is consumed in the operational phase (around 90% for fixed networks).

Various studies show that FTTH is considerably more energy efficient than technologies involving legacy infrastructure. The type of FTTH solution that delivers the greatest energy efficiency depends on the number of subscribers and bandwidth. Point to point FTTH lines are the most energy efficient for high bandwidth consumption, while FTTH PON architectures are more energy efficient for low use or constrained bandwidth scenarios. ADSL, cable technologies and FTTC are significantly less energy efficient then FTTH for a given bandwidth.

According to our estimations, a complete migration from the current technology mix in the EU to all fibre would result in emissions from the use of broadband access falling from 15.5 Mio t CO2 to 3.2 Mio t (fibre technology mix) and to 1.1 Mio t of CO2 (only PtP connections) per year, if the existing power sources remained unchanged. This represents a reduction in emissions of more than 90% if all broadband connections in the EU moved to PtP FTTH.

Dark fibre is also an important supporting element for 5G, which is predicted to be significantly more energy efficient than previous generations of mobile technology, as well as enabling other sectors to become more energy-efficient.

Estimates of the potential impact on greenhouse gas emissions of smart building and smart transport solutions vary widely. Estimates of the savings achievable from the application of smart building technologies range from 15-50%, depending on the starting point and assumptions. As regards transport, a 2019 study estimates that initiatives to support driverless electric freight vehicles could reduce the impact of transport on the climate by 60%, while reductions of up to 90% could be achieved for countries with a low-carbon electricity mix, like Sweden.

4.1 Energy efficiency of fibre vs legacy networks

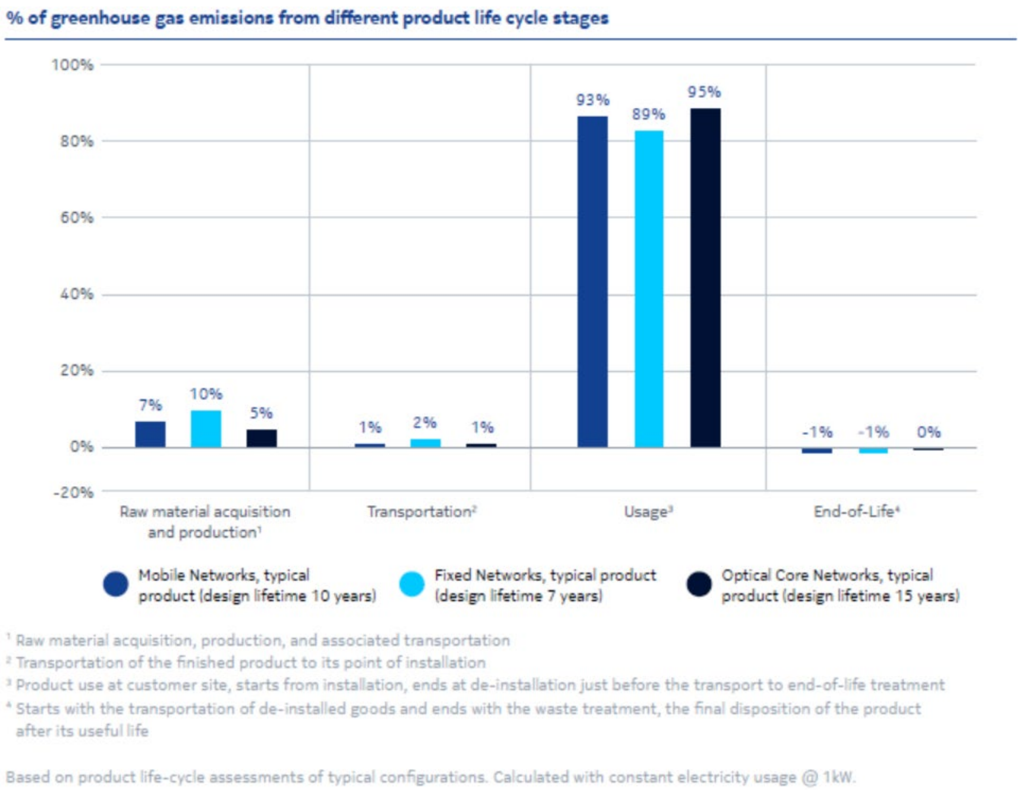
While the most significant energy savings are likely to result from the *use* of digital applications, it should be noted that installation and use of digital infrastructure including fixed and mobile telecommunication networks also involves energy consumption. The impact of telecom networks on the environment should therefore be considered, alongside their impact on bandwidth and innovation, when considering policies which aim to support deployment and adoption of very high capacity broadband.

4.1.1 Environmental impacts of network construction

When a new network is built, environmental impacts can be expected from the extraction of materials and installation of the networks.

However, as can be seen from the following diagram, the energy consumption (and thus greenhouse gas emissions) associated with the production, transportation and end-of-life treatment of telecom infrastructure is likely to be limited, especially when compared with the operation of the infrastructure.

Figure 4-1: % of greenhouse gas emissions at different product lifecycle stages



Source: Nokia (2020).

Moreover, evidence suggests that the environmental impact of constructing using modern fibre technologies is considerably less than would be incurred in the extraction and construction of a copper network. For example, a report from Corning[59], suggests that the extraction of 2 kg copper needed to produce a 200-foot length of copper wire would produce around 1,000 kg CO_2 emissions. Creating the equivalent length of fibre

59 “Corning Helps Data Centers Go Green with Fiber”, Corning, April 2010.

optic cabling would produce just 0.06 kg CO2e, less than 0.01% of the emissions associated with copper.

Thus, when networks reach the end of their lifecycle, which is considered to be the case for copper, replacement with fibre should be recommended from the perspective of the environmental costs associated with construction.

4.1.2 Environmental impacts of network operation

As network operation can give rise to significant energy consumption, the operational efficiency of different telecoms technologies should be a key focus when comparing their environmental impact.

Looking at the different parts of a telecommunication network, power consumption per device is highest in the core and transport network and lowest in access. However, the total energy requirements in the access network are the highest due to the high number of access nodes.[60] Access technologies are also likely to be a key determinant of differences in power consumption, as core networks have for some time been provided via fibre connections.

When assessing the efficiency of different access network solutions, it is important not to restrict the comparison to an assessment of energy consumed by each network type, but also to consider the bandwidth offered in each case, to ensure a like for like comparison, and reflect the economic and societal benefits of higher capacity networks, that have been recognised in studies for the European Commission as well as regulatory authorities.[61]

Solutions that are currently available in the access network include point to point fibre infrastructure (P2P-FTTH), as well as point-to-multi-point fibre e.g. GPON, FTTC (VDSL-Vectoring), DOCSIS 3.0 and above and copper. The maximum capacities available from these technologies differ. Whereas upgraded copper networks such as FTTC/VDSL today provide bandwidths that typically exceed 50Mbit/s, and future evolutions e.g. to VDSL-Super-Vectoring might provide downlink data rates of about 500 Mbit/s, Gigabit speeds are not feasible with upgraded copper unless fibre is deployed very close to the building. Both upgraded copper access and PON are aimed at the consumer market and thus typically provide for asymmetric services, i.e. a higher data rate on the downlink compared to the uplink. Conversely, P2P-FTTH can readily offer symmetrical Gigabit speeds with the capacity to further extend bandwidths over

60 Bolla, R., Bruschi, R., Davoli, F., Cucchietti, F. (2011): Energy Efficiency in the future internet: a survey of existing approaches and trends in energy-aware fixed network infrastructures, IEEE Commun. Survey Tutorials, 13, 223 – 244.

61 Godlovitch, I. et al (2015): Support for the preparation of the impact assessment accompanying the review of the regulatory framework for e-communications, A study prepared for the European Commission;
Godlovitch, I. et al. (2018): The Benefits of Ultrafast Broadband Deployment, Report for Ofcom.

time, and can thus be seen as a future-proof technology. As discussed in the WIK (2020) study on Future electronic communications markets susceptible to ex ante regulation, point to point architectures are also associated with other benefits besides bandwidth, including the capability to offer very low latency, facilitate competition through physical unbundling, and support the deployment of 5G.[62]

The power consumption of each of the different access technologies depends on the active equipment used and the capacity provided.

The capacity which a Passive Optical Network (PON) provides to customers is determined by backhaul capacity, Optical Network Unit (ONU) access rates and the number of ONUs that share a connection to an Optical Line Terminal (OLT). The remote node in the network architecture does not consume power as it includes a passive splitter. The signal is distributed from the OLT to the building without further amplification or signal processing.

With a PtP network, each connection has its own dedicated fibre, which will eventually be connected to the backbone. A switch that connects a PtP network to the backbone must therefore have as many ports as there are fibres. With GPON, only one fibre needs to be connected. PtP therefore requires more signal processing.

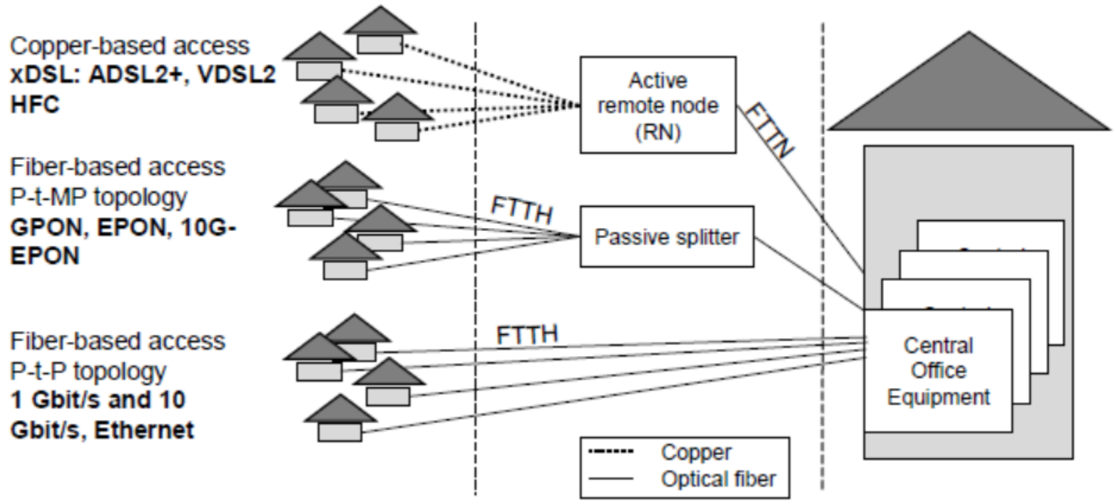
In a FTTC (VDSL-Vectoring) network, more active equipment close to the customer premises is needed. The street cabinet is not only equipped with a DSLAM for VDSL, but also technology for signal processing. Additional active equipment also generates more heat that has to be dissipated. In many cases, ventilation slots are no longer sufficient. Additional active coolers in turn consume more energy.

In a 2011 study, Aleksić and Lovrić (2011)[63] compared the energy efficiency of copper based access (xDSL, ADSL2+, VDSL2 and HFC) with fibre based access (both PtP and PtMP). An illustration of the different technologies and associated architectures is shown below.

62 https://ec.europa.eu/digital-single-market/en/news/study-future-electronic-communications-product-and-service-markets-subject-ex-ante-regulation

63 Aleksić, S., Lovrić, A.(2011): Power Consumption of Wired Access Network Technologies, in: American Journal of Engineering and Applied Sciences (AJEAS), Vol. 4 (2011), No. 4; pp. 531 – 539.

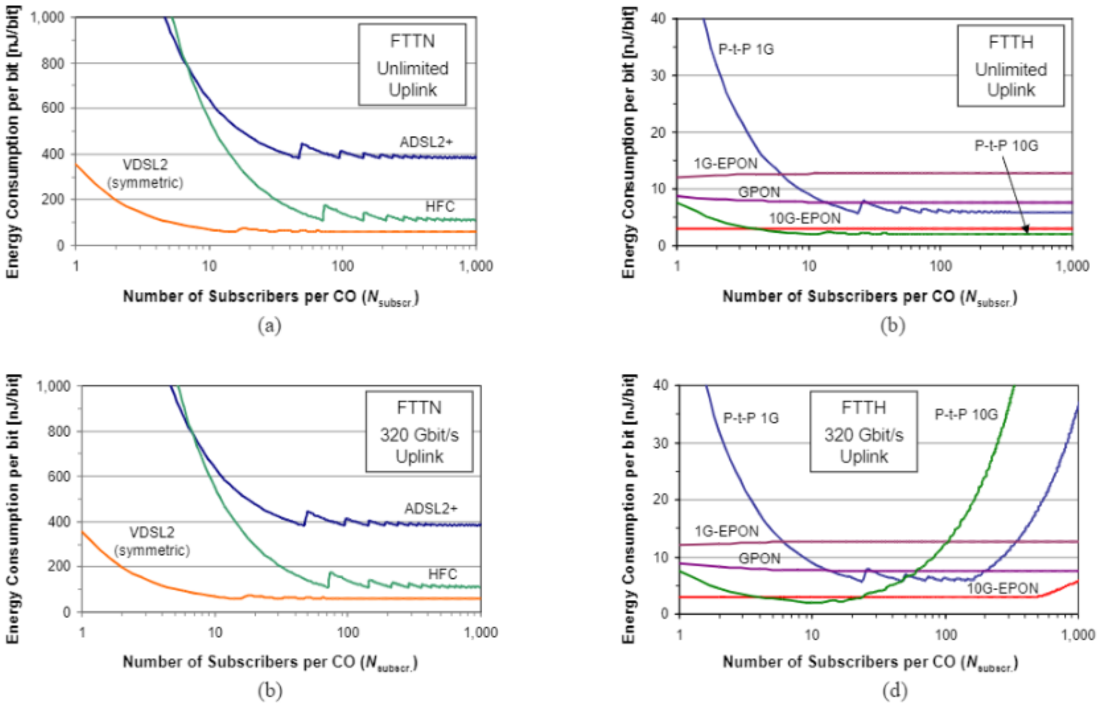
Figure 4-2: Access network technologies



Source: Aleksić and Lovrić (2011).

Aleksić and Lovrić (2011) compared two cases. In the first, they assumed unlimited available capacity in the Central Office, while in the second case, the capacity in the Central Office is limited to 320 Gbit/s. The results are shown in Figure 4-3.

Figure 4-3: Power efficiency of (a) FTTN and (b) FTTH access options when assuming an unlimited available capacity in CO as well as (c) FTTN and (d) FTTH when the available capacity of the CO uplink is limited to 320 Gbit/s



Source: Aleksić/Lovrić (2011).

The findings suggest that FTTH is considerably more energy efficient than technologies involving legacy infrastructure, but that the type of FTTH solution that delivers the greatest energy efficiency depends on the number of subscribers at the Central Office and on whether capacity was constrained or not. PtP FTTH lines were the most energy efficiency in a high use unconstrained scenario, while PON architectures were more energy efficient in low use or constrained bandwidth scenarios. ADSL, cable technologies and FTTC were found to be significantly less energy efficient for given bandwidths.

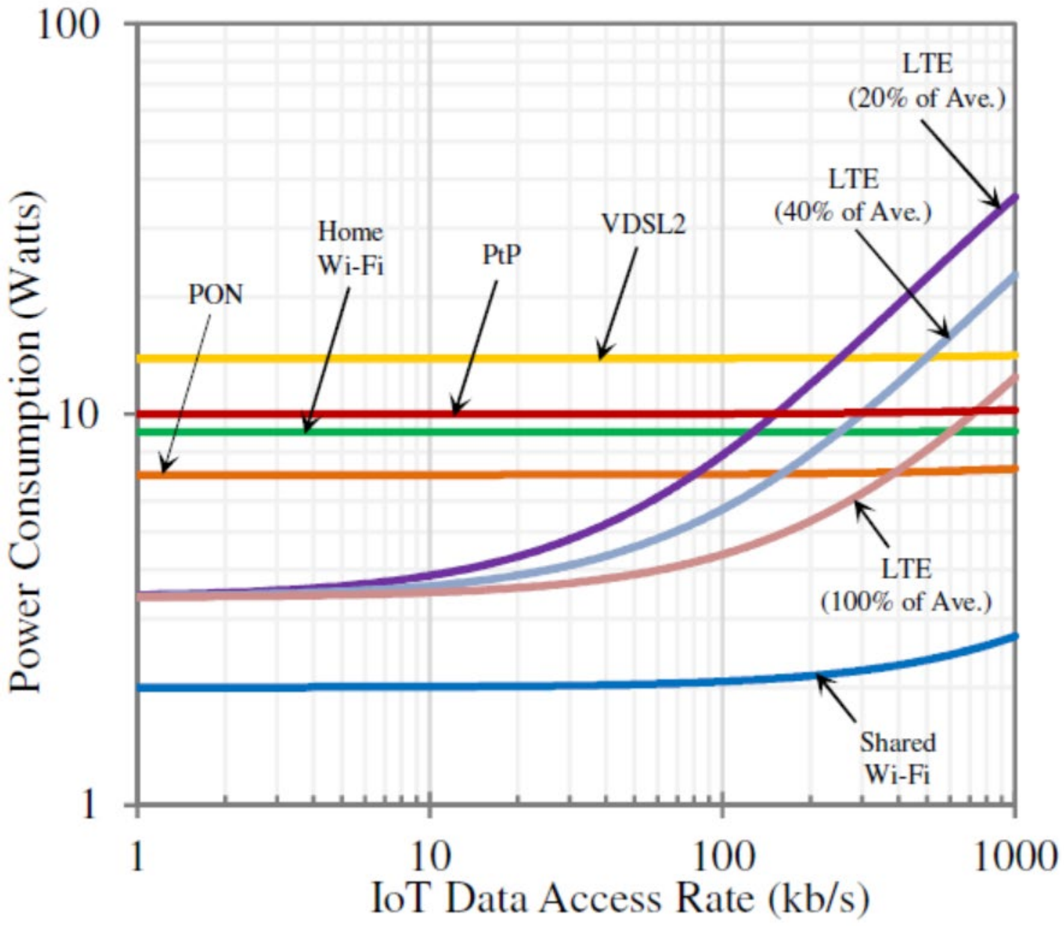
Similarly, a study by Baliga et al. (2011)[64] concludes that the most efficient technology is FTTH PON for low access rates and FTTH PtP for very high access rates. The study finds that a network using FTTC/N access consumes 1.5 times the power of a network using a PON Access due to the active equipment at the cabinet. The study also

64 Baliga, J., Ayre, R., Hinton, K., Tucker, R.S. (2011): Energy Consumption in Wired and Wireless Access Networks, in IEEE Communications Magazine ,July 2011.

concludes that a PtP access network involves a high power consumption but when there is significant bandwidth demand, the consumption for a PtP FTTH network is lower per Gigabit than other Gigabit-capable technologies including FTTH PON and DOCSIS.

Fibre was also found to be the most highly performing managed telecom infrastructure for IoT applications requiring high data rates.[65] The study authors found that, while LTE solutions were more energy efficient than wired solution up to data rates of around 100kbit/s, wired solutions were more appropriate at higher rates, with VDSL2 having significantly worse energy efficiency than PON or PtP FTTH-based solutions.

Figure 4-4: Power consumption per IoT gateway for different access network technologies



Source: Grey et al. (2015).

65 Gray, C., Ayre, R., Hinton, K., Tucker, R.S. (2015): Power Consumption of IoT Access Network Technologies, IEEE ICC 2015, Worksop on Next Generation Green IT, p. 2818 – 2823.

Translating energy efficiency to environmental impacts, Aleksix and Lovric found in a 2014 study,[66] that deployment of an all fibre infrastructure could lead to a 88% reduction in greenhouse gas emissions per MBit in Europe than using a combination of copper and coax infrastructure.

A 2018 study by Carbon Smart,[67] also concludes that when the overall lifecycle of different technologies are considered, energy per transmitted Mbit is lowest for FTTH PtP infrastructures in the long run.

4.1.3 Estimated environmental impact of moving to all-fibre solutions

For the purpose of this study, we have performed calculations to estimate the impact of migrating to all fibre networks, based on updated technical data. We compare DSL (incl. VDSL), Cable and FTTH/C in terms of their power consumption and their EU-wide impact on carbon emissions.

We base our analysis on a study by Obermann (2020)[68] for DSL and fibre technologies and the European Code of Conduct by the European Commission (2020)[69] for cable technologies. Based on the assumptions in these two documents we assume a capacity of 1 GBit/s that is fully used for the whole year and a 100% rate of network utilisation. We focus the analysis on the access network, excluding power consumption beyond the customers' access point (i.e. power associated with the customer premise equipment CPE).

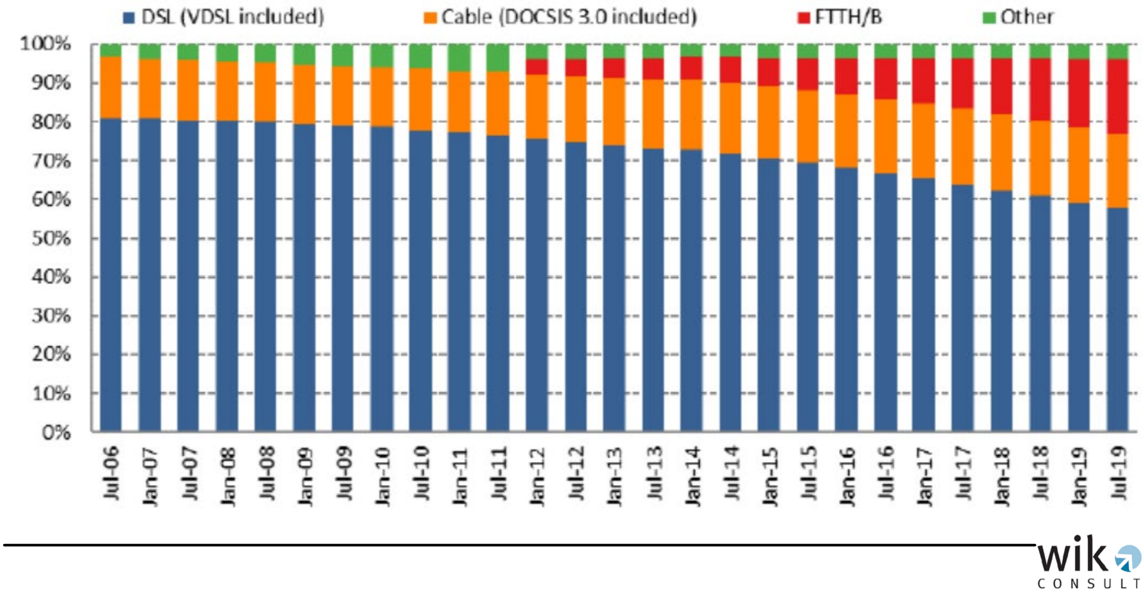
Based on the power consumption (in W) for the different network types we derive a yearly energy consumption for the different technologies. We then multiply the consumption values with the respective CO_2 emission factors (g CO_2 per kWh) for the European Union.

On this basis, we consider the impact of changing from the current technology mix of the EU to scenarios based on 1.) a range of different full fibre solutions (GPON96p, GPon16p, XGS-PON and GbE PtP) and 2.) a pure GbE PtP deployment of fibre networks.

The current mix of broadband technologies in the EU shown in the following figure.[70] For our analysis, we disregard the "other" technologies.

66 See Aleksix, S & A.Lovric (2014). Energy Consumption and Environment Implications of Wired Access Networks. American Journal of Engineering and Applied Sciences 4 (4), 531-539.
67 https://www.carbonsmart.co.uk/wp-content/uploads/2018/04/Digital-Infrastructure-WhitePaper.pdf
68 Obermann, K. (2020): Nachhaltigkeitsvergleich der Zugangsnetz-Technologien FTTC und FTTH.
69 European Comission (2020): Code of Conduct on Energy Consumption of Broadband Equipment, Version 7.1.
70 European Commission (2020): Digital Economy and Society Index (DESI) 2020, Thematic chapters.

Figure 4-5: Fixed broadband subscriptions – technology market shares in the EU (% of subscriptions), July 2006-July 2019



Source: European Commission (2020)

We conclude that if there was a complete migration from the current technology mix in the EU to all fibre (with the above described mix of fibre technologies) the power consumption would be reduced from 52,608 GWh to 10,857 GWh. Moreover, if there is complete switch to PtP connections the power consumption would decrease further to 3,376 GWh. In terms of CO_2 emissions this would mean a reduction from 15.5 Mio t CO_2 to 3.2 Mio t (fibre technology mix) and to 1.1 Mio t of CO_2 (only PtP connections) under the current power generation mix.

The calculations thus show that there is a significant environmental benefit that could be gained from switching to fibre technologies in the EU. A reduction in CO_2 emissions associated with the operation of telecom access networks of more than 90% in the EU might be achieved, if all households had PtP FTTH connections installed instead of the current technology mix.

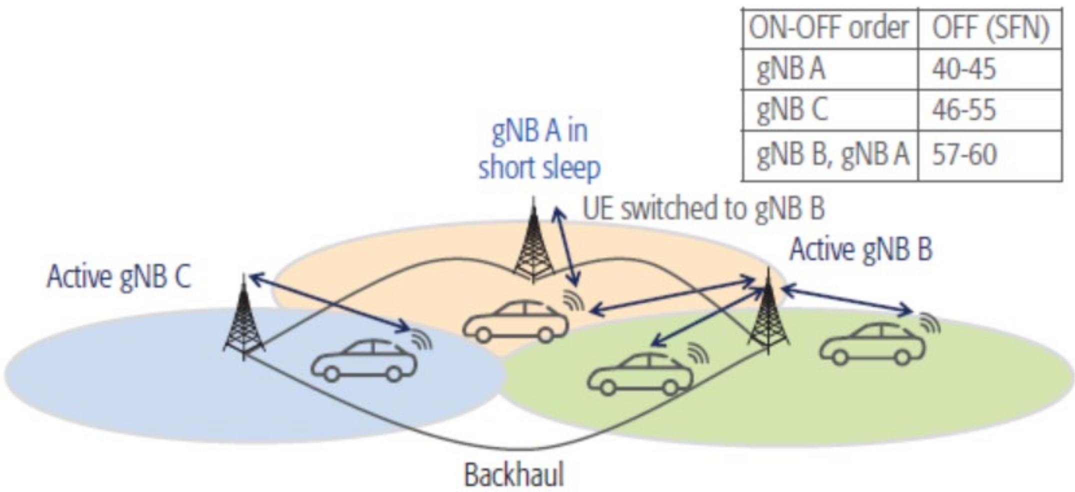
4.1.4 5G Networks

In addition to their vital role in the deployment of future-proof fixed broadband networks, fibre is also an essential component for the core elements of mobile networks, and will increasingly be needed for backhaul and fronthaul as 5G is deployment and bandwidth demand increases. The move to 5G will also have important implications for energy consumption.

Specifically, it is expected that "the network energy efficiency or power efficiency is required to be increased to 100-fold in 5G wireless networks as compared with that of 4G wireless networks."[71] Network energy efficiency is seen as a basic principle in the network design of 5G networks.[72]

Mukherjee (2018) identifies different areas for energy efficiency in 5G networks.[73] A first measure is on-/off switching of gNBs. When there is a set of adjacent gNBs, they can coordinate and save energy without jeopardizing the URLCC character of 5G.[74] Figure 4-6 shows an example.

Figure 4-6: Coordinated gNB on-off-switching to improve infrastructure energy efficiency without increasing delay



Source: Mukherjee (2018).

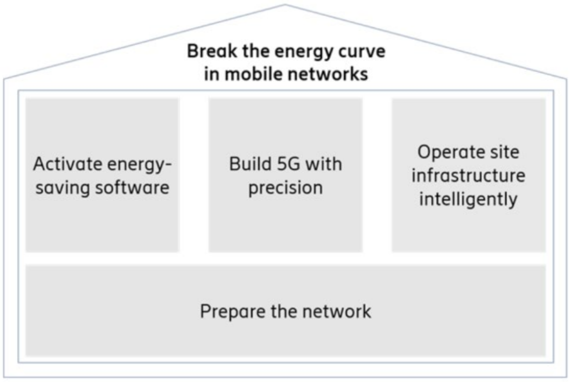
Secondly, energy might be saved by reorganising retransmissions, i.e. sending back incorrectly received data."[75]

71 Cheng, W., Zhang, X., Zhang, H. (2016): Statistical-QoS Driven Energy-Efficiency Optimization Over Green 5G Mobile Wireless Networks,in: IEEE Journal on Selected Areas in Communications, Volume: 34, Issue 12.
72 3GPP (2017): TR 38.913, Study on Scenarios and Requirements for Next Generation Access Technologies, June 2017.
73 Mukherjee, A. (2018): Energy Efficiency and Delay in 5G Ultra-Reliable Low-Latency Communications System Architectures, IEEE Network, March/April 2018, p.55-61.
74 Mukherjee, A. (2018): Energy Efficiency and Delay in 5G Ultra-Reliable Low-Latency Communications System Architectures, IEEE Network, March/April 2018, p.57 ff.
75 A potential solution is to bundle the original transmission and retransmission in the same TTI [Transmission Time Interval] as a preemptive measure, which can be activated after monitoring preceding HARQ [Hybrid Automatic Repeat Request] feedback from UEs. Note that the preemptive retransmission approach can benefit both infrastructure EE as well as device EEMukherjee, A. (2018):

Finally, Mukherjee (2018) argues that increased energy efficiency might also be achieved through using the decentralised structure of 5G networks. Firstly, the central unit (CU) of a 5G system might route "URLLC traffic to whichever DU is currently not already serving eMBB data".[76] The idea is thus similar to off/on-switching of gNBs. Secondly, data caches might be deployed close to the network edge. This technique avoids the need to send all data from and to the core network.

The Swedish telecommunications company Ericisson takes a holistic approach to reducing energy consumption from 5G networks as Figure 4-7 shows.

Figure 4-7: The elements and benefits of breaking the energy curve



Source: Ericsson (2020).

Ericsson describes these pillars as follows. Preparing the network means to invest in the newest technology for the whole network, i.e. without maintaining the legacy network. This way, in low traffic areas, a payback period of three vears from energy savings alone might be achieved.[77] Acitivating energy-saving software will bring svings by, e.g. machine learning. "Features such as Micro Sleep Tx (MSTx) and the Low Energy Scheduler Solution (LESS) can reduce radio equipment energy consumption by up to 15% while maintaining the same user experience."[78] Building 5G with precision means adding no extra hardware to networks but having it where it is needed so that no

Energy Efficiency and Delay in 5G Ultra-Reliable Low-Latency Communications System Architectures, IEEE Network, March/April 2018, p.58.

76 Mukherjee, A. (2018): Energy Efficiency and Delay in 5G Ultra-Reliable Low-Latency Communications System Architectures, IEEE Network, March/April 2018, p.59.

77 Ericsson (2020): Breaking the energy curve, An innovative approach to reducing mobile network energy use.

78 Ericsson (2020): Breaking the energy curve, An innovative approach to reducing mobile network energy use.

futher energy consumption is necessary.[79] Finally, according to Erisson's approach, site infrastructure should operate intelligently, i.e. introducing AI and predictive maintenance. Ericsson estimates that through this mechanism site energy usage and site visits can be reduced, achieving energy savings of up to 15%.[80]

This latter aspect is crucial for the contribution of 5G to energy savings not only within the mobile network but with regard to its implementation in many parts of the economy and society, including its role in supporting smart farming, robotics, mobile edge computing and automation.[81] 5G also enables the industry to produce more energy efficiently by means of "interoperability and interaction of various machines (e.g. sensors, actuators, and controllers) by providing seamless connectivity with low bandwidth needs. The fifth generation (5G) is a key enabling technology to revolutionize the future of industrial CPIoTS"[82] (Cyber-physical Internet of things system). Moreover, transport systems and smart cities profit from 5G through better resource allocation and higher energy efficiency.[83]

Further details of the effects of digitisation (including digital applications supported via 5G) are provided in the following section.

4.2 The effects of digitisation on the carbon footprint

As the case studies conducted for this exercise show, beyond the operational savings that can be made by switching to fibre, significant additional environmental gains can be made through the digitisation of industry and public services.

As an illustration, the World Economic Forum estimated in 2019, i.e before the Coronavirus breakout, that CO_2 emissions could be reduced by 15% globally as a result of digitisation.[84] Two sectors are commonly seen as key to this transformation: buildings and transport, although as discussed in section 3.1, other sectors including industry, farming and forestry are also relevant in achieving carbon neutrality in Sweden and elsewhere.

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79 Ericsson (2020): Breaking the energy curve, An innovative approach to reducing mobile network energy use.

80 Ericsson (2020): Breaking the energy curve, An innovative approach to reducing mobile network energy use.

81 Valecce, G., Strazzella, S. Grieco, L.A. (2019): On the interplay between 5G, Mobile Edge Computing and robotics in Smart Agriculture scenarios, In: Palattella M., Scanzio S., Coleri Ergen S. (eds) Ad-Hoc, Mobile, and Wireless Networks. ADHOC-NOW 2019. Lecture Notes in Computer Science, vol 11803. Springer, Cham.

82 Li, S. et al (2018): Energy-Efficient Resource Allocation for Industrial Cyber-Physical IoT Systems in 5G Era, IEEE Transactions on Industrial Informatics, Volume: 14, Issue: 6 , June 2018.

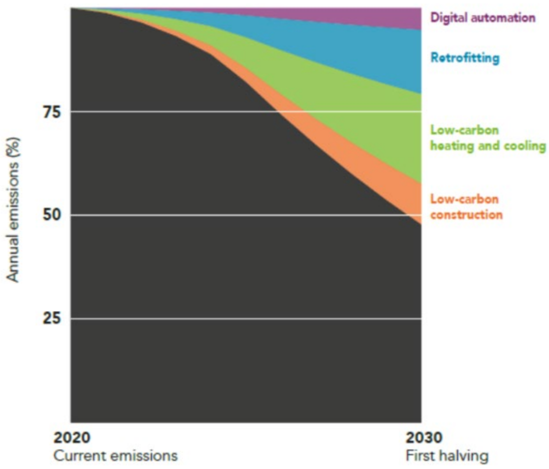
83 Dinh, D.V. et al. (2020): ICT Enabling Technologies for Smart Cities, 22nd International Conference on Advanced Communication Technology (ICACT).

84 Ekholm, B, Rockström, J. (2019): Digital technology can cut global emissions by 15%. Here's how, available at: https://www.weforum.org/agenda/2019/01/why-digitalization-is-the-key-to-exponential-climate-action/, last accessed: 16 June 2020.

4.2.1 Potential savings from smart buildings

Buildings were responsible for "9 $GtCO_{2e}$ globally in 2016, and have decreased slightly since, with about 60% coming from residential and 40% from non-residential buildings".[85] Figure 4-8 shows estimates for how digitisation and other measures could decrease CO_2 emissions from buildings in the coming ten years.

Figure 4-8: Trajectory of CO_2 emissions from buildings



Source:Global Climate Action Summit (2018)

In terms of digital automation, energy savings in buildings can be achieved by automatically regulating processes that need energy, e.g. lightning, cooling and heating. This reaches from simple movement sensors to IoT-based smart equiptment that is connected to the user or, by means of AI, "learns" how the building is being used.[86] In this way, the energy consumption of a building is minimised without a loss in comfort for its inhabitants.

Although the projections from the Global Climate Action Summit show a relatively limited role from digital automation on emissions from buildings, these are global projections, and experience from Sweden, such as that provided by Sisab show that significantly greater efficiencies could be achieved through this mechanism.

85 Global Climate Action Summit (2018): Exponential Climate Action Roadmap.
86 Global Climate Action Summit (2018): Exponential Climate Action Roadmap.

The Climate Group considers that "better building design, management and automation could save 15% of North America's buildings emissions, while globally, smart buildings technologies would enable 1.68 GtCO2e of emissions savings[…].[87]

BT (2016) estimates that total reductions of 1.528Gt in EU ICT-enabled carbon reductions could be achieved by 2030, with smart building technology contributing 0.310 Gt in reductions from a "combination of specific building software and remote controls that lead to intelligent homes and workplaces."[88]

Meanwhile, DIGITALEUROPE, the trade association representing digitally transforming industries in Europe, estimates that ultimately there is an energy saving potential from smart buildings of 50%.[89]

4.2.2 Potential savings from transport and logistics

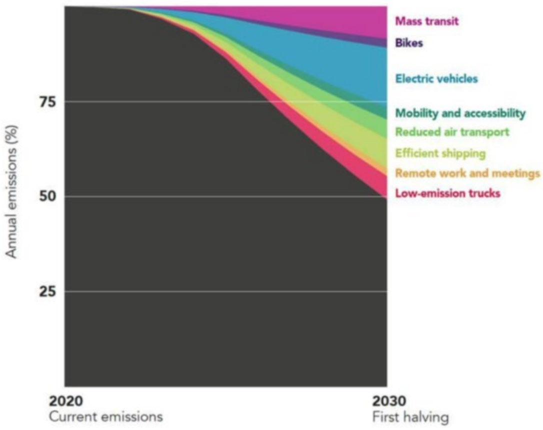
Digitisation can also contribute to tackling climate change in the field of transport and logistics.

As discussed in section 3.2.2, remote working has a role to play. In this context, it is notable that, in a 2020 study of the German market, Losse-Müller et al.[90] estimated that possible reductions of 8% in passenger transport could be achieved in the aftermath of the Coronavirus pandemic. The authors reached these conclusions based on the potential for increased use of home office workplaces and virtual meetings that substitute for business travel. These developments would also mean that space in office buildings could be saved, although the implications on energy use of such office closures could not be determined.

However, as can be seen in Figure 4-9, projections from the Global Climate Action Summit suggest that remote work and meetings are only part of a much wider range of solutions and initiatives that could reduce emissions in the field of transport.

87 Climate Group (2020): SMART 2020: Enabling the low carbon economy in the information age.
88 BT (2016): The role of ICT in reducing carbon emissions in the EU, May 2016
89 DIGITALEUROPE (2020): Digital contribution to delivering long-term Climate Goals, 05 FEB 2020, available at: https://www.digitaleurope.org/resources/digital-contribution-to-delivering-long-term-climate-goals/
90 Losse-Müller et al. (2020): Zwischenbilanz COVID-19: Umweltpolitik und Digitalisierung.

Figure 4-9: Trajectory of CO_2 emissions from transport



Source:Global Climate Action Summit (2018)

"The real game-changer will be electric and driverless cars and trucks. 5G is a pivotal technology for safety, efficiency and reliability in this space. Driverless vehicles will accelerate a shift in the traditional business model of vehicle ownership towards mobility and transportation as a service. This means fewer people will own a car, instead ordering shared rides from driverless electric vehicles or catching a driverless bus. Within industry, Ericsson, Telia and Einride are working on a connectivity-based 5G solution that could lead to an exponential transformation of short-distance transport on public roads. The project is based on Einride's T-pod, a continuously operating driverless vehicle, and aims to make all road freight transportation electric. Such a sustainable and cost-competitive solution may replace more than 60% of today's transport impact. Einride estimates the CO2 reduction potential per pallet of freight when transitioning from diesel to electricity to be 90% for countries with a low-carbon electricity mix, like Sweden. It will also reduce emissions of harmful NOx and ultrafine soot particles."[91]

BT agrees that significant energy savings could be made through connected private transportation systems, i.e. the connection of vehicles to foster car and route sharing and smart logistics, i.e. "decrease in air, train, maritime and road freight through maximisation of vehicle capacity and logistics sharing".[92] BT estimates that savings from digitisation of logistics and mobility could reduce CO2 levels in the EU by 0.166 Gt.by 2030.

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91 Ekholm, B, Rockström, J. (2019): Digital technology can cut global emissions by 15%. Here's how, available at: https://www.weforum.org/agenda/2019/01/why-digitalization-is-the-key-to-exponential-climate-action/, last accessed: 16 June 2020.

92 BT (2016): The role of ICT in reducing carbon emissions in the EU, May 2016

The Climate Group (2020) estimates that through smart logistics, i.e "a host of efficiencies in transport and storage, […] Europe could deliver fuel, electricity and heating savings of 225 MtCO2e. The global emissions savings from smart logistics in 2020 would reach 1.52 GtCO2e, […]".[93]

Meanwhile, Digital Europe has also estimated that "Digitising the logistics sector will significantly reduce CO2 emissions through optimisation, by enabling driverless and connected cars, flexible charging services, as well as mobility-as-a service solutions" leading to an estimated 3.6GT CO2 reduction in the transport sector.[94]

Although the figures from the different sources differ (which might be due to different calculation methods) they all highlight the significant potential for digitisation to tackle climate change.

It should be borne in mind that an increase in digitisation is also likely to be associated with greater energy consumption through the increased use of IT equipment and server farms. It is therefore important to look at the net effects of digitisation after taking these factors into account. However, as discussed in section 3.3.2, there is also the potential to reduce energy consumption from IT equipment through consolidating this equipment into fewer locations, and waste energy from such server farms can also be used to provide energy for nearby facilities or district heating.

Thus, implementation of digital technology should be coupled with efficiencies in and re-use of energy associated with ICT to best support climate goals in the EU and worldwide.

5 The role of neutral networks in the green new deal

The European Commission has identified the "European Green Deal" as one of its key priorities for the coming years. Targets include ensuring that there are no net emissions of greenhouse gases by 2050, that economic growth is decoupled from resource use and that no person or place is left behind.[95]

In this chapter, we consider the role that dark fibre could play in supporting these aims and its status as an essential infrastructure.

In papers published alongside its European Green Deal initiative the European Commission notes that:

93 Climate Group (2020): SMART 2020: Enabling the low carbon economy in the information age.
94 DIGITALEUROPE (2020): Digital contribution to delivering long-term Climate Goals, 05 FEB 2020, available at: https://www.digitaleurope.org/resources/digital-contribution-to-delivering-long-term-climate-goals/, last accessed: 16 June 2020.
95 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

- Transport accounts for a quarter of the Union's greenhouse gas emissions and is still increasing, with road transport accounting for more than 70% of these emissions. The Green New Deal seeks a 90% reduction in these emissions by 2050.[96]
- Buildings account for 40% of energy consumed in the EU;[97] and
- The EU's industry accounts for 20% of emissions[98]

In its February 2020 Communication, the Commission highlighted that digitisation can provide an important part of the solution.[99] The Communication notes that:

KEY FINDINGS

In its European Green Deal, the Commission has acknowledged that digital solutions can advance the circular economy, support the decarbonisation of all sectors and reduce the environmental and social footprint of products placed on the EU market.

However, in order to achieve positive effects, data centres and telecommunications will need to become more energy efficient, reuse waste energy, and use more renewable energy sources. According to the Commission, they can and should become climate neutral by 2030.

The experience of Stockholm, and Sweden more generally, shows that efficiencies in the operation of broadband networks and climate neutral data centres can be achieved. At the heart of these efficiencies has been a passive fibre network, which has been operated as a utility for the benefit of the City, its businesses, workers and inhabitants.

Neutral fibre networks have been designated as an "essential service" in some US districts. During the Coronavirus outbreak telecom engineers were designated as "essential workers" in the UK, allowing fibre deployment to continue.

Given the pivotal role of fibre networks in ensuring an environmentally sustainable economic recovery, there may be a case for environmental considerations to be reflected in policies aimed at supporting the deployment and take-up of very high capacity networks by national Governments and the EU as a whole.

> ***Digital solutions can advance the circular economy, support the decarbonisation of all sectors and reduce the environmental and social footprint of products placed on the EU market. For example, key sectors***

96 https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6726
97 https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6725
98 https://ec.europa.eu/clima/sites/clima/files/strategies/progress/docs/swd_2019_396_en.pdf
99 https://ec.europa.eu/info/sites/info/files/communication-shaping-europes-digital-future-feb2020_en_4.pdf

> ***such as precision agriculture, transport and energy can benefit immensely from digital solutions in pursuing the ambitious sustainability objectives of the European Green Deal. Digital solutions, and data in particular, will also enable a fully integrated life-cycle approach, from design through sourcing of energy, raw materials and other inputs to final products until the end-oflife stage.***

However, the report also notes that the ICT sector also needs to undergo its own green transformation. The environmental footprint of the sector is significant, estimated at 5-9% of the world's total electricity use and more than 2% of all emissions. Specifically, the Commission recommends that:

> ***Data centres and telecommunications will need to become more energy efficient, reuse waste energy, and use more renewable energy sources. They can and should become climate neutral by 2030.***

The experience of Stockholm, and Sweden more generally, shows that efficiencies like these can be made while boosting growth and sustainable development.

- Sweden's GDP has continued to increase while levels of CO2 have been in decline
- Stockholm's schools have achieved 35% savings in energy use through smart building applications which save on heat and energy use
- Trials with smart transport have reduced congestion
- A high proportion of Stockholm's workforce were able to work remotely during the Coronavirus pandemic, and healthcare provision was moving online even before the pandemic struck, saving unnecessary travel
- Waste energy from datacentres as well a Stokab's cross-connector sites has been re-used to support district heating

These developments have been supported by a neutral dark fibre infrastructure, over which service and application providers have been free to innovate, in the fields of data warehousing, monitoring of air and water pollution, smart buildings, eHealth, AI-driven learning applications and beyond.

Moreover, in its architecture and business model, Stockholm's dark fibre infrastructure has also facilitated energy saving, by providing a route towards a greener technology, which could reduce emissions by up to 90% compared with legacy technologies, and by enabling active equipment to be concentrated in specific areas where resources can be shared and waste energy re-used.

The role of fibre in supporting growth and jobs has been well-established.[100] As this study shows, fibre also has an important role to play in supporting energy efficiency to meet the goals of the European Green Deal. As such, there may be a case to consider investment in broadband not only from an economic perspective, but as a utility which plays a vital role in supporting the societal and environmental goals of nations and communities within Europe and beyond.

In recognition of its pivotal role in society, a number of cities have declared fibre as an essential infrastructure, including the City of Bangor in Maine US which noted in a 2018 declaration that fibre should be prioritised as an essential service "just as with water, sewers and electricity".[101] In April 2019, the City Council of Bozeman, Montana also adopted a resolution[102] which declared broadband as an "essential infrastructure", and committed the City to consider expanding the existing City-owned fibre network.

Within Europe, fibre infrastructure can be classified as a Service of General Economic Interest in the context of EC State aid notifications.[103] In the context of the coronavirus pandemic, the UK Government classified information technology and "data infrastructure" as an essential service, with telecommunications workers designated as "key workers",[104] enabling the fibre deployments of companies such as Cityfibre to continue during the outbreak.[105] The Danish utility group EWII has also called for fibre to be designated as a fundamental infrastructure, with the same status as utilities.[106] The Swedish Civil Contingencies Agency (MSB) has also designated infrastructure for telecoms as critical for society during the Corona epidemic.[107].

There is evidence[108] to suggest that when municipalities engage in broadband roll-out, they apply different calculations in their investment plans compared with commercial players. Specifically, while private investors made investment decisions on the basis of the expected profitability of a project (as determined by population density, penetration,

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100 See for example Castaldo, A.; Fiorini, A.; Maggi, B. (2015): Fixed broadband connections and economic growth: a dynamic oecd panel analysis, Public Finance Research Papers, Istituto di Economia e Finanza: http://www.digef.uniroma1.it/sites/default/files/pubblicazioni/economia/e-pfrp17.pdf; Falk, M.; Biagi, F. (2015): Empirical studies on the impact of ICT usage on employment in Europe, Institute for Prospective Technological Studies Digital Economy Working Paper 2015/14 https://ec.europa.eu/jrc/sites/default/files/JRC98693.pdf ;Faulhaber, G.; Hogendorn, C. (2000): The Market Structure of Broadband Telecommunications, The Journal of Industrial Economics 48 (3) http://assets.wharton.upenn.edu/~faulhabe/Broadband.pdf

101 https://muninetworks.org/sites/www.muninetworks.org/files/2018-07-Bangor-ME-Resolution-Fiber-Essential-Infrastructure.pdf

102 https://muninetworks.org/content/city-leaders-bozeman-montana-declare-broadband-essential-infrastructure

103 WIK for EC DG Regio: The Broadband State aid rules explained, SMART 2013/0064, Brussels 2013

104 https://www.gov.uk/government/publications/coronavirus-covid-19-maintaining-educational-provision/guidance-for-schools-colleges-and-local-authorities-on-maintaining-educational-provision

105 https://www.mkfm.com/news/local-news/city-fibre-continues-to-carry-out-essential-works-throughout-milton-keynes/

106 https://www.telecompaper.com/news/ewii-classifies-fibre-as-essential-infrastructure--1308168

107 https://www.msb.se/contentassets/f58722b3995c4ac2b9e8578a28b1ad33/200602-samhallsviktig-verksamhet-under-coronapandemin.pdf

108 Wernick, C.; Bender, C. (2017): The Role of Municipalities for Broadband Deployment in Rural Areas in Germany: An Economic Perspective, in: Digiworld Economic Journal, No. 105, 1st Q 2017.

and ARPU, WACC), public investors tend also to take into consideration welfare effects. This may lead them to prioritise coverage across a given area (up to the point of cost recovery) rather than profit maximisation. As can be seen in the case of Sweden and other cases including rural deployments in Austria and early deployments in the Netherlands,[109] the involvement of municipalities can also lead to differences in the business models and architectures chosen, with point to point dark fibre deployments more prevalent in community broadband deployments, as a means of reducing digging and fostering innovation in services and applications.

As concerns over the environment go well beyond local communities, there may be a case for environmental considerations to be reflected in policies aimed at supporting the deployment and take-up of very high capacity networks by national Governments and the EU as a whole.

6 Recommendations

Policies aimed at fostering the deployment and take-up of very high capacity broadband connections have typically focused on the economic and social benefits associated with high speed broadband, alongside the economic costs of deploying these networks. However, in view of the vital role that broadband has to play in achieving the European Green Deal (and in reducing existing emission levels), policy-makers could usefully take greater account of the environmental costs and benefits when developing recommendations concerning broadband. For example:

- Energy efficiency could be taken into account in the context of public funding or other public support given to telecom network deployment. Consumers could also be made aware of the energy efficiency of broadband connections in the context of any broadband labelling schemes
- Facilitating the transition from legacy copper and cable infrastructure to full fibre could contribute to significant energy savings in the operation of telecoms network. Efforts to support this transition coupled with the switch-off of legacy infrastructure could contribute to stablising or reducing the carbon footprint of the telecom sector while supporting increased bandwidths.
- Examples such as Sweden illustrate how the participation of municipalities in the provision of neutral dark fibre infrastructure can contribute to innovation in the fields of environmental monitoring and controls in buildings and for transport and elsewhere, as well as contributing to reduced requirements for digging. When pursuing strategies to support VHC broadband, Governments and local authorities should consider the role that could be played by municipal networks

109 See case studies for Nogig and Amsterdam CityNet in WIK (2018) The role of wholesale only models in future networks and applications https://www.stokab.se/Documents/Nyheter%20bilagor/The%20role%20of%20wholesale%20only_WIK.pdf

in supporting deployment and take-up, as well as in promoting wider societal and environmental goals.

More generally, in view of its essential role in the Coronavirus pandemic and its importance in supporting environmentally sustainable broadband and digital services for the future, there may be a case to consider fibre as an essential infrastructure for the digital revolution, in much the same way as roads, railways, and the exploitation of fossil fuels powered the industrial revolution.