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Study for the Danish Energy Agency

Analysis of the Danish Telecommunication Market in 2030

Authors:
Ilsa Godlovitch
Dr Christian Wernick
Dr Bernd Sörries
Dr Sonia Strube Martins
Julian Knips
Matthias Wissner
Dr Sebastian Tenbrock
Matthias Franken

WIK-Consult GmbH
Rhöndorfer Str. 68
53604 Bad Honnef
Germany

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wik CONSULT

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WIK-Consult GmbH
Rhöndorfer Str. 68
53604 Bad Honnef
Germany
Phone: +49 2224 9225-0
Fax: +49 2224 9225-63
eMail: info@wik-consult.com
www.wik-consult.com

Person authorised to sign on behalf of the organisation

General Manager	Dr Iris Henseler-Unger
Director Head of Department Postal Services and Logistics	Alex Kalevi Dieke
Director Head of Department Networks and Costs	Dr Thomas Plückebaum
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Registered at	Amtsgericht Siegburg, HRB 7043
Tax No.	222/5751/0926
VAT-ID	DE 123 383 795

0 Executive summary

Denmark currently performs well against international benchmarks for the digital economy and society. However, new developments and challenges lie ahead, and the Danish authorities wish to ensure that Denmark can maintain and enhance its leadership in digital communications in the years to come, in line with the aspirations set out in the Political agreement on Telecommunication, as well as meeting challenging targets on the environment.

This study seeks to contribute to the DEA's understanding of trends in the telecom sector over the coming 10 years and the opportunities and challenges ahead with a view to creating the best possible framework for the telecommunications market in Denmark.

Key findings are discussed below.

0.1 Denmark's position in digital infrastructure and services

Denmark is competitive in many areas associated with telecoms infrastructure and services, although some gaps remain.

Benchmarks against 11 other developed markets in Europe and internationally show that Denmark ranks highly in deployment of FTTH networks (with a comparatively high coverage of these networks in rural areas). However, there is a risk that the speed of FTTH roll-out might slow down. Furthermore, the take-up of very high bandwidth connections remains more limited. This may be due to the fact that, notwithstanding recent progress in this area, a significant price gap remains between lower speeds and higher capacity Gigabit connections.

Denmark is amongst the top performers in the availability and quality of mobile services. 99% of households can access 4G services, and customers in Denmark benefit from high speeds and low latency in mobile broadband. However, data on geographic availability of 4G connections shows that some coverage gaps remain.

Denmark performs very well on the international stage as regards the degree of digitization of industry and public services. The IMD Digital Competitiveness Index 2019 ranks Denmark on fourth place internationally in terms of its digital competitiveness.[1] In the metric of "Future Readiness", Denmark even reaches the second place (behind the US) after leading this section for the two years prior. A high proportion of Danish businesses uses online sales channels and Denmark is considered a world leader in some smart applications such as eHealth.

1 The countries ranking above Denmark are the United States, Singapore and Sweden, available at: https://www.imd.org/wcc/world-competitiveness-center-rankings/world-digital-competitiveness-rankings-2019/.

0.2 The potential to exploit smart applications

Denmark is already active in exploiting smart applications across a variety of sectors.

- Denmark is close to completing the installation of smart electric metres recording hourly consumption in every household by 2020, and has committed to exploiting renewable energy sources such as offshore wind in a bid to achieve carbon neutrality
- Smart city applications have been trialed in cities such as Copenhagen. For example, the City is collaborating with private sector actors including Cisco and TDC in an incubator which has brought solutions such as smart waste management and the measurement of air pollution top the city. Smart lighting has also been deployed in a project dating from 2013.[2]
- The City of Padborg is at the centre of developments to build a 5G network and test autonomous driving applications for the transport industry
- Denmark is a leader in the use of telemonitoring solutions. One case involved the use of telemonitoring to permit the early discharge of pre-term babies, saving costs and increasing customer satisfaction.[3] Denmark has also pioneered access to medical data via the app "Medicinkortet" (Medication Record)
- In the field of e-Education, Denmark has deployed interactive services and applications to support learning within classrooms, while distance learning is used to supplement educational offers in rural areas
- Denmark also performs well against a number of eGovernment metrics, but progress could be made in expanding the use of open data
- The project “Farm machine interoperability”[4] aims to foster IoT applications and increase production efficiency.

Future evolutions in smart applications are likely to involve the increased use of sensors to gather data and process it within the cloud with the support of AI. Applications involving cameras are also likely to increase e.g. transport monitoring and enforcement in the context of smart cities, or analyzing crop status in the context of smart farming. In energy, smart grid systems will require ultra-reliable and secure connections. Meanwhile, sensitive applications such as remotely assisted surgery and automated driving are likely to require ultra-low latencies as well as reliability.

2 See https://www.citelum.com/news/citelum-and-the-smart-lighting-project-in-copenhagen-recognized-at-the-green-solutions-awards.

3 See https://cimt.dk/gb/telemedicine-premature-children/ and https://norden.diva-portal.org/smash/get/diva2:1297054/FULLTEXT01.pdf.

4 See https://www.iof2020.eu/trials/arable/farm-machine-interoperability.

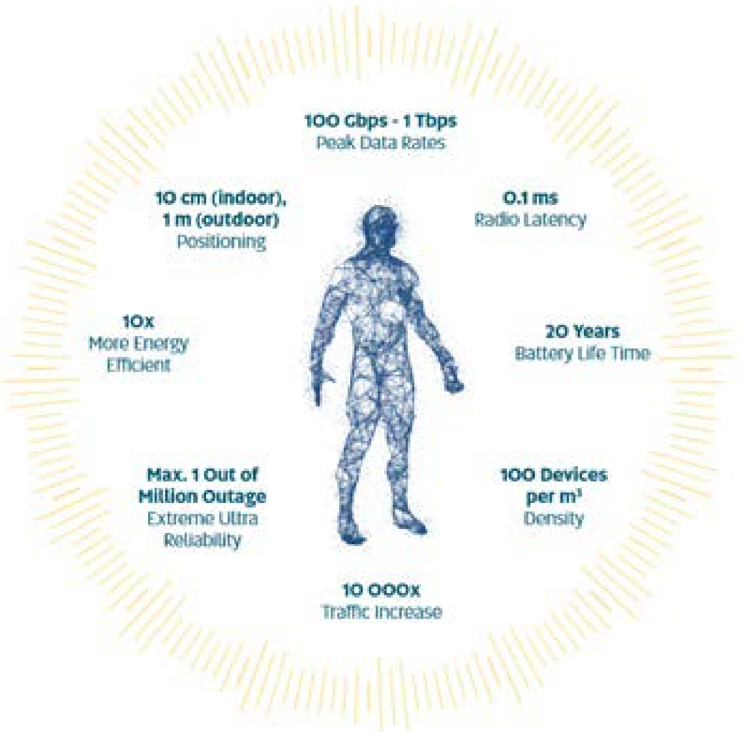
0.3 Upcoming technological developments

The demands of future smart applications, are likely to require high capacity connections and associated 5G connectivity to be widely available not only to all households, businesses and public institutions, but also along highways and to remote locations such as farms.

5G is expected to achieve considerable advances on currently deployed technologies in terms of peak data rates, network energy efficiency and latency. Through the use of network slicing, 5G will also enable the provision of innovative services and applications which have specific quality of service requirements. As such, network slicing is likely to play an important role in supporting the delivery of many of the smart applications described above.

Although 5G is still in its infancy and the rollout is far from complete, the next generation 6G is already being researched, and is expected to be introduced in 2030. Available literature suggests that under the 6G standard, the architecture of mobile networks will not change, but 6G may provide a new level of quality of service, further supporting the evolution of applications developed in conjunction with the 5G ecosystem.

Figure 0-1: Key Performance Indicators 6G



Source: 6G Flagship (2019).

Although fixed wireless access via 5G could provide an alternative to fibre in very rural areas, 5G is not expected to replace fixed networks, although. Rather, in order to enable the rollout of 5G and in the future 6G networks, a fibre connection will be increasingly essential, e.g. to connect the RAN with the core network.

At the same time as wireless technologies are evolving, fixed technologies are also evolving to support higher bandwidths, symmetry and lower latency. For operators relying on traditional twisted pairs, the next stage beyond FTTC/VDSL is G.fast with bandwidths of up to 1Gbit/s. G.mgfast can be expected within the next 3 years, with a target bandwidth of between 5-10Gbit/s. Meanwhile the recently developed cable DOCSIS 4.0 standard will provide for 10/10Gbit/s symmetric access.

However, evolutions of copper and cable networks will themselves require significant deployments of fibre deeper within the network, and a significant performance gap is likely to remain between these incremental investments and fibre to the premise networks, especially when deployed in a point to point architecture.

0.4 Impact of technological and market developments on the environment and society

Modern fixed and wireless technologies are more energy efficient than their predecessors. For example, Ericsson notes that the energy efficiency of 5G is intended to be 10 times better than 4G for the same data volumes. Likewise, a 2014 study suggests that FTTH infrastructure is associated with 88% lower greenhouse gas emissions per Gigabit than a network composed of FTTC/VDSL and DOCSIS technologies. However, while the new technologies are energy efficient, overall data consumption is expected to increase, offsetting these savings. Moreover, the deployment of smart applications is likely to be associated with the increased use of cloud computing power and data centres, which have been shown to be energy intensive.

Rather, the main environmental benefit is likely to result from the efficiency savings made possible through the digitization of industry and public services. For example:

- Buildings are responsible for 36% of EU Emissions. Assessments of the impact of smart building systems suggest energy savings of 18% for offices, 14% for retail stores and hospitals could be achieved
- Studies suggests that teleworking could reduce traffic by 2.7% and air pollution by 2.6-4.1% alongside reductions in emissions
- In a 2018 study, McKinsey suggests smart city applications could reduce emissions by 10-15%

- Agriculture is responsible for around 10% of green house gas emissions in the EU (and 22% in Denmark)– mainly via Methane (CH_4) and nitrous oxide (N_2O). Precision farming could help to reduce reliance on fertilizers and pesticides, as well as energy. Fuel consumption savings have been estimated at 10% in the context of the Danish project “Farm machine interoperability”.

Various studies also highlight the potential social benefits that can be achieved from digital applications including reductions in the urban rural divide, supporting employment and social services in rural areas.

0.5 Impact on business models

Services associated with smart applications and the digitization of industry involve a wide range of players, making it essential for different players in the value chain to collaborate to achieve results.

The respective roles of different plays in the evolving “smart application” ecosystem are not yet clear, and may differ for different use cases. However, it seems likely that:

- Systems integrators will play a more significant role in acting as solutions providers to industry and the public sector, offering services such as unified communications alongside cloud computing and IoT solutions
- Companies could decide to outsource IT solutions entirely or become more involved in their provision (for example by deploying or contracting to deploy their own private network), or by co-investing in the development of platforms associated with their industry[5]
- Public authorities may play an active role in the development and/or procurement of smart city solutions, as well as potentially in the deployment of networks (which is common in Sweden, but not envisaged in Denmark), WiFi and potentially in future 5G small cell connectivity.[6] They could also play a pivotal role as regards planning procedures for 5G antennas and fibre backhaul
- Road operators may be involved in the deployment of networks for connected automotive mobility
- OTTs will play an increasingly important role in content delivery (where their services may displace managed TV), as well in providing platforms and developing applications for smart services.

5 An example is the investment by Audi in Cubic telecom, a supplier of platforms for connected automotive mobility.

6 See Smart Investments for Smart Communities, available at: https://ec.europa.eu/digital-single-market/en/news/cef2-study-workshop-smart-investments-smart-communities.

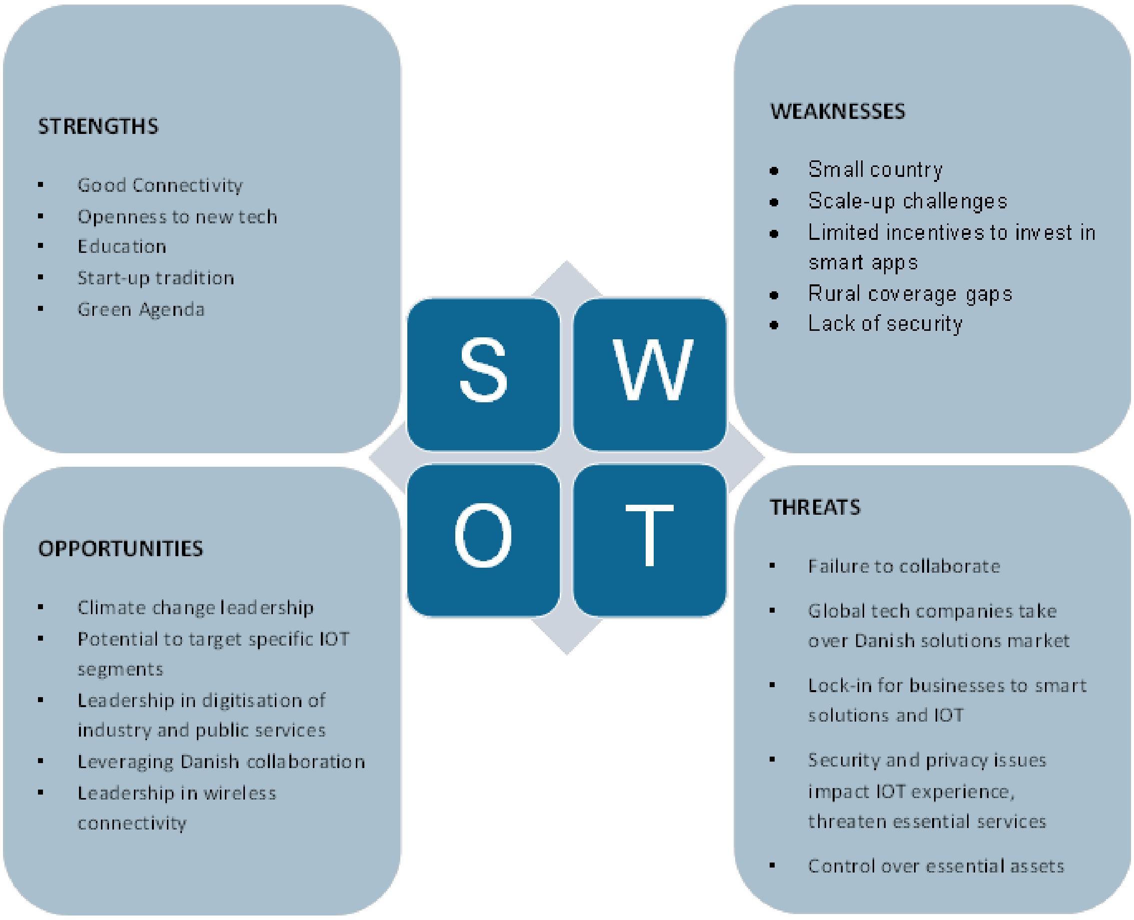
In this evolving and expanding ecosystem, the role of telecoms operators may evolve with larger and/or international players seeking to move down the value chain into the provision of cloud services and IoT solutions, while smaller telecom providers may focus on infrastructure provision, pursuing a wholesale only model in which they seek to attract other players to develop services and applications over their infrastructure.

0.6 Strengths, weaknesses, opportunities and threats for the Danish ICT industry and customers

Stakeholders interviewed for this study noted that Denmark benefits from a number of strengths in digital infrastructure and the culture of developing and using digital applications. However; they also highlighted weaknesses in a number of areas which could undermine Denmark's efforts to become a European and global leader in the field of climate change and digitization.

Key points are highlighted in the diagram below.

Figure 0-2: SWOT analysis: Denmark's position in digital infrastructure and services



Source: WIK.

0.7 Focus areas

Drawing on the opportunities and challenges for digitization in the Danish market, as well as feedback from stakeholders, we have identified areas where action could be considered.

These areas include:

- Spectrum policy, in light of the upcoming auction of spectrum in the 3.5Gz band, as well as consideration of the relevance of millimeter frequency bands for FWA deployment
- Consideration of the role of network sharing, access and the relevance of spectrum for alternative actors to deploy private networks in the context of 5G

- Planning permissions associated with the deployment of 5G antennas
- Incentivisation of smart energy investments
- The role of broadband state aid in facilitating full coverage in rural areas
- Future needs for connected highways
- Fostering investment in future-proof VHC infrastructure and support for open networks and platforms over which innovation can thrive.
- Digital hubs and innovation vouchers
- Solutions and standards which enable switching in the IoT area
- Collaborating at EU level to support regulations which ensure IT security, and the effective management of data in an IoT environment.

As digitisation will involve a wide set of industries and public services, we would recommend a cross-sectoral focus within the public administration to ensure that synergies between electronic communications, energy, industrial policy, transport, health and education, can be effectively realized.

Contents

Glossary

10G-EPON	10Gbit/s Ethernet Passive Optical Network
4G	4th generation mobile networks
5G	5th generation mobile networks
6G	6th generation wireless, i.e. successor to 5G cellular technology that will be able to user higher frequencies than 5 G networks and provide higher capacity and lower latency
ACEEE	American Council for an Energy-Efficient Economy
AI	Artificial Intelligence
AR	Augmented Reality, i.e. interactive experience with real world objects enhanced by computer-generated perceptual information
CAM	Connected and Automated Mobility
CCTV	Closed Circuit Television, i.e. video surveillance
CDMA	Code Division Multiple Access
COPD	Chronic Obstructive Pulmonary Disease
C-V2X	Cellular vehicle-to-everything
D2D	Device to Device
DEA	Danish Energy Agency
DOCSIS	Data Over Cable Service Interface Specification, an international telecommunications standard that permits the addition of high-bandwidth data transfer to an existing cable television (CATV) system
DSL	Digital Subsriber Line
EPON	Ethernet Passive Optical Network
FCC	Federal Communications Commission, telecommunications regulator in the US
FMS	Farm Management System
FTTC	Fibre to the curb
FTTH	Fibre to the home
FTTP	Fibre to the premise
FWA	Fixed Wireless Access
G.fast	“G” stands for the ITU-T G series of recommendations; fast is an acronym for fast access to subscriber terminals
GB	Gigabit
Gbit/s	Gigabit per second
GDP	Gross Domestic Product
GHz	Gigahertz (unit to measure wave frequencies)
GPON	Gigabit Passive Optical Network.

GPS	Global Positioning System
GSMA	GSM (Global System for Mobile Communications) Association, global association of mobile network operators and other players in the broader mobile ecosystem (as associated members)
HFC	Hybrid Fibre Coaxial network, i.e. broadband network combining optical fibre and coaxial cable
HPC	High Performance Computing
HVAC	Heating, Ventilation, Air Conditioning
ICT	Information Communications Technology
IEEE	Institute of Electrical and Electronics Engineers, worlds largest technical professional organization dedicated to advancing technology
IoT	Internet of Things
ISP	Internet Service Provider
IT	Information Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicators
LoRaWAN	LoRA: low-power wide-area network technology, WAN: Wide Area Network
LPWA	Low Power Wide Area Network
LTE	Long Term Evolution
LTE-M	LTE-MTC (Machine Type Communication)
M2M	Machine-to-Machine, i.e. communications between networked devices
Mbit/s	Megabit per second
MDU	Multi Dwelling Units
MEC	Multi-access edge computing or mobile edge computing, an ETSI-defined network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network and, more in general at the edge of any network
MNO	Mobile Network Operator
MOOC	Massive Open Online Classes, online course for unlimited participaton and open access via web
MVNA	Mobile Virtual Network Aggregator
MVNO	Mobile Virtual Network Operator
NB-IoT	Narrowband IoT
NFV	Network Functions Virtualization
NG-PON2	Next-Generation Passive Optical Network 2, also known as TWDM PON
NSI	National Sundheds-it, National Board of Health in Denmark

OECD	Organisation for Economic Co-operation and Development
OTT	Over the top (OTT), i.e. film and television content provided via a high-speed Internet connection rather than a cable or satellite provider/streaming content to customers directly over the internet
PON	Passive Optical Network
R&D	Research and Development
RAN	Radio Access Network
SDN	Software Defined Networking
SE	Syd Energi
SigFox	Communications service provider with focus on the IoT, based in France
SIM	Subscriber Identity Module
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TDC	Formerly Tele Danmark Communications (largest telecommunications company in Denmark)
TDM-PON	Time-Division Multiplexing Passive Optical Network
URLLC	Ultra-reliable and low latency communication
US	United States
V2I	Vehicle to Iinfrastructure communication
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle communication
VDSL	Very high speed digital subscriber line
VHC	Very high capacity
VNI	Visual Networking Index, provided by Cisco that provides a forecast of global fixed and mobile internet traffic updated each year
VNPaaS	Virtual Network Platform as a Sevice
VR	Virtual Reality
VULA	Virtual Unbundled Local Access
WDM	Wavelength Division Multiplexing
WDM-PON	Wavelength Division Multiplexing-Passive Optical Network
WiFi	Wireless Fidelity, i.e. a wireless networking technology that uses radio waves to provide wireless high-speed Internet and network connections
WIK	Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste
WLAN	Wireless Local Area Network
XG-PON	10-Gigabit-capable Passive Optical Network

Tables

Figures

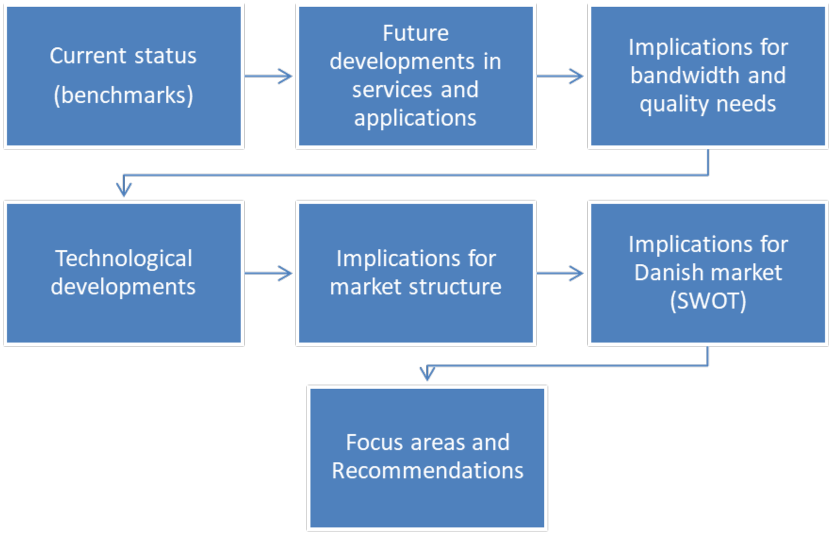
1 Introduction

Denmark currently performs well against international benchmarks for the digital economy and society. However, new developments and challenges lie ahead, and the Danish authorities wish to ensure that Denmark can maintain and enhance its leadership in digital communications in the years to come, in line with the aspirations set out in the Political agreement on Telecommunication, as well as meeting challenging targets on the environment.

This study seeks to contribute to the DEA's understanding of trends in the telecom sector over the coming 10 years and the opportunities and challenges ahead with a view to creating the best possible framework for the telecommunications market in Denmark.

Our analysis is based on the following steps. We begin by analysing the Danish telecom market and its position internationally, providing a "baseline" for the assessment of future developments. We then move to an analysis of future applications for connectivity and the implication of these applications for the environment and society. On this basis, we consider Denmark's future requirements for bandwidth and quality of service and assess relevant technological developments and potential market structures. We will conclude with an assessment of opportunities and challenges for the Danish market, based on a SWOT analysis, and suggest focus areas.

Figure 1-1: Study methodology



Source: WIK.

- Chapter 2 considers the current status of connectivity and digitisation in Denmark compared with 11 advanced international comparator countries
- In chapter 3, we discuss developments in services and applications, with reference to six industrial and public use cases
- In chapter 4, we review the technological requirements associated with industrial and public use cases for connectivity and consider potential technological developments in the period towards 2030
- Chapter 5 considers the impact of future digital applications and technologies on the environment and society
- In chapter 6, we consider different scenarios for business models going forwards and their relevance to the Danish market.
- In chapter 7, we perform a SWOT analysis of the Danish market and identify focus areas which may be relevant for the future development of digital infrastructure and services.

2 Denmark in context

In this chapter, we assess the current status of network deployment, market structure and service up-take in Denmark compared with international benchmarks.

We cover respectively: developments in fixed and mobile broadband, IoT and M2M and the uptake of digital technologies and services by Government, industry and consumers.

For each key indicator, we identify the top performers and discuss the reasons for their strong performance, with particular attention to any policy initiatives (such as early spectrum assignment or state aid) that may have supported their results and/or structural characteristics in the market (such as very high housing density) which may indicate the degree to which the countries offer experience that is relevant to the Danish market.

- Fixed connectivity is considered in section 2.1
- We review Denmark's performance in mobile connectivity in section 2.2
- The status of IoT and M2M deployment is considered in section 2.3
- We review benchmarks on the digitisation of industry and public services in section 2.4; and
- We draw preliminary conclusions regarding Denmarks current strengths and weaknesses in the field of connectivity and digitisation in section 2.5.

2.1 Fixed broadband

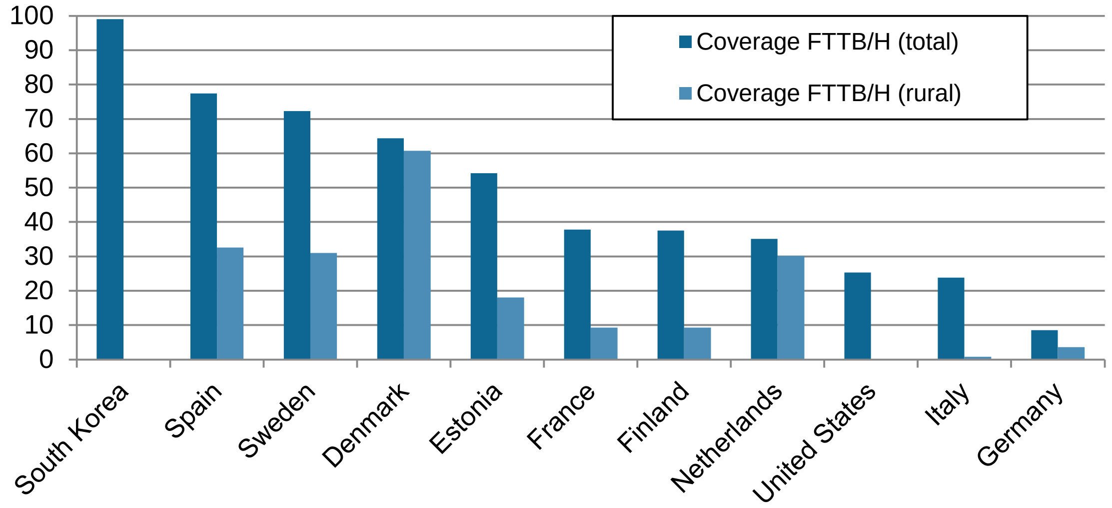
2.1.1 FTTH coverage

FTTH is becoming the prevalent technology for fixed broadband access worldwide, as it offers the potential for high and symmetric bandwidths and supports high levels of quality of service and reliability. Denmark is one of the more advanced economies in Europe with fibre networks passing almost two thirds of households, a significantly higher rate than in Germany and the UK, as well as France, Finland and the Netherlands. Denmark is also unusual in that the fibre coverage in rural areas is close to that achieved in the more densely populated urban areas.[7] This can help those in rural areas to take advantage of modern applications such as E-Health or E-

7 Denmark is one of the few countries where the rural FTTH coverage is almost equal to the total coverage (60.77% rural vs. 64.36% total), while others have huge differences in this regard. Here again, Spain and Sweden can serve as examples with a total FTTH coverage of over 70% of households but only a bit over 30% of rural households. The only country in the EU with a higher rural fibre coverage than the total coverage as of 2018 is the UK, albeit on a low level, with a rural coverage of 5.87%.

Government and can also be beneficial for the environment as it enables workers with long commutes to work partly from home. However, some countries including Sweden and Spain (shown in the diagram below), as well as Portugal[8] and South Korea, have achieved higher FTTH coverage levels, and the expansion in Danish FTTH networks has slowed in recent years.[9]

Figure 2-1: Coverage FTTB/H total vs. rural in %, 2018, 2016 for KR



Source: WIK based on EU Commission[10], IHS Markit[11] and Telegeography[12]; no rural coverage available for South Korea and the United States.

Denmark's comparatively strong performance in fibre results mainly from the involvement of utility companies in the deployment of FTTH. The largest fibre provider in the market is Norlys, a company created by the merger of the fibre utility Syd Energi (SE) and the cable operator Stofa. Most other fibre operators besides Norlys are relatively small, organized as cooperatives and typically wholesale-only operators, offering their services to customers through platforms such as Waoo!. The incumbent TDC has limited fibre coverage, largely based on its earlier acquisition of Dong.[13] TDC

8 See EU Digital Agenda Key Indicators, available at: https://ec.europa.eu/digital-single-market/en/digital-scoreboard.

9 Fibre coverage in Denmark increased by 5-6 percentage points each year from 2011 to 2015. However, since then, the growth halved with less than 7.5 percentage points growth in the three years to 2018.

10 See EU Digital Agenda Key Indicators, available at: https://ec.europa.eu/digital-single-market/en/digital-scoreboard.

11 See Ofcom (2017): International Communications Market Report 2017, available at: https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2017/international.

12 See https://geoisp.com/us/.

13 See Godlovitch, I.; Lucidi, S.; Stumpf. U. (2014): Analysis of market structures in the Danish broadband market, Bad Honnef, 28 August 2014, available at:

has announced its intention to deploy fibre in areas not already served by utility networks, but it remains to be seen how far and how quickly this deployment will proceed.[14]

One factor that may be holding back more rapid FTTH deployment in Denmark is the extensive coverage of cable.[15] TDC's extensive cable network coupled with that of Norlys means that almost 70% of households have access to fast cable networks in Denmark, while at the end of 2018, 73% of Danish households had the possibility to subscribe to a connection with gigabit download speed (via cable or FTTH). The presence of one Gigabit network can undermine the business case to deploy a parallel network in areas where network duplication is not economically feasible. While cable is likely to meet user needs for Gigabit connectivity in the short term, WIK analyses conducted for authorities in the UK, Germany and Belgium, suggest that further upgrades to cable networks, approaching FTTB, are likely to be necessary to support use cases for many households and small businesses in the period towards 2025. Use cases beyond 2025, as well as 5G deployment and their successors are also likely to require deep fibre penetration.

Countries which have achieved higher fibre penetration than Denmark have in some cases benefited from historic developments or demographic factors which cannot be replicated in the Danish market. For example, in Spain, fibre deployment was stimulated in the first instance by alternative operators, who made use of the extensive duct and pole access regulation to deploy competing networks, triggering the incumbent to respond.[16] Various factors including high quality ducts and relatively dense housing in some areas also lowered the cost of deploying fibre and thus improved the business case in Spain. South Korea has also benefited from the prevalence of MDUs and intense infrastructure competition.[17]

The situation in Sweden is more analogous to that of Denmark, with local providers deploying fibre on a regional basis. However, an important difference is the role of municipalities (as opposed to utility companies) in deployment[18] and the widespread adoption of wholesale only models, without exclusive agreements with retail providers. This may have a number of implications. As municipal networks are publicly owned,

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https://www.wik.org/index.php?id=meldungendetails&L=1&tx_ttnews%5Bpointer%5D=20&tx_ttnews%5BbackPid%5D=85&tx_ttnews%5Btt_news%5D=1673&cHash=c54ab41df0aaa0cae973e3de548f78ec

14 TDC wants to roll out fibre to up to 1 million households and businesses over the coming years, available at: https://tdcnetco.com/ (in Danish).

15 See Godlovitch, I.; Strube Martins, S; Wernick, C. (2019): Competition and investment in the Danish broadband market.

16 See Godlovitch, I.; Strube Martins, S. (2019): Prospective competition and deregulation – An analysis of European approached to regulating full fibre.

17 See Godlovitch, I.; Henseler-Unger, I.; Stumpf, U. (2015): Competition & investment: An analysis of the drivers of superfast broadband, Study for Ofcom, Bad Honnef, July 2015, available at: https://www.wik.org/index.php?id=702.

18 See Ministry of Enterprise and Innovation (2017): A Completely Connected Sweden by 2025 – a broadband Strategy, available at: https://www.government.se/information-material/2017/03/a-completely-connected-sweden-by-2025--a-broadband-strategy/.

they may have different incentives and priorities in deploying broadband infrastructure e.g. to support public institutions and smart city applications. On the other hand, municipalities may have less experience than utilities in deploying infrastructure and providing services. Wholesale only models have the advantage that they enable a wide range of actors to provide services, and thus support innovation in telecom services as well as applications. On the other hand (depending on the terms of the agreement), exclusive agreements with specific partners can be linked to guaranteed take-up, which provides greater security for network investment. Municipalities are however able to support the deployment of broadband through an array of means e.g. streamlining the administrative processes regarding permits, proactive communication with citizens and operators regarding coverage issues and demands or by rolling out passive physical infrastructure (e.g. ducts).

In the absence of extensive ducts and high population densities, supporting full fibre deployment in Denmark may require a mix of strategies to facilitate further local deployments and render fibre deployment more attractive for TDC compared to incremental cable upgrades. State aid might also be required in some areas.

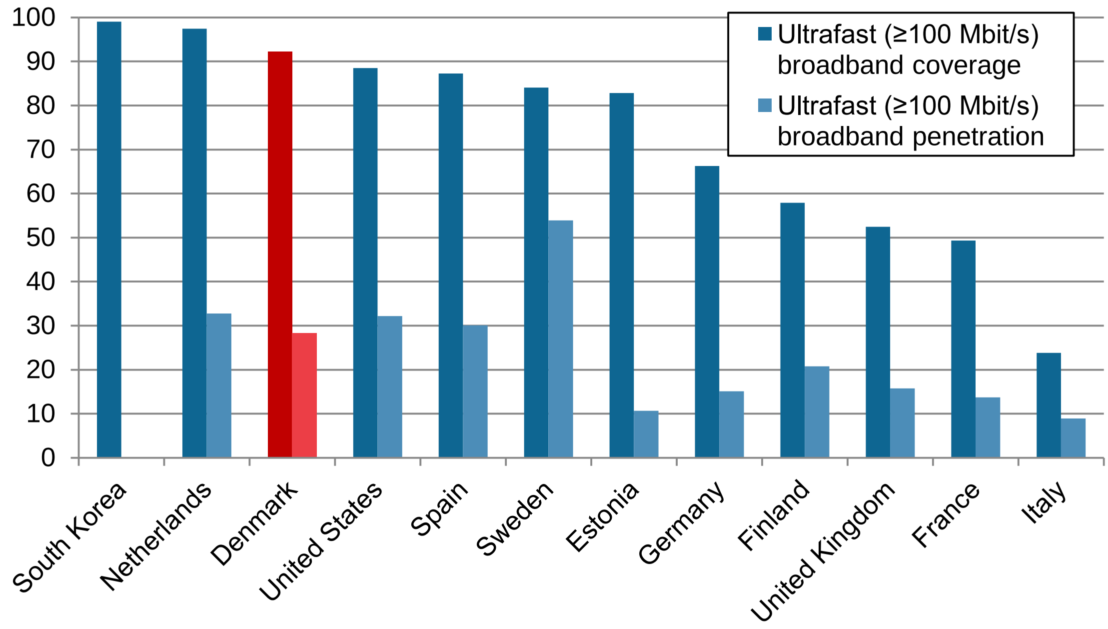
2.1.2 Take-up of ultrafast broadband connectivity

High take-up of faster broadband connections is crucial to establish a business case for the companies that roll out next generation networks and in particular more costly fibre to the home/building networks. A high take-up also signals that there is a demand for fast broadband, potentially supporting greater investment in these networks.

Notwithstanding the increasing availability of ultrafast broadband networks, a majority of customers have subscribed to ultrafast broadband[19] access in only a few countries. In Denmark around 30% of households who could subscribe to an ultrafast access line do so, a similar level to other countries in countries in Western Europe, where the take-up ranges from 28-38%. Exceptions are Germany with only 22.75% take-up and most notably Sweden, where almost two thirds of households who can access ultrafast broadband subscribe to it. Even when subscribing to ultrafast broadband, there is limited demand for download speeds at rates significantly above 100 Mbit/s. Data from the Danish telecommunications regulator reveals that only 6.5% of all broadband subscriptions offered speeds of at least 300 Mbit/s.

19 Broadband access with a download speed of at least 100 Mbit/s.

Figure 2-2: Ultrafast broadband coverage and penetration in %, 2018, 2017 for US, 2016 for KR.



Source: WIK based on EU Commission[20], IHS Markit[21] and FCC[22]; the value for the US is based on population, not households; no penetration available for KR.

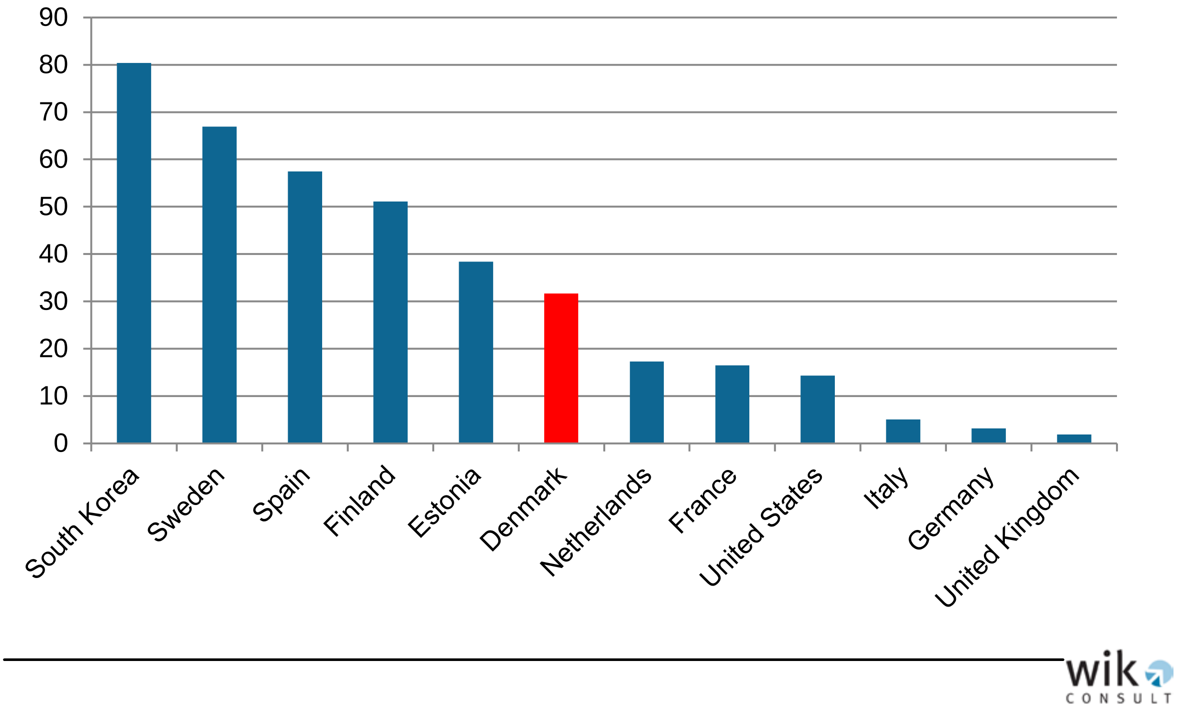
Looking at take-up by technology the total fixed broadband market, in Denmark 31.62% of broadband connections were provided through the fibre network in 2018 (up from 25.9% in 2016). While the frontrunner is again South Korea with a FTTP market share of around 80%, Sweden has also achieved a take-up rate of two thirds of connections via fibre. One remarkable development can be seen in Spain, where fibre rose from 3% of all fixed broadband subscriptions in 2012 to 57.49% in 2018. Highly developed countries with a low fibre footprint and a high overall number of broadband connections, such as Germany and the UK, can be found near the bottom of this statistic.

20 See EU Digital Economy and Society Index (DESI), available at: https://ec.europa.eu/digital-single-market/en/desi.

21 See Ofcom (2017): International Communications Market Report 2017, available at: https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2017/international.

22 See FCC (2019): 2019 Broadband Deployment Report, available at: https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2019-broadband-deployment-report.

Figure 2-3: FTTB/H technology market share as % of all broadband connections, 2018



Source: WIK based on OECD.[23]

Taking these figures alongside those for the take-up of ultrafast connections, suggests that there are many customers in Denmark which are subscribing to fibre, but which are not yet benefiting from the full capabilities of fibre, which can extend to 1Gbit/s connections. Evidence from a number of studies conducted by WIK[24] suggests that open fibre networks – and especially those based on passive fibre (unbundled) access – tend to support competition in speed as ISPs compete on speed alongside price when given the scope to differentiate their offers. This suggests that a shift towards this model might contribute to uptake of higher bandwidths in Denmark.

Greater differentiation between the offers available via fibre and those available via cable and FTTC networks, as could be supported by retail competition over the fibre network, might also contribute to increased take-up of fibre infrastructure in areas in

23 OECD broadband statistics, available at: http://www.oecd.org/sti/broadband/broadband-statistics.

24 Godlovitch, I. et al. (2016): Regulatory, in particular access, regimes for network investment models in Europe, available at: https://op.europa.eu/en/publication-detail/-/publication/c0da75d9-9a8c-11e6-9bca-01aa75ed71a1.
Godlovitch, I.; Sörries, B.; Gantumur, T. (2017): A tale of five cities: The implications of broadband business models on choice, price and quality, available at: https://www.stokab.se/Documents/Nyheter%20bilagor/A%20tale%20of%20five%20cities.pdf.
Godlovitch, I.; Strube Martins, S; Wernick, C. (2019): Competition and investment in the Danish broadband market.

which it is available.[25] Other supporting measures could include, standardization of fibre wholesale offers (to improve the prospects for retail competition over multiple networks), and measures to support switching between platforms. Attention to advertising standards and/or the introduction of a labelling scheme concerning “fibre” connectivity might also help to ensure that customers make fully informed choices when presented with the option of a full fibre connection compared with partial fibre or cable connectivity.[26]

2.1.3 Fixed broadband speeds and quality

The speed of fixed network connections is typically higher in countries with a higher penetration of FTTH networks, as operators with FTTH tend to adapt their marketing strategy to showcase the speeds available (often lifting minimum speeds to 100 Mbit/s or more). FTTH networks are also more reliable than copper networks, and thus the actual realized speed tends to be closer to the advertised speed than in a copper environment.[27]

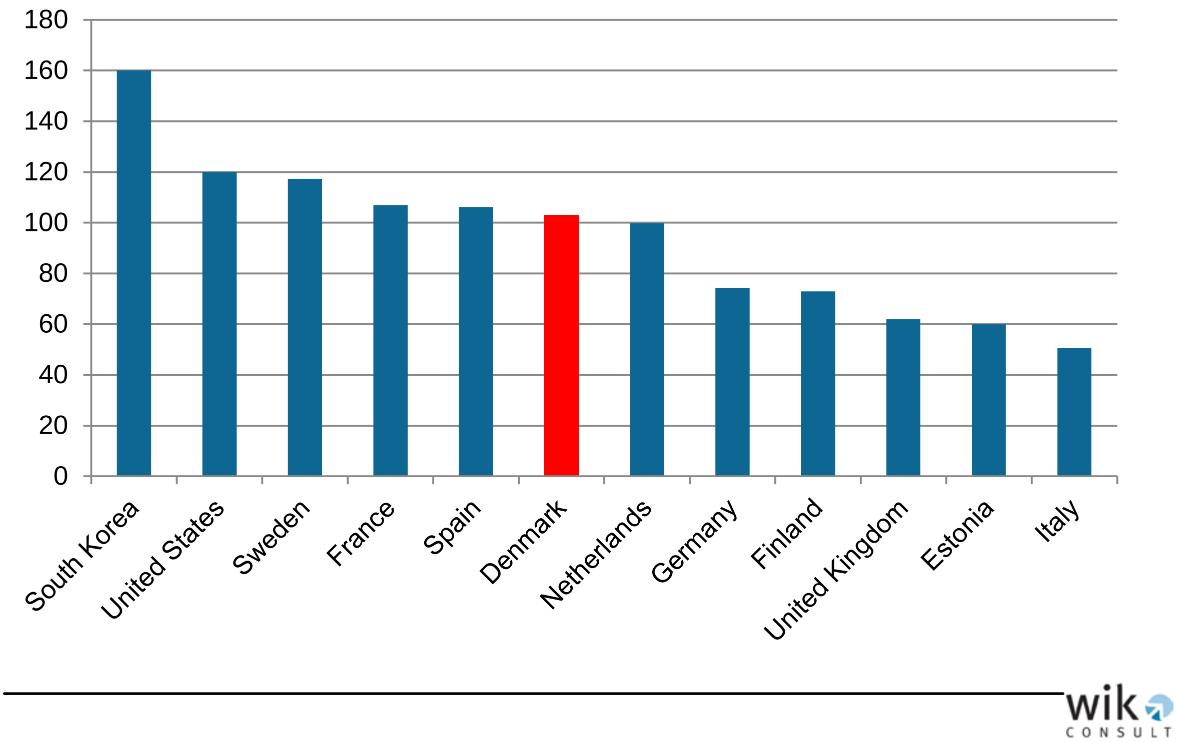
Data from Speedtest.net shows that the average actual download speed measured for fixed broadband connections in Denmark was 102.88 Mbit/s in August 2019. While there is a relatively large gap between speeds achieved in Denmark and those achieved in countries such as South Korea, with 160 Mbit/s on average, Denmark’s speed is similar to those achieved by other European countries with a comparable fibre footprint, and higher than in countries where the primary next generation access technology available to end-users has been FTTC/VDSL such as in Germany (74.33 Mbit/s), UK (61.92 Mbit/s), Italy (50.54 Mbit/s).

25 Various studies have highlighted positive effects of physical unbundling on ADSL speeds and take-up. See for example Nardotto, Valletti, Verboven (2015) Unbundling the incumbent: evidence from UK broadband, available at: https://onlinelibrary.wiley.com/doi/full/10.1111/jeea.12127 and Analysys Mason, available at: https://www.analysysmason.com/About-Us/News/Newsletter/Disentangling-unbundling-broadband-AMQ-Jul2012/.

26 See Fibre-Systems.com (2018): FTTH Council Europe calls for end to misleading fibre advertising, available at: https://www.fibre-systems.com/news/ftth-council-europe-calls-end-misleading-fibre-advertising.

27 See Quality of Broadband Services in the EU (2015), available at: https://ec.europa.eu/digital-single-market/en/news/quality-broadband-services-eu and Ofcom (2018): UK home broadband performance, measurement period November 2018, available at: https://www.ofcom.org.uk/research-and-data/telecoms-research/broadband-research/home-broadband-performance-2018.

Figure 2-4: Fixed broadband download speeds in Mbit/s, August 2019



Source: WIK based on Speedtest.net.[28]

Assuming that competitive retail offers are available, further deployment and utilitisation of FTTH networks in Denmark would likely increase the broadband speeds delivered to end-users.

Alongside speed, reliability and low latencies will also be crucial for the use cases of the future. Home entertainment applications such as virtual reality headsets for gaming and 8K displays (possibly within VR headsets) are not the only purposes for which not only high bandwidths but also low latencies will be required.[29] Modern health applications used to monitor and treat patients remotely need to offer (quasi) real-time communication between doctor and patient and doctor and medical equipment in the patients' home. The same applies for any form of video communication, be it for eHealth, interactive eLearning purposes or for office workers working remotely. Several studies show that FTTH architecture offers lower latency than DSL or HFC networks,

28 See Speedtest Global Index, evaluated for September 2019, available at: https://www.speedtest.net/global-index.

29 See https://www.ofcom.org.uk/__data/assets/pdf_file/0016/111481/WIK-Consult-report-The-Benefits-of-Ultrafast-Broadband-Deployment.pdf, p. 27.

making it crucial especially in rural areas where remote applications may even be more important than in urban areas.[30]

2.1.4 Broadband usage

The data traffic generated globally is increasing by more than 25% every year.[31] Key drivers include expanding access to broadband Internet in developing countries as well as the growth in the use of data heavy applications in the developed world.[32] For Western Europe a 22% increase every year from 2017 to 2022 is forecast. In Denmark, every fixed broadband subscription generated 183.6 GB download traffic per month by the end of 2018. Data from 2017 for other countries shows similar consumption in Sweden, South Korea and the UK, while others such as Germany, France and Italy lag behind with less than 30 GB per household per month. As explored in the 2015 study by WIK,[33] a core reason for the different consumption patterns may be differences in the take-up rates between these countries of data intensive applications such as online video streaming services and gaming. The high data consumption in Denmark also suggests that there could be demand for higher bandwidth connections, which would enable more efficient and high quality access to video-based applications.

The chart below shows that the share of Internet users consuming videos online is high in most developed countries, though there are some differences with Denmark, Korea and the US at around 90% and the Netherlands and Germany almost 10% lower. This lower take-up of one of the most data-heavy online applications, is likely to affect the total traffic generated in a country.

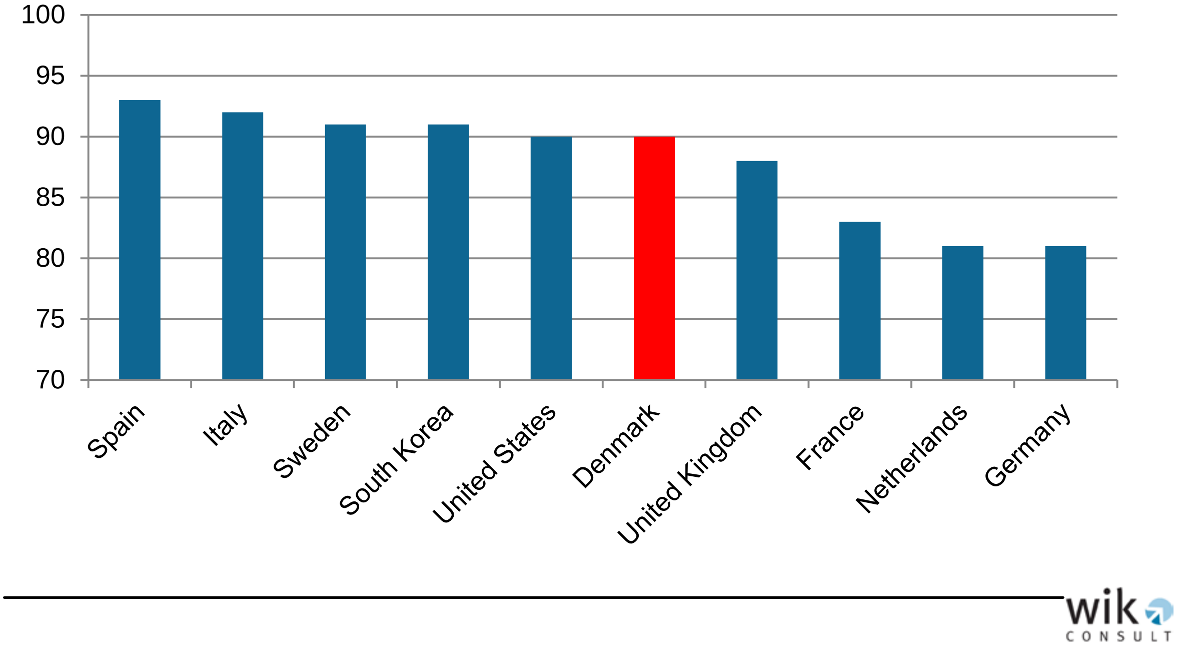
30 See https://www.ofcom.org.uk/__data/assets/pdf_file/0016/111481/WIK-Consult-report-The-Benefits-of-Ultrafast-Broadband-Deployment.pdf, Annex II.

31 See https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html.

32 Data and forecasts from Cisco VNI highlight the strong role played by Internet video in driving bandwidth demand, available at: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html#_Toc532256795.

33 See Godlovitch, I.; Henseler-Unger, I.; Stumpf, U. (2015): Competition & investment: An analysis of the drivers of superfast broadband, Study for Ofcom, Bad Honnef, July 2015, available at: https://www.wik.org/index.php?id=702.

Figure 2-5: Share of Internet users consuming video content online in %, 2018



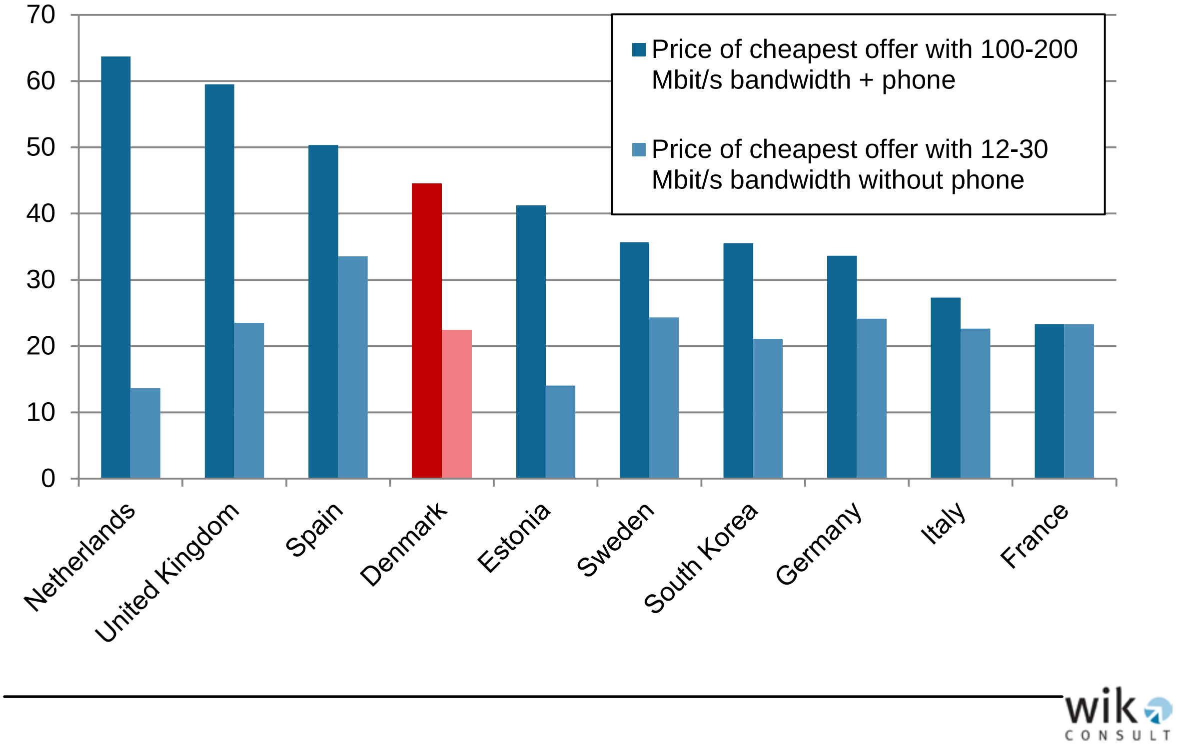
Source: WIK based on Globalwebindex via datareportal.com.[34]

2.1.5 Fixed broadband pricing

The prices for fixed broadband in Denmark as investigated by empirica for the European Commission in 2018 are near the European average. Low bandwidths in particular are relatively inexpensive, especially when not bundled with a telephony offer, which has a relatively high premium in Denmark.

34 See Kemp, S.: Digital 2019: Global Digital Overview. For datareportal.com, citing survey data from Globalwebindex, available at: https://datareportal.com/reports/digital-2019-global-digital-overview.

Figure 2-6: Fixed broadband prices in EUR PPP, 2017



Source: WIK based on empirica & TÜV Rheinland for the EU commission.[35]

However, a significant premium is charged for higher bandwidths in Denmark, which may be depressing demand. There are some signs that operators are reducing the gap between high and lower bandwidth offers. For example, the brand YouSee, subsidiary of the incumbent TDC handling the consumer business, has decreased the price for the gigabit line so that it is about 40% more expensive than the cheapest 50 Mbit/s subscription.[36] Further price competition for higher bandwidth offers could be supported through open passive wholesaling solutions, such as those seen in Sweden, but would require greater levels of broadband infrastructure investment by alternative operators, than has been seen to date.

2.1.6 Fibre as a backbone for mobile networks

Fibre networks are needed not only to bring fixed broadband to homes and business Internet users, but also to connect mobile network towers and base stations with fibre, a development which will become increasingly important with the deployment of 5G, and

35 See empirica & TÜV Rheinland (2018): Fixed Broadband Prices in Europe 2017, available at: https://ec.europa.eu/digital-single-market/en/news/fixed-broadband-prices-europe-2017.

36 See https://yousee.dk/bredbaand/overblik.aspx#bredbaand.

subsequent installation of small cells.[37] Countries with existing FTTH infrastructure that is accessible for all current and potential mobile operators are likely to be able to support a more rapid deployment of 5G. For example, the availability of municipal fibre was central to the deployment of competing 4G networks in Sweden.[38] It will also be important for fibre to be widespread in rural areas to support availability of 5G in those areas. In this sense, the relatively high rural FTTH coverage in Denmark puts it in good stead compared with countries where rural fibre has been less widely developed. An analysis by WIK in the context of a study for the European Commission on future EU funding requirements for the Gigabit Society[39], also suggests that subsidies for fibre backhaul for 5G and socio-economic drivers in remote communities could be an important enabler to ensure that ultrafast broadband, including potentially via 5G technologies, is available to all.

2.2 Mobile broadband

2.2.1 4G coverage and availability

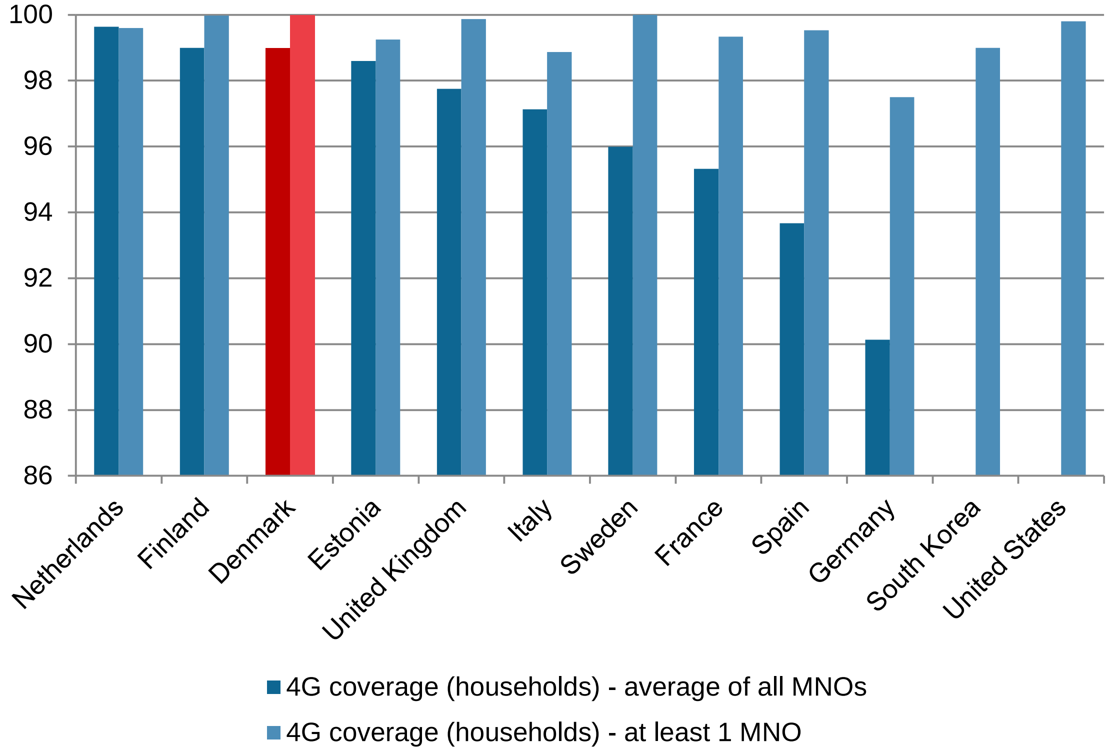
4G coverage in terms of households passed is high in all the countries investigated. However, there are differences in the degree to which the various countries have achieved coverage by all operators in the market. Denmark is one of the leading countries in the world in terms of 4G deployment with every household being served by at least one mobile network operator and an average coverage of 99% of households for the four MNOs. While there are other countries with comparable numbers, such as the Netherlands and Finland, the larger European countries such as Spain and Germany lag behind in this regard. Germany, one of the countries which is known to have difficulties with mobile broadband coverage in rural areas, has reached 97.5% coverage of households with at least one 4G network but only 90.13% household coverage on average for its three MNOs.

37 See Godlovitch, I.; Lucidi, S.; Sörries, B. (2019): Competition and investment in the Danish mobile market.

38 See Godlovitch, I.; Sörries, B.; Gantumur, T. (2017): A tale of five cities: The implications of broadband business models on choice, price and quality, study for Stokab, Bad Honnef, 2 June 2017, available at: https://www.stokab.se/Documents/Nyheter%20bilagor/A%20tale%20of%20five%20cities.pdf.

39 See preliminary report findings presented at the CEF2 Study Workshop – Smart Investments for Smart communities, available at: https://ec.europa.eu/digital-single-market/en/news/cef2-study-workshop-smart-investments-smart-communities.

Figure 2-7: 4G coverage in % of households, 2018 (2017 for US, 2016 for KR)



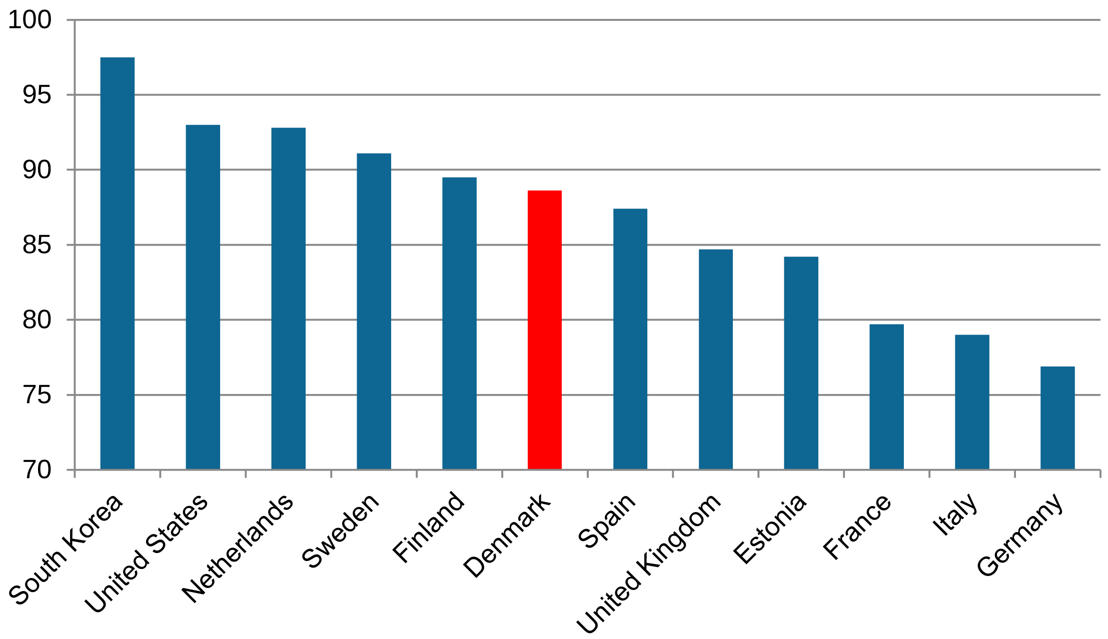
Source: WIK based on EU Commission[40] and FCC[41]; no average value available for South Korea and the United States.

More telling than the coverage on a household basis is the time users have 4G services available on their phones as measured by Opensignal. While frontrunners such as South Korea have 97.5% 4G availability, Denmark is at 88.6%, putting them among the top European countries. Notably, Sweden has a 4G availability of 91.1%. Again, there is a relative weakness of network coverage in some of the larger countries, namely Germany, France and Italy, which have availability below 80%.

40 See EU Digital Economy and Society Index (DESI) and Digital Agenda Key Indicators, available at: https://digital-agenda-data.eu/ and for South Korea: International Digital Economy and Society Index (I-DESI) 2018, available at: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018.

41 See FCC (2019): 2019 Broadband Deployment Report, available at: https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2019-broadband-deployment-report.

Figure 2-8: Percentage of time a user has 4G available, 2019



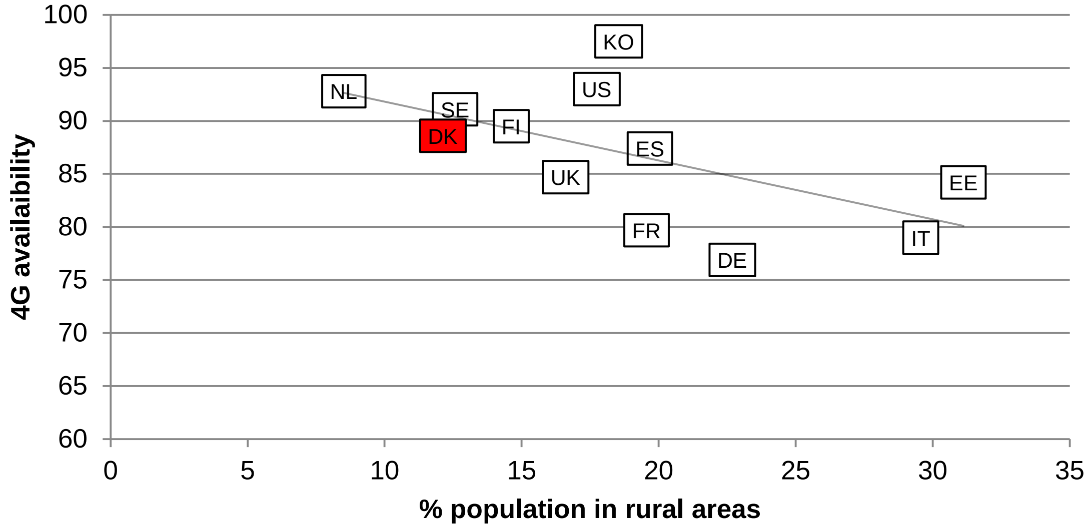
Source: WIK based on Opensignal.[42]

One potential reason for the divergence in availability might be demographic differences such as population density and the share of people living in rural areas. However, when we compare these measures against availability, no clear correlation can be seen. While an analysis of data from Speedcheck.org[43] shows a slight correlation between population density and mobile broadband speed, an analysis of a sample of Opensignal data regarding population density and 4G availability shows virtually no correlation at all. A minor correlation in these sample countries can be found between 4G availability and the share of people living in rural areas in a country, showing that countries with a higher share of rural population tend to have lower 4G availability.

42 See Opensignal (2019): The State of Mobile Network Experience, available at: https://www.opensignal.com/reports/2019/05/global-state-of-the-mobile-network.

43 See Speedcheck (2019): Mobilfunk Report 2019 (in German), available at: https://www.speedcheck.org/de/.

Figure 2-9: 4G availability & rural population in %, 2019/2018



Source: WIK based on Opensignal[44] and Worldbank.[45]

One of the reasons why the linkages may not be clear is that measures have been taken in some countries to support coverage even in remote areas.

Mobile network sharing agreements between operators to achieve higher rural coverage have been concluded in several countries in one form or another. In Spain, the operators Orange and Vodafone use roaming especially in rural areas[46], in the UK there is a joint venture between Telefónica and Vodafone to build masts[47]. Neither country has a very high 4G availability, but they score higher than other large EU countries such as France and Germany. Sweden, which is very sparsely populated in many regions, has gone further, with a joint venture and 4G spectrum sharing between two of the operators, and achieves a good mobile network coverage.[48] In Denmark

44 See Opensignal (2019): The State of Mobile Network Experience, available at: https://www.opensignal.com/reports/2019/05/global-state-of-the-mobile-network.

45 See Worldbank World Development Indicators, available at: https://data.worldbank.org/indicator/SP.RUR.TOTL.

46 See BEREC (2018), Report on infrastructure sharing BoR (18)116, as well as Orange (2019): Orange and Vodafone strengthen their mobile and fixed network sharing agreements in Spain, available at: https://www.orange.com/en/Press-Room/press-releases/press-releases-2019/Orange-and-Vodafone-strengthen-their-mobile-and-fixed-network-sharing-agreements-in-Spain.

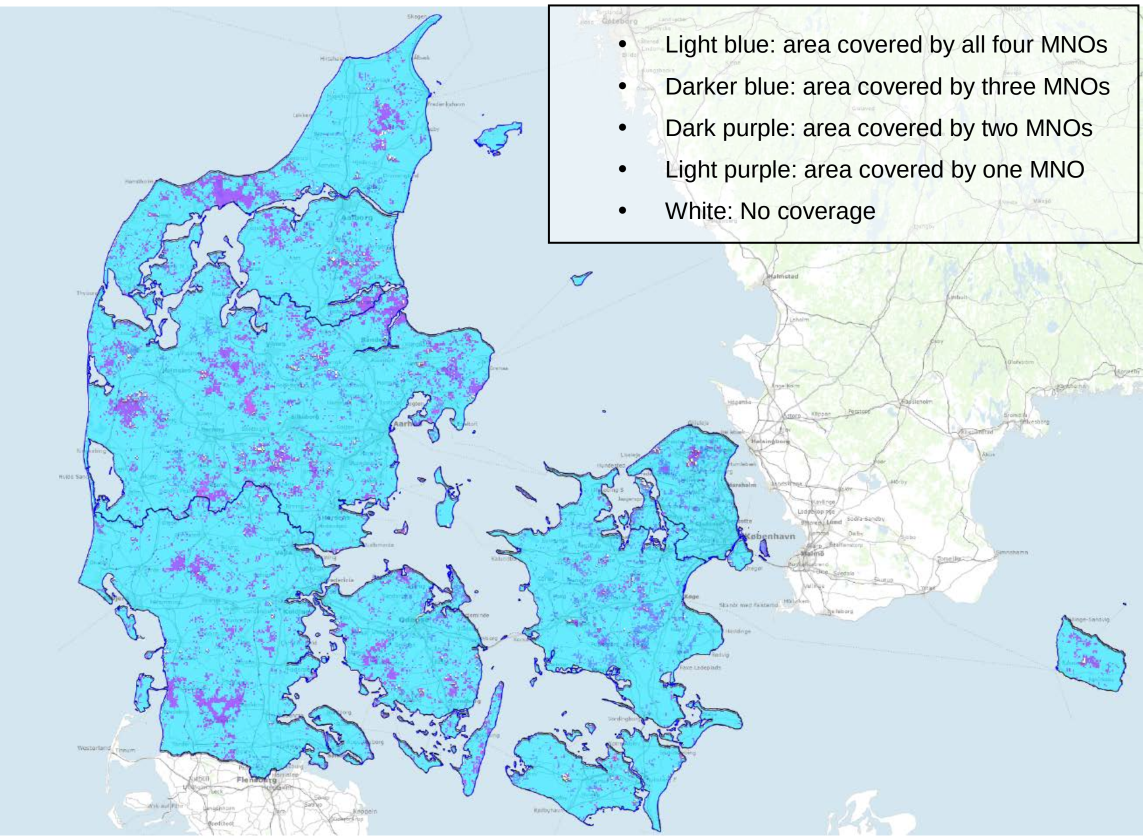
47 See Warrington, J. (2019): Vodafone and O2 eye sale of phone mast joint venture CTIL to speed up UK's 5G rollout, in: City A.M., 23.01.19., available at: https://www.cityam.com/vodafone-and-o2-eye-sale-phone-mast-joint-venture-ctil-amid/.

48 See OECD (2018): OECD Reviews of Digital Transformation: Going Digital in Sweden, p. 46, available at: https://www.oecd.org/sweden/oecd-reviews-of-digital-transformation-going-digital-in-sweden-9789264302259-en.htm.

there is a network sharing agreement between Telenor and Telia in place.[49] While there is no proof that infrastructure sharing leads to improved (rural) coverage, the numbers strongly suggest that this is the case.

On the map extract shown below, the coverage in Denmark for 4G with at least 10 Mbit/s download speed is shown. For lower speeds below 10Mbit/s, the coverage for all four mobile network operators is almost complete.[50] This shows that in most parts of the country all four MNOs offer their 4G network (light blue). There are a few areas on Zealand where three networks are available (blue). There is however also a proportion of the country marked in dark purple where only two networks are available, especially in the North of the country. Areas in pink with only one operator or in white without any coverage are rare.

Figure 2-10: Danish 4G coverage map (at least 10 Mbit/s available), October 2019



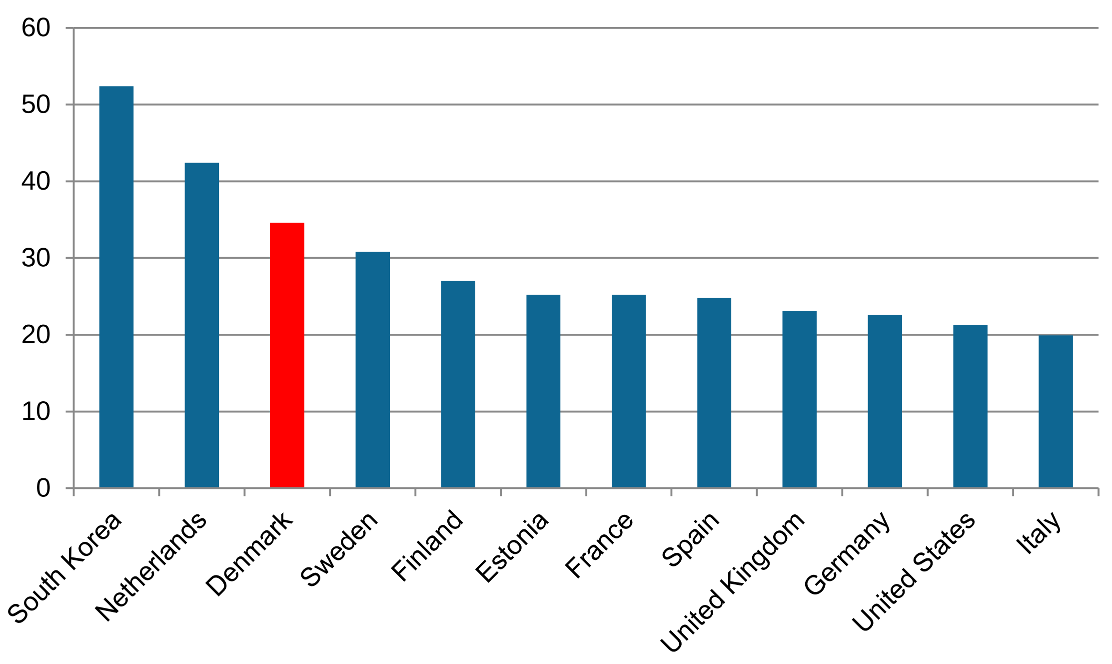
Source: Danish Broadband Atlas.[51]

49 See Bæk, M. (2018): Balacing infrastructure sharing – The Danish experience, available at: https://news.itu.int/balancing-infrastructure-sharing-the-danish-experience/.
50 This information can be found in the Danish broadband map available at: https://tjekditnet.dk/kort.
51 See Danish Broadband Atlas Map, available at: https://tjekditnet.dk/kort.

2.2.2 Mobile broadband speeds and latency

Alongside its advanced performance on 4G coverage, Denmark is also one of the most advanced countries when discussing mobile broadband speed. Data from Opensignal shows that Denmark's mobile networks deliver an average speed of 34.60 Mbit/s, faster than in most European countries. Internationally, South Korea is the only country which delivered on average more than 50 Mbit/s in this network test.

Figure 2-11: Mobile broadband speeds in Mbit/s, 2019



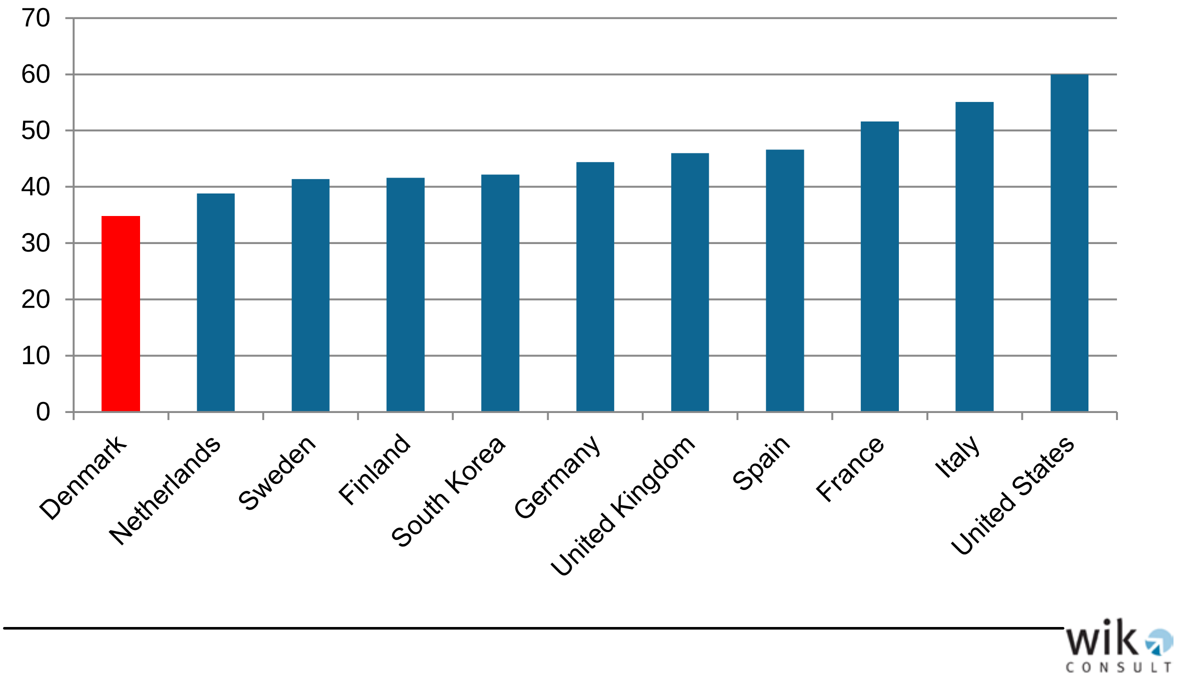
Source: WIK based on Opensignal.[52]

In terms of latency in mobile (4G) networks, while no country in the world manages an average measured latency of less than 30 milliseconds, Denmark is already in a good position with 34.60ms latency. Most other European countries, such as Sweden, Germany, Spain and the United Kingdom all achieve average latencies in the 40-46ms range. Even South Korea had an average latency of more than 40 milliseconds when the measures were taken by Opensignal at the beginning of 2019. Lower latencies than

52 See Opensignal (2019): The State of Mobile Network Experience, available at: https://www.opensignal.com/reports/2019/05/global-state-of-the-mobile-network.

the ones currently seen are not likely to be possible in practice with 4G networks, but can only be achieved through 5G.[53]

Figure 2-12: Mobile broadband latency in milliseconds, 2019



Source: WIK based on Opensignal.[54]

High speed and especially low latency in mobile networks matter most for new applications building on 5G technology and the Internet of things. Applications such as connected cars need high data rates and a low latency to function properly and are not able to rely on fixed broadband networks due to their mobile nature.

2.2.3 Mobile broadband usage

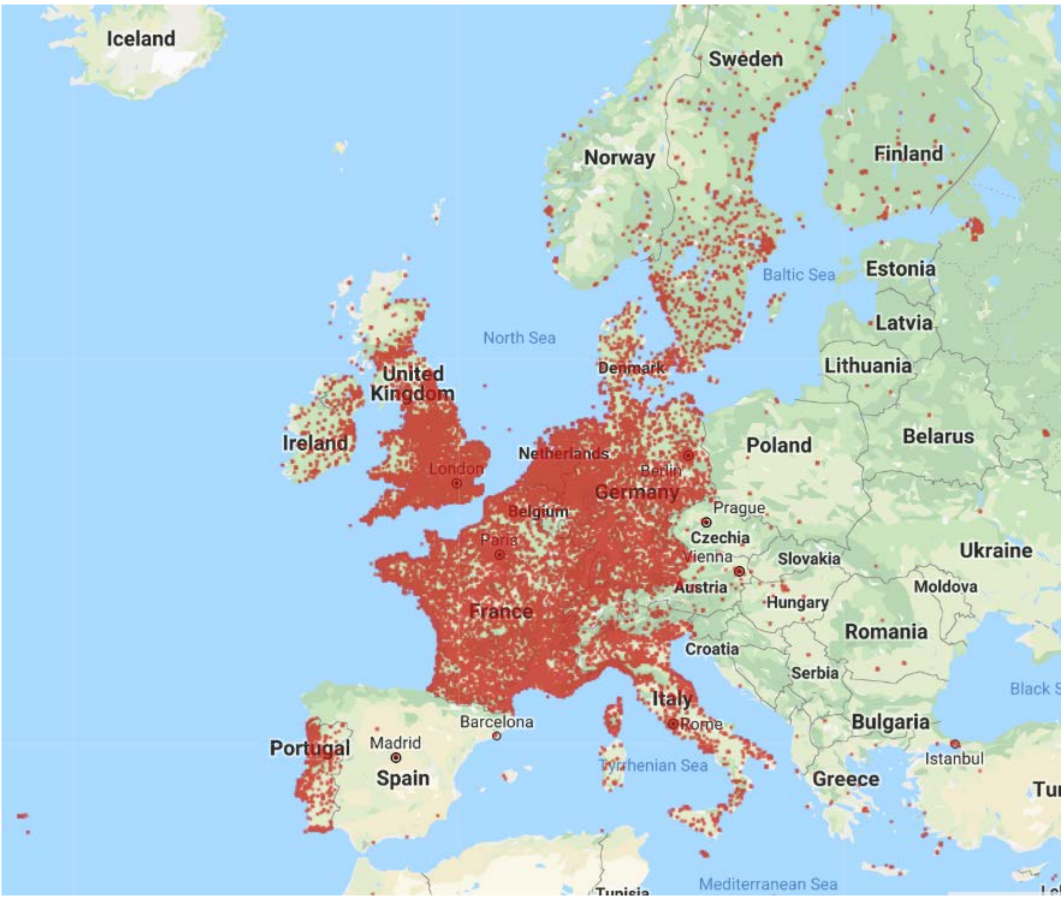
The data traffic currently generated through mobile networks varies greatly between countries. While Finland is the lone frontrunner among the OECD countries with almost 20 GB per subscription per month in 2018, Spain and Germany use less than 3 GB. Denmark has a relatively high consumption, similar to Sweden and South Korea, with 7.64 GB/month. While those traffic volumes increased in the last few years and will increase further with the increasing availability and use of mobile applications in a connected world, there may be a number of reasons for the disparities between countries. On the one hand, more widespread data-heavy applications are likely to lead

53 See Kavanagh, S. (2018): 5G vs 4G: No Contest, available at: https://5g.co.uk/guides/4g-versus-5g-what-will-the-next-generation-bring/.

54 See Opensignal (2019): The State of Mobile Network Experience, available at: https://www.opensignal.com/reports/2019/05/global-state-of-the-mobile-network.

to more data usage. On the other hand, data caps persist in most countries, which mean that unlimited high speed data is not available to most users. Additionally, where countries have widespread available of public Wi-Fi hotspots (see following figure), there may be less need to route traffic via the mobile network.

Figure 2-13: European coverage of Boingo networks (WiFi hotspots), 2019



Source: Boingo Wireless.[55]

2.2.4 Mobile broadband pricing and take-up

The prices for mobile broadband access in Denmark are competitive. In 2018, the Danish prices for all common mobile broadband baskets were at least 25%, typically even 40% or more, below the EU average in terms of purchasing power parity.[56] While

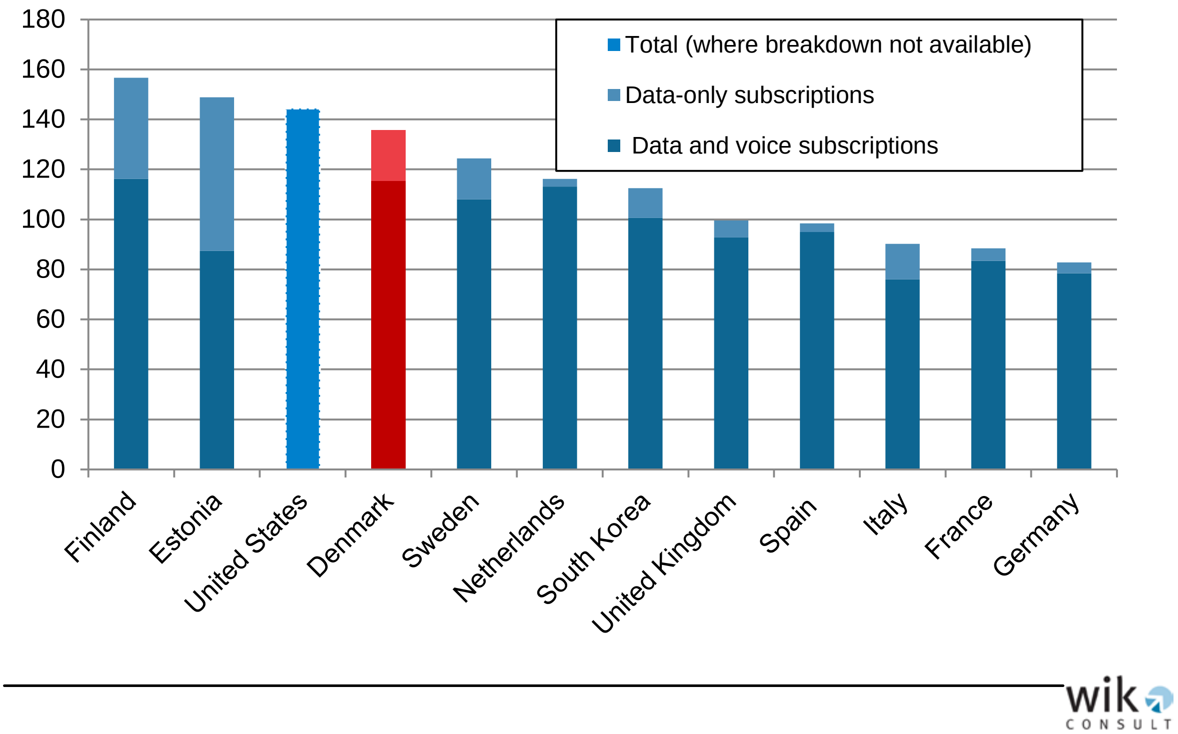
55 Boingo Wireless is a provider with WiFi hotspots all around the globe, the hotspot map of other operators such as FON looks similar with Western and Northern Europe. See https://wifi.boingo.com/ and https://fon.com/maps/.

56 See empirica & TÜV Rheinland (2019): Mobile Broadband Prices in Europe 2018, available at: https://ec.europa.eu/digital-single-market/en/news/mobile-broadband-prices-went-down-europe-2018.

there are other countries with even lower prices such as Italy or France, the prices in Spain are more than double those paid by customers in Denmark. In the developed markets outside Europe, the prices are also higher than the European averages.

Potentially supported by low prices and high quality, mobile broadband take-up is very high in Denmark with 135.7 mobile subscriptions per 100 inhabitants in 2018. While a few countries have higher take-up, such as Finland, the US and Estonia, most countries lie below this mark. The OECD average lies at 109.7 subscriptions per 100 inhabitants. Germany and France are at the bottom of the countries investigated with less than 90 subscriptions. Not considering "data-only" plans but only data + voice, i.e. plans typically used for smartphones, Denmark lies at 115.3 subscriptions per 100 inhabitants, which is near the top of the OECD and at about the same level as Finland.

Figure 2-14: Mobile broadband subscriptions per 100 inhabitants, 2018



Source: OECD.[57]

While 1.8 billion worldwide connections are predicted to be based on 5G in 2024[58], the number of connections of this new standard that are currently in use are not influencing the market data yet. Denmark is one of the few European countries where the 700 MHz spectrum band has already been auctioned, while the 3.4-3.8 GHz band will follow in

57 See OECD broadband statistics, available at: http://www.oecd.org/sti/broadband/broadband-statistics.

58 See Ericsson (2019): Mobility Report Q2 2019, available at: https://www.ericsson.com/49d1d9/assets/local/mobility-report/documents/2019/ericsson-mobility-report-june-2019.pdf.

2020.[59] Commercially, 5G has only been launched in a few countries (e.g. Germany) but only for a small number of base stations and with only a few supporting smartphone models, which means that in most countries, no impact on the market can yet be measured. The first market outcomes can be found in South Korea, where the considerable lead in terms of the deployment of 5G networks is visible in the development of the speed test data measured by the platform Speedtest.net.[60] South Korea has not only doubled the average speed of the users performing a speed test within the last five months, but also displays 1.5 times the speed of the second fastest country (Australia). This implies that international comparisons currently depend to a great extent on the deployment of 5G and that the mobile broadband speeds should increase soon in those countries where the rollout of 5G networks and corresponding devices is imminent.

2.3 Internet of Things (IoT) and Machine-to-Machine (M2M)

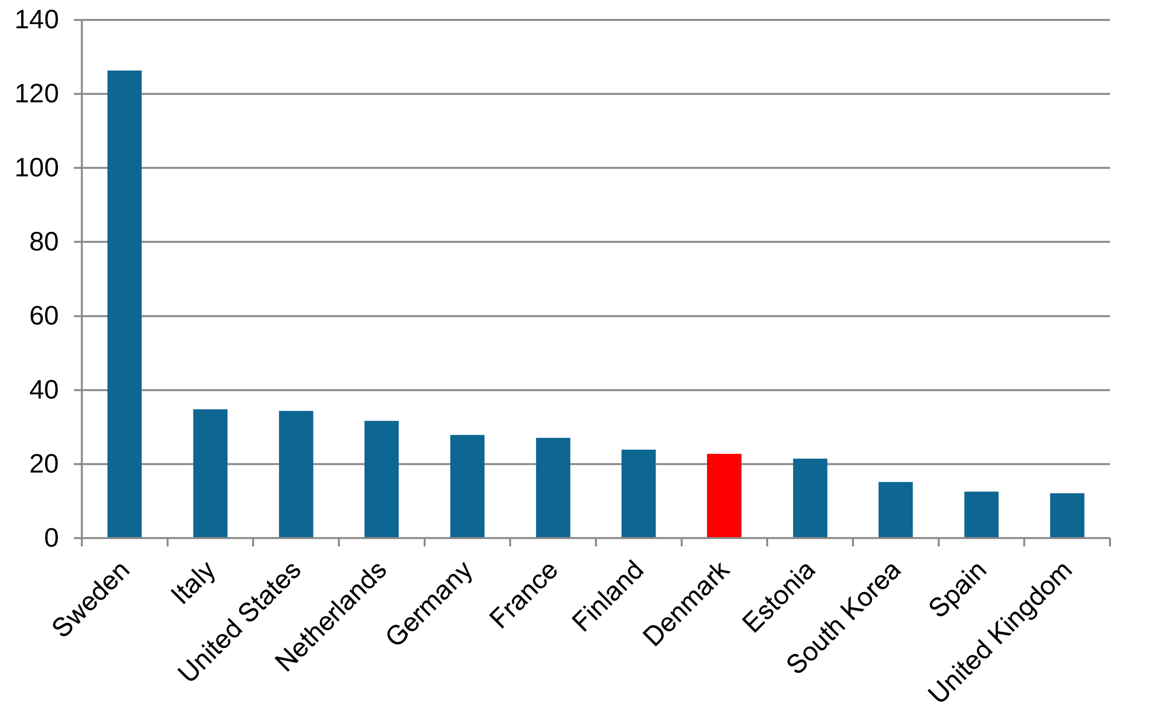
With 22.78 SIM-cards used for M2M purposes per 100 inhabitants, Denmark is positioned slightly above average among the OECD countries. The lone frontrunner on this metric is Sweden with more than 125 M2M SIMs per 100 inhabitants at the end of 2018. Among the countries with a relatively low number of M2M SIM-cards (15 or less per 100 inhabitants) are South Korea, Spain and the United Kingdom. It is however not certain, how many of these M2M SIM-cards are in use in the particular country, as the regulatory bodies of the countries may report this in a different manner. Some likely only include the M2M SIM-cards sold and operatored in the country, others may include the M2M SIM-cards sold worldwide by operators from this country.[61]

59 See 5G European Observatory (2019): 5G Observatory Quarterly Report 4 - Up to June 2019, available at: http://5gobservatory.eu/wp-content/uploads/2019/07/80082-5G-Observatory-Quarterly-report-4-min.pdf.

60 See https://www.speedtest.net/global-index/south-korea#mobile.

61 According to the Swedish telecommunications regulator PTS, 70% of the reported M2M SIM-cards are sold by Telenor Connexion to equip large industrial users and car manufacturers (e.g. Volvo) worldwide, see: https://statistik.pts.se/en/the-swedish-telecommunications-market/tables/mobile-call-services-and-mobile-data/table-18-machine-to-machine-m2m/ and https://www.telenor.com/wp-content/uploads/2018/05/Handelsbanken-Cellular-IoT-Day-Telenor-Connexion.pdf.

Figure 2-15: Number of M2M SIM-Cards per 100 inhabitants, 2018



Source: WIK-Consult based on OECD.[62]

Moreover, a review of SIM cards alone may not provide the full picture regarding the development of the "Internet of Things" as IoT connectivity can be provided not only via mobile networks, which rely on licensed spectrum frequencies and require a mobile subscription, but also through unlicensed spectrum. For communication between "things" in unlicensed spectrum, technologies such as Wi-Fi or Bluetooth are used for short ranges. For longer ranges there are other technologies making use of this spectrum, such as LoRa or Sigfox. Depending on the technology mix and the strategies of operators in the specific country, the number of M2M SIM-cards can vary independent of the level of total IoT utilization.

One driver for the adoption of IoT services is the use of data for services such as Smart Farming and Smart Energy, which can help achieve environmental goals, e.g. through more efficient and targeted use of energy to water plants.[63] The same applies for sensors measuring potential environmental risks.

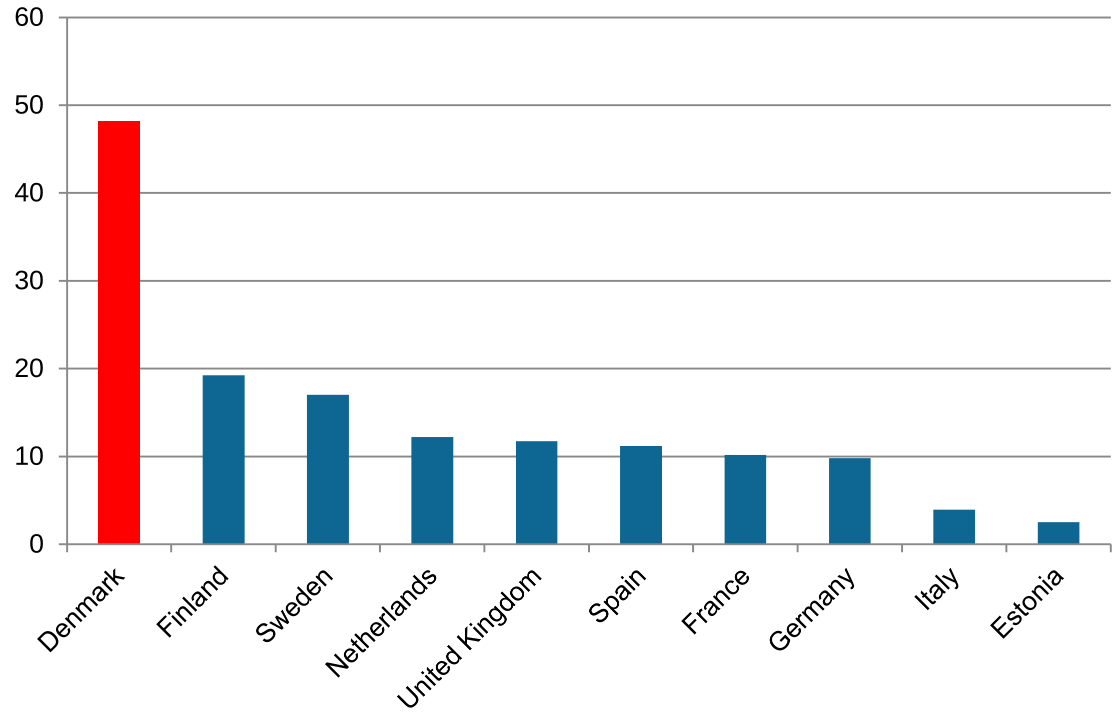
62 See OECD broadband statistics, available at: http://www.oecd.org/sti/broadband/broadband-statistics.
63 See GeSI (2015): #SMARTer2030 – ICT Solutions for 21st Century Challenges, p. 42, available at: http://smarter2030.gesi.org/downloads/Full_report.pdf.

IoT is not only relevant for rural and agricultural areas but also for applications in larger cities, characterised as “Smart City” applications. This includes intelligent traffic control and smart meters that help reduce emissions from traffic and inefficient use of resources. It is estimated, that “Smart City” applications can reduce greenhouse gas emissions by up to 15%.[64]

Another facilitator of fast broadband access and IoT is the use of smart grids (mainly) for electricity networks. In times of more and more fluctuations from the supply side because of a higher use of renewable energies, which are harder to plan, the grids need to be able to deal with a lot more fluctuations. Smart grids and associated IoT sensors can help by e.g. charging an electric car when the it is the best moment for the electricity network. Denmark is one of the leading countries in investment in smart grids and in testing out ways to reduce energy consumption through grid technology.

64 See McKinsey Global Institute (2018): Smart Cities: Digital solutions for a more livable future, available at: https://www.mckinsey.com/~/media/mckinsey/industries/capital%20projects%20and%20infrastructure/our%20insights/smart%20cities%20digital%20solutions%20for%20a%20more%20livable%20future/mgi-smart-cities-full-report.ashx.

Figure 2-16: Investment in Smart Grids (R&D and demonstration projects) per capita, ongoing in 2017



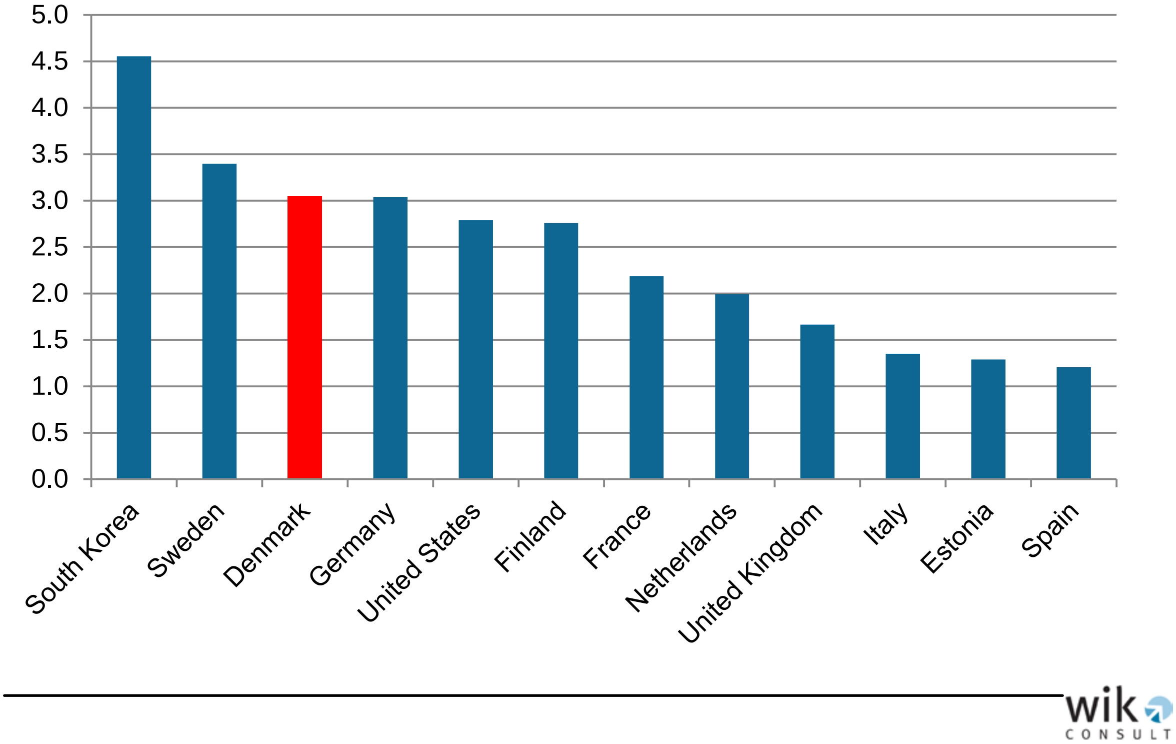
Source: WIK-Consult based on EU.[65]

2.4 Digitisation of industry and public services

One indicator for the general degree of innovation in a country is the money that is invested in research and development (R&D). Research and Development expenditures are highest in South Korea with 4.55% of GDP in 2017. The country with the highest expenditure in Europe is Sweden with 3.4%. Denmark and Germany both lie slightly above 3%. The gap between South Korea and the other countries in the sample (and most countries in the world respectively) is large, as are the differences in research and development efforts within Europe.

65 See Gangale, F., Vasiljevska, J., Covrig, F., Mengolini, A., Fulli, G., Smart grid projects outlook 2017: facts, figures and trends in Europe, available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC106796/sgp_outlook_2017-online.pdf.

Figure 2-17: R&D Expenditures as % of GDP, 2017



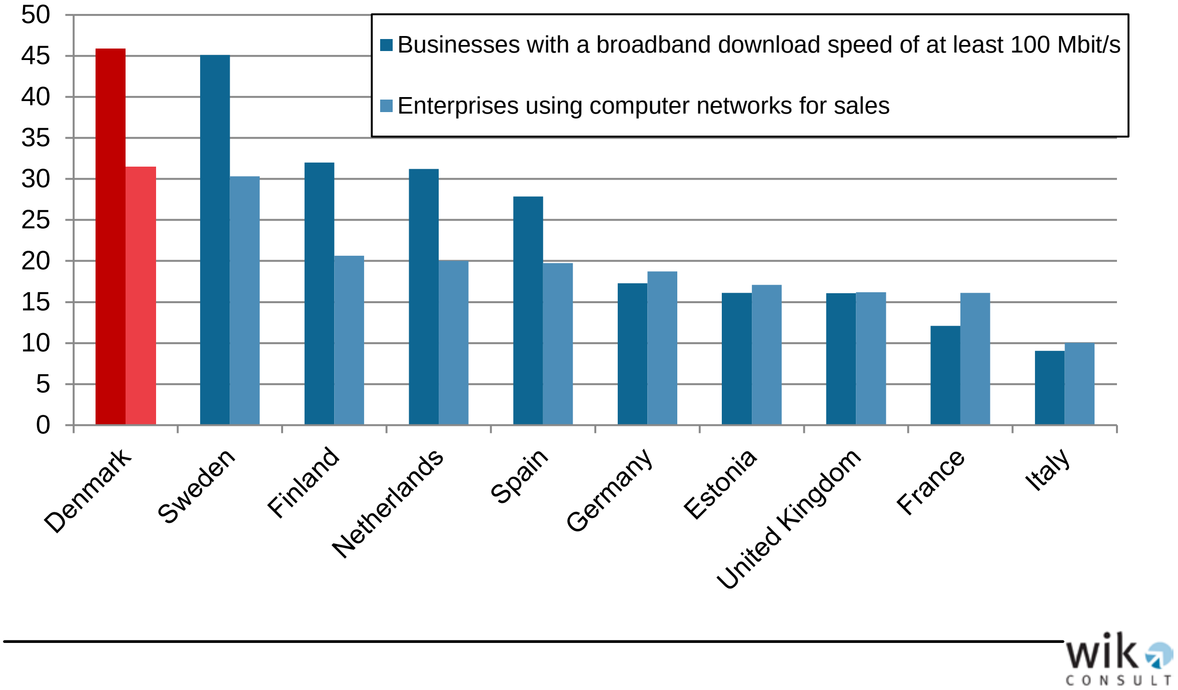
Source: WIK-Consult based on OECD[66] and Worldbank.[67]

Most companies, independent of the exact industry they are in, need a fast broadband connection to be competitive. Denmark is the country in the EU with the highest share of businesses using broadband access lines with at least 100 Mbit/s download speed (45.85% in 2018). The only other country which comes close is Sweden. This is a very high adoption of fast broadband among businesses, which should support the further digitization of business processes and commerce. In some countries including France and Italy, less than 15% businesses access fast broadband.

66 See OECD, Gross domestic spending on R&D, available at: https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm.

67 See Worldbank World Development Indicators, available at: https://data.worldbank.org/indicator/IP.PAT.RESD.

Figure 2-18: Business and Enterprise digitisation, 2018



Source: WIK-Consult based on OECD[68] and EU Commission.[69]

An important case of digital change in the economy within the recent years is the rise of e-Commerce. Danish businesses are the frontrunners in the EU in adoption of e-Commerce. In 2018, 31.5% sold goods through the Internet[70]. This is again an achievement which only a few other countries such as Sweden and Finland have surpassed. Some countries, such as Italy have less than a third of the e-Commerce adoption of Denmark, while the EU average is at 17%. More broadly, in the DESI of the EU, Denmark ranks third in the e-Commerce index and fourth in the business digitization index. The share of highly digitized enterprises in Denmark is especially high. Only Finland has the same share of businesses with a very high degree of digitization at more than 10%.[71]

One important use of fast broadband subscriptions for businesses, which requires high and symmetric bandwidths is access to cloud storage. Use of cloud computing services by businesses is relatively high in Denmark with about 40% of business using some

68 See OECD Dataset ICT Access and Usage by Businesses, available at: https://stats.oecd.org/Index.aspx?DataSetCode=ICT_BUS.

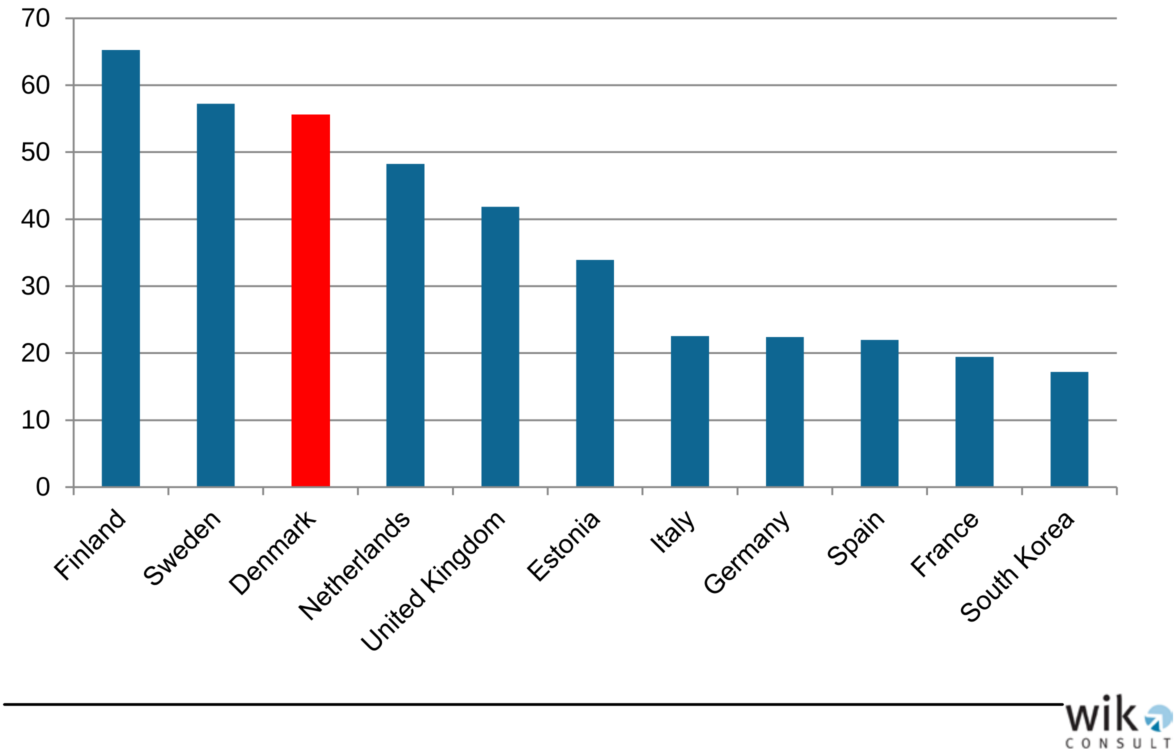
69 See EU Digital Agenda Key Indicators, available at: https://ec.europa.eu/digital-single-market/en/digital-scoreboard.

70 This includes all companies with at least 10 employees and at least 1% of revenue through computer networks, excluding the financial sector.

71 The EU measures 12 binary metrics (e.g. if the business has Internet for at least 50% of employees; if the business has a website), every business answering with a “Yes” in at least 10 of these metrics, receives a score of “Very high”.

type of cloud computing service in 2018. The larger European countries such as Germany, France or Italy lie far below, with around 20% in business use of cloud services.

Figure 2-19: Businesses purchasing cloud computing services in %, 2018 (2017 for KR)



Source: WIK-Consult based on OECD.[72]

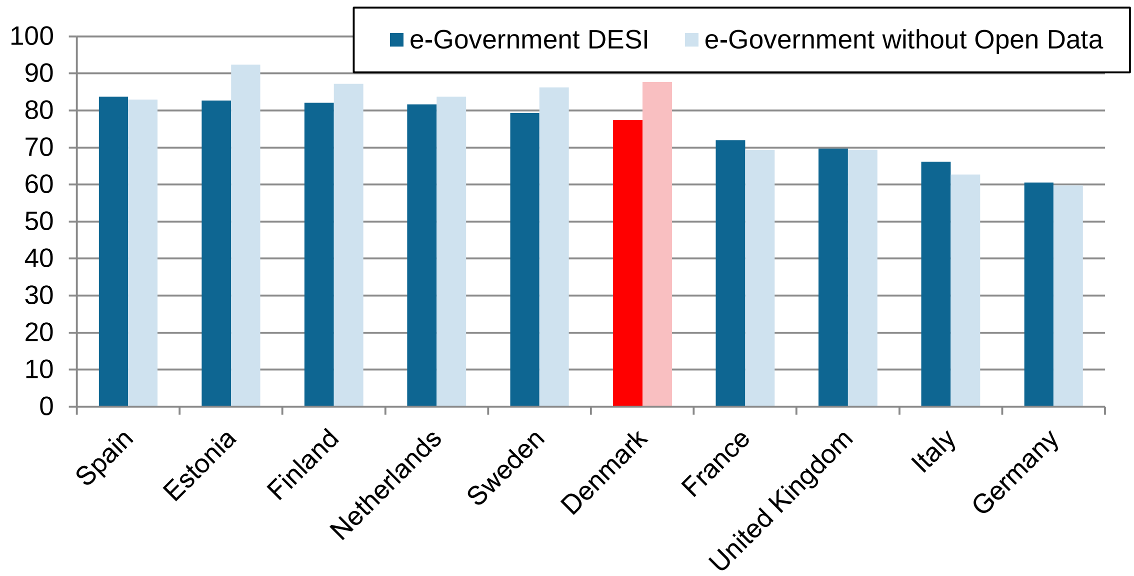
Alongside business use of digital services and e-Commerce, widespread adoption of Internet services by private citizens is important to enable them to benefit from these services. Denmark has the highest percentage of Internet users in Europe with over 95% of its population between 16 and 74 making use of the Internet. While other countries such as the UK, Finland or Germany are not that far behind, it is especially visible that the Internet adoption is lower in Southern Europe. Specifically in Italy, only 72.4% of people use the Internet at least once a week. In the developed countries beyond Europe one can also see a lot of differences. While South Korea is on a similar level to Denmark regarding Internet use, the US comes closer to some regions of Southern Europe, with a significant share of non-users. The Digital Economy and Society Index (DESI) by the EU ranks Denmark at first place for the indicator “Use of

72 See OECD Dataset ICT Access and Usage by Businesses, available at: https://stats.oecd.org/Index.aspx?DataSetCode=ICT_BUS.

Internet Services by citizens", especially because of the high number of people regularly using the Internet.

Especially for older people and people living in remote areas it can make life easier if public services are available online as this reduces long and costly trips to the inner cities. Availability of these services may in turn also drive Internet use and broadband take-up. The quality of eGovernment and eHealth services is assessed in the "Digital Public Services" metric of the DESI, where Denmark is ranked fifth, behind Finland, Estonia, the Netherlands and Spain. While Denmark scores well in most of the more detailed statistics, the relatively low level of use of open data should be highlighted, without which they would be in one of the leading positions in this index.

Figure 2-20: e-Government Index DESI, 2018

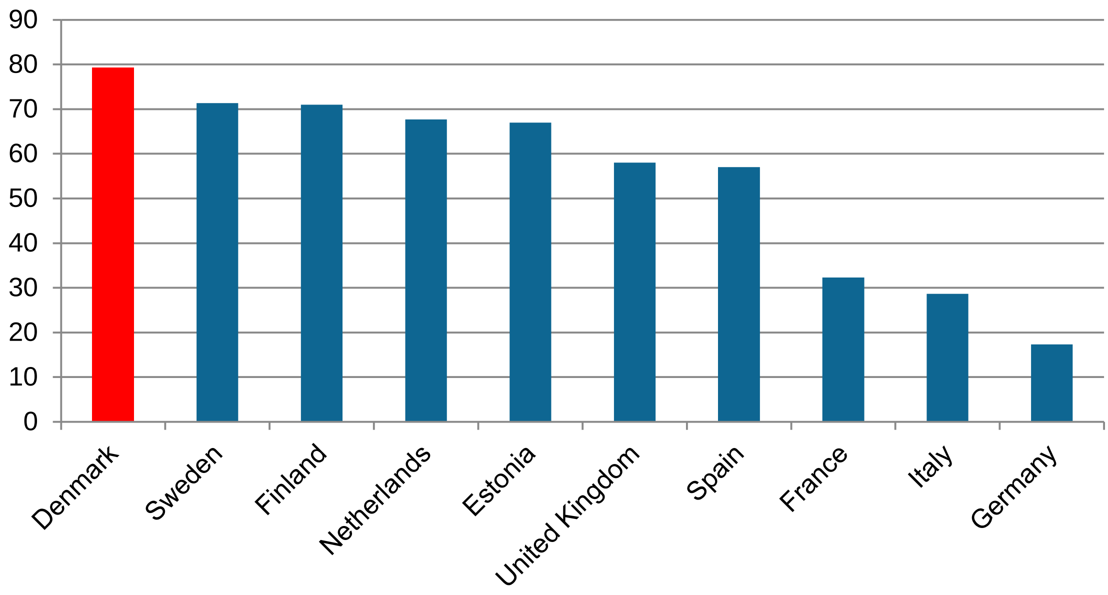


Source: WIK-Consult based on EU Commission.[73]

In terms of the e-Health index within the DESI, Denmark is one of the frontrunners with a very high score. One of the most important points within this metric is that it is much more common in Denmark for general practicioners to share medical data with each other.

73 See EU Digital Economy and Society Index (DESI), available at: https://ec.europa.eu/digital-single-market/en/desi.

Figure 2-21: e-Health index DESI, 2018



Source: WIK-Consult based on EU Commission.[74]

2.5 Conclusions concerning Denmark's position in telecoms and digitisation

The IMD Digital Competitiveness Index 2019 ranks Denmark on fourth place internationally in terms of its digital competitiveness.[75] In the metric of "Future Readiness", Denmark even reaches the second place (behind the US) after leading this section for the two years prior. Indicators where Denmark does not score highly are especially in the capital area, i.e. the market capitalization of its IT and media stocks and investment in telecommunications.

Overall, this overview supports the conclusion that Denmark is competitive in many areas associated with telecoms infrastructure and services.

For the future it is important for Denmark not to let FTTH expansion slow down further than in previous years, and to foster a competitive environment in which end-users are made aware of the benefits of, and can have a choice of and switch to fibre-based broadband offers.

74 See EU Digital Economy and Society Index (DESI), available at: https://ec.europa.eu/digital-single-market/en/desi.

75 The countries ranking above Denmark are the United States, Singapore and Sweden. See https://www.imd.org/wcc/world-competitiveness-center-rankings/world-digital-competitiveness-rankings-2019/.

In the mobile broadband market, Denmark is well placed concerning 4G/LTE expansion. The high coverage and take-up needs to be transferred over to the next technology generation, 5G. The rapid expansion of 5G should not only deliver higher speed to end users but also ensure a wider use of IoT applications through lower latencies.

3 Developments in services, applications and technologies

Developments in services and applications (both personal and IoT) will be key drivers of Denmark's communications needs in the period to 2030. Trends are likely to include:

- Drive towards energy efficiency and reduced climate impact including through smart building technologies, changes in travel arrangements
- Demand for connectivity everywhere at every time
- The move from a focus on interpersonal communications towards mass communications and connected things[76]
- The increasing sophistication and usage of robots within industry and public services such as healthcare
- Usage by individuals is also likely to be affected by the transition from "broadcast" media to "on-demand" solutions including OTT content,[77] and from simple voice communications towards "Rich Communication Services" including video and conference calling
- Immersive media and tactile Internet including low latency applications in the field of automotive mobility, healthcare etc, and the introduction of VR and AR into the fields of education and training (as well as gaming, where they are already becoming established)[78]

76 According to Cisco, there will be 3.6 networked devices per capita by 2022, up from 2.4 networked devices per capita in 2017. There will be 28.5 billion networked devices by 2022, up from 18 billion in 2017. WIK follows these trends closely. We have current data on the number of connected devices used by consumers in Germany as well as relatively recent data on consumers in Sweden. In addition WIK has developed its own models on the penetration of M2M and car connectivity solutions. For the estimates of the development in Denmark we can draw on these insights. See Arnold, R.; Kroon, P.; Tas, S.; Tenbrock, S. (2018): The socio-economic impact of FTTH, Bad Honnef, WIK-Consult.; Cisco Systems Inc. (2019): Cisco Visual Networking Index: Forecast and Trends, 2017–2022 White Paper. Cisco Systems, Inc.; Godlovitch, I.; Arnold, R.; Gries, C.-I.; Marcus, S.; Tas, S. (2019): Technological developments and roaming. Brussels: European Commission.; Taş, S.; Arnold, R. (2019): Die Auswirkungen von OTT-1 Diensten - WIK-Diskussionsbeitrag Nr. 440. Bad Honnef, Tenbrock, S.; Arnold, R. (2016): Die Bedeutung von Telekommunikation in intelligent vernetzten PKW - WIK Diskussionsbeitrag Nr. 413. Bad Honnef.

77 WIK has been monitoring this transition since 2015 for Germany with annual representative surveys. We find that currently half of the time spent watching audiovisual content is spent online. For Sweden, this figure increases to 59%. We expect to see similar trends in Denmark. See Arnold, R.; Schneider, A. (2018): For your eyes and ears: OTT Streaming Services in Germany. Bad Honnef, Cologne: WIK and Fresenius University of Applied Sciences.

78 Tactile Internet refers to a futuristic telecommunications infrastructure which will feature very low latency, ultra high reliability and availability as well as high security standards. It will facilitate the introduction of new and innovative technologies and shape the future of human–computer interaction. Individuals will be able to fully immerse themselves in virtual realities in the future, so that the line between reality and fiction likely blurs. Such an experience requires humans to receive realistic feedback via all their senses. Thus latency has to match human reaction times. Immersive media is therefore subject to high broadband requirements which will only be met by Tactile Internet infrastructures. See Arnold, R.; Kroon, P.; Taş, S.; Tenbrock, S. (2018): The socio-economic impact of FTTH. Bad Honnef.

- Trends towards individual device use and IoT and the consequent multiplication of connected devices.

In addition, applications requiring real-time big data processing is likely to increase demand for access to High Performance Computing (HPC) facilities by industry as well as for research needs. [79]

In this chapter, we elaborate on the main developments in fixed and mobile applications and services and their implications infrastructure requirements for consumers, businesses and "things".

With the aid of interviews with market leaders in Denmark and elsewhere, we then describe in more detail current and future use cases for communications – in six key areas:

- **Smart energy** is addressed in section 3.1
- We look at developments in **smart cities** in section 3.2
- The case of **intelligent transport** is reviewed in section 3.3
- **Smart healthcare and homecare** is considered in section 3.4
- **E-learning and remote working** is reviewed in section 3.5; and
- We discuss **smart agriculture** applications in section 3.6.

3.1 Smart energy

3.1.1 What do we mean by "smart energy"?

Smart energy including smart grids and meters, offers the prospect of enabling more efficient energy use, with associated environmental benefits and reduced costs. Smart energy involves connecting devices and developing applications to measure and control the generation and use of energy.

For example, ICT can be used by grid operators to monitor processes in the grid and boost the efficiency of energy transmission. This is crucial in a system with a high feed-in from intermittent energy sources such as wind and photovoltaic generation and will become increasingly important as demand for electricity increases as a result of the growing use of electric vehicles and heat pumps.

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79 The assessment of future requirements for HPC connectivity has been conducted in the context of a study concerning the future EU funding requirements to support the Gigabit society (SMART 2017/0018).

ICT can also be used by electricity generators to monitor faults and tailor power generation to meet the prevailing requirements.

On the consumer side, smart meters offer the potential for new customer services and products. They allow the introduction of time or load dependent tariffs and provide consumers with (real-time) information on their energy consumption. Smart meters can also be connected to wider “home automation” systems.

It can be said that smart energy supports the energy system with “eyes and hands”, i.e. generating information that was invisible before and making it possible to react on the basis of the data collected.

3.1.1.1 What potential benefit could smart energy bring to the environment and society?

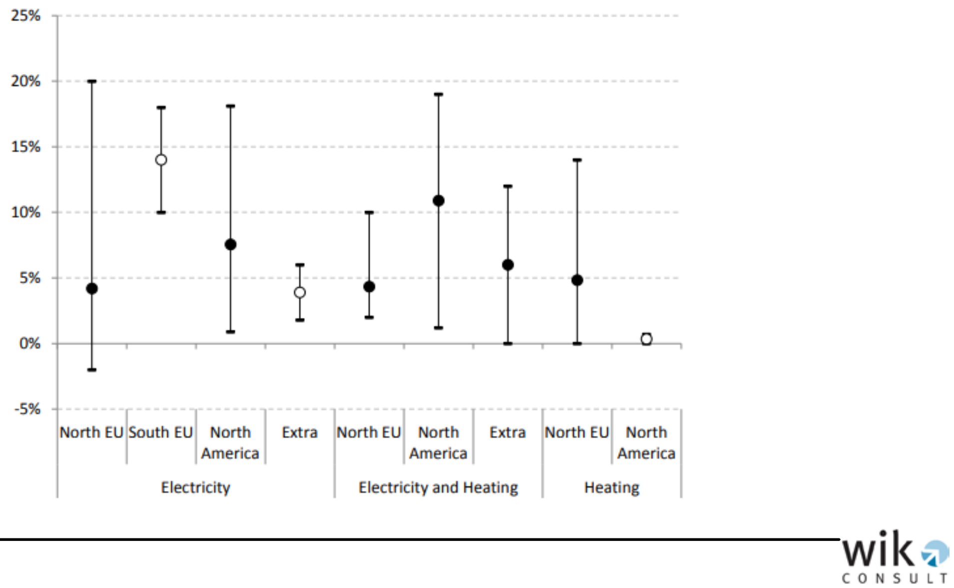
Smart energy can deliver cost savings and environmental benefits in all elements of the energy value chain, from generation through to transmission, distribution and usage.

For example, as regards to generation, when wind and photovoltaic plants are remotely controlled, grid operators can react to changing weather conditions and control the feed-in of electricity by regulating the electricity produced. This can lead to a higher share of “clean” power, thereby helping to reduce CO_2 emissions.

Meanwhile, better understanding of energy consumption and sources of energy waste in households and firms can lead homes and businesses to make energy savings. There is a long list of literature on this issue.[80] However, the energy savings depend on the country, type of feedback and energy carrier as well as on the attidudes of consumers. Figure 3-1 provides a synopsis of different studies indicating the minimum, maximum and average savings, which may be achievable as a result of customers having feedback on their energy consumption.

80 See for example: Choi et al. (2009): Analysis of energy savings using smart metering system and IHD (in-home display), in: 2009 Transmission & Distribution Conference & Exposition: Asia and Pacific;
Bager and Mundaca (2017): Making ‘Smart Meters’ smarter? Insights from a behavioural economics pilot field experiment in Copenhagen, Denmark, in: Energy Research & Social Science, Volume 28, June 2017, Pages 68-76;
Mack et al. (2019): Bridging the electricity saving intention-behavior gap: A German field experiment with a smart meter website; Energy Research & Social Science, Volume 53, July 2019, Pages 34-46.

Figure 3-1: Maximum, minimum and average savings per consumption type and geographical area due to feedback on energy consumption. White average bullets refer to dataset composed by few studies (i.e. ≤3).



Source: Serrenho et al. (2015).

A further benefit for consumers is the contribution of smart meters to intensified competition. Smart meters can support switching amongst suppliers, as the necessary data can be transferred electronically. Switching suppliers with a few clicks in turn reduces transaction costs and can lead to lower prices for consumers as suppliers face more intense competition.

Finally, smart meters contribute to the stability of the energy system. The data collected can be used to improve forecasts about the future situation in the grid. Concrete action can be undertaken to stabilise the grid in the event of impending brownouts or blackouts. As an outage (especially in the power supply) could create significant costs for society (given the reliance on power for critical services) as well as the economy, the benefits of understanding and being able to manage demand and associated supply, are considerable.

3.1.1.2 Examples in Denmark and elsewhere

Denmark is already at the forefront of smart energy transformation in Europe. One of the initiatives close to completion is a requirement to install smart electric meters recording hourly consumption in every household by 2020. At the beginning of 2019, the penetration rate was about 80%.[81]

In 2018, the Danish Government signed an energy agreement with the support of all sitting parties in the Parliament that set a target that 50 percent of Denmark's energy needs should be met by renewable energy in 2030.[82]

Key elements of the agreement include a commitment to construct offshore wind farms, as well as providing funds for onshore wind and solar energy and a targeted effort to realise energy savings and strengthen research in this field.

3.1.1.3 Technological dependencies

A number of options are available to support connectivity to the electricity grid. Connectivity can be delivered via a fixed (e.g. fibre, DSL, cable, powerline) or mobile (e.g. SigFox, LoraWan, GSM, CDMA, LTE, satellite, 5G) infrastructure.

SigFox and LoraWAn are better suited for in-house applications and IoT, while the connection of smart meters through a wide area network can be delivered through the other technologies mentioned with 5G as a possible option for the future. An important consideration is to select a technology, which benefits from an established ecosystem in terms of standards, availability of hardware from different manufacturers, and can be readily installed by engineers.

The connectivity needed for the energy system itself depends on the requirements of different applications. To support processes within the grid such as monitoring and addressing critical events, a delay beyond a few seconds must be avoided, whereas for tasks such as billing, speed is less of an issue. Likewise, high "Quality of service (QoS)", "reliability" and low "latency", are essential in cases where data is needed to stabilze the grid or prevent it from collapsing, but may not be needed in other cases.

Generally, a decision must be taken by grid companies as to whether to rely on public or private (dedicated) ICT infrastructure. Grid companies' requirements for reliability are often set as high as 99,999%. Likewise the choice of technology depends on requirements regarding latency and QoS. These requirements are typically fullfilled through decicated ICT infrastructure or in the future might also be accomplished with 5G network slices.

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81 See https://www.euractiv.com/section/energy/news/smart-meter-woes-hold-back-digitalisation-of-eu-power-sector/.

82 See https://stateofgreen.com/en/partners/state-of-green/news/new-danish-energy-agreement-a-green-focus-towards-2030/.

Another important factor is that the ICT infrastructure is primarily needed where the consumers and generators are located. Thus coverage of the infrastructure is important to ensure that it aligns with the distribution of household and generation sites throughout the country.

3.1.1.4 Potential evolution

Currently generators, electricity grid operators and customers rely on the technologies discussed above. At the moment there is no urgency to upgrade these technologies, because current technologies are sufficient to support existing applications. Even grid critical issues can be accomplished with LTE or powerline technology.

However, certain applications may require more advanced connectivity, and the energy sector can be expected to exploit new technologies as they emerge. For example, monitoring power lines or gas grids with drones would require 5G for image transmission. The implementation of these new applications is of course subject to availability, reliability and the cost-benefit ratio.

Another question concerns whether the energy industry will have the capacity to build up sufficient private ICT infrastructure to achieve the promise of high reliability and QoS, and what role energy companies may play in this context.

One important consideration in Denmark is that a large number of energy distribution companies are engaged in their own fibre deployments.[83] At the moment, fibre is mainly used to connect the substations. This could provide a solid basis on which to support the smart energy applications of the future, and could even enable these companies, if they wish, to self-supply 5G services. For example, 37% of suppliers in Germany have announced their intention to acquire their own spectrum and act as infrastructure suppliers.[84] Gaining access to network slices on 5G networks might be another way for energy companies to support QoS requirements for future smart energy applications. Smart energy also raises data protection, security and regulatory questions.

The energy supply is a crucial sector for the society and economy. Once the energy system relies on ICT infrastructure, the data running on this infrastructure must be protected against all attacks and disturbances from outside. Contractual and legal safeguards may be needed as well as effective monitoring and enforcement. EU Commission Regulation (EU) 2017/2196 on establishing a network code on electricity emergency and restoration builds a legal framework.

83 Falch et al. (2016): New Investment Models for Broadband in Denmark and Sweden, in: Nordic and Baltic Journal of Information and Communications Technologies, Vol: 2016, Issue: 1. This issue calls for a clear differentiation of costs, however. There was some arguing about cross-subsidising when implementing fibre for the purposes of energy companies.

84 Detecon (2019): 5G in der Energiewirtschaft – Ergebnisse der Detecon-Marktumfrage [„5G in the energy industry – Results of the detecon market poll“], Juli 2019.

Another important issue is to consider that smart investments by energy companies, be they in generation, transmission or in metering, are adequately incentivised and rewarded.

The rollout of smart meters is mainly driven by European Directives. Danish distribution system operators (DSOs) are obliged to install smart electricity meters to all consumers by the end of 2020. Furthermore, all (other) meters must be remotely readable in 2027 at the latest. This heavily stimulates the implementation of smart meters.

The Danish Ministry of Climate, Energy and Building in 2013 published a Smart Grids Strategy. One of the tasks was to look closer at "*whether financial regulation of the grid companies has been organised to provide the right incentives to invest in the smart grid."* To our knowledge there is no special incentive for grid companies to invest in smart grids under the Danish incentive regulation so far.

A project called "EcoGrid" was launched in 2011 to demonstrate a smart grid in reality on the island of Bornholm. In 2019, the main results of the successor "EcoGrid 2.0" were published. One of the main findings was that *"Utilisation of existing data through new software and technology (e.g. machine learning) is an important factor in the digitalisation. With data from smart meters, machine learning and digitalisation we can utilise data to do more than we initially believed – move consumption, integrate more renewable energy production, monitor consumption, optimise grid operation, identify future bottlenecks and improve the utilisation of power grid capacity."*[85]

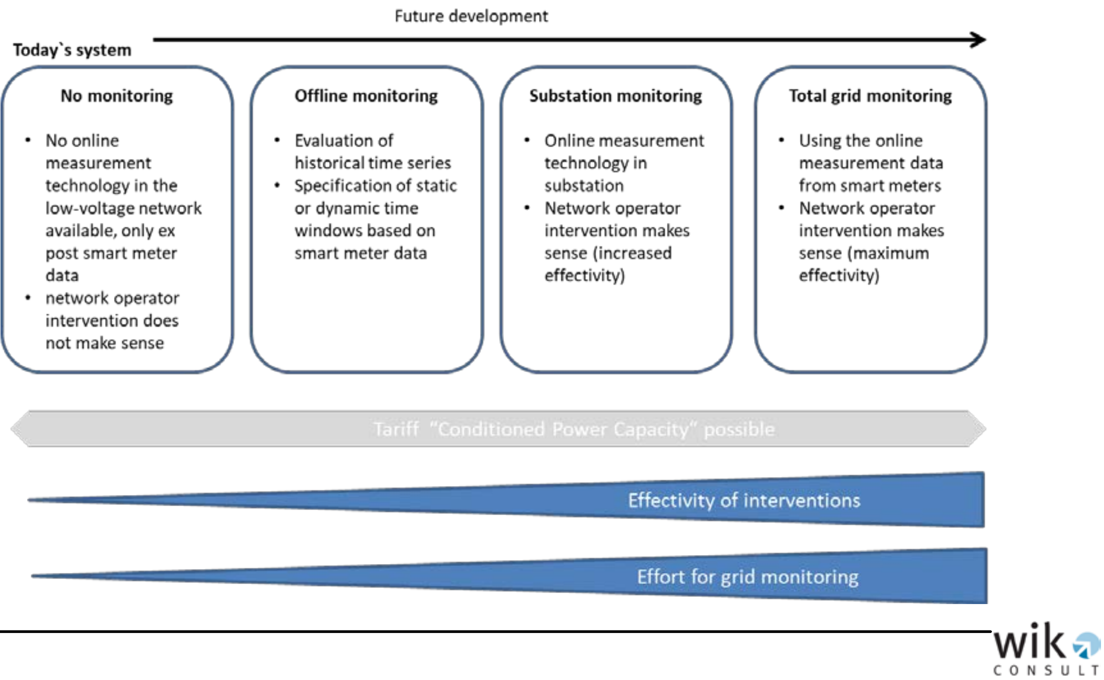
The realisation of such a system requires data gathering by sensors and monitoring systems to provide actors with the information they need. IoT is one element to do this. However, whenever the application becomes grid critical (i.e. the energy grid relies on ICT to run smoothly and without any distrurbances or blackouts) there must be an ultra –reliable infrastructure in place.

Although electric cars are not as popular as in other Nordic countries, the number is expected to increase in Denmark in the coming years and will also change the requirements on the electricity grids. To keep security of supply on a high level, the ICT infrastructure must deal with the changing loads and load patterns that come along with this development. This means that (as long as fibre is too expensive) a mobile solution needs to be installed that can respond to the new requirements.

With this development the grid monitoring has to evolve as the following figure shows.

85 EcoGrid 2.0, Main Results and Findings, September 20th 2019.

Figure 3-2: Steps to digitise distribution networks



Source: WIK, bet, EY (2019): Digitalisierung der Energiewende, Topthema 2: Regulierung, Flexibilisierung und Sektorkopplung ["Digitisation of the energy transition, Top Issue 2: Regulation, Increased flexibility and sector coupling".] Translated from German.

An accompanying element in this procees is to offer customers a conditioned power capacity. This means that they are guaranteed to always get a certain capacity (e.g. 5 kW for a household) but everything that goes beyond is a kind of flexible capacity that the grid operator can use to stabilize the grid. To incentivise such an offer the customer pays a lower price.

3.2 Smart cities

3.2.1 What do we mean by smart city applications?

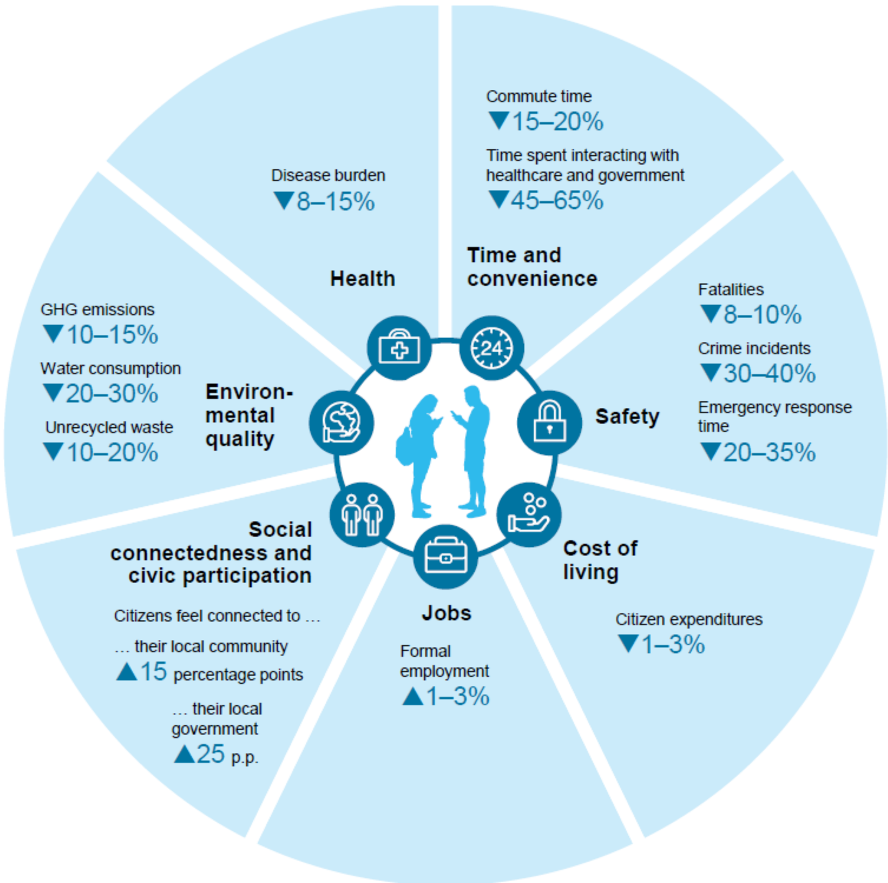
Smart city applications offer the prospect of using technology to control energy use for public lighting and buildings, as well as guiding traffic flows and supporting more sustainable mobility solutions including public transport, car and bicycle sharing schemes, as well as automated driving. Smart city applications can also be used to enforce environmental schemes such as congestion charging, and support efficiency in public services such as waste management.

3.2.2 What potential benefits can smart city applications bring to the environment and society?

Smart city applications can have a significant impact both on the local environment and in the delivery of public services.

A 2018 study by McKinsey[86] which reviewed “smart” applications across 50 cities suggests that these applications “could reduce fatalities by 8–10 percent, accelerate emergency response times by 20–35 percent, shave the average commute by 15–20 percent, lower the disease burden by 8–15 percent, and cut greenhouse gas emissions by 10–15%. The following diagram illustrates the fields in which Smart Cities could create an impact and the estimated savings and enhancements that could be achieved as a result.

Figure 3-3: Impact of smart city applications, McKinsey estimates



Source: McKinsey 2018 Smart cities: Digital Solutions for a more livable future.

86 https://www.mckinsey.com/~/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/Smart%20cities%20Digital%20solutions%20for%20a%20more%20livable%20future/MGI-Smart-Cities-Full-Report.ashx.

3.2.3 Examples in Denmark and elsewhere[87]

Copenhagen Solutions Lab[88] is the City of Copenhagen's incubator for smart city initiatives. The laboratory opened in 2016 as a public-private partnership between Cisco, TDC, Citelum and the City of Copenhagen.[89]

The Lab works across 7 departments within the City's administration to support the development and adoption of technological solutions which increase efficiency and reduce environmental impacts. The Lab plays an important role in contributing to Copenhagen's target of achieving carbon neutrality by 2025.

The Lab has recently announced a new initiative to measure air quality, in association with Google. Equipment is mounted on Google Streetview cars, and an algorithm enables the measurements to be extrapolated to cover the entire city. The output will be a heat map, the first of its kind in Europe, although this technique has been used in the US. Data like this will be made public, enabling private companies to develop applications and citizens to adapt their behaviour. For example, more than 50% of Copenhagen residents cycle to work, and information on air quality could enable them to avoid polluted routes. The information also provides an opportunity for the city to adapt its planning to take pollution levels into account e.g. by adjusting the positioning of roads, pedestrian areas schools and public institutions. Information such as this could also provide evidence to support plans to mitigate pollution, for example by banning diesel cars or requiring cruise ships to limit emissions. However, 70% of the pollution in Copenhagen comes from other cities and regions, so it is also necessary to look at how technology might be used to clean the air.

Another project concerns "smart waste". The scheme was initially started through the "Living Labs" programme and has since scaled to cover one quarter of public garbage containers. Under this scheme, sensors are mounted in garbage bins, which emit data to signal when they should be emptied. The initiative has allowed more efficient route planning, saving time and fuel. The business case suggested that 10% savings could also be made to the cost of garbage collection. The city also deploys sensors for traffic management along the major highways.

Cisco, one of the partners in Copenhagen Solutions, notes that they have conducted a number of projects and pilots for the City in recent years. These include support for smart parking and street lighting, as well as establishing centres to monitor air quality. When commissioning smart city projects, the City of Copenhagen takes into account not only financing savings, but also the environmental impact. For example, Cisco has estimated that moving from traditional street lighting to smart street lighting could

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87 Case studies in this section are based on interviews conducted in October 2019 with Copenhagen Solutions Lab, Cisco, and Stokab.
88 See https://cphsolutionslab.dk/.
89 See https://investindk.com/cases/cisco-chooses-copenhagen.

reduce CO2 emissions in the City of Copenhagen by 23,000 tons per year, while implementation of traffic management systems in Copenhagen were estimated to permit a reduction of 18 tons in CO2 emissions. Smart building systems where light and heating requirements can be monitored and controlled via an IP network have enabled public authorities and private companies to save further energy and reduce costs. Cisco has also supported smart communications between ships and harbours, which can facilitate the loading and unloading process.

Turning to the neighbouring capital of Stockholm, the city has plans to connect 500 city cabinets at all major street crossings with fibre over a period of 3 years. Stokab, the municipal fibre company owned by the City of Stockholm, notes that fibre has been installed to most buildings in Stockholm, in the street environment, connectivity is mostly analogue and based on copper wires. This provides only 2Mbit/s connectivity which does not allow sufficient capacity to transmit data from the street corners to the central processing unit for analysis.

With current low levels of connectivity, schedules for traffic lights are set for specific time periods and settled in adcance, whereas if lights were connected via fibre, traffic patterns could be analysed and changes could be made in real time. Stokab notes that dynamic capacity in traffic lights could be used to prevent traffic jams in urban areas, and can have a positive impact on the environment and energy consumption by reducing waiting times for cars and making buses more attractive. Stokab 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.

Moreover, 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.

Another important application of cameras at the street level is to enforce rules over when or which vehicles can drive (e.g. in the context of bans on certain types of fuel for environmental purposes), or which charges might be applicable (e.g. in the context of congestion charging). Assessments could also be made concerning the length of vehicles and whether they comply with any restrictions applicable. The use of manual or limited controls today means that many breaches are missed. Real time data could direct police to specific streets, or enable the use of automated penalties.

Cameras also play an important role regarding security and safety. If you can analyse the traffic situation, you could see what can be done to avoid accidents, and respond to accidents with an automated alarm. CCTV also plays an important role in deterring and addressing criminal activity.

More generally, Stokab notes that, if there is a digital and physical platform supported by fibre and with sites available to install physical infrastructure, it is easy to add on new services and applications, rather than needing to develop a bespoke infrastructure and application for each case. Stokab considers that a neutral fibre infrastructure lowers the threshold for the City to establish new services created by private actors. This network could also be used by private actors for e g IoT,and as a backbone for the 5G networks.

3.2.4 Technological dependencies[90]

Various connectivity solutions are required to address different smart applications.

Applications based on sensors typically require low bandwidth and limited power, to support longer battery lifetimes in the field. They also necessitate long range radio signals that can pass readily through barriers. Networks supporting these devices are typically based on narrowband IoT or LORA, and data is transmitted intermittently based on schedules or trigger events. 4G and Wifi would consume too much power.

Conversely, high bandwidths and always on connectivity are required for applications such as video-driven traffic light control systems, which remotely combine and process data from cameras to predict and respond to traffic flows. Bandwidth requirements are particularly high when multiple cameras are involved e.g. in the context of roundabouts. Fibre connectivity is recommended for these applications.

Meanwhile, very low latency is relevant for applications which require fast response times or are critical to health and safety. A prime example is automated cars, responsive connectivity to communicate with each other and with the road, enabling real-time steering and emergency braking.

At the application level, smart city applications rely on low power sensors or cameras and big data processing to interpret and react to data associated with traffic, weather conditions, waste. Geospatial technology is also important for applications relating to transport management and connected vehicles.

3.2.5 Potential evolution

Future smart city applications, including the use of cameras for data gathering and traffic management, as well as law enforcement, are likely to necessitate the

90 Observations in this section are based on interviews conducted for the study in October 2019 with Cisco.

deployment of fibre and energy sources alongside roads, with break-outs at traffic lights and other street furniture, coupled with the deployment of 5G for applications requiring wireless connectivity including automated driving.

In technical terms, Stokab observes that only two fibres are needed to support most smart city applications. However, more fibres should be installed to support competition and ensure that the infrastructure is fully future-proof, and the cost of additional fibres is marginal according to Stokab. Stokab is planning to install 24 cables to street furniture and around 1000 fibre cables in the backbone network.

A key question for public authorities concerns who will deploy infrastructure in roads and how infrastructure can be made available for the deployment of 5G antennas as well as for the development of smart applications. As this infrastructure will also be important for future "mobile" applications including automated driving, it is also important to consider how a coherent nationwide framework can be developed for the connectivity and digitisation of roads.

3.3 Intelligent transport

3.3.1 What do we mean by "intelligent transport"?

Intelligent transport involves measures to reduce the time taken to travel and increase users' comfort and safety. It may include

- the sharing of (real-time) information about existing traffic flows, and, in the context of public transport - seat availability
- measures to support "road safety and efficient infrastructure usage"[91] and
- intelligent applications that are increasingly being installed in cars. Fully autonomous vehicles (automated driving) could represent part of a future intelligent transport system.

3.3.2 What potential benefit could intelligent transport bring to the environment and society?

Intelligent transport systems reduce congestion and make travel more efficient, thereby reducing opportunity costs and enabling travellers to engage in more productive activities. Smart systems, which interpret and forecast traffic flows can lead travellers to their destination in a shorter timeframe, while integrated information and systems can enable travellers to use different forms of transport to complete their journey.

91 Choudhary (2019).

As travelling time is reduced, emissions from engines and drive systems are reduced as well, which helps to mitigate climate change and improve air quality.

As systems evolve towards autonomous driving, further important benefits can be realised including increased safety for drivers, other road users and pedestrians. In the long run, automated mobility could also cut costs and increase efficiency for commercial transport functions (such as the transportation of goods, taxis etc.).

3.3.3 Examples in Denmark and elsewhere

A project called “Nordic Way” aims at increasing road safety by enabling *“vehicles, infrastructure and network operators to communicate safety hazards and other information from roads in the Nordic countries between different stakeholders.”*[92]

The system works by uploading and sharing information via the cloud. For example, in defined areas, vehicles utilize GPS and the mobile network to create two-way-communication between the vehicle and the surrounding infrastructure. One application involves communications to cars about the status of traffic lights. After stopping at a red light, the car is automatically turned off and then reactivated when the light changes to green. Further applications include automated user payments and support in maintaining speed limits.[93]

The city of Pattburg is building a 5G network in the Pattburg transport centre. In the testing field autonomous driving of vehicles (e.g. between two storage buildings) may be tested. In the long-run a nationwide roll-out is thinkable and desired by the transport industry.

Meanwhile, in Berlin, Germany, trials are under way[94] of a system which can improve safety by warning surrounding vehicles of a vehicle breakdown.[95] The technology is called “LTE-Vehicle-to-anything (V2X)” and provides network technology in the roadside and in-car base stations.

3.3.4 Technological dependencies

The technological requirements for intelligent transport depends on the applications in each case.

92 See https://www.nordicway.net.
93 See https://www.nordicway.net.
94 By Fraunhofer Fokus.
95 LTE-V2X – mehr Verkehrssicherheit durch Direktkommunikation („LTE-V2X- more traffic safety through direct communication“)(2019), available at: https://www.internationales-verkehrswesen.de/lte-v2x-direktkommunikation/, translated from German.

There are already a variety of smartphone applications available that help consumers and professional drivers to reduce the time spent between their starting point and destination.[96] For these applications, the public mobile network is sufficient.

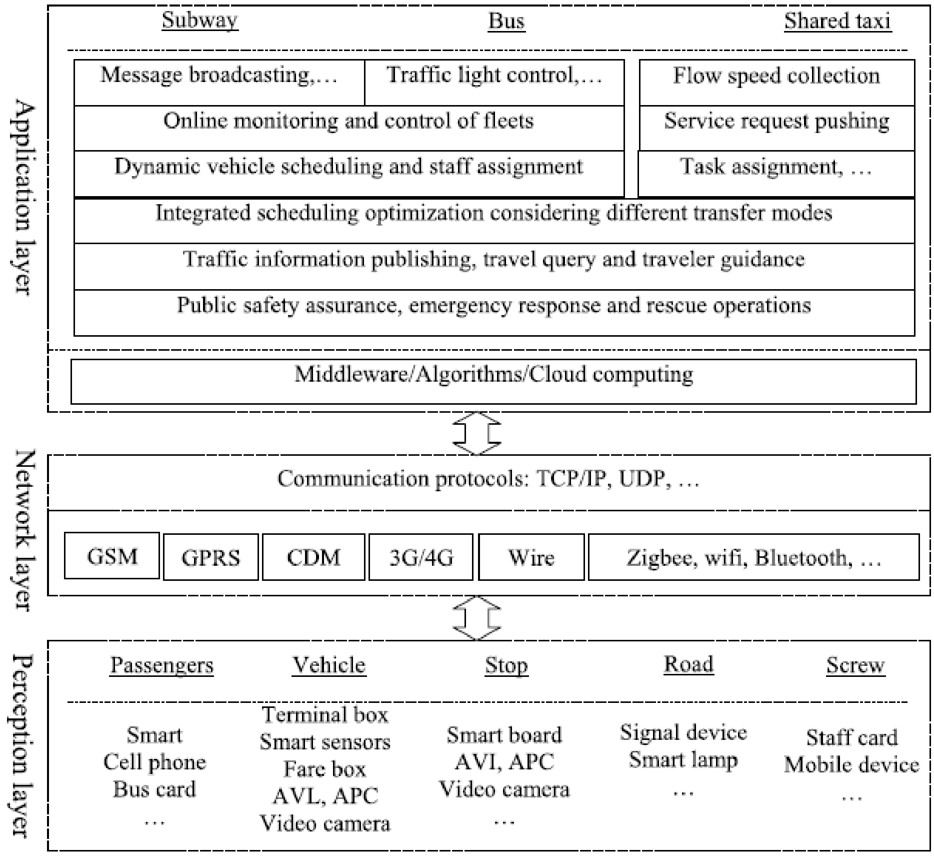
Meanwhile, a range of technical solutions are used to support the evolving use of IoT to address challenges faced by public transport systems (such as fluctuating passenger flows and vehicle breakdowns).[97]

The following diagram illustrates different technologies that may be used to support an IoT-based public transport system. It shows that the applications are manifold and can be supported with different forms of connectivity. It also highlights how information from sensors and data gathering devices (the perception layer) link through to smart public transport applications.

96 For an overview see for example: https://meetingoftheminds.org/12-innovative-urban-transportation-apps-4708.

97 Luo et al. (2019): A New Framework of Intelligent Public Transportation System Based on the Internet of Things, in: IEEE Access, Volume 7, 2019.

Figure 3-4: Architecture of an IoT-based integrated public transport system



Source: Luo et al. (2019).[98]

The system works on a mobile network, using different standards, depending on the information transmitted and network availability.

Generally, there are two main technologies in use. One - IEEE 802.11p (pWLAN) bridges only a few hundred meters. The technology standard is mature and can be used today. It was particularly developed and testet for the needs of automotive applications. However, there is a lack of an overarching infrastructure, as seen in mobile radio, enabling road users to be connected with a control centre.

The other key technology is LTE, which also competes with C-V2X as a radio technology for communication between vehicles.The LTE specification is considered to be more efficient in terms of range and availability. C-V2X builds on an already

98 Idem.

established and widespread technology that enables both network-based and direct communication (LTE device-to-device).[99]

In the case of autonomous driving, LTE-V2X provides the *"technology for direct vehicle-to-vehicle communication as well as vehicle-to-infrastructure or vehicle-to-network communication."*[100] The networked cars can *"communicate such information as position, speed or obstacles to all other networked vehicles in the area,"*[101] and this technology may lay the ground for future 5G CAM developments.

For fully autonomous driving however, there is a need for an ecosystem that is integrated and widely available, as well as meeting strict quality of service requirements. 5G will likely be needed to perform this function (see next section).

3.3.5 Potential evolution

For autonomous vehicles, ultra-reliable and low latency communication (URLLC) is needed. *"We need to look at how long it takes for the message to be transmitted between sensors and then get to the computer in each car, and then how long it takes for the computer to make a decision, and all of this has to be in less time than a human would take to make a decision—2 milliseconds. We need a network supporting this, and 5G is that network."*[102]

A basis for the implementation of this application is the Cellular Vehicle-to-Everything (C-V2X) standard that interconnects vehicles with other vehicles, the infrastructure, pedestrians and the network. The following diagram shows the different communications models V2V, V2I, V2P (direct link) and V2N (Up/Downlink).

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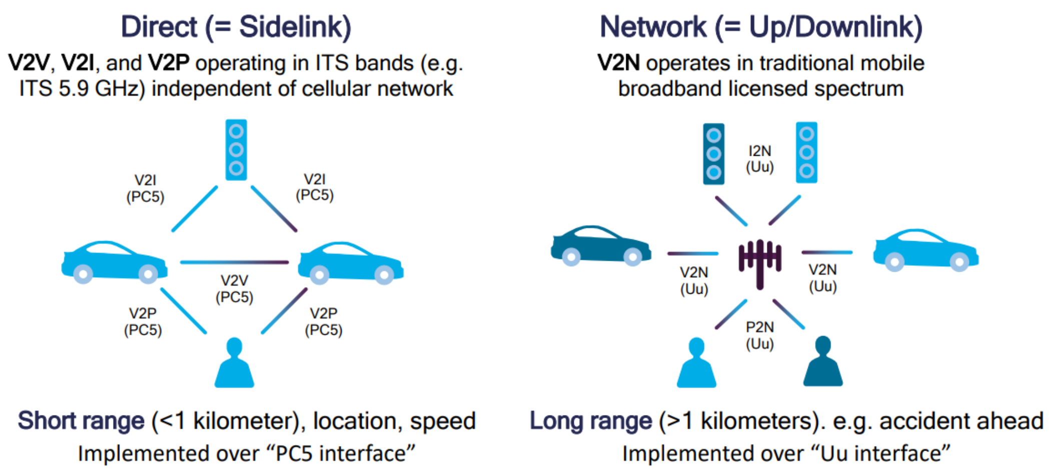
99 See https://www.elektronik-kompendium.de/sites/net/2407231.htm.

100 LTE-V2X – mehr Verkehrssicherheit durch Direktkommunikation („LTE-V2X- more traffic safety through direct communication")(2019), available at: https://www.internationales-verkehrswesen.de/lte-v2x-direktkommunikation/, translated from German.

101 LTE-V2X – mehr Verkehrssicherheit durch Direktkommunikation („LTE-V2X- more traffic safety through direct communication")(2019), available at: https://www.internationales-verkehrswesen.de/lte-v2x-direktkommunikation/., translated from German.

102 Jane Rygaard of Finnish tech firm Nokia in an interview with BBC, see https://www.bbc.com/news/business-45048264.

Figure 3-5: C-V2X communication models



Source: 5GAA.

Requirements for autonomous driving are quite strict. Autonomous vehicles may drive very close to each other and at higher speeds (up to 200 km/h). Therefore an autonomous vehicle requires full road network coverage to work driverless in all geographies.[103]

For this reason, fibre backhaul alongside roads is one of the main prerequisites for autonomous driving. Moreover, the power supply infrastructure may also need to be redesigned to ensure power supply for base stations.

3.4 Smart healthcare and homecare

3.4.1 What do we mean by smart healthcare?

E-Health or smart health refers to ICT in healthcare. E-Health can involve networking amongst healthcare practioners, the consolidated collection and processing of medical data as well as remote monitoring and interventions for patients in a home or hospital setting.

Demographic change is an important driver for applications in telemonitoring and telecare. Key drivers are that the life expectancy is on the rise and senior citizens and other vulnerable segments of the population expect to lead an independent life without being overly dependent on their families and medical facilities. Meanwhile, the ready availability and exchange of medical records, coupled with connectivity amongst

103 Campolo et al. (2017): 5G Network Slicing for Vehicle-to-Everything Services, in IEEE Wireless Communications, Volume: 24, Issue: 6.

specialists and the application of AI can support more efficient and accurate diagnoses and treatment for all patients.

A more detailed description of some of the applications follows.

3.4.1.1 Remote consultations

When hospitals and medical practices are connected, doctors can consult with one another and interact. For instance, when a patient with a certain disease or condition seeks medical assistance in a rural area, with a limited number of doctors, the contacted doctor might not have the required specialist knowledge. Broadband networks enable rapid contact with other doctors who can assist in diagnosis and therapy options. In addition to teleconsultations, tele medical interventions could be supported, with the patient in a remote healthcare facility. When data can be transferred in real-time, a specialized doctor can directly assist other practictioners, using audio visual services that virtually connect them to the patient. The specialist can suggest tests, assist in diagnosis and advise on treatments without being present.

These technologies mean that medical emergencies can be treated more quickly and patients can begin therapy without having to consult the specialist directly. Medical costs can be significantly reduced by avoiding delays in diagnosis, which could otherwise lead to damaging long term effects.

3.4.1.2 Remote monitoring

Another application of telemedicine, is to enable doctors to remotely supervise patients with a medical condition in their home in real time. Patients with long term diseases (e.g. diabetes) or those prone to heart attacks and strokes can be externally monitored via sensors that measure vital functions. Examples of specialized monitors and alarms that could be used in this setting include fall alarms, wandering alarms, hypothermia alarms, and movement monitors. Some solutions also include alert systems to remind the person wearing the monitor to take medication or carry out exercises.

When these sensors signal a medical emergency, doctors might be able to advise on preventative measures or invite patients for treatment without a prior appointment. Thus, medical responses can be accelerated and potentially life saving treatments can be initiated before a medical team sees the patient in person. The same applies to rehabilitation measures.

Medical costs can be significantly reduced when a patient can move home earlier and continue their rehabilitation practices through continuous external supervision. Sensors can also be used to evaluate the course of rehabilitation and changes can be advised according to the individual’s progress.

3.4.1.3 Storage and processing of medical records and scans (Electronic health records)

Remote consultations can be facilitated if healthcare practioners have external access to a patient's medical file with records and scans: They should be able to consult them anywhere and without delay if the patient, who has sole control over his file, agrees.

Depending on the specific model, the data (including medical history, medication and allergies, immunization status, laboratory test results, radiology images, vital signs (including those transmitted via sensors), personal statistics such as age and weight, and billing information[104]) can be stored centrally or shared between different facilities. The aggregation of patient data also enables the development of AI tools to support in processing tests and scans.

3.4.2 What potential benefits could smart healthcare bring to the environment and society?

Smart healthcare can deliver significant benefits in a range of areas.

A general assessment of the economic impact is challenging, due to the wide variety of e-Health applications available. However, some studies estimate that efficiency could be increased by up to 5% while the overall saving can exceed 0,5% of a country's GDP. Denmark is cited as a country in which relatively high efficiency gains have already been achieved via high adoption of e-health solutions.[105]

Cost savings in existing treatments can then enable scarce healthcare resources to be spread into other fields and areas.

The social benefits of eHealth can be even higher as more efficient and accurate diagnoses and treatments can contribute to saving lives. Another social benefit is that elderly people as well as patients with disability and diseases can be empowered to participate more actively in their communities. Remote monitoring and intervention can also bring the benefits of modern healthcare to areas that might otherwise be poorly served, with the potential to improve quality of life, and reduce regional divides.[106]

Smart healthcare can also bring intangible benefits such as enabling patients to return home earlier or be treated from home. For example, telemonitoring solutions not only

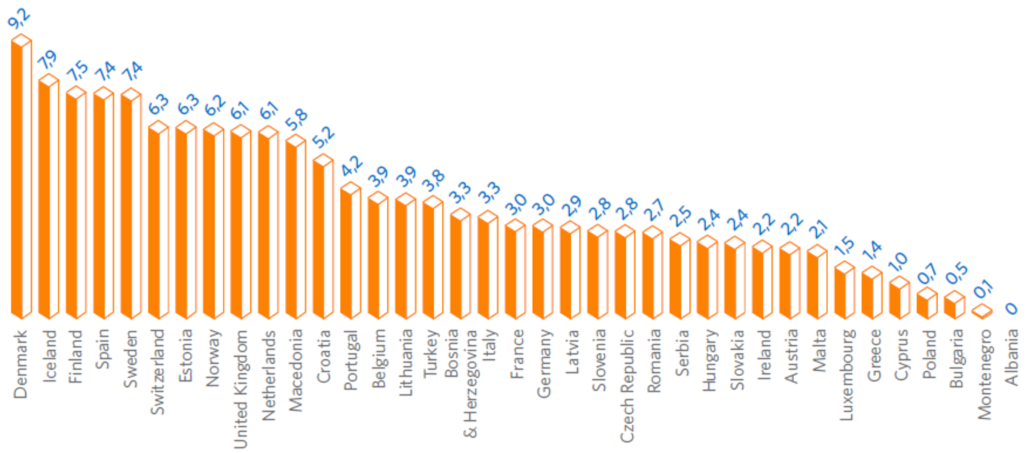
104 See https://web.archive.org/web/20140530024928/http://topmobiletrends.com/mobile-technology-contributions-patient-experience-parmar/.
105 See https://ec.europa.eu/digital-single-market/en/news/transforming-ehealth-political-and-economic-advantage.
106 See http://ehealth-impact.eu/fileadmin/ehealth_impact/documents/ehealthimpactsept2006.pdf.

reduce medical and transportation costs but also empower patients to lead a self-determined life.[107]

3.4.3 Smart healthcare Initiatives in Denmark

According to various benchmarks, Denmark is the frontrunner in Europe in the field of Digital Healthcare and has deployed a variety of care services and applications that address the needs of senior citizens. Well-developed eHealth solutions can also be found in Iceland, Finland, Spain and Sweden.

Figure 3-6: E-Health Index in European Countries in 2016
(by Polityka Insight calculations)



Source: Polityka Insight (2017).[108]

Telemonitoring solutions (also called “telecare”) – portable and fixed –play an important role in Denmark. One prominent example is the home monitoring of COPD patients by TeleCare North that has been considered successful and will be further expanded in the future.[109] This solution is reported to have increased rehabilitation activities by 9% (thus

107 See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5800160/.
108 See https://ec.europa.eu/digital-single-market/en/news/transforming-ehealth-political-and-economic-advantage.
109 See https://www.healthcaredenmark.dk/media/1625194/HCD-Telehealth-white-paper-v1-single-0318.pdf and http://www.ehealthforregions.net/fileadmin/user_upload/Virtuelt_seminar_Ehealth_for_regions_2._november_2016.pptx.pdf.

contributing to patients' functional ability), while reducing the number and length of hospitalisations by 11% and 20% respectively.[110]

Another example is the practice of telemonitoring preterm babies in Denmark: An early discharge of mother and baby from the hospital with support while ensuring close supervision via a telemedicine solution proved very successful: The families can return home an average of 22 days earlier than was previously possible. This innovation has not only saved costs and released hospital beds, but increased customer satisfaction amongst the parents who were able to benefit. Overall 300 babies have been supported in this way since the scheme was established.[111]

"Virtual hospital" solutions have also included support for "camera pills" for colonoscopy diagnostics. As a non-invasive procedure, it can be carried out in the patient's own home, significantly reducing the risk and discomfort while achieving accurate results.

Although Denmark is a densely populated country by European standards, some Northern and Western parts are less populated and thus the distance to the closest doctor or hospital might be substantially higher than in urban areas. Rural areas may also lack specialists, making remote consultations and supported interventions all the more important.[112]

Denmark has also pioneered access to medical data. For example, the app "Medicinkortet" (Medication Record) gives patients an overview of their current medical prescriptions, and has been downloaded more than 400,000 times.[113]The Government's approach for the coming years has been elaborated in a Digital Health Strategy 2018-2022 complete with targets and focus areas.[114]

A number of agencies are involved in support for Denmark's e-Health programme.

- Established in 1994, MedCom is as a public funded, non-profit cooperation. MedCom facilitates the cooperation between authorities, organizations and private firms linked to the Danish healthcare sector. It is financed and owned by The Ministry of Health, Danish Regions and Local Government Denmark. MedCom's role is to contribute to the development, testing, dissemination and

110 See https://whitepaper.healthcaredenmark.dk/media/6503/hcd-telehealth-white-paper-v1-single-0318.pdf.

111 See https://cimt.dk/gb/telemedicine-premature-children/ and https://norden.diva-portal.org/smash/get/diva2:1297054/FULLTEXT01.pdf.

112 See https://www.healthcaredenmark.de/news/news?id=15436; https://www.theguardian.com/world/2016/feb/02/for-pensioners-something-is-spot-on-in-the-state-of-denmark, https://norden.diva-portal.org/smash/get/diva2:1297054/FULLTEXT01.pdf and https://japan.um.dk/da/nyheder/newsdisplaypage/?newsID=7670B2AB-E33D-4892-AF63-AA3B70BA1868.

113 See https://sundhedsdatastyrelsen.dk/da/diverse/download.

114 See https://sundhedsdatastyrelsen.dk/da/diverse/download.

quality assurance of electronic communication and information in the healthcare sector in order to support excellent continuity of care.[115]

- Denmark has also established the National Sundheds-it (NSI) (National Board of Health), which is integrated into the Danish Health Data Agency. This central institution defines the framework conditions for the digitisation of the Danish healthcare system and sets standards for the creation of interoperability.[116]

Welfare Tech is a collaboration that involves (private) companies, public actors and research institutions. It aims to improve the quality and efficiency of healthcare services by employing innovative technologies for specific and customized purposes.[117]

3.4.4 Technological requirements: today and in the future

Today data volumes associated with many telemedecine and telecare solutions are not very high, and can mostly be satisfied through standard fixed, mobile and wireless broadband connections. The following figure shows suggested broadband requirements for healthcare facilities in the US as of 2010.

115 See https://www.medcom.dk/medcom-in-english/about-medcom.
116 See https://services.nsi.dk/en/OmNSIservices.
117 See https://www.healthcaredenmark.dk/media/1625194/HCD-Telehealth-white-paper-v1-single-0318.pdf.

Table 3-1: Actual Broadband Requirements[118]

Delivery Setting	Use Profile	Key Assumptions	Rec. Bandwidth (Mbps)
Solo Primary Care Practice	• Supports practice management functions (billing, scheduling, etc.), email and web browsing • Allows simultaneous use of EHR and high-quality SD video consultations • Enables non real-time image downloads • Enables remote monitoring	• Three total users per doctor for EHR and other general web-based activities • Image files (~10MB) should download in less than 30 seconds	≥ 4
Small Primary Care Practice (2–4 physicians)	• Supports practice management functions (billing, scheduling, etc.), email and web browsing • Allows simultaneous use of EHR and high-quality SD video consultations • Enables non real-time image downloads • Enables remote monitoring • Makes possible use of HD video consultations	• Three total users per doctor for EHR and other general web-based activities • Two simultaneous high-quality SD video consultations • Image files (~10MB) should download in less than 30 seconds	≥ 10
Nursing Home	• Supports facility management functions, email and web browsing • Enables remote monitoring of resident population • Allows simultaneous use of EHR and high-quality SD video consultations • Enables non real-time image downloads • Makes possible use of HD video consultations	• Five simultaneous users of general facility management and web-based activities • Two simultaneous high-quality SD video consultations • Image files (~10MB) should download in less than 30 seconds	≥ 10
Rural Health Clinic (~5 practitioners)	• Supports clinic management functions (billing, scheduling, etc.), email and web browsing • Allows simultaneous use of EHR and high-quality SD video consultations • Enables non real-time image downloads • Enables remote monitoring • Makes possible use of HD video consultations	• Three total users per practitioner for EHR and other general web-based activities • Two simultaneous high-quality SD video consultations • Image files (~10MB) should download in less than 30 seconds	≥ 10
Clinic / Large Physician Practice (5–25 physicians)	• Supports clinic management functions (billing, scheduling, etc.), email and web browsing • Enables real-time image transfer • Allows simultaneous use of EHR and high-quality SD video consultations • Enables remote monitoring • Makes possible use of HD video consultations	• Specialty services (e.g., radiology, orthopaedics, dermatology) provided • Three total users per practitioner for EHR and other general web-based activities • Large image files (~20MB) should transfer in less than 10 seconds • Five simultaneous high-quality SD video consultations	≥ 25
Hospital	• Supports hospital management functions (billing, scheduling, etc.), email and web browsing • Enables real-time image transfer • Allows simultaneous use of EHR and high-quality SD video consultations • Enables continuous remote monitoring • Makes possible use of HD video consultations	• PACS in place for real-time diagnostic imaging • Very large image files (~50MB) should transfer in less than 5 seconds • Multiple simultaneous high-quality SD video consultations	≥ 100
Academic / Large Medical Center	• Same as hospital	• Same as hospital, but scale of demands on largest medical centers drives exponential bandwidth needs	≥ 1 Gbps

Source: Health Care Broadband in America (2010).

118 See https://transition.fcc.gov/national-broadband-plan/health-care-broadband-in-america-paper.pdf.

However, upcoming e-Health applications are likely to require more advanced forms of connectivity involving increased bandwidths quality of service and/or reliability,[119] or raise policy or regulatory questions:

- **Virtual reality:** Certain medical conditions are treated with VR technology. For instance, VR solutions can help to address some symptoms associated with dementia. E.g. at nursing homes virtual images of fields, farm animals and barns are shown (via optical devices) to older people who grew up in rural areas.[120] VR is also used to treat patients with phobias.[121] Moreover Augmented Reality may have applications in surgery. Without blocking the surgeon's view, AR can indicate a patient's life sign, medical images and next surgical steps.[122] VR and AR require very low latencies and high bandwidths, typically supported with FTTH and/or 5G connections.

- **Big data processing:** The routine aggregation and transmission of patient data including scans and medical records is likely to require considerably higher and symmetric connectivity for healthcare centres than is present today.[123] Point to point fibre connections may be needed not only for hospitals but also for other healthcare centres processing and exchanging this data. Data storage and exchange also raise other regulatory questions. For example, systems are needed to ensure that patients can give consent to, and be made aware of the nature of personal data that is being stored. Legal concerns and privacy issues could also be considered.[124]

- **Artificial intelligence:** The aggregation of data in the medical field provides significant scope to use AI to analyse patterns and develop algorithms to detect specific medical conditions. One application might be the analysis of scans e.g. in the field of radiology where AI can detect patterns that are invisible to the human eye.[125] Another field is AI data analysis from medical device sensors might detect irregularities with pacemakers enabling them to be repaired/replaced more quickly. Moreover AI is used to evaluate and prioritise emergency calls. For example, by listening and evaluating an incoming call, AI can detect patients with a stroke/cardiac arrests and prompt the emergency

119 Quality of service metrics can be particularly important for the use of Health IT. Latency, reliability, packet loss and jitter can be even more important than bandwidth in the specific solutions, available at: https://transition.fcc.gov/national-broadband-plan/health-care-broadband-in-america-paper.pdf.
120 See https://www.healthline.com/health-news/heres-how-vr-can-help-people-with-dementia#What-the-study-found.
121 See https://www.npr.org/sections/13.7/2016/09/01/491991386/can-cute-virtual-reality-spiders-help-reduce-arachnophobia.
122 See https://healthcare-in-europe.com/en/news/augmented-reality-is-the-future-of-surgery.html.
123 See preliminary findings from the study for the European Commission "Smart investments for smart communities", available at: https://ec.europa.eu/digital-single-market/en/news/cef2-study-workshop-smart-investments-smart-communities.
124 See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2888022/ and https://www.physicianspractice.com/electronic-health-records-ehrs/its-time-rethink-technology-your-exam-room.
125 See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6199205/.

caller to ask additional questions for confirmation.[126] At the same time, use of AI for such critical applications could raise ethical issues and questions concerning liability, which may require regulatory guidance.

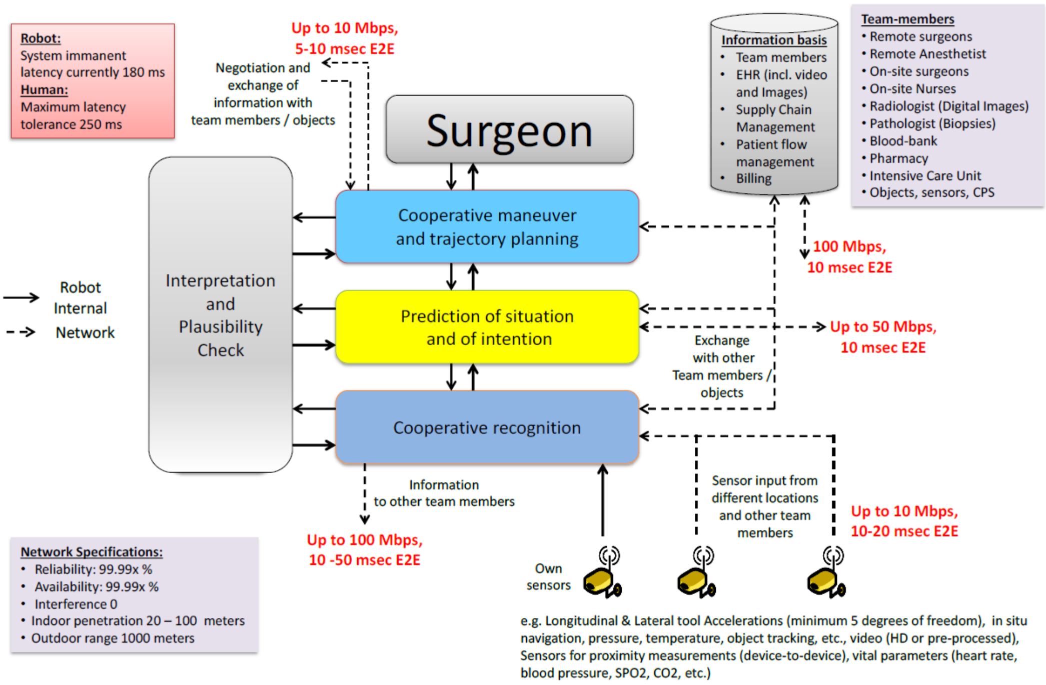
- **Drones** might be used in the future to reduce the transportation costs of the last mile. Especially in remote areas (like small islands in Denmark), drones can clearly reduce the transportation costs and deliver medication and medical equipment more quickly. However, legislation could be needed for that business case to be realized. In addition, a nation-wide 5G network (with 100% geographic coverage) would be necessary in Denmark so the drones can be controlled even in remote areas.

- **Robotics:** Currently, robotics is used in the fields of assisted living technology and with certain medical conditions, such as paralysis. In the latter, exoskeletons are used to support the rehabilitation: with smart skeletons, rehabilitation measures can be performed at the patients' home without medical staff present. The sensors of the exoskeletons can evaluate data, transmit information to medical staff (that is virtually present) and even induce emergency measures like preventing a fall. Another example is the support of robotic systems for surgical interventions. Robotic surgery is designed to overcome the limitations of existing minimally invasive surgical procedures and improve the capabilities of surgeons. Robotic surgeries require very low latency and a very low packet loss rate (especially with haptic feedbacks): Currently fiber technology is often used, but future 5G might also be an alternative.[127]

The following diagram depicts the requirements for co-ordination in a robotics assisted tele-surgery scenario, highlighting the bandwidth, latency and reliability requirements.

126 See https://www.sciencedirect.com/science/article/pii/S0300957218309754.
127 See https://arxiv.org/pdf/1803.03586.pdf.

Figure 3-7: Requirements for co-ordination in a robotics assisted tele-surgery scenario



Source: 5G PPP White Paper on Vertical Health Sector.[128]

As these examples illustrate, fibre and advanced mobile technology (LTE and future 5G) can be regarded as prerequisite for the next evolutions in innovative medical services and applications. These technologies enable very high bandwidths transmitting of large volumes of data with a very low latency. However, with some of the services/applications mentioned above, the transmission rate is not the most important performance criterion, rather a stable and reliable broadband connection is considered as paramount.

3.5 E-learning and remote working

3.5.1 What do we mean by e-learning?

E-learning refers to the use of ICT in all areas of education (pre-school, school, university and continuing vocational education). Applications and instruments are

128 See https://5g-ppp.eu/wp-content/uploads/2016/02/5G-PPP-White-Paper-on-eHealth-Vertical-Sector.pdf.

available for all conceivable disciplines and age groups, both for teachers and learners. E-learning should allow greater flexibility in learning and adaptation to specific interests and learning progress.

3.5.2 What benefits can be realized?

E-Learning can be used the improve the quality and efficiency of education, potentially achieving better results than using traditional teaching methods alone.

New technologies will also allow the use of innovative learning techniques (interactivity, simulations, virtual environments), which will enhance the digital competence of users.[129]

The cost of teaching and learning can be reduced through applications addressing a large number of participants. Another benefit is that some e-Learning applications are independent of time and space. Thus flexibility and the elimination of unnecessary and costly travel to classrooms provide further significant advantages.[130]

3.5.3 eLearning initiatives in Denmark

Denmark has implemented a wide range of digital education initiatives where new and innovative e-learning solutions and equipment can be tested.[131] New services and applications are available for both students and teachers and encompass every age group and field of study.

The aim is for students to gain digital competence and knowledge from an early age. In many communities all students are equipped with their own devices (laptops or pads) for educational purposes, and in some cities, learning devices are also provided for children in kindergarten. [132] By using individual devices, students can use learning tools that are adapted to their individual level and learning progress.[133]

Interactive services and applications involving a group of students or whole classes are very common in Denmark. Some innovative solutions include augmented reality (e.g. in game-based learning approaches) whereas others introduce tactile Internet (for example with a haptic overlay bringing together the student and teacher).

In more remote areas within Denmark, long distance learning is particularly important for tertiary as well as primary and secondary school education. Specialised services

129 See http://www.about-elearning.com/definition-of-e-learning.html.
130 See https://www.researchgate.net/publication/292907310_Impact_of_E-Learning_on_Learning_and_Realizing_Information_Society.
131 See http://www.eun.org/documents/411753/839549/Country+Report+Denmark+2017.pdf/7a0b9045-cd44-4831-875a-e42306beeefe.
132 See https://core.ac.uk/download/pdf/159629895.pdf.
133 See https://digst.dk/media/16165/ds_singlepage_uk_web.pdf and https://www.oecd.org/denmark/42033180.pdf.

and applications are now available to meet the requirements of universities and their students and teaching staff. Massive Open Online Classes (MOOC) are playing an increasing role as a wide variety of specialized classes and courses are supplied by tertiary institutions.[134]

Innovative technologies have also been used to support vocational training. For example:[135]

- **Virtual Reality:** VR can simulate difficult work scenarios that cannot be easily recreated. For instance, safety and emergency training operations can be emulated so that workers can learn how to react in specific crisis scenarios. Some solutions combine VR with immersive environments, such as training for emergency situations for power plants and other critical infrastructure as well as military operations. VR has a strong appeal in these fields due to its cost efficiency and ability to replicate challenges associated with large-scale emergencies.

- **Tactile Internet:** The immersive environments associated with the tactile Internet (including visual, audio and haptic elements) is used to train medical staff. The teacher is able to feel the learner's movements when they undertake a task involving fine motor skills, and make corrections as necessary. The learner will be able to see, hear and feel the exact movements their trainer has made, be they an engineer, pilot or surgeon. For example, surgeons can learn how to work with human bodies and the direct effects of their treatments are instantly recreated. As a result, the costs of training medical staff can be substantially reduced and the real-time interaction with a living human body can be better replicated.

- **Artificial Intelligence:** AI is implemented in many distance-learning applications where it is able to detect learning patterns and progress as well as identifying strengths and weaknesses of the student. Drawing on these inputs, the technology can then support adaptations in learning and learning methods specifically suited to the individual learner's needs and knowledge.

3.5.4 Technological requirements for eLearning

A comprehensive and high-capacity broadband infrastructure serves as an enabler for a wide range of innovative services and applications that are often referred to as "digital classrooms" or "digital schools".

134 See https://www.mooc-list.com/countries/denmark and https://moocs.ku.dk/report/UCPH_MOOC_report_2015.pdf.

135 A large part of the implemention of innovative technologies like AI and VR focuses on higher education available at: https://static1.squarespace.com/static/551b6f21e4b0b4693e02e908/t/5cdb63fe7817f7d645be1f1d/1557881861531/Nordic+%26+Baltic+XR-Edu+Report_4-2019.pdf.

Interactivity, augmented / virtual reality and tactile Internet all require high quality parameters in terms of broadband access: High bandwidth for interactive and augmented reality solutions and very low latency (less than 1 ms) for tactile internet solutions. For the latter, especially services and application including haptic interactions over a long distance necessitate quality parameters that only fiber and advanced mobile (5G) technologies can deliver.

In addition, remote students require high bandwidth symmetric connections which will enable them to engage in remote lectures and seminars.

3.5.5 What do we mean by teleworking?

The term telework is closely related to the home office and generally refers to professional activities that are not carried out at the central location of an employer, but are carried out via various communication channels either at home or on the move.

Teleworking makes the working relationship more flexible. For example, arrangements can be made that allow a large part of the working time to be used from a freely selectable location and only for important meetings to actually drive to the office. In theory, team members don't even have to be in the same country to work together and share the progress of a project.

In more times, the types of work occupation which can rely on telework has expanded. While telework was mainly limited to the classical “office work” in the beginning, increasingly employees in “industrial” sectors can benefit from teleworking. With many machines and technical equipment monitored by smart technologies, the supervising employees can remotely access and control the machines and equipment. Their physical presence at the working place is no longer necessary.

The concepts of virtual meetings are also constantly evolving. A Virtual Reality conference enables participation in a meeting from anywhere in the world. Using VR glasses you can access an interactive meeting room with numerous functions, such as using virtual boards together and creating interactive media and models in this virtual environment. The participating persons in the room are pictured as avatars.

3.5.6 What are the social and environmental benefits?

Through remote meetings, business trips (and thus environmental costs) can be significantly reduced, while at the same time the efficiency of business processes can be increased and decision-making accelerated.

Workers' benefits may range from shorter working hours, lower work-related personal expenditure and a better work-life balance, including a better ability to reconcile work with disabilities, illnesses or care responsibilities.[136] Teleworking is also associated with “increased job satisfaction, organizational commitment, and job performance and lower work stress and exhaustion.”[137]

3.5.7 Teleworking in Denmark

In 2006, although more than a quarter of the Danish employees already participated in telework to some extent, relatively few people (112,000) teleworked on a regular basis.[138] However, according to current OECD data, the share of teleworking people increased to 42% as of 2015. Denmark has in practice the highest share of teleworking among the OECD countries observed.[139]

3.5.8 Technological requirements for teleworking

Comprehensive coverage of high capacity broadband is vital to support teleworking on a widespread basis.

Applications such as high-definition videoconferencing, cloud solutions and virtual call centres are likely to increase the demand for high and symmetric bandwidths as well as high quality parameters in terms of transmission speed, latency and packet loss.[140]

3.6 Smart agriculture

3.6.1 What do we mean by “smart agriculture”?

Smart farming has the potential to support more productive and sustainable agricultural production. It involves the collection and processing of data and the use of modern technologies such as robotics, sensors and AI to support the efficient and sustainable use of resources. Blockchain may also have applications in supply chain management and tracking.

3.6.2 Examples in Denmark and elsewhere

A number of projects have been established across Europe to support the use of ICT in agriculture.

136 See https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_534548/lang--en/index.htm.
137 See https://journals.sagepub.com/doi/10.1177/1529100615593273.
138 See https://www.eurofound.europa.eu/publications/article/2008/telework-in-denmark.
139 See https://read.oecd-ilibrary.org/science-and-technology/how-s-life-in-the-digital-age/penetration-of-teleworking-2015_9789264311800-graph19-en#page2.
140 See https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_531111.pdf.

"Farm Machine Interoperability" is a Danish project that operates under the Framework of the „Internet of Food and Farm" 2020 programme. The project aims to support interoperability for machine-to-machine communication by addressing different digital standards. This should help to foster IoT applications and increase production efficiency in agriculture.[141] Expected results are, for example, a fuel consumption of -10%, farmers' ability to invest in IoT technologies of +25%, and soil fertility of +10%.[142]

Efforts in the past to agree on one common standard have not worked. A new approach is therefore to send the data that is being generated (which is mainly machine data, e.g. how much fuel is being used, how much time is needed for different processes) to a cloud and transform it. All data can talk together there. Then the data is sent back and translated again. The application relies mainly on the public mobile network.

There are also examples of how the 5G standard can be used in agriculture. In Shropshire in the United Kingdom one hectare of land is autonomously farmed by machines ("Hands Free Hectare"). There is a mission control van next to the field that autonomously manages a drone and a tractor in the field. The mission control van is currently powered by a small wind turbine, which is also located next to the field. Hands Free Hectare currently uses a combination of radios (eg 433 MHz, 2.6 GHz and 5.6 GHz) to allow the tractor and drone to work autonomously.

Meanwhile, Dutch communications provider KPN has tested a 5G application on a test farm in Valthermond, Drenthe. The test used a camera drone for potato cultivation, which provided accurate images of the field. The images were processed via a mobile connection and sent to a machine, which then applied plant protection products to the plants in real time and with very precise dosage.[143]

3.6.3 What potential benefit could smart agriculture bring to the environment and society?

The Internet of Food and Farm programme cites a range of benefits resulting from smart agriculture. *"At field level, the implementation of IoT sensors produces not only economic benefits, it also yields positive environmental impacts due to improved resource management in terms of water, fuel and pesticide inputs."*[144]

It also suggests that *"acquisition of soil, crop and climate data in production and storage of key arable and vegetable crops"* might reduce soil fertility loss by 20%, increase crop yield by 5% and reduce field analysis and time cost by -70%.[145]

141 See https://www.iof2020.eu/trials/arable/farm-machine-interoperability.
142 See https://www.iof2020.eu/trials/arable/farm-machine-interoperability.
143 See https://overons.kpn/en/news/2018/kpn-tests-5g-applications-for-precision-farming-in-drenthe.
144 See Iof (Internet of Food and Farm), 2020., available at: www.iof2020.eu.
145 See IOF2020.EU.

So on the one hand, digitalisation reduces input of resources and thus costs and potentially also prices for end consumers, and on the other hand provides for lower environmental damage.

The use of blockchain to track the whole production process could also serve to support trust and promote sustainability, as well as ensuring that goods are delivered in good conditions. For example, in the case of wine it is possible to deliver more than 80% in good shape and reduce the returns due to damage by 60%.[146] This saves resources and money while also increasing customer satisfaction.

A further possible benefit of smart farming is to use ICT to combat climate change. *"Measuring and monitoring land use change including land degradation and desertification is supported by the expanded use of new information and communication technologies (cellphone based applications, cloud-based services, ground sensors, drone imagery), use of climate services, and remotely sensed land and climate information on land resources […]."*[147]

3.6.4 Technological dependencies

As regards communication infrastructure, LTE is currently mainly used in the area (fields) and WLAN in buildings (such as stables). However, one problem is that LTE is not widely available in many rural areas. Thus, agricultural machines often incorporate three SIM cards to increase connectivity. Another problem is that LTE does not guarantee the required latency times for time-critical communications which may be essential for autonomous machines. WLAN on a farm scale therefore tends to be limited to indoor usage.

Another challenge in using LTE for farm applications is that all data is transported via provider networks, which is not necessarily the case with 5G, where data can also be kept locally.

The requirements for latency, speed and quality of service vary depending on the case. Of course, for applications in the fields, wireless solutions are required. As the number and variety of sensors increases, so does the generated data. But only a fraction of this data is critical in the sense that it needs to be sent near real time and with high reliability. Most of the data is stored in the machines and only the important information is sent to a central hub (e.g. oil filter is not working well).

Meanwhile, low latency and reliability are needed for autonomous machines, because their driving accuracy must be continuously controlled. There is a need not only to monitor the system, but also the outcomes. This may require increasing bandwidths and reliability, especially as the number of sensors or data sent through sensors increases,

146 See IOF2020.EU.
147 See IPCC (2019).

real-time demands increase, and secure connectivity is required. Low latencies are also required to act swiftly in the case of emergencies. All these requirements would be facilitated or improved by the use of 5G.

3.6.5 Potential evolution

For most applications in the field today (e.g. predictive maintenance, half-autonomous harvesting etc.), LTE is sufficient. However, as noted above, LTE availability in agricultural areas can be patchy, and more could be achieved through the implementation of 5G networks.

5G will also be essential for future applications requiring ultra-low latency such as autonomous machines.

5G is also likely to offer other advantages for farming e.g. by enabling the establishment of ad-hoc mobile networks. For example, it may not be necessary to have connectivity at all places all the time but just during times of harvesting or spraying.

Hurdles in the implementation of 5G for smart agriculture may include a lack of clarity over property rights for spectrum coverage in areas during or after their assignment. Ready access to information on existing frequency allocation on a local level could therefore be helpful.

Furthermore the current data ownership may hinder the full exploitation of potentials. As the farmers own the data, they are often not willing to give it so that data could be used for analysis or benchmarking with data from other regions or farmers. This hampers the enhancements of making processes more efficient and more effective, because there is no sufficient data base. A change in farmers` attitude is needed while respecting individual data protection concerns.

Another problem is that farmers are not sufficiently trained for the use of the new technologies. There are advisory services that should focus more on this issue.

Blockchain is another application that is little used in farming today, but could support the future evolution of the sector. *“Blockchains, as a distributed digital ledger technology which ensures transparency, traceability, and security, is showing promise for easing some global food supply chain management challenges, including the need for documentation of sustainability and the circular economy for stakeholders including governments, communities, and consumers to meet sustainability goals. Blockchain-led transformation of food supply chains is still in its early stages[….].”*[148]

148 See IPCC (2019).

4 Technological requirements and developments towards 2030

In this chapter we firstly summarise the technological requirements associated with future applications and services (section 4.1), and then consider the next stage in the evolution in mobile and fixed technologies (section 4.2).

4.1 Implications of new services for connectivity needs

The use cases described in the previous chapter have varying requirements for connectivity. Key parameters which determine the connectivity needs include:

- What are the **coverage requirements**?

  This question addresses the need for a high network reach which can be necessary to technically implement the use cases. High network coverage, may also be important to enable consumers – including those in rural areas - to realise the benefits of customer-facing applications such as e-Health and e-Education.

- Does the service or application require wireless connectivity or **mobility**?

  For some connected objects, wireless connectivity may be necessary or desirable, for example if the connected devices are likely to be deployed “in the field” in areas where fixed connections are scarce. Going further, some connected objects such as automated cars are intrinsically mobile, and therefore require fully mobile connectivity.

- What are the required **downstream/upstream transmission capacities**?

  Some of the use cases require the transmission of high data volumes in realtime and as a result require high bandwidth data rates which can only be provided with very high capacity networks.

- What are the **quality of service requirements** (low latency, availability, IT security etc.)?

  Some use cases do not depend on the transmission of high data volumes but do require networks which are able to ensure high quality of service in terms of low latency and high availability. IT security targets can imply that data transmission must take place on dedicated networks. This may mean that public mobile networks cannot be used for the implementation of certain use cases where IT security obligations or needs are paramount.

- **Is communication and/or data processing local or remote**?

  - Does the use case use the public mobile network or a private dedicated network?

    This question refers to the use of self-contained (5G) networks that are not part of a public mobile network. Such private radio networks are planned independently of capacities of public mobile radio networks. They represent a communication solution tailored to the specific requirement of the application. Similar to D2D, data transmissions in private networks do not have to be taken into account when dimensioning public networks. The only requirement here is access to the relevant frequencies.

  - Is the data transmitted between end devices (D2D) or over the public mobile network?

    This refers to the question whether the data transmission takes place via public mobile radio networks or not, i.e. whether the transmission takes place directly between two terminals located in the immediate vicinity and is therefore not routed via the access and core network of the public mobile network. With this so called Direct-to-Direct (D2D) functionality, terminal devices in the immediate vicinity are enabled to exchange data directly, whereby only the frequency used is coordinated by the base station. As a result, this means that the requirements of the D2D-transmitted data streams do not have to be met by a public mobile radio network, which affects capacity planning.

  - Is the data saved and processed at the location of the use case or in a remote cloud server?

    While within some use cases it is conceivable that data storage and processing will take place largely de-centrally at the application site, these process steps could also be outsourced to a private or public cloud. This is of great relevance for the requirements of telecommunications infrastructures, since for the latter the data has to be transferred from the application location to the cloud via a mobile and/or fixed network. Insofar as this happens, there are specific requirements for latency and subsequently for the location of the public cloud.

  - What are the **energy requirements** of the device and application?

    Some applications are likely to require a power source to be available alongside connectivity. Other applications are associated with devices that must be autonomous and need to operate at a low power to extend the device’s lifetime.

A common theme applying to several of the use cases discussed in the previous chapter is the need for fast broadband with low latency and high reliability. Widespread coverage with wireless or fully mobile technologies is also required in some cases. The technological requirements of the major use cases are discussed below and summarised in a table.

4.1.1 Smart energy

The implementation of smart grids and smart meters will require distribution network operators and/or metering point operators to establish a large number of new functionalities in their respective infrastructures via wired or wireless communication infrastructures. In addition, electricity consumers must be equipped with modern measuring equipment and intelligent measuring systems (Smart Meter Gateways).

As explained in chapter 3.1, low latency and reliability are essential in applications which support processes within the smart grid. In addition, for monitoring tasks where data is needed to stabilize the grid and prevent it from collapsing, quality parameters are of crucial importance. Ericsson estimates the required latency for teleprotection in smart grids to be 8 ms with a reliability of 99,9%.[149] The required latency and QoS parameters have implications for the choice of technology and usually is ensured by opting for a dedicated ICT infrastructure. In the future 5G network slices could also be an option which fulfills the requirements for smart grids.

While in the case of metering sytems used at the premises of electricity consumers, the quality of service parameters may not be that relevant, the network reach plays an important role as the ICT infrastructure must be available to all customer locations.

Applications to monitor and support the efficient generation of electricity e.g. via wind turbines may also require connectivity to fixed, but remote locations.

4.1.2 Smart cities

In the context of use cases for Smart Cities (see chapter 3.2) the implementation of IoT applications requires high coverage and depending on the use case high bandwidths as well as low latencies[150]. Wireless connectivity is also needed for some sensors. The transmission of high definition videos and/or the use of AI implies high bandwidth requirements, for example when video-driven control systems remotely combine and process data from cameras to predict and respond to traffic flows. As discussed in the use case, more advanced smart city applications will require fibre to be deployed in the

149 See Ericsson (2017).5G Systems – Enabling the transformation of industry and society.White Paper.
150 See Fraunhofer FOKUS ():Public IoT – Das Internet der Dinge im öffentlich Raum, available at: https://cdn0.scrvt.com/fokus/36c5e4909a46af02/982714594f78/WP_Public_Internet_of_Things_web.pdf.

streets and connected to street furniture such as lamp posts, traffic lights and bus shelters, with associated provision for 5G antennas.

4.1.3 Intelligent transport

The sharing of realtime information about the existing traffic flow situation and in the context of public transport implies the transmission of data between vehicles, traffic infrastructure (such as traffic lights, streets, parking spaces etc.) and networks (see also chapter 3.3).

The data transmission e.g. between traffic lights, public transport infrastructure and parking systems to provide realtime information on the traffic situation, available parking space and to optimise traffic flows accordingly requires a high network coverage with high capacity networks which enable the use of artifical intelligence.[151]

For autonomous vehicles ultra-reliable and low latency communication is needed. Autonomous vehicles (automated driving) includes the following transmission categories:

- Vehicle-to-vehicle (V2V)
- Vehicle-to-Network (V2N)
- Vehicle-to-Infrastructure (V2I)

3G and 4G mobile networks are far from being able to transmit the data that an autonomous vehicle is estimated to produce in the future (4 terabytes in 90 minutes)[152]. This is unlikely to change in the medium term. Furthermore, it should be considered that manufacturers produce their vehicles for the global market and must therefore also take into account that there are countries with insufficient mobile coverage.

However, there are technical solutions to deal with this issue:

- V2V and V2I communication takes place based on D2D transmission so that it is not relevant for the dimensioning of the public mobile network. The data generated by the sensors in the car is processed in the car and only relevant delta-information is transmitted over the mobile network.
- The actual planning of the driving will take place in the vehicle itself and not through a centralised driving platform, which would be located in an edge cloud. On the one hand, the latency requirements of a centralised driving platform outside the vehicle would be very high and would mean that a large number of

151 Stokab interview (2019).
152 See Intel (2017): For Self-Driving Cars, There's Big Meaning Behind One Big Number: 4 Terabytes; https://newsroom.intel.com/editorials/self-driving-cars-big-meaning-behind-one-number-4-terabytes/.

edge clouds are needed. Further the the safety requirements for the mobile network would be hard to realise. Redundancies and network hardening (e.g. battery buffering for transmitters that ensure supply when the low-voltage network is disconnected) would have to be implemented in the mobile network in order to achieve systemic availability far above that of today's mobile networks.

- In situations in which the autopilot is not able drive safely due to atypical weather, traffic or road conditions, a teleoperator should be switched on until the autopilot is able to take over the driving independently again. Studies assume that by 2025 highly automated vehicles will not be able to cope with all road traffic situations. In this case, it will be necessary to transmit the video and sensor data from the vehicle to the teleoperator via the mobile network. While the downstream requirement is low, upstream data rates of at least 10-20 Mbit/s per vehicle must be reliably guaranteed.[153] The vehicle is controlled by the teleoperator at low speeds, so that the latency requirements will be relevant, but not in the range of less than 5 ms. It is to be expected that the teleoperator will rarely have to intervene and that the requirements will therefore remain moderate. One reason for this is that the penetration of autonomous vehicles will be low during the introductory phase and therefore only a few vehicles will have to be controlled. On the other hand, autonomous driving is improved over time, so that fewer situations arise per vehicle in which a teleoperator has to be connected. Nevertheless, the teleoperator application requires full mobile network coverage along traffic routes.[154]

It is possible that the technical solutions described are an interim solution on the path to central driving platforms in Edge-Clouds and that the connectivity requiremnets for autonomous vehicles will increase significantly in the long term. For the horizon of this study it seems more realistic that use cases related to autonomous vehicles refer to live-maps updates, firmware-upgrades and teleoperator guided autonomous driving. These use cases can be realized with moderate bandwidths and latency requirements along traffic routes of 10-20 Mbps per vehicle and low latency of 5 ms or less. The availability and reliability of networks however has to be very high and should achieve 99,9%.[155]

153 See Fraunhofer FOKUS (2016): Netzinfrastrukturen für die Gigabitgesellschaft, available at: https://cdn0.scrvt.com/fokus/5468ae83a4460bd2/65e3f4ee76ad/Gigabit-Studie_komplett_final_einzelseiten.pdf.

154 See Fraunhofer FOKUS (2016): Netzinfrastrukturen für die Gigabitgesellschaft, available at: https://cdn0.scrvt.com/fokus/5468ae83a4460bd2/65e3f4ee76ad/Gigabit-Studie_komplett_final_einzelseiten.pdf; DotEcon/Axon (2018): Study on Implications of 5G Deployment on Future Business Models, Studie für BEREC, BoR (18) 23 and 5G PPP (2015): 5G Automotive Vision.

155 See Ericsson (2017).5G Systems – Enabling the transformation of industry and society.White Paper.

4.1.4 Smart healthcare and homecare

As mentioned above in chapter 3.4, currently data volumes associated with telemedecine are not very high, and can mostly be satisfied through standard fixed, mobile and wireless broadband connections. However, upcoming e-Health applications which rely on virtual reality, tactile internet[156] and big data may require more advanced forms of connectivity. To fully benefit from future smart healthcare, the connectivity needs also will have to be met in rural areas.

The tactile Internet for example, holds great potential especially for smart healthcare and can for example enable the performance of a physiotherapeutic treatment on a patient living in a remote area. However, to obtain a reliable diagnosis, the data signals being transmitted over the network have to be reliable, accurate and in real-time. The network must be capable of transmitting large volumes of data almost instantaneously. Virtual and augmented reality require a high-resolution feedback system in real time to provide a seamless user experience. Ericsson suggests that a latency of less than one millisecond and a reliability of nearly 100% is required.[157] The use of virtual reality also requires low latencies and bandwidths of potentially more than 200 Mbit/s.[158] Today's VR systems require 100-to-200 Mbit/s to provide only a one-way immersive experience.[159]

4.1.5 E-Learning and remote working

A comprehensive and high-capacity broadband infrastructure serves as an enabler for a wide range of innovative services and applications that are often referred to as “digital classrooms” or “digital schools”. To avoid a rural/urban devide the network reach of high-capacity broadband infrastructure play an important role.

Interactivity, augmented / virtual reality and tactile internet all require high bandwidth for interactive and augmented reality solutions.

As mentioned before in chapter 3.5.4, remote students require high bandwidth symmetric connections which will enable them to engage in remote lectures and seminars.

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156 The term tactile Internet refers to a network system which is characterised by very low latency and ultra-high reliability, enabling reaction times similar of those of humans. Maier, M. et al. (2016), "The Tactile Internet: Vision, Recent Progress, and Open Challenges", IEEE Communications Magazine, 54(5), 138-145, p.139.

157 See Ericsson (2017).5G Systems – Enabling the transformation of industry and society.White Paper, p.4.

158 See Wireless World Research Forum (2016). Outlook: Visions and research directions for the Wireless World – A New Generation of e-Health Systems Powered by 5G. White Paper, p.19. ITU (2014), "The Tactile Internet", ITU-T Technology Watch Report, Geneva, p.6.

159 See Bastug, E. et al. (2017), "Towards Interconnected Virtual Reality: Opportunities, Challenges and Enablers", IEEE Communications Magazine, 55 (6), 110-117, p.114.

4.1.6 Smart agriculture

The Farm Management System (FMS) is at the heart of smart farming applications. It combines and evaluates (image) data from the field (e.g. soil condition, temperature, humidity, pest infestation) and from external data sources such as weather services or seed data from agricultural companies. Smart farming not only requires the transmission of data to and from the farm mangement system to retrieve data and video streams from autonomous vehicles or drones. It also requires networking between vehicles in the field in the context of autonomous agricultural machines to coordinate the autonomous driving between several vehicles (D2D).[160]

The requirements for smart agriculture use cases to a great extent depend on the cloud solution chosen to gather data as well as on the need for realtime data transmission:

Some applications with real-time requirements, such as weed detection and plant-specific treatment based on it, require the use of hardware with high computing and storage capacity. It is conceivable that this is not stored in the FMS, but carried into the field on agricultural vehicles. Such a solution would have the consequence that the transmission of image material over the mobile network would not be necessary and thus the requirements for mobile radio networks would decrease accordingly.

Data offloading for non realtime critical data reduces the bandwidth requirements. The data is "collected" in the field from vehicles or drones and transmitted to the FMS at the farm via WLAN and the broadband connection available there (offloading).

Despite these options to reduce connectivity requirements for mobile networks in the case of smart farming, it is foreseeable that the full potential of smart agriculture use cases can only be exploited with mobile network coverage. The extent to which the use cases impose capacity and real-time requirements depends to a large extent on the two options to reduce requirements which have been discussed. Although it is not possible to make reliable statements about the future technical implementation of the use cases, there are indications that some applications are dependent on a 5G-supported real-time connection to the FMS. Direct data transmission and processing in the FMS makes it possible to reduce duplication of hardware in agricultural machines and can thus significantly reduce the total cost of ownership. A second aspect is the combination of different data. The real-time availability of all data from sensors and agricultural equipment in the FMS can enable the development of new services and business models and thus generate additional potential benefits.

160 See Sörries, B,; Queder, F.; Neu, W,; Elbanna, A.; Ockenfels, M.; Plückebaum, T.; Nett, L. (2018): 5G-Konnektivität in der Gesamtarchitektur von Gigabitnetzen,study for the German Ministry of Transport and Infrastructure (confidential).

4.1.7 Overview of connectivity requirements

Table 4-1: Overview of connectivity requirements

Application category	Application	Bandwidth	Coverage/network reach	Relevance of wireless connectivity and/or mobility	QoS (low latency, high availability etc.)	Relevance of dedicated networks/IT security	Energy requirements
Smart Energy	Smart grids	0	++ to implement use cases	5G allows for edge clouds	Latency ≤ 8 ms reliability nearly 100%	++	++
	Smart meters	0	++ to implement use cases	Fixed and wireless technologies can be used for smart metering	0		
	Monitoring and support of efficient electricity generation	0	Connectivity to remote locations	Fixed or wireless connectivity			++
Smart Cities	Smart city using AI, sharing of realtime data between traffic lights, public transport infrastructure and parking systems	++ Smart city: 300 Mbps DL, 60 Mbps UL	++ to implement use cases	wireless networks and mobility often required, 5G or very high capacity fixed networks for AI in smart cities fibre in the road and in each lamppost	++	++	High data volumes generate high energy requirements, 5G reduces energy requirements
	sensor based without high definition video and AI	0	++	wireless connectivity and depending on the use case mobility			Limited power to prolong battery lifetime
Intelligent transport	Video driven traffic light control systems	++	++	Fixed or wireless connectivity fibre networks recommended			
	Autonomous driving (vehicle-to-infrastructure communication)	Upstream 10-20 Mbps per vehicle	Full mobile network coverage along traffic routes	Mobility required, 5G for edge cloud	Latency ≤ 5 ms reliability nearly 100%	++	
	Sensor based applications	0	Fixed or wireless	Narrowband IoT or LORA	Limited packet loss		Limited power to prolong battery lifetime
Smart healthcare and homecare	Remote consultations with video applications	++	++ To avoid rural/urban divide and to profit from environmental benefits	fibre or 5G	For real-time transmission low latency and reliability required	++	
	Remote hospital appointments using video applications	++	Connectivity to remote areas depending on location of hospitals	fibre or 5G	Limited packet loss and low latency	++	
	Smart healthcare using robotics, virtual reality, Big Data,, AI	++ ≥200 Mbps (one way immersive experience)	++ To avoid rural/urban divide and to profit from environmental benefits	fibre or 5G	++ latency ≤ 1 ms realiability nearly 100%	++	
	Remote monitoring with sensors	0	++	Fixed or wireless connectivity	Low latency and reliability	++	
	Remote surgery and examination	++	++		Down to 1 ms Realiability nearly 100%	++	
	Electronic health records	++	0	VHC or 5G	0	++	High data volumes generate high energy consumption
E-learning	Interactive innovative technologies using VR, tactile internet and/or AI	++ symmetric bandwidths	++ To avoid rural/urban divide	fibre or 5G	++ latency ≤ 1 ms, low jitter, high reliability	0	
Remote working	Home office, virtual meetings, cloud usage	++	++	VHC or 5G	+	++	
Smart agriculture	Sensor based without videos	0	++ to implement use cases	wireless networks required	Depends on use case, low latency e.g. for emergencies		Limited power to prolong battery lifetime
	Autonomous machines	0	++	Wireless connectivity and mobility required	High reliability, low latency		
	Sensor based real-time transmissions involving AI and/or Big Data, transmission of high definition videos (e.g. from drones to identify pests)	++	++	Wireless connectivity	Low latency and limited packet loss, reliability		High data volumes generates high energy consumption
Edge Computing	edge clouds to provide closer and faster link between data centres and customers	++ 1 Gbps		wireless connectivity	<20 ms latency	++	

Note: **O** = Low specific importance
+ = High importance
++ = Very high importance

VHC networks include FTTH, DOCSIS 3.1 and Fixed Wireless Access solutions which allow for very high bandwidth transmissions.

Sources: European Commission (2016): Commission Staff working document accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Connectivity for a COmpetitive Digital Single Market - Towards a European Gigabit Society SWD (2016) 300 final, available at: https://ec.europa.eu/digital-single-market/en/news/communication-connectivity-competitive-digital-single-market-towards-european-gigabit-society;
Sörries, B,; Queder, F.; Neu, W,; Elbanna, A.; Ockenfels, M.; Plückebaum, T.; Nett, L. (2018): 5G-Konnektivität in der Gesamtarchitektur von Gigabitnetzen,study for the German Ministry of Transport and Infrastructure (confidential);
Intel (2017): For Self-Driving Cars, There's Big Meaning Behind One Big Number: 4 Terabytes, available at: https://newsroom.intel.com/editorials/self-driving-cars-big-meaning-behind-one-number-4-terabytes/;
Ericsson (2017).5G Systems – Enabling the transformation of industry and society.White Paper;
DotEcon/Axon (2018): Study on Implications of 5G Deployment on Future Business Models, study for BEREC, BoR (18) 23;
5G PPP (2015): 5G Automotive Vision; Interview with Stokab (2019); Interview with Cisco (2019); Interview with Copenhagen labs (2019)
Huawei; Roland berger (2019): Position Paper 5G Applications, available at: https://www-file.huawei.com/-/media/CORPORATE/PDF/public-policy/Position_paper_5G_Applications.pdf.

Bandwidth and quality requirements for households and businesses are likely to continue to expand, with increasing requirements for symmetric connectivity[161].

4.2 Upcoming technological developments

Today's smart applications have been supported by increased availability of reliable connectivity alongside developments in wireless technologies. However, mobile and fixed networks were not designed with these applications in mind, and in many cases new services and applications have evolved around the limitations of existing technologies. For example, the existing mobile radio networks today are tailored around demand from smartphones, tablets and laptops and dimensioned in such a way that an exogenously defined amount of data can be transmitted at moderate latency according to the best-effort principle. As a result, the coverage and capacity of mobile radio networks currently depends primarily on the respective local density of the private and business data demand that a provider wants to address. Similarly, very high capacity fixed infrastructure has been designed to serve business and residential premises, with less attention to the connectivity requirements of roads, objects or remote antennas.

The applications of the future will require enhanced capabilities of wireline and wireless communication networks and in several cases, greater reach. New applications making

161 Residential fixed broadband demand already is growing and is expected to continue increase in the future driven by the bandwidth requirements of applications such as 4k/8k TV, VPN, cloud and gaming. Also, augmented and virtual reality are becoming more and more important for these applications. These developments require high levels of quality of service including low latency. With reference to future demand for fixed broadband services the DEA has commissioned a separate report.

processes in industry more efficient and productive need higher bandwidth, resilience and determined QoS, currently not provided by wireless networks.

4.2.1 Evolving mobile technologies

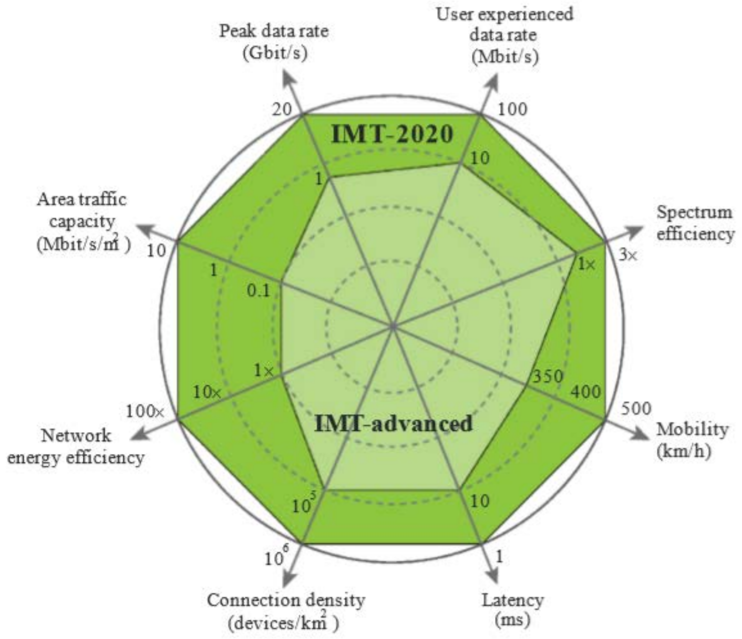
Thus far, a new mobile communications technology has been introduced about every ten years. 4G has been introduced since 2009 and the rollout of 5G has recently started slowly.[162] The Danish Energy Agency awarded 700, 900 and 2,300 MHz bands in April 2019 and raised in total €296 million. Aditionally, 5G test trials by TDC, Huawei and Telia have been started using 100 MHz in the 3.5 GHz band.[163]

The capabilities of 4.5G (IMT-advanced) compared to 5G (IMT-2020) are shown in the following figure. It is clear that 5G will achieve considerable advances on currently deployed technologies, for instance in terms of peak data rate (Mbit/s), network energy efficiency and latency (ms). However, not all these capabilities are available simultaneously.

162 See Cave, M., & Bourreau, M. (2017). Towards the successful deployment of 5G in Europe: What are the necessary policy and regulatory.

163 See European 5G Observatory (2019). Major European 5G Trials and Pilots, available at: https://5gobservatory.eu/5g-trial/major-european-5g-trials-and-pilots/.

Figure 4-1: Enhancement of key capabilities from IMT-Advanced to IMT-2020



Source: ITU.[164]

To enable all of the capabilities 5G is promising, several key technologies are required. One important aspect, which can be relevant for all communications networks, is the virtualization and software based approach of operating networks. The key technologies in this context are Software Defined Networking (SDN) and Network Functions Virtualization (NFV), which are complementary but co-dependent. SDN focuses on managing the network dynamically and enables neworks-as-a-service. NFV means the virtualization of resources and providing network functions for higher-layer network services.[165]

SDN and NFV are likely to be instrumental in the development and roll-out of innovative services, applications, and products as well as in facilitating major trends with substantial economic and societal impact. Virtualization also offers a great cost-saving potential as regards operating and using networks. For example, Virtual Network Platform as a Sevice (VNPaaS) is expected to achieve savings up to 7.1% in total telco costs for companies. Savings enabled by the virtualization of mobile core networks may range from 3.7% to 5% of the total costs of telecommunication providers. The overall benefits of these technologies are not limited to cost savings, but also provide more

164 See ITU (n.d.). IMT-2020 BACKGROUND, available at: https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/060R1e.pdf.

165 See ETSI (2019). Network Functions Virtualisation (NFV), available at: https://www.etsi.org/technologies/nfv.

flexibility and automisation of operating networks. An open question is who operates the data centers necessary for the increasing virtualization of network functions.

Another key technology often mentioned in the context of 5G is Network Slicing. According to the ITU (2018) it *"permits a physical network to be separated into multiple virtual networks (logical segments) that can support different RANs or several types of services for certain customer segments, greatly reducing network construction costs by using communication channels more efficiently."*[166] The key benefit of network slicing is that it enables a multitude of requirements to be fulfilled according to demand. The GSMA expects that Network Slicing will enable operators to generate $300 billion in revenue by 2025.

Most of the use cases already presented, such as intelligent mobility, smart cities or energy have the potential to benefit from Network Slicing.[167] To support various vertical industries, it will be essential to take into account their specific requirements in the context of Network Slicing.

The key word "real-time" communication is often referred to one essential capability of 5G. This means, the latency respectively reaction time is very low, down to one millisecond. A multitude of use cases ranging from autonomous vehicles to smart health to smart agriculture have identified a need for short latency times. In order to achive these latencies, (mobile) edge computing (MEC) is often assigned a significant role. MEC means the use of smallest data centers in the network, which can process data directly at the location of the application and forward it quickly. As a result, it is not required to run longer distances through the entire network and latency can be significantly reduced.[168]

Nevertheless, it has to be taken into account that edge computing is associated with a high level of infrastructure costs. Therefore, experts question whether widespread implementation is likely in the years to come and indeed whether the ultra short latencies for many applications are really needed. Due to high costs, mobile edge cloud computing needs a strong and stable business case which does not exist yet. The business cases heaviliy depends on the willingness to pay of users.

Although 5G is still in its infancy and the rollout is far from complete, the next generation 6G is already being researched. Given the development of previous mobile communictions generations, it is expected that 6G will be introduced in 2030. The university of Oulu (Finland) has founded the initiative "6G Flagship" and describes the vision as follows:

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166 See ITU (n.d.). IMT-2020 BACKGROUND, available at: https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/060R1e.pdf.

167 See GSMA (2018). Network Slicing Use Case Requirements, available at: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/07/Network-Slicing-Use-Case-Requirements-fixed.pdf.

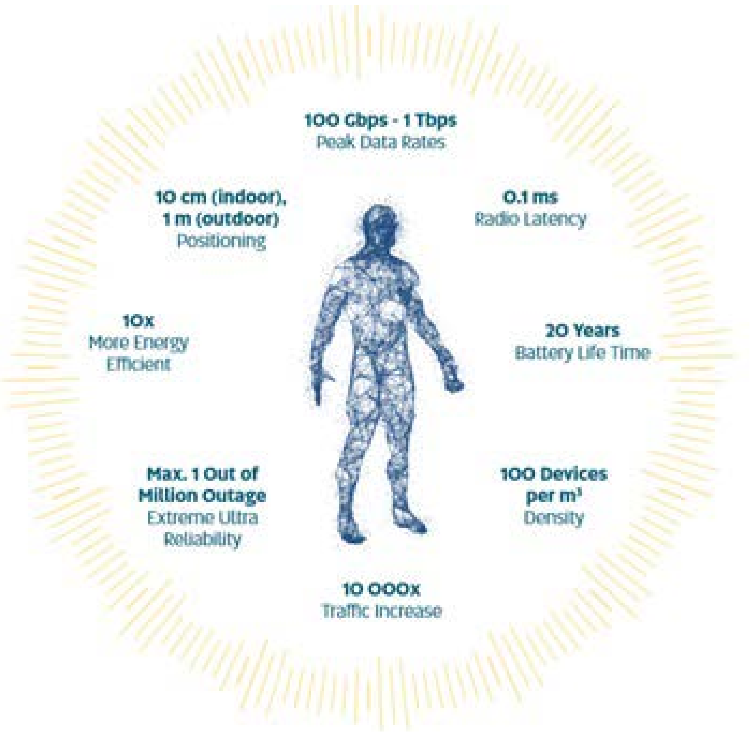
168 See Luber, M. & Donner, A. (2019). Was ist Multi Access Edge Computing (MEC)?, available at: https://www.ip-insider.de/was-ist-multi-access-edge-computing-mec-a-830163/.

"6G will emerge around 2030 to satisfy expectations not met with 5G, as well as, the new ones fusing AI inspired applications in every field of society with ubiquitous wireless connectivity."[169]

If this vision translates into the 6G standard, it implies that the architecture of mobile networks will not change, but rather that 6G will most likely provide a new level of quality of services (e.g. determined latency).

After the first 6G Wireless Summit in March 2019, a white paper was published, which includes the key performance indicators (KPIs). Many of them are already relevant for 5G, but need to be expanded for 6G. The drivers named for 6G are sustainability, society, productivity and technology.[170]

Figure 4-2: Key Performance Indicators 6G



Source: 6G Flagship (2019).

With these capabilities, 6G will focus even more on society and lives of people than with 5G to address the challenges of the future (e.g. climate change, urbanization etc.). That is why the communication infrastructure will be more complex in terms of flexibility of

169 See Pouttu, A. (2018). 6Genesis – Taking the first steps towards 6G, available at: http://cscn2018.ieee-cscn.org/files/2018/11/AriPouttu.pdf.
170 See 6G Flagship (2019) Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence, available at: http://jultika.oulu.fi/files/isbn9789526223544.pdf.

networks, differentiated service quality or the increasing role of data. To achieve the advantages of 6G, it is necessary to rely on a high level of automation and cloud technology in order to avoid exorbitant operating costs.[171]

The Chinese vendor Huawei recently announced that it had started reseach on 6G at its research facility in Ottowa. Nevertheless, 6G is at an early phase and commercialization is ten years away.[172]

In order to enable the rollout of 5G and in the future 6G networks, a fibre connection is essential, e.g. to connect the RAN with the core network. The advantages of fibre are related to its longevity, high capacity and reliability.[173] A fibre connection is seen as a central requirement for the 5G technology. According to Cisco, copper-based networks will not be able to support the exponential growth in traffic. The FTTH Council has conducted a study on the value of convergence between 5G and FTTH. According to their estimates, the cost savings due to convergence for a fibre 5G network is between 65% and 96%. Moreover, the additional investments for enabling a full fibre network 5G ready are between 0,4% to 7.2%.[174]

Allthough the attention is focused strongly on 5G and therefore mobile networks, Cisco VNI predicts that by 2022 there will still be more traffic offloaded to Wi-Fi than retained on mobile networks.[175] Comparable to the mobile network generations (1G to 6G), the newest evolution of Wi-Fi standards is called “Wi-Fi 6” (802.11ax). Compared to Wi-Fi 5, it promises to increase the average user throughput more than four times and the number of concurrent users by more than three times.[176] Since Wi-Fi 6 can supply more devices at the same time, it could also become relevant for IoT applications. Allthough Wi-Fi 6 has just started in 2019 and the rollout will take place over the next years, plans for Wi-Fi 7 have been already published. It is expected to support up to 30 Gbp/s of throughput and is likely to arrive in 2024.[177]

For the upcoming technological developments it will be crucial to achieve very high reliability and safety in networks. One reason for this is the development towards a cashless society, which can be observed above all in the Scandinavian countries. The

171 See 6G Flagship (2019) Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence, available at: http://jultika.oulu.fi/files/isbn9789526223544.pdf.

172 See Tomás, J. (2019). Huawei started research on 6G ‘a long time ago’, CEO says, available at: https://www.rcrwireless.com/20190930/5g/huawei-started-research-6g-long-time-ago-ceo-says.

173 See ITU (2018). Setting the Scene for 5G: Opportunities & Challenges, available at: https://www.itu.int/en/ITU-D/Documents/ITU_5G_REPORT-2018.pdf.

174 See Meersman, R. (2019). 5G and FTTH: The Value of Convergence, available at: https://www.ftthcouncil.eu/documents/COM-190313-FibreFor5G-ConvergenceStudy-Presentation-RafMeersman%20-%20v4%20-%20publish.pdf.

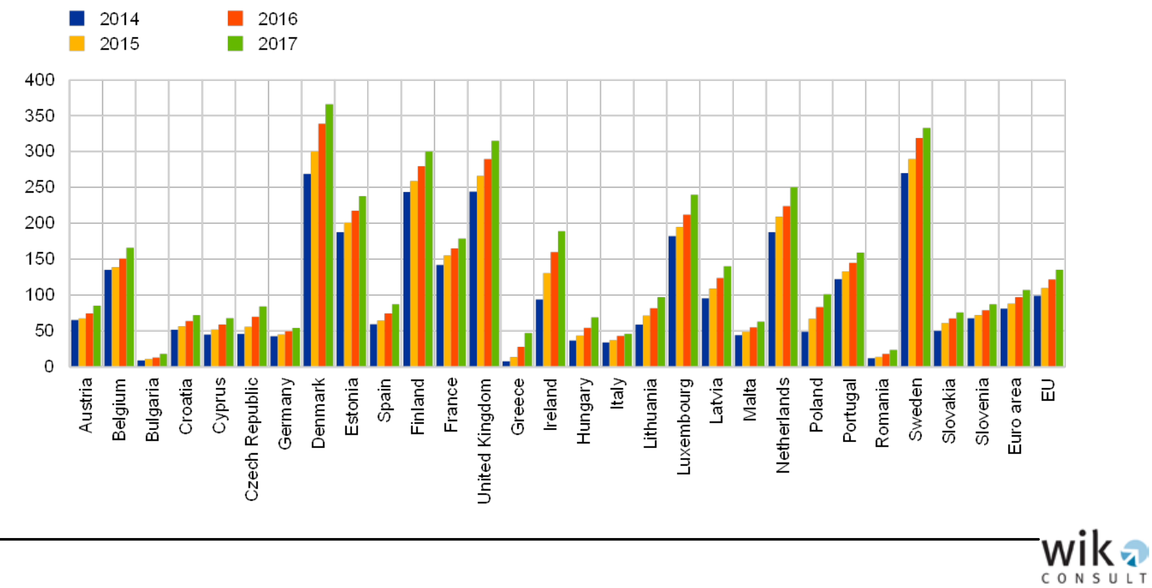
175 See Cisco (2019). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022, available at: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.pdf.

176 See Huawei (2019). Huawei Wi-Fi 6 (802.11ax) Technology WhitePaper, available at: https://e.huawei.com/en/material/networking/wlan/f3ae84efd98d440eb457b4caf405b509.

177 See Shankland, S. (2019). Wi-Fi 6 is barely here, but Wi-Fi 7 is already on the way, available at: https://www.cnet.com/news/wi-fi-6-is-barely-here-but-wi-fi-7-is-already-on-the-way/.

number of card transactions per inhabitant is highest in Denmark with more than 350 per year. By comparison, the EU average is below 150 transactions per inhabitant.

Figure 4-3: Number of card payments per inhabitant (2014-2017)



Source: ECB (2019).[178]

Sweden might be the first cashless society in 2023. Today cash accounts for less than 1% of total transactions in Sweden.[179] These developments have a lot of advantages, but for a cashless society it will be especially important that transactions are secure.

Internet of Things (IoT) applications will play a significant role for various use cases in the future. Particulary due to the extremely high number of objects to be connected, energy efficiency is considered to be of great importance of many applications. Low energy consumption, low sensor costs, simple installation and the support of many devices play a decisive role in networking a large number of objects. Therefore, the development of Mobile IoT is crucial to address this requirements. Mobile IoT includes low power wide area (LPWA) technologies, which has been standardised by the 3GPP as a secure operator IoT Network. Two complementary technologies can be distinguished. One is Long-Term Evolution for Machines (LTE-M) and the other is Narrowband Internet of Things (NB-IoT).[180]

178 See ECB (2019). Card payments in Europe – current landscape and future prospects: a Eurosystem perspective, available at: https://www.ecb.europa.eu/pub/pubbydate/2019/html/ecb.cardpaymentsineu_currentlandscapeandfutureprospects201904~30d4de2fc4.en.html#toc1.

179 See Fourtané, S. (2019). Sweden: How to Live in the World's First Cashless Society, available at: https://interestingengineering.com/sweden-how-to-live-in-the-worlds-first-cashless-society.

180 See https://www.gsma.com/iot/mobile-iot/.

For the success of Mobile IoT the coordination with the 5G technology is also important. Therefore, when standardizing NB-IoT and LTE-M, 5G specifications are also taken into account to ensure coexistence. Mobile IoT promises to enable key applications such as smart metering to reduce energy consumption and smart environmental monitoring to reduce emissions in cities in the 5G future.[181]

LPWA network technologies will become more and more important in the future. According to a study by Machina Research[182], over 3 billion LPWA M2M conections are predicted to exist by 2023. Furthermore 56% of active LPWA connections are expected to be in licenced spectrum by 2022. The increasing importance of LPWA technology is also reflected in the expected revenue. According to a forecast by Analysis Mason, global revenue will rise to 5 billion us dollars by 2025.[183]

In order to use the potential of Mobile IoT solutions, rollout is crucial. So far 123 Mobile Commercial IoT networks have been launched worldwide (October 2019). Of these, 34 are LTE-M and 89 NB-IoT networks. In Denmark, three operators are active on the market. TDC and Telia have launched commercial NB-IoT networks, Telenor both LTE-M and NB-IoT networks.[184]

4.2.2 Evolutions in fixed connectivity

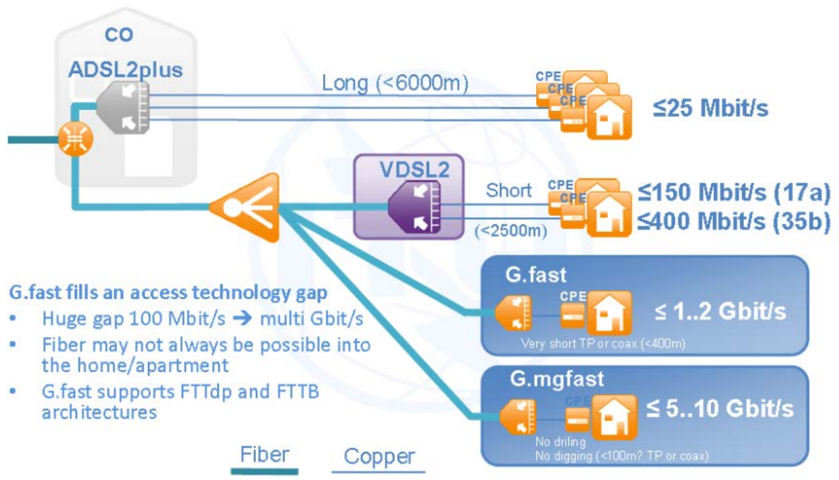
Developments in fixed connectivity over the coming decade, are likely to relate to the expanding deployment of FTTH and the development of optical equipment which serve to increase the bandwidth available via FTTH, and open up potential new unbundling opportunities. The capabilities of fixed wireless access are also likely to be enhanced.

For operators relying on traditional twisted pairs, the next stage beyond FTTC/VDSL is G.fast. In G.fast deployments, fibre in the access network is extended to the distribution point (FttDp) close to the homes or inside larger multi-dwelling units (MDUs). The fibre architecture used for the backhaul can be GPON, XG-PON, EPON and 10G-EPON. A G.fast DSLAM today aggregates up to 48 copper access lines, with interference prevention through the use of vectoring, and can achieve bandwidths of up to 1.2Gbit/s. An advantage of this technology for owners of legacy infrastructure is that it avoids the need to replace in-building wiring, and thus can be more readily accepted by end-users. A further evolution in this technology towards G.mgfast can be expected within the next

181 See GSMA (2018). Mobile IoT in the 5G Future, available at: https://www.gsma.com/iot/wp-content/uploads/2018/05/GSMA-5G-Mobile-IoT.pdf.
182 See https://machinaresearch.com/news/with-3-billion-connections-lpwa-will-dominate-wide-area-wireless-connectivity-for-m2m-by-2023/.
183 See https://www.gsma.com/iot/mobile-iot/.
184 See https://www.gsma.com/iot/mobile-iot-commercial-launches/.

3 years, with a target bandwidth of between 5-10Gbit/s.[185] Trials of this technology have taken place in the UK.[186]

Figure 4-4: Overview of DSL access solutions



Source: ADTRAN "G.FAST enabling the Gigabit Society".[187]

At the same time, coax-based technologies are also evolving towards multi-gigabit bandwidths. The 2013 DOCSIS 3.1 specification provides for 10 Gbit/s downstream and 1-2 Gbit/s upstream, while the 10/10 Gbit/s full symmetrical specification was released in 2019 as DOCSIS 4.0. Increased bandwidths over the cable network are supported by a range of measures including improvements in encoding, moving low-usage TV challenges into on-demand mode, and moving fibre deeper into the access network to the group amplifier and ultimately to the last amplifier (so-called deep fibre). In this sense, cable-deployments are also moving towards FTTB/FTTdp.

Evolutions in the active equipment used to drive fibre optic networks are also increasing capabilities for FTTP. For point to point architectures, 100 Gbit/s Ethernet interfaces are state of the art today and upgrades to 400 Gbit/s are under development, thus enabling data rates per end customer up to this level individually and on demand.

For point to multi-point architectures, 10Gbit/s EPON symmetric was standardised some time ago,[188] and initiatives are under way to adopt standards for 25Gbit/s and 50Gbit/s.[189]

185 See https://gfastnews.com/article-list/5-10-gigabit-g-fast-424-and-848-mhz.
186 See https://www.ispreview.co.uk/index.php/2017/08/bt-adtran-reasearch-g-mgfast-10gbps-broadband-copper-lines.html.
187 https://portal.adtran.com/web/fileDownload/doc/33601.

Evolutions in technology are also serving to increase quality of service capabilities (including latency) available via shared “mass-market” technologies including DOCSIS and FTTH PON. These improvements, alongside the potential for next generation DOCSIS to deliver symmetric bandwidths, may make these technologies more attractive for some types of business use. However, the shared nature of these solutions is likely to limit their suitability for the most demanding business applications and backhaul. A summary of the capabilities of these different technologies including relative QoS characteristics is available in the 2018 WIK report “Benefits of Ultrafast Broadband”.[190]

A development that has occurred in the context of PON is the use of wavelength division multiplexing (WDM), whereby multiple colours of light are used to create multiple “point to point” channels on a single fibre. NG-PON2 is a first specification of this kind. A combination of TDM-PON and WDM-PON is also foreseen running at 100 Gbit/s. Since each of the WDM wavelengths can be individually coupled into a fibre, these wavelengths can be used for different purposes e.g. for enterprise services, mobile backhaul and fronthaul and/or by different operators in the form of wavelength unbundling.[191]

Developments in SDN/NFV on fixed networks are also likely to improve the degree to which access seekers can differentiate their offers on the basis of wholesale access, enabling a wider degree of control than has been possible via bitstream or VULA-based offers. However, SDN/NFV-based access would still leave the control over the selection and upgrade of the active equipment with the network owner. It thus offers less innovation potential over the network than fibre unbundling.

Fixed wireless access in the context of 5G can also be expected to develop over the next decade. Depending on the frequency band used, FWA can bridge distances of multiple km for rural applications to 500 m in urban applications. Fastweb has conducted trials of FWA in Italy and plans commercial deployment in 2019 in at least 2 cities. Fastweb observed that in its trials, it could achieve download speeds of up to 1Gbit/s with a maximum distance of 500m. Key benefits were considered to be the flexibility and speed of deployment as civil works were not needed in the last mile. Installation requires receiving equipment to be installed on the balcony or roof of the

188 See IEEE802.3av released in 2009.
189 See http://www.ieee802.org/3/ca/.
190 See Table 2.2 https://www.ofcom.org.uk/__data/assets/pdf_file/0016/111481/WIK-Consult-report-The-Be nefits-of-Ultrafast-Broadband-Deployment.pdf.
191 See Plückebaum, T. and Sanchez Garcia, J.E. (2016). “GPON and TWDM-PON in the context of the wholesale local access market.” WIK-report for ComReg, June 9, 2016, Bad Honnef, available at: https://www.comreg.ie/publication/gpon-twdm-gpon-context-wholesale-local-access-market/ and Kroon, P.; Plückebaum, T.; Sanchez Gracia, J.; Sabeva, D. and Zoz, K. (2017): “Study into current and future technological access options to all fixed telecommunications infrastructures in the Netherlands.” Den Haag, June 21, 2017, Bad Honnef, available at: https://www.acm.nl/nl/publicaties/publicatie/17463/Onderzoek-toegang-tot-vaste--telecommunicatie netwerken/.

building.[192] Fastweb noted that these bandwidths require the use of spectrum in the millimetre band between 26-28GHz. 5G FWA has also been deployed by Verizon and AT&T in selected cities in the US, with Verizon reporting speeds of between 300Mbit/s-1Gbit/s.[193]

192 See https://www.wik.org/fileadmin/Konferenzbeitraege/2019/Gigabit_society/Tiziana_Talevi_1510_2019_WIK_Conference_Bruxelles.pdf.

193 See https://www.fiercewireless.com/5g/verizon-delivers-standards-based-5g-home-chicago.

5 Impact of technological and market developments on the environment and society

To achieve international or national sustainability goals, for instance to reduce greenhouse gas emissions in accordance with the Paris Climate Agreement (20% by 2020 and 40% by 2030, compared to 1990), reduce greenhouse gas emissions in Denmark by 70 percent by 2030 compared to 1990 or that Denmark is a net-zero emission society in 2050, technological developments can play an important role. In this chapter, we draw on the case studies discussed in chapter 3, as well as literature[194] to discuss the effect of technological advances in telecoms on climate and environmental change, agricultural transformation, traffic systems, fintech and the digitisation of the welfare state.

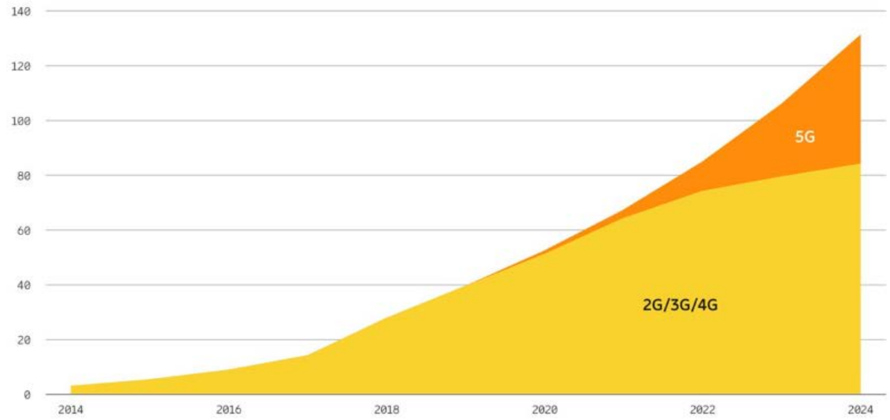
The environmental impact of digitisation should be considered both in terms of the implications of increased bandwidth consumption and IT on energy use (which is likely to be negative for the environment), and the implications of smart applications, which can in many cases have a positive environmental and social impacy.

5.1 Impact of modern telecoms infrastructure on energy consumption in the telecom sector

With increasing mobile data traffic, the relevance of energy efficiency is becoming more important. Ericsson (2019) predicts a 30% compound annual growth rate between 2018 and 2024 in global mobile traffic. In this context, 5G plays a crucial role, as 5G networks will account for about 35% of total global traffic in 2024. In order to compensate for the increasing data traffic, the standardization of 5G has from the outset attempted to significantly improve energy efficiency. Thus, the energy efficiency of 5G is intended to be ten times better than that of 4G.

194 A study by WIK for Ofcom (2018): Benefits of Ultrafast Broadband provides a comprehensive literature overview of the impact of ultrafast broadband.

Figure 5-1: Global mobile data traffic (EB per month)



Source: Ericsson (2019).[195]

Because the radio access network (RAN) has the highest energy demand, there is also the greatest potential for savings. Ericsson has developed a RAN energy-saving software feature which enables up to 15% of the overall energy consumption.[196]

In addition, ultrafast fixed broadband (and especially the use of FTTH) should have a positive impact on pollution and emissions. Aleksix and Lovric (2014)[197] have investigated the implications of wired access networks on energy consumption and environment. They found that deployment of all FTTH/B infrastructure could lead to 88% less greenhouse gas emission per bit in Europe than using copper and coax infrastructure.

Nevertheless, it should be taken into account that while energy savings may be achieved by network operators in the installation of modern FTTH or 5G technologies, cloud operators might consume additional energy on data centres. Moreover, energy efficiency is not the same as energy reductions, as greater demand for bandwidth may outweigh the reductions in energy expended for a given amount of data.

Thus, the most significant impact on energy consumption is expected to result from the use of telecoms to support digitisation.

195 See Ericsson (2019). Mobile data traffic outlook, available at: https://www.ericsson.com/en/mobility-report/reports/june-2019/mobile-data-traffic-outlook.

196 See Ericsson (2019). Energy performance, available at: https://www.ericsson.com/en/about-us/sustainability-and-corporate-responsibility/environment/product-energy-performance.

197 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.

5.2 Impact of digitisation on energy consumption and the environment

Based on the UK market, SQW (2013)[198] estimated that achieving faster broadband by 2024 could lead to a reduction of 2.3 billions km in annual commuting distance. This means annual net carbon dioxide equivalent savings about 0.24 million tonnes.

Buildings are responsible for around 40% of all energy consumption in the EU as well as 36% of CO2 emissions.[199] Therefore the potential for saving energy and CO2 emissions in the buildings sector is huge. One solution for greater energy efficiency can be the use of Smart Buildings. The Scope of Smart Buildings includes for instance energy, lighting and water applications, which can all play an essential part for more energy efficiency and environmental sustainability.

With more energy efficiency from buildings a 5-6% reduction of EU energy consumption is estimated. Moreover can smart HVAC (Heating, Ventilation, Air Conditioning) and smart lighting lead to cost saving of 24-32%.[200] According to the ACEEE (American Council for an Energy-Efficient Economy) smart technologies can reduce the energy consumption of buildings by about 20%. This may be achieved by interconnected technologies, occupancy sensors or complex energy management systems. The estimated average energy savings range between 18% for offices, 14% for retail stores and hospitals and 8% for hotels.[201]

In the context of Smart Cities, Cisco has estimated that moving from traditional street lighting to smart street lighting could reduce CO2 emissions in the City of Copenhagen by 23,000 tons per year, while implementation of traffic management systems in Copenhagen were estimated to permit a reduction of 18 tons in CO2 emissions.

Giovanis (2018)[202] explores the relationship between teleworking, air quality and traffic in Switzerland. He shows that teleworking can reduce traffic by an average of 2.7% and thus air pollution by 2.6-4.1%. Because passenger cars are responsible for about 12% of total EU emissions of CO2, teleworking can be one instrument for reducing them.[203] Another important instrument will be intelligent mobility, which has been already investigated as one specific use case.

198 See SQW (2013). UK Broadband Impact Study. Study conducted for the European Commission.

199 See EC (2019). Energy performance of buildings, available at: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/overview.

200 See EC (2019). Smart Building: Energy efficiency application, available at: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Smart%20building%20-%20energy%20efficiency%20v1.pdf.

201 See ACEEE (2017). Smart buildings save energy and improve occupant comfort, available at: https://aceee.org/blog/2017/12/smart-buildings-save-energy-and.

202 See Giovanis, E. (2018). The relationship between teleworking, traffic and air pollution. Atmospheric Pollution Research, 9(1), 1-14.

203 See EC (2019). Reducing CO2 emissions from passenger cars, available at: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en.

There are multiutude challenges for the environment and society caused through mobility and transport. Dependency on fossil fuels, growing car park, congestion, pollution and noises require new intelligent mobility solutions. Technological developments like autonomous vehicles, shared and sustainable mobility or finding parking lot systems can be part of this.[204]

One relevant aspect is the traffic in big cities which can be addressed by intelligent mobility respectively smart city solutions. A frequently quoted figure - 30% - concerns the traffic in cities caused by the search for a parking space.[205] This number makes clear that intelligent mobility in cities has to include intelligent parking, to decrease traffic, emission and noise. One option to solve this issue can be the implementation of sensors at parking slots, which signalize if it is available or not.[206] Developing intelligent mobility solutions is so critical, because the transport sector is responsible for about 20% emissions of green house gases (2015) in the EU-28 Member States.[207]

Agriculture is also a significant source of green house gases, being responsible for roughly 10% of emissions. While in the transport sector, CO2 is most relevant, farming influences climate change with two main greenhouse gases, Methane (CH4) and nitrous oxide (N2O).[208] Therefore, technological developments can help to reduce for instance the use of fertilizers and pesticides. In Denmark, the agricultural sector issues 22% of green house gases, which is more than EU average. Thus, there is a particularly strong case for Danish farmers to seek out and implement innovative emission reducing technologies.[209]

For example, smart farm machines have been developed which are able to identify via artificial intelligence the condition of every single plant. Thus, herbicides are only used for plants that are actually infected and no longer preventatively used for the whole field.[210] The use of drones for agriculture can also be implemented to accurately dose crop protection products. A Dutch communication provider has already tested drones for this kind of precision farming in the context of potato cultivation.[211] Again, less crop protection products which might be harmful to the environment must be used.

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204 EIP-SCC (2019). Intelligent Mobility for Safer, Greener, & Smarter Cities, available at: https://eu-smartcities.eu/news/intelligent-mobility-safer-greener-smarter-cities.
205 See Dowling, C., Fiez, T., Ratliff, L., & Zhang, B. (2017). How Much Urban Traffic is Searching for Parking? Simulating Curbside Parking as a Network of Finite Capacity Queues. arXiv preprint arXiv:1702.06156.
206 See Reichl, D. W., Ruhle, E. O., & Wirsing, D. W. S. (2017). Mobilfunk der 5. Generation.
207 See EC (2015). EU agriculture and climate change, available at: https://ec.europa.eu/agriculture/sites/agriculture/files/climate-change/factsheet_en.pdf.
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210 See http://www.bluerivertechnology.com/.
211 See KPN (2018). KPN tests 5G applications for precision farming in Drenthe, available at: https://overons.kpn/en/news/2018/kpn-tests-5g-applications-for-precision-farming-in-drenthe.

5.3 Social impacts of digitisation

In addition to environmental aspects, technological developments can also have an impact on social developments. Increasing urbanisation and the associated rural depopulation can lead to rural regions being increasingly left behind. It is estimated that urban regions will increase by 24.1 million people while rural regions will shrink by 7.9 million persons by 2050 in the EU. That is why ICT and digitisation are essential to restructure rural regions, for instance by delivering public services or generating new employment opportunities. In Denmark, more than 60% of rural areas have been shrinking (2001-2011)[212] Around 12% of the Danish population lives in rural areas.[213]

There is also significant potential for rural areas from e-health such as telemedicine and e-learning. Myrvang and Rosenlund (2007)[214] investigated how e-health can benefit rural areas in Norway. They found that e-health can strengthen the availability of health care services in rural areas and even has a potential of counteracting rural demigration. Peck et al. (2015)[215] reviewed international experience on digital health in rural areas. They concluded that if digital health applications have been implemented successfully,[216] the impact on patients was positive in different rural contexts. Nevertheless they outlined, the prerequisite for digital health is to invest in modern technology.

Meanwhile, Forzati and Mattson (2012)[217] have found for Sweden that on average 10% higher FTTP/FTTB penetration is correlated with a 1.1% higher employment rate. Singer et al. (2015)[218] found for Canada that fibre deployment to 100% of a region is associated with an increase in employment of about 2.9%. Again, support for employment in rural areas can be an important factor in sustaining those areas and limiting depopulation.

212 See ESPON (2017). Shrinking rural regions in Europe, available at: https://www.espon.eu/sites/default/files/attachments/ESPON%20Policy%20Brief%20on%20Shrinking%20Rural%20Regions.pdf.
213 World Bank development indicators 2017.
214 See Myrvang, R., & Rosenlund, T. (2007). How can eHealth benefit rural areas-a literature overview from Norway. Baltic eHealth.
215 See Peck, F., Jackson, K., & Marshall, A. (2015). Digital health and its application in rural areas: a review of international experience.
216 The study authors consider successful implementation as implementation that has been introduced with sensitivity regarding issues of privacy culture and trust.
217 See Forzati, M. & C. Mattson (2012): Socio-economic return of FTTH investment in Sweden.
218 See Singer, H., Caves K. and A. Koyfman (2015) Economists Incorporated: The empirical Link Between Fibre-to-the-Premises Deployment and Employment: A case study in Canada, Annex to the Petition to Vary TRP 2015-326, Bell Canada.

6 Implications of new applications for telecoms and digital industries

In this chapter we describe the implications of technological and service developments on the roles of existing and potential new players in the market. As markets could evolve in a number of directions, our discussions are based around **potential strategies for different operator groups**, which may be relevant in light of current trends in the Danish fixed and mobile markets,[219] and stakeholder interviews.[220]

6.1 The value chain for smart applications

The digitisation of industry and public services has created a new market for connectivity, with different drivers and requirements compared with the traditional markets of connectivity for residential and business customers. Many of the upcoming applications require additional focus on quality, availability and reliability of connections.

Business models to address these markets are still evolving, but one clear trend is that smart applications involve a number of players across the value chain.

As industries become "smart", providers of the core services such as logistics and transportation, healthcare, education or manufacturing have the potential to become actors in the digital value chain rather than just customers of telecoms and digital service providers.

For example, as illustrated in the chart below, connected automotive mobility requires collaboration between road authorities, application providers, telecommunication operators and car manufacturers, as well as facilitation through a supportive regulatory regime.

219 As discussed in the 2019 studies for the DEA on competition and investment respectively in broadband and mobile communications.

220 Stakeholder interviews and meetings were conducted in the course of November 2019.

Figure 6-1: Stakeholders in the delivery of Connected Automotive Mobility

	OEM	Road	Telco	Platform	Regulator
Commercialisation Statement	Premium segment with own CAM platform Shared Vehicles in city	For some actors: activation and responsibility of the service		Google/ Apple	
Facilitator			Active Participer *Co-devlopement*		Pilots to help actors identify needs and costs
Possible way to address consumers	At the vehicle sale Digital platform in the vehicle	Through tolls (pay per use)	Mobile plan	Through Application	
Prerequisites	Sensors Connectivity V2V, V2I, V2N	V2I Infrastructure Fibre infrastructure	V2N Infrastructure	Integration with OEM	Area Permit

wik CONSULT

Source: IDATE Digiworld.

Meanwhile, smart city applications require partnerships involving local authorities, equipment and application providers (including those supplying sensors and equipment for the processing of big data) and suppliers of connectivity.

Moreover, as digital systems become more complex, specialist “integrators” can act as middlemen covering some of all of an industry’s requirements.

6.2 The role of systems integrators

Whereas previously companies procured connectivity services from telecommunication providers, the association representing business-end users of electronic communications reports[221] that many large businesses now purchase IT solutions from systems integrators such as Microsoft or Cisco. Voice and video conferencing “applications”, IoT and big data solutions are provided alongside connectivity to support company specific requirements. The important role played by systems integrators is confirmed by research reports into purchasing for IoT.[222] However, business end-users also report that their reliance on single providers for complex solutions carries the risk of lock-in.

6.3 The role of vertical industries

As they seek to digitise their operations, industrial actors are considering what role they should play directly in digitisation or even connectivity. In some cases, “digitisation” is wholly outsourced.

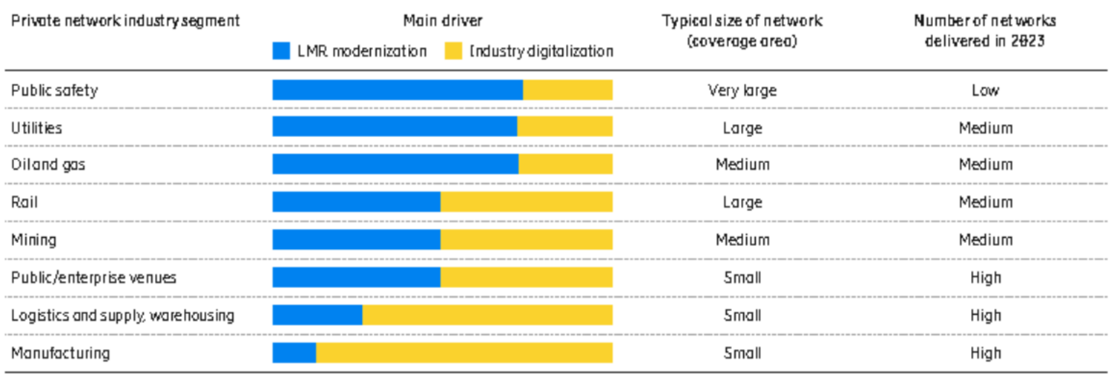
221 Interview with INTUG conducted Nov 2019.
222 See for example https://www.abiresearch.com/press/system-integrators-quickly-becoming-iot-gatekeeper/.

In other cases, vertical industries have themselves made investments in specialist firms which develop platforms and negotiate connectivity with electronic communication providers. One example is the investment made by Audi[223] in Cubic Telecom, an Irish company which provides mobility solutions inter alia for autonomous vehicles. In the case of automated connected mobility, widespread (and cross-border) connectivity is needed, and therefore it is not realistic for the car industry to play a direct role in the developing connectivity to support the applications under development. Thus car manufacturers partner with applications providers which also act as MVNOs, or directly with MNOs.

However, in cases where digitisation occurs in a more localised area e.g. in relation to manufacturing or agriculture, vertical industries can play a direct role in connectivity. For example, in the German 5G spectrum auction, the upper part of the 3.6GHz band was not included in the auction to mobile network operators. Rather 100MHz was made available for local assignments.[224] Business owners could then operate a local/regional mobile network by themselves,[225] or outsource such task to their equipment supplier, to a MNO or a MVNO.

The following figure illustrates the degree to which industry digitisation is driving the development of private corporate networks in selected sectors.

Figure 6-2: Industry segments evaluating private LTE/5G networks



Source: Ericsson (2019).

223 See https://www.cubictelecom.com/Media/PressRelease/28.
224 See http://www.bundesnetzagentur.de/lokalesbreitband.
225 The notion of micro-operators is related to this type of use. See for a discussion Matinmikko, Latva-aho, Ahokangas & Koivumäki (2017); Jurva (2018). As is the notion of vertical specific VNMOs. See for a discussion: "Leadership with 5G in Europe" Lemstra (2018).

6.4 The role of public authorities

Public authorities are also in the front line in developments concerning digitisation, as they facilitate smart cities, as well as (in some cases depending on their responsibilities) smart healthcare and education. Copenhagen solutions lab provides an example of collaboration between the City of Copenhagen, applications and connectivity providers.

In some countries, where local regulations permit it, cities can take an even greater stake in the deployment of digital infrastructures. For example, in Sweden, the municipally owned wholesale only fibre network company Stokab has been tasked with deploying connectivity in the streets and to street furniture, thereby supporting smart transport and other smart city applications, while the City is planning to facilitate access by third parties to Stokab fibre via access points at street furniture. Stokab characterises their network as a “platform” on which others can deploy 5G and develop smart city and other applications.

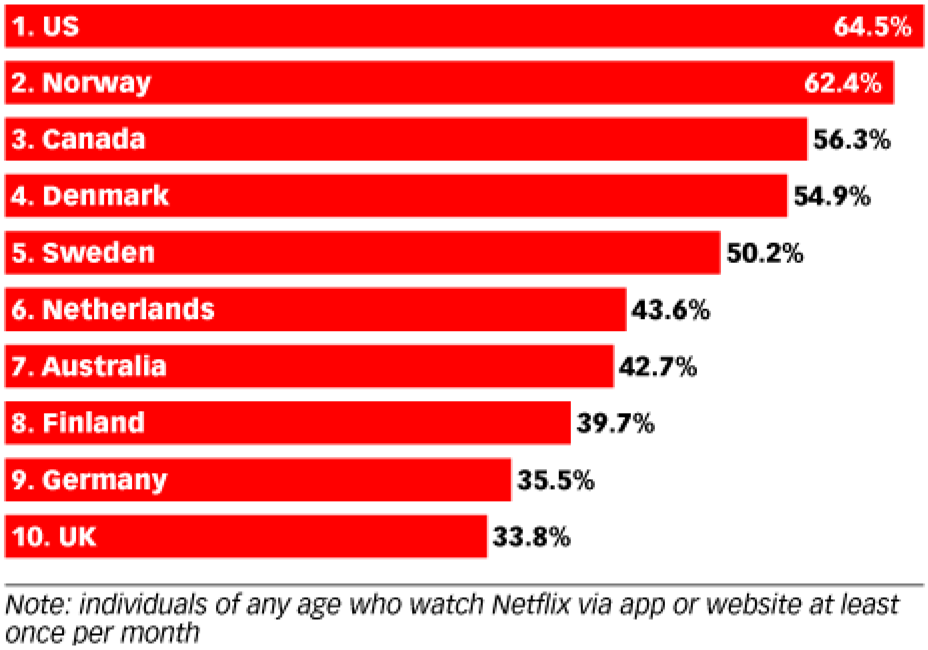
Public utilities may also be called on to support these aims.

More generally, whether they directly engage in telecom provision or smart applications themselves, via their control and/or implementation of planning processes, local authorities will play a vital role in determining the degree and pace of 5G deployment.

6.5 The role of OTTs

OTTs have played an expanding role, especially in Nordic countries, in the provision of communications services and video. Denmark came fourth in a global survey of Netflix penetration (see following figure).

Figure 6-3: Top 10 countries, ranked by Netflix user penetration, 2018
% of digital video viewers



Source: eMarketer, July 2018.

As such, over time, customers' reliance on "managed" communications and video has been reduced or supplemented with alternative offers. This process is already well advanced in corporate communications, which often now rely on OTT applications for video conferencing and collaboration. Over time, as younger generations rely more on OTT content rather than linear broadcasting, the trend away from broadcast TV towards on-demand viewing (known as cord-cutting) can be expected to accelerate. Denmark is one of a number of countries globally in which pay-TV subscriptions have been in decline.[226]

OTTs have also been involved in developing smart applications. For example Copenhagen Solutions Lab is collaborating with Google on measuring air pollution.[227]

226 See https://technology.ihs.com/602563/pay-tv-subscriptions-declined-in-14-markets-in-2017-as-cord-cutting-takes-toll-ihs-markit-says.

227 See https://cphsolutionslab.dk/en/news/google-samarbejde-giver-nyt-luftforureningsbillede.

6.6 The role of telecom operators

Within this enriched value chain, the role of telecoms operators is evolving. In some cases, telecom operators have sought to move downstream on the value chain, adding content to their services, or focusing on supporting IoT applications.[228]

However, the potential to invest and expand in these field depends (in the field of content) on high local market shares, or in the case of some IoT applications, the capability to sustain high quality connectivity nationwide or potentially (in the case of connected cars) on a continental or global basis.

For telecom operators which do not have these opportunities, another option is to act as a dumb pipe for smart services. Demand for connectivity is set to increase, not only through increased use by households but also in connection with industrial and public use cases. As a scarce resource, ownership of spectrum provides the potential for telecom operators to act as conduits for the delivery of smart applications directly to businesses or public authorities (e.g. via private networks), or to aggregators. Ownership of fibre, which is economically challenging to replicate, but is becoming an increasingly vital infrastructure for mobile backhaul as well as fixed connectivity, also provides scope for telecoms operators to profit from trends in digitisation.

6.7 The role of MVNO/As

One category of telecom providers that has moved decisively into the IoT and smart application space are so-called mobile virtual network operators and aggregators. These companies often specialise in achieving widespread (even global) coverage via a mix of access agreements with MNOs in different countries and roaming agreements in other cases. Such global connectivity is important for mobile connected things such as cars, as well as for installation in connected things that may be sold cross-border, and for connected laptops and tablets. Players in this space include companies such as Transatel and Cubic Telecom (described above). Further discussion of the business models of these companies is provided in the 2019 WIK study for the European Commission: “Technological developments and roaming”.[229]

228 See for example Vodafone engagement in connectivity for the automotive sector https://www.vodafone.com/business/iot/end-to-end-solutions/automotive.

229 See https://ec.europa.eu/digital-single-market/en/news/technological-developments-and-roaming-smart-20180012-0.

7 Implications for the Danish market

To assess the implications of technological change and evolving business models on the Danish market, we conducted interviews with Danish stakeholders (including consumer and industrial representatives as well as representatives from the telecom sector) during the third quarter of 2019. We then discussed the provisional findings from our research at a stakeholder workshop in Copenhagen on 25 November 2019.

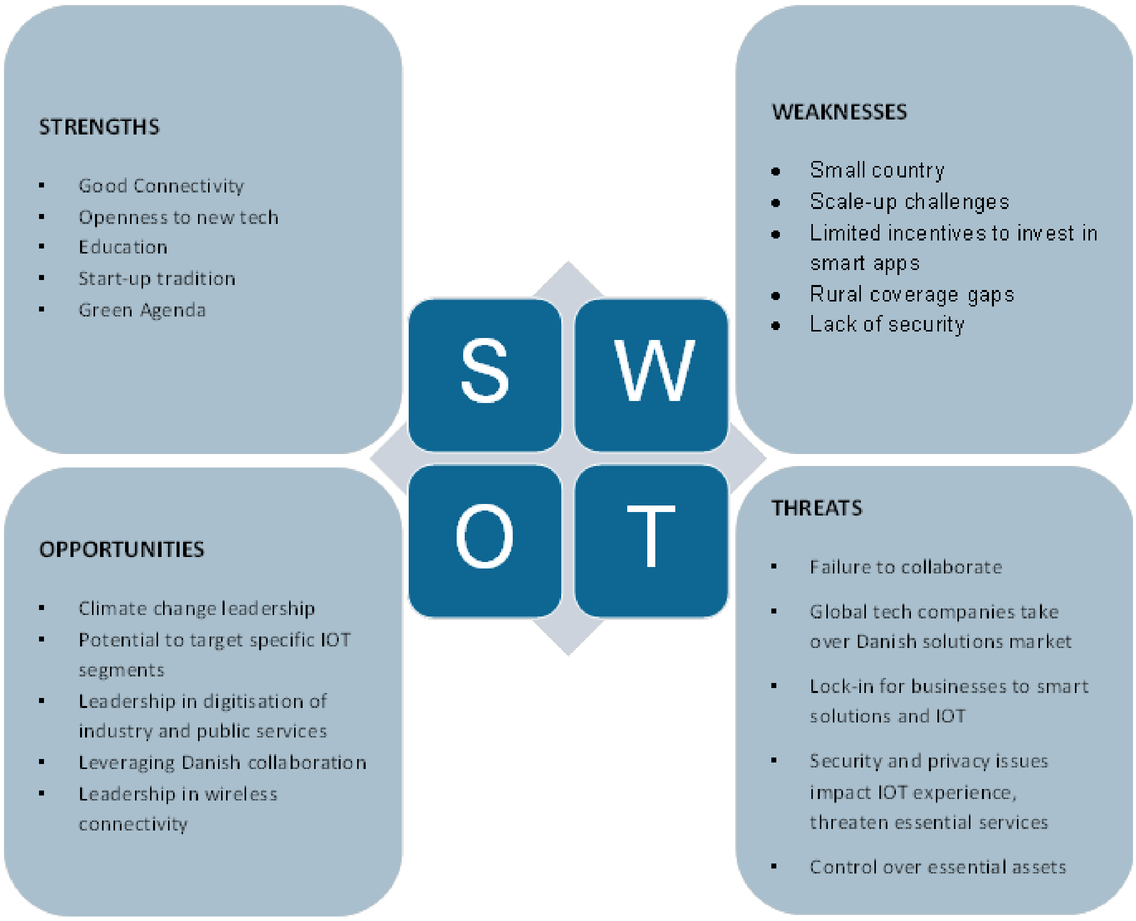
In this chapter we describe the strengths, weaknesses, opportunities and challenges identified by Danish stakeholders and consumers, and discuss policy themes that may be relevant to support Denmark in achieving its digital goals.

7.1 SWOT analysis

Stakeholders interviewed for this study noted that Denmark benefits from a number of strengths in digital infrastructure and the culture of developing and using digital applications. However; they also highlighted weaknesses in a number of areas which could undermine Denmark's efforts to become a European and global leader in the field of climate change and digitization. We identified further potential strengths and weaknesses from the review of Denmark's current market position and potential evolution in the digital value chain.

Key points are highlighted in the diagram below.

Figure 7-1: SWOT analysis: Denmark's position in digital infrastructure and services



Source: WIK.

Key strengths visible from the benchmarking conducted for this study include relatively good levels of fixed and mobile connectivity, a high degree of digitization in both industry and public services, and openness to innovation and investment. Stakeholders also noted that Danish consumers were highly educated, were early to try new technologies and had high levels of trust in digital services. Denmark was considered to have a strong tradition of supporting start-ups and, as a small well-connected society, provided a good platform for test-beds and experimentation.

On the other hand, being a small country was perceived as a weakness, as small Danish companies might not be well positioned in the new value chain, which supports global scale. Stakeholders also expressed concern that, while Denmark produced start-ups, it was not effective at enabling those businesses to scale-up, leaving innovative companies to move abroad or be acquired. While consumers and small businesses were open to new technologies, they were also vulnerable to attack, as a high proportion lack security protection. Regarding infrastructure, some stakeholders highlighted challenges associated with the fragmentation of very high capacity infrastructure in Denmark and remaining coverage gaps. Concerns were also expressed about perceived restrictive planning practices which could hamper the deployment of new mobile networks.

Stakeholders considered that Denmark had the opportunity to achieve leadership in a number of areas including action to prevent climate change. Moreover, Denmark could aspire to maintain and extend its position in digitization of industry and public services, supported by extensive wireless and fixed VHC infrastructure. There was also the potential Danish start-ups to specialize in specific IoT segments. Several stakeholders highlighted Denmark's success in collaboration as a key strength which it could leverage to achieve success in these areas.

On the other hand, there were concerns that if the industry failed to collaborate effectively, the ecosystem could fail and these goals could remain elusive. Other perceived threats to Denmark's ambitions included the potential for global technology companies to take over the Danish solutions market, while other regions such as China bypassed Denmark (and Europe) in the deployment and exploitation of wireless technology. Some stakeholders considered that control over essential assets such as fibre and spectrum could present a threat to the development of a competitive ecosystem. Similarly lack of competition and systems to support switching could lead to businesses and public institutions being "locked-in" to smart solutions and IoT applications. A further concern was that a breach of security or privacy could undermine consumer trust in technology and IoT. Security breaches could also present a threat to essential services. Some stakeholders also highlighted concerns that high levels of taxation on electricity could impede the transition to electric cars.

7.2 Focus areas

Drawing on the opportunities and challenges for digitization in the Danish market, as well as feedback from stakeholders, we have identified areas where action could be considered.

These areas include:

- Spectrum policy, in light of the upcoming auction of spectrum in the 3.5Gz band, as well as consideration of the relevance of millimeter frequency bands for FWA deployment
- Consideration of the role of network sharing, access and the relevance of spectrum for alternative actors to deploy private networks in the context of 5G
- Planning permissions associated with the deployment of 5G antennas

- Incentivisation of smart energy investments
- The role of broadband state aid in facilitating full coverage in rural areas
- Future needs for connected highways
- Fostering of investment in future-proof VHC infrastructure and support for open networks and platforms over which innovation can thrive.
- Digital hubs and innovation vouchers
- Solutions and standards which enable switching in the IoT area
- Collaborating at EU level to support regulations which ensure IT security, and the effective management of data in an IoT environment.

As digitisation will involve a wide set of industries and public services, we would recommend a cross-sectoral focus within the public administration to ensure that synergies between electronic communications, energy, industrial policy, transport, health and education, can be effectively realized.

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