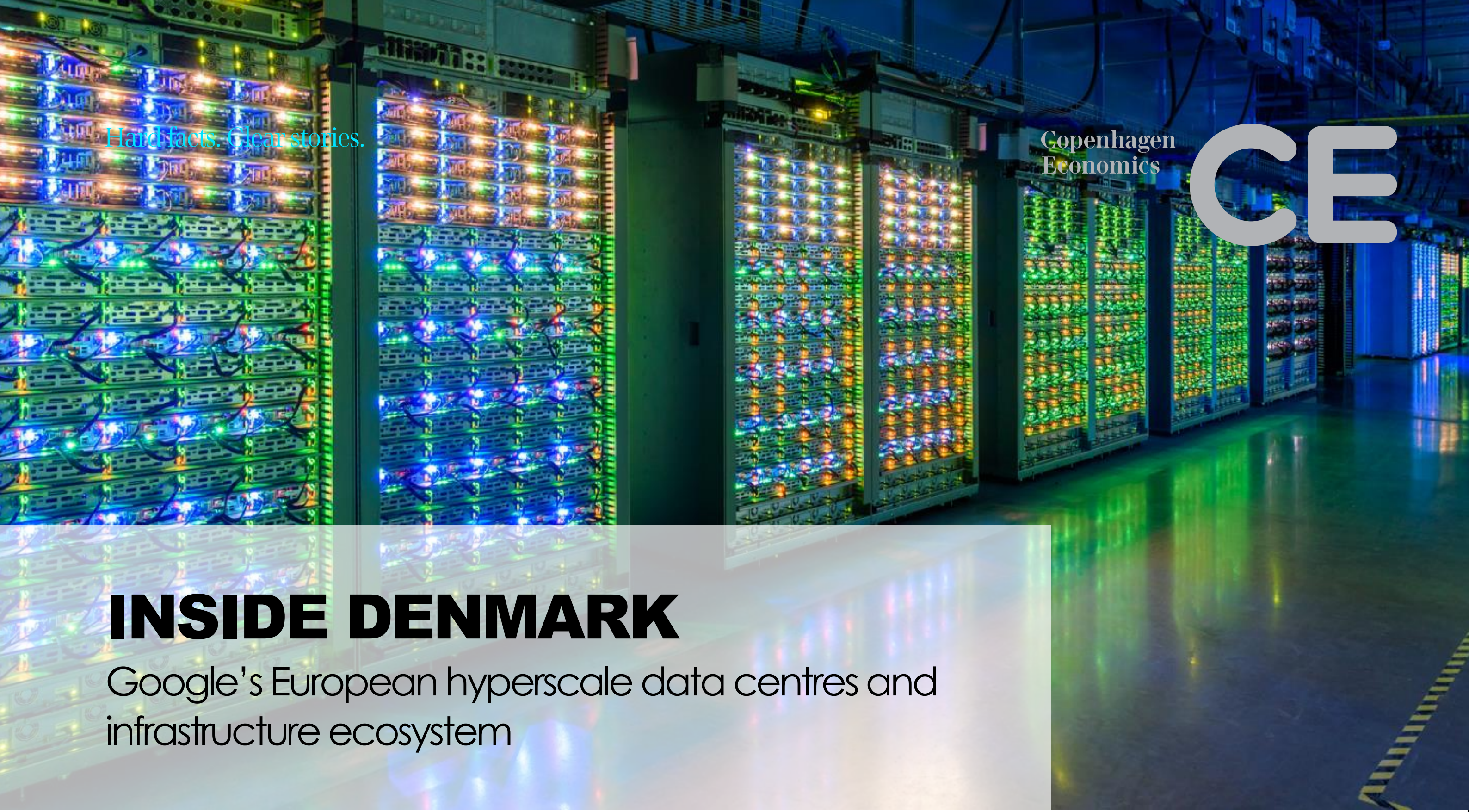

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INSIDE DENMARK

Google's European hyperscale data centres and infrastructure ecosystem

PREPARED FOR GOOGLE
NOVEMBER 2020

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Dear Reader,

This research piece on Denmark follows the September 2019 pan-European research 'Google's hyperscale data centres and infrastructure ecosystem in Europe: economic impact study' (available here). The following pages provide a deep dive into the economic effects descending from Google's Fredericia data centre and related network infrastructure ecosystem in Denmark.

Google has invested heavily and widely in data centres and related infrastructures in Europe. Currently, it operates hyperscale data centres across Europe: Fredericia in Denmark, St. Ghislain-Mons in Belgium, Hamina-Kotka in Finland, Dublin in Ireland, and Eemshaven-Groningen and Agriport in the Netherlands.

DENMARK: A VITAL CONNECTION IN EUROPE

Denmark is well advanced on a path of digital transformation – capitalising on their current and future infrastructure assets. The country is amongst EU leaders in terms of digital connectivity in the EU. Its Strategy for Denmark's Digital Growth and its Digitisation pact reflect Danish policy-makers active and ambitious stance to continue developing Denmark into a leading digital economy. It also represents a direct acknowledgment of the benefits of digital transformation.

Growth and jobs. Denmark is a gateway to Europe for global network infrastructure, as shown by the case study of Google. The company is now facilitating even greater EU-wide connectivity via Denmark. It has done so as part of a wider infrastructure programme which – specifically over the period 2018 to 2020:

- Delivered total cumulative investments of **EUR 600 million** in the Fredericia data centre and related network infrastructures.

- This has supported **EUR 750 million in GDP** in Denmark.

- Furthermore, **2,600 jobs per year on average** during the same period have been supported.

Network infrastructure. This digital infrastructure effort includes an important, often underappreciated, part of Google's European economic contribution, namely the investment in network connectivity such as fibre links spanning the European continent and linking Europe to the global internet.

In addition to the digital transformation supported by Google's investments, Google's Fredericia hyperscale data centre is on the forefront of the green transition in digital energy. From day one of operation, its energy demand will be met almost entirely by carbon-free energy, making it one of Google's cleanest data centres anywhere in the world.

Energy efficiency. Every time we as users choose to rely on services provided online, we channel indirect demand for energy. As traditional non-digital activities continue to shift to new digital applications, the way energy is being consumed is changing. The data centre industry has **significantly raised its energy efficiency**. In fact, recent global research established that while demand for data driven services has increased exponentially (by 550 percent) over the past 10 years, data centre energy usage has remained relatively stable (increasing by only 6 percent)[1]. At the same time, there is potential to improve efficiency even further. We estimate that, if across Europe all business email servers were hosted by data centres as efficient as Google's, this would **save the equivalent of the annual household consumption of electricity in Ireland**.

Renewable energy. Driving the green revolution forward, Google is also the largest corporate buyer of renewable energy sources. It does so by committing to and signing Power Purchase Agreements (PPAs), key enablers for the renewable energy project developer/investor. As of September 2020, Google had signed 24 PPAs for energy production from European wind and solar farms to match the energy consumption of its data centres. In addition, in September 2020 Google stated that it will be carbon-free by 2030[2].

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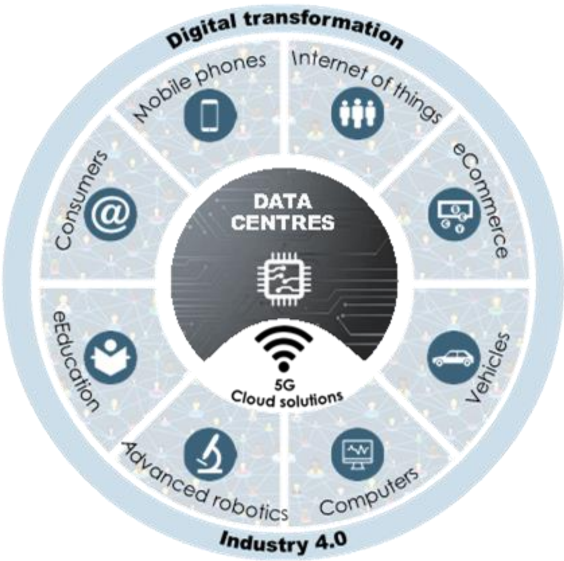
1 Masanet, E, et.al. (2020) Recalibrating global data center energy-use estimates
2 Google (2020), Our third decade of climate action: Realizing a carbon-free future. https://blog.google/outreach-initiatives/sustainability/our-third-decade-climate-action-realizing-carbon-free-future/

1 DATA CENTRES SHAPING THE DIGITAL FUTURE THROUGH CLOUD COMPUTING

The cloud has transformed how companies purchase ICT equipment and services. Cloud computing removes the need for large up-front investments in hardware and software otherwise required for companies to compete in the market. New entrants can increasingly gain access to the storage space and computing power capacity they need in a pay-as-you-go manner and subscribe to advanced applications at an affordable price. Behind the cloud, millions of servers are quietly and efficiently operating in hyper-scale data centres. These data centres are the “brains” of digital infrastructure around the world. They are the physical assets that store, process and/or distribute the data that customers send to the cloud. Hence, to facilitate future growth in data traffic, storage and processing driven by consumers’ and firms’ use of cloud computing, investments in data centres need to increase.

Figure 1
Data centres at the heart of the European digital future



Source: Copenhagen Economics

Current EU-level and national policies increasingly understand the benefits that the cloud can bring. A priority of the current European Commission is ‘a Europe fit for the digital age’ – focusing on the advancement of Artificial Intelligence, the Internet of Things and Big Data in Europe, and harnessing the opportunities from data sharing.[3] Given the benefits linked to the cloud, there is increasing policy attention on how to support its role as part of the EU’s digital transformation ambition and the building of a European data economy.

In parallel, the current European Commission has stated that it will prioritise progressing the Green Deal for Europe. Therefore, the sustainability angle will be key in underpinning each of the policy

[3] Ursula von der Leyen, 2019, *A Union that strives for more – My agenda for Europe*, and European Commission, 2019, *Mission letter to Margrethe Vestager, Executive Vice-President-designate for a Europe fit for the digital age*.

efforts that can contribute to the success of the European digital transformation, such as work in the areas of:

- The European Cloud initiative
- The Internet of Things (IoT)
- Building a European data economy including big data
- Artificial Intelligence (AI)
- High-Performance Computing

For these digital advancements to take place, the cloud is a key pillar. In turn, an effective, sustainable and efficient cloud needs support from well-functioning digital infrastructure with data centres at the core. National policy makers and other interested parties also vested in the development of the digital economy in the EU should thus continue to foster support for the data centre and related infrastructure layer, as discussed in our September 2019 study.[4]

[4] Copenhagen Economics (2019) Google's Hyperscale Data Centres and Infrastructure Ecosystem in Europe.

Box 1 Digital and cloud policy in Denmark

The EU Digital Economy and Society Index shows that over 40 per cent of Danish firms have incorporated cloud computing services of at least medium-high sophistication, making it the country with the fourth highest share in the EU.[5]

Cloud computing is established as an integral part of numerous advanced digitisation policy initiatives in Denmark. This holds true both for the usage of cloud computing technologies in the public sector as well as advanced digital solutions as a tool for improving the Danish business environment.

In the Danish Digital Strategy, one of its concrete focal points is the removal of barriers for using cloud solutions in the public sector at national, regional and local levels of administration.[6] In addition, Cloud Computing feeds into multiple of the other initiatives, including *Automatic business reporting* and *Good data and efficient data sharing.*

The recent National Strategy on Artificial Intelligence also lists access to cloud solutions as a likely precondition for successfully harnessing the potential of AI in Denmark.[7]

Digitisation and the use of new technologies in the public sector is stated to be an ongoing political priority going forward. Building on the Digital Strategy, a so-called Digitisation pact (link) has come into place, a political agreement which emphasises a continued and accelerated digitisation in the public sector, based on transparency, new technologies and "world class" cohesive digital services.[8]

In parallel with the initiatives within the Public Sector, the Danish government has a strategic focus on digitisation as a driver for growth in the business sector. This is described in the Strategy for Denmark's Digital Growth, which outlines 38 initiatives for increasing the uptake of technological solutions among Danish businesses.[9] Many of these initiatives promote the use of advanced digital solutions such as big data analysis, machine learning, IoT and Blockchain technologies, which all to some degree rely on cloud computing technologies and solutions. The strategy is backed by funding of around 1 billion DKK towards 2025.

The increasing demand for cloud services (e-mails, music, general data storage, etc) means that global internet companies like Google are now among the most efficient facilitators of global data centre growth. Global internet companies are especially efficient as they are able to consolidate storage and cloud-processing of data in 'hyperscale' data centres.[10] This translates to larger-scale, purpose-built facilities with a focus on operational costs and efficiency that are better positioned to meet the growth in demand for cloud services and the like. The importance of these efficiency gains is evident in global market trends. Cisco estimates that by 2021 hyperscale data centres will

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5 European Digital Society and Economy Index 2020
6 The Danish government (2016), A stronger and more secure digital Denmark
7 The Danish government (2019, National Strategy for Artificial Intelligence
8 The Danish government (2019), Digitaliseringspagt – En ny retning for det fællesoffentlige samarbejde
9 The Danish government (2018), Strategy for Denmark's Digital Growth
10 Hyperscale data centres refer to those data centres that have an ability to scale their computing capacity in response to increased demand. Scaling in turn refers to the ability to increase computing power through better infrastructure, storage facilities, or memory.

constitute around 53 per cent of data centre servers globally – up from 27 percent in 2016.[11] Similarly, Arizton estimates that the hyperscale data centre market will continue to expand from 2019 to 2024 at a compound annual growth rate (CAGR) of 9 per cent.[12] In terms of the entire 'datasphere' (the data lifecycle from creation, capture, and replication) growth projections from IDC suggest the total size will increase from 33 ZB[13] in 2018 to 175 ZB by 2025, representing a CAGR of 27 percent.[14]

Therefore, just as is the case for players across the industry, there is expected growth in user demand for Google services. These include many services widely used for general productivity and consumer benefit (provided with open access akin to public goods) such as Gmail, Google Maps, Search and Android. This suggests that Google's investments in data centres in Europe will continue (as observed in the past years) to increase over time as demand for and use of these services expands given the important consumer benefits delivered. As summarised below (and analysed in our September 2019 report), as users choose to rely on services provided online, cloud infrastructures play a key role in an efficient delivery of these services, including in terms of energy efficiency. Besides, we find that the data centre industry has significantly improved its energy efficiency performance, while Google's data centres outperform the industry average. Furthermore, an important recent development associated with the Covid-19 crisis is a societal push for faster and deeper digital transformation across sectors of economic activity. Consequently, **Google's economic contribution to Denmark and Europe will very likely continue to increase in importance**.

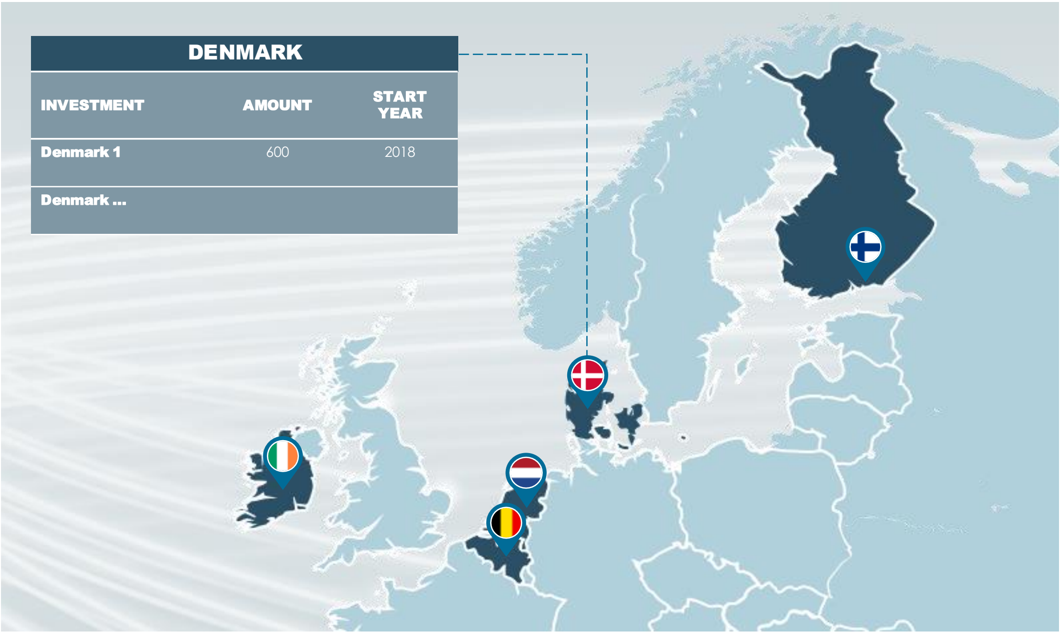
11 Cisco (2018), Global Cloud Index (2016-2021), see: https://newsroom.cisco.com/press-release-content?articleId=1908858
12 Arziton (2019) Hyperscale Data Center Market - Global Outlook and Forecast 2019-2024
13 This refers to 'zettabytes', were 1 ZB is equal to 1000^7 bytes
14 IDC (2018) The Digitization of the World: From Edge to Core

2 QUANTIFYING THE GDP AND JOBS IMPACTS OF GOOGLE'S DATA CENTRE INVESTMENTS

Google's investments in digital infrastructure in Denmark help to propel the country further forward as a leading digital economy. These digital infrastructure investments include data centres, network infrastructure and equipment, management, and access and computation – elements that are vital to sustaining our increasingly digital culture.

As one of the largest technology companies in the world, Google serves a significant share of users from their data centre in Denmark. Google's data centre at Fredericia started construction in 2018 before becoming fully operational in 2020 (see Figure 2).

Figure 2
Ongoing investment in Google's national data centre



Source: Copenhagen Economics based on Google data centre website and data provided by Google

Every time a firm (domestic or foreign) invests in construction and infrastructure like Google's data centre in Denmark, it is reasonable to ask – how much of this investment will remain local versus will leave the region or country (via imports, etc)? To help answer this question, we have applied an established economic (input - output) model to measure the impact of Google's investments. We do this by measuring two dynamics – supported economic activity (GDP) and supported jobs (FTEs)[15] by Google in Denmark.[16]

15 FTE refers to Full Time Equivalent job, where 1 FTE equals 40 hours per week

16 The CE input / output model compared the Google expenditure sectoral pattern and mapped it against the official national statistics, from Denmark Statistics. The model is calibrated on the basis of Eurostat sectoral accounts that are built on the latest information on the EU countries' national economy and sectoral patterns, across all value chains.

We find that when considering the direct, indirect, and induced effects, Google's total investments in the Fredericia data centre and related infrastructures has a supported economic impact of **EUR 750 million in GDP cumulatively over the period 2018-2020.** This impact has exhibited a peak impact of EUR 370 million per year.

Through these expenditures, Google's Fredericia data centre and related infrastructures supports an ongoing employment contribution of up to **2,600 FTE jobs per year** (during 2018-2020) including direct, indirect, and induced effects.

We find that in 2019 the data centre construction and operation supported jobs primarily in the construction (approx. 500 FTEs throughout the year) and security and business support industries (approx. 10 FTEs throughout the year).

In addition to these industries, data centre activity at Fredericia stimulates consumer consumption, as workers spend their wages throughout the Danish economy. These induced effects support jobs mostly in private services, as this is where employees tend to spend their wages. This mechanism supports approx. 260 FTEs throughout the year in private service industries, such as retail trade, transport, hotels and restaurants, real estate, legal, accounting, and employment activities, as reported below in Figure 3.

Figure 3
A year in the life of building a Data Centre – Jobs supported by the Fredericia data centre and related infrastructure, by industry
Year 2019

Note: 'Other private services' include (but are not limited to) retail trade, transport, hotels and restaurants, real estate, legal, accounting and employment activities.
Source: Copenhagen Economics based on data provided by Google, Eurostat and World Input-Output database

Some of these industries, such as security, are proximity services and therefore are supplied locally, whereas other goods or services can be supplied from further afield. The jobs supported by Google will therefore not only support local employment in Jutland around Fredericia but also employment in other parts of Denmark. Similarly, as supply firms and workers spend the income obtained from data centre work on other products and services, the indirect and induced ripple effects extend to both the local communities and the rest of Denmark.

3 SPILLOVERS FROM THE DATA CENTRE INVESTMENT: STRENGTHENED SKILL BUILDING FOR THE COUNTRY

The economic literature on the role of foreign direct investments in promoting a country's productivity points to skills transfers as a key channel by which a country stands to benefit from these kinds of investments, especially relative to new technologies.

In the case of data centre investments, the case study of Google shows a particular form of skill transfer, taking place via collaboration with educational institutions aimed at promoting the skill base in the local and national workforce. This delivers win-win-win benefits to students, to Google and other firms operating data centres (or industries relying on comparable skills), as well as the country as a whole, since an up-to-date skill base is key to succeed in a knowledge economy.

Box 2 Repurposing traditional skills to steer the future of Data Centres

Fredericia College of Marine and Technical Engineering (Fredericia Maskinmesterskole, FMS) is a higher education institute of approximately 650 students. Founded to train marine engineers for the commercial shipping industry, the school now trains students to become Operation and Maintenance Engineers (OMEs). A shift to bring OMEs onshore began around 30 years ago in Denmark, when industries such as energy production and pharmaceuticals realised that the generalised skillset of OMEs were perfectly adaptable to their operational needs. As a result, 80 percent of OMEs now work onshore. However, the maritime roots of the education remain pertinent reminders of the need for skilled and flexible engineers who can operate and maintain an entire ecosystem of technical components.

In 2018, Google met representatives from FMS. This resulted in a common realisation that these skills could also be used to steer the operations and maintenance of their then, soon to be built, hyperscale data centre in Fredericia. This can best be described as a watershed moment, where the internal workings of a typical Google data centre were shown to align very well with the current skill set of FMS's training of OMEs. In many ways, it was discovered that the running of data centres is like running a ship – with many different things happening at once.

Since then, FMS has worked very closely with Google, as well as the Danish *Data Center Industry* (DDI) Association to develop a training programme tailored specifically for data centres that builds on current training modules for OMEs. Highlighting the significant synergies between the OME's maritime heritage and the current challenges faced in data centres, there are now plans to adapt the ship training simulator for specific data centre scenarios. This adds the unique possibility to simulate a full 'mission', dealing with critical operations whilst monitoring the human factor. As a result, OMEs will already have faced the stressful and demanding environment of an unidentified problem within a data centre in a carefully controlled environment.

A critical driver for this engagement between Google and FMS is the ever-increasing demand for skilled generalists to work in the data centres. Hence after the first round of students who started in August 2020 graduate, they will face very high job security. This is especially important in a regional area that is struggling to retain skilled young adults. Therefore, Google's engagement in this region through FMS is a step that will both have positive economic and social repercussions into the future.

Google is also helping FMS to connect with other institutions spanning across the EU. This network promises to expand the horizon of students from all these regions, increasing knowledge sharing, as well as encouraging foreign students to a region often overlooked in favour of larger cities.

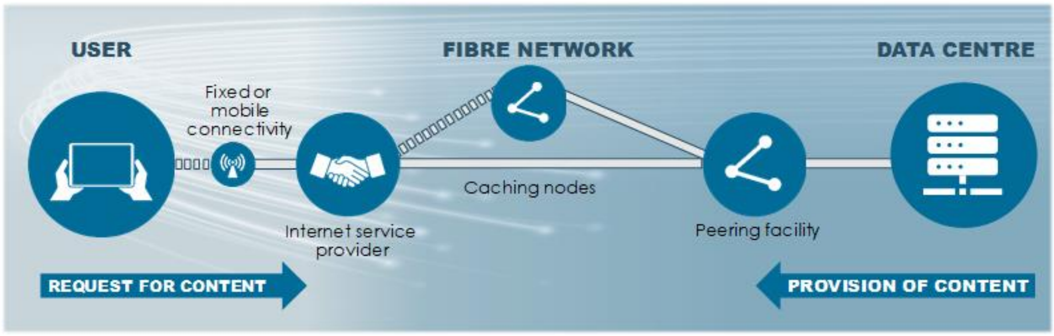
Source: Interview with Jens Færgemand Mikkelsen, Fredericia Maskinmesterskole, July 6th, 2020

4 NETWORK INFRASTRUCTURE STRENGTHENS LINKS BETWEEN DENMARK, EUROPE AND THE WORLD

A key driver encouraging network investment is to bring the benefits of Google computing and cloud resources closer to customers. In internet network design jargon, this is the often-underappreciated role of "edge" infrastructure – the vital links in proximity to where consumers and firms use digital services. Providing network connectivity allows Danes to reach core cloud services by connecting with Google closer to their point of use. By facilitating this connection on dedicated infrastructure in nearby cities or towns, the speed at which these cloud services can be reached is increased. In effect, this brings the services of the harder-to-reach Fredericia data centre closer to Danish consumers, ensuring a faster and more responsive cloud experience.

From a consumer's perspective, the visible reality of the internet tends to be what is regarded in the industry as internet access links. Internet access links consist mainly of Internet Service Providers (ISPs) – often telecommunications companies that provide either 1) fixed services in the home or office, often accompanied by a modem, or 2) mobile services through mobile telephone subscriptions or other similar wireless devices, see Figure 4. Thus, some consumers might believe that ISPs are the only firms backing connectivity infrastructure – however, this is incorrect.

Figure 4
How data centres reach users: Google's design, high level view



Source: Copenhagen Economics based on Google

The inner network part of the internet (less visible compared to the connections to homes and firms) is what is referred to as the backbone of the internet (split broadly onto the 'core' and 'edge'). At the core, data centres host files and apply computational processes so that the information can serve users' requests. To reach users, hosting activity needs high capacity transport networks that connect data centres to peering facilities. This network infrastructure (increasingly fibre) reaches peering facilities, or Points of Presence (PoPs), at the 'edge', connecting Google's network to the rest of the internet. At that point, PoPs serve as the connecting points for the ISPs at the front end of the internet. From the PoPs, internet traffic is handed over to ISPs, which take over the responsibility for carrying the internet services to homes and offices. In addition to this, Google also maintains the Google Global Cache (GGC) network through caching nodes, provided to ISPs. These smaller pieces of infrastructure at the "edge" enable basic data requests to be brought even closer to consumers, providing even greater responsiveness.

As a result, **Google procures and maintains a major global network connecting key infrastructure** such as data centres, cities and towns, and network hubs. Google's network connects Europe through several major sub-sea landing points to the rest of the world. Of equal importance – and perhaps a surprise to some – Google's global network includes a **major terrestrial network spanning across Europe**. Covering the continent, this network includes key north-south and east-west connectivity corridors, extensive city-scale networks, edge networks to more regional locations, and access connectivity to more far-flung corners of Europe. Ultimately, Google's network connectivity effort reflects the business and market imperative to ensure the best experience for firms' users and customers within Denmark and abroad.[17]

Box 3 Fibre network connectivity linking Fredericia and Denmark to Europe and the world

Denmark is of ever-growing importance to Google. While it is well known that the firm has invested in land in Aabenraa and Fredericia (with significant work already done to construct Google's first Danish data centre), what may be underappreciated is the critical role of the firm's investment in network infrastructure traversing the country.

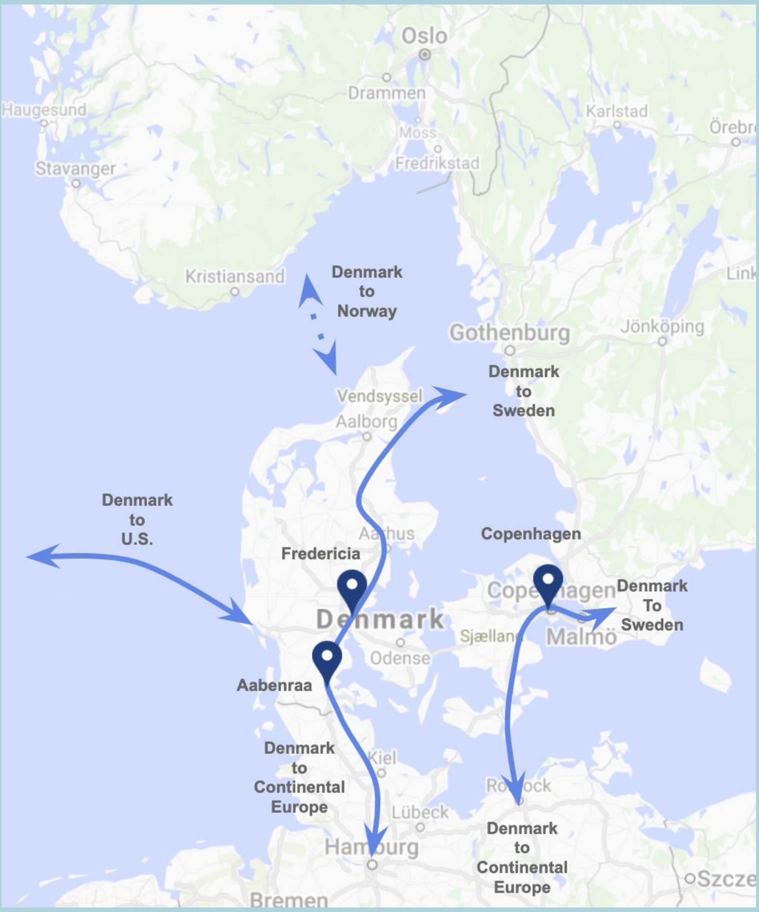


Fig. 1 Map of Danish connectivity investments involving Google

[17] Read more about these in the main report, found here.

Today, the Danish network infrastructure supported by Google's investments provides a critical corridor of connectivity between Northern Europe and the rest of the world. International connectivity between Google's data centres in Belgium, Ireland, and the Netherlands join up on multiple routes through Denmark to reach Google's Finnish data centre. In the future, as and when Google develops its Northern Europe DC footprint further, this will also increase the key role of the Danish diverse, open network infrastructure, available in a competitive market. Specifically, Google has invested so to support terrestrial connectivity between the Nordics and continental Europe. This includes key routes from continental Europe through Southern Denmark into North Jutland, as well as from Rostock, Germany via subsea links to Copenhagen and onwards to key Nordic locations. Furthermore, key international network infrastructures such as new subsea routes from Denmark to Norway are coming on stream, strengthening the pan-European network mesh.

Fig. 2: Havfrue, the first Trans-Atlantic cable from Scandinavia to U.S. since 2001

Looking beyond European networking, Google has invested significantly – working with a consortium of partners – to build the first trans-Atlantic cable from Scandinavia to North America since 2001. This new-generation submarine cable, called Havfrue (Danish for "mermaid"), links Denmark directly to the U.S. After a long voyage, this new inter-continental cable has already been successfully landed in Denmark and is expected to be in service by the end of 2020.

Fig. 3 The final bight crown of the Havfrue cable leaves the vessel

In addition to decade-long partnerships with international and pan European vendors operating in the Danish market, Google also supports local suppliers and Internet Service Providers (ISPs), by partnering on key 'last mile' connectivity projects associated with the data centre infrastructure. This has implications for Cloud enterprise services – both at a global and local/national level – meeting businesses where they are. Google's investments in networking infrastructure are expected to bring Cloud Interconnect to Copenhagen within 2020. This will enable Danish enterprises to connect to Google Cloud locally and access directly the latest Cloud services. Coupled with the forthcoming completion of the Fredericia data centre, this combined infrastructure will enable Danish Cloud customers to access leading edge technology at very low latency.

Source: Interview with Fionnán Garvey, Global Network Acquisition at Google in August 2020.
Further information on the role of subsea cables is in the Copenhagen Economics (2019) Google's Hyperscale Data Centres and Infrastructure Ecosystem in Europe.

5 DATA CENTRES HELP DIGITAL USERS CONSUME ENERGY MORE EFFICIENTLY AND SUSTAINABLY

Every time we choose to use services online, we channel indirect demand for energy. As traditional non-digital activities continue to shift to new digital applications, the way energy is being consumed is changing. Therefore, we need to examine

(i) the efficiency of this energy use;
(ii) the sustainability of its supply; and
(iii) the role of energy users' procurement in promoting renewable energy

Energy efficient provision of online services via cloud and data centres

Contrary to the belief that the rapidly increasing demand for data will lead to a one-to-one increase in energy usage, ongoing improvements in global data centre efficiency have prevented this from transpiring. In fact, **data centre energy usage over the past 10 years has remained relatively stable** (increasing by only 6 per cent), **despite the exponential growth in demand** for data driven services (by 550 per cent).[18] This confirms the energy efficient trajectory and achievements of digital solutions provided via cloud computing through hyperscale data centres.

While storing and processing data requires energy to deliver services, Google's solutions exhibit a meaningful improvement to the energy efficiency of this data-handling process. Large data centres like Google's site at Fredericia are significantly more energy efficient than the individual servers that they often replace. By pooling the server needs of many customers in this manner, a lot of energy can be saved. Indeed, we have analysed the yearly energy savings that moving service to a cloud-based provision delivers and we find significant savings (see calculation reported in the box below).

Sustainable supply of energy for data centres

As well as improving the energy efficiency of delivering digital services, Google also aspires to ensure that its energy consumption is as sustainable as possible. Since 2017, Google has matched 100 per cent of the annual energy demand of its data centres and offices with direct purchases of renewable energy on a global basis. Continuing to operate data centres with entirely clean energy is a key objective for firms like Google, the wider corporate world and our societies.

At the same time, even though the company buys a total amount of renewable energy matching its electricity use each year, it must still contend with times and places when the sun does not shine or the wind does not blow – indeed a society-wide challenge. During those hours, Google data centres (and likely most other energy users across the economy) often must rely on electricity sources such as coal and gas power plants, which emit carbon. Tackling this societal challenge, in a significant further step, Google announced its intent to run on carbon-free energy everywhere, at all times (24/7), by 2030.[19] In other words, the company is raising further its sustainability by shifting from a 'global and annual' match, to a 'local and hourly' match of clean energy to its use – a first in the corporate world.

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18 Masanet, E, et.al. (2020) Recalibrating global data center energy-use estimates

19 See Google (2018) Moving toward 24x7 Carbon-Free Energy at Google Data Centers: Progress and Insights and Google (2020) 24/7 by 2030: Realizing a Carbon-free Future, https://storage.googleapis.com/gweb-sustainability.appspot.com/pdf/24x7-carbon-free-energy-data-centers.pdf ; https://www.gstatic.com/gumdrop/sustainability/247-carbon-free-energy.pdf

Machine Learning and Artificial Intelligence tools can be used to help achieve this complex balancing act. Google is now integrating carbon-intelligent computing platforms into their data centres, having already tested such solutions. These systems would allow data centres to balance server usage with clean energy across time. This means that some percentage of that computing power can be shifted to times when greener sources of energy are in surplus. [20] The scale of the data centre matters in both achieving business and environmental aims, giving a socio-economic advantage to hyperscale data centres. [21]

Box 4 National energy savings of handling e-mail through the cloud

Many services can be handled through the cloud, but as an illustrative example we look at the implications of shifting e-mail handling services to cloud servers. This is, however, just one example where moving from in-house servers to data centre storage would greatly increase energy efficiency. An in-house e-mail server can use up to 175 kWh annually per user. This can be compared to the 3.3 kWh annually per user used in an average European data centre.[22] In contrast, Google's even more efficient data centres use only 2.2 kWh annually per user.[23]

For our calculation we assume that Danish firms that are not using cloud are using in-house equipment. We estimate the related electricity for in-house storage to be 124 GWh annually. This estimation is based on official survey statistics capturing the number of staff working with computers in firms of different sizes, and the share of cloud use by firm size. Average cloud use across companies is calculated to be 37 percent.[24]

Hence, moving all e-mail services to the cloud based in data centres with an efficiency equivalent to Google's would:

- Reduce current electricity use for e-mail services in individual companies by 124 GWh.
- Increase electricity consumption in data centres by 4 GWh.

Based on the distribution of firm sizes in the national economy, we estimate that the above corresponds to a net reduction in current usage of 97 per cent, equivalent to a decrease by 121 GWh.[25] This is broadly equivalent to about 8 per cent of annual consumption of electricity by Denmark's retail sector in 2018.[26]

Source: Copenhagen Economics, based on Eurostat

Renewable energy procurement supporting the Danish digital transformation

The high energy efficiency of the Fredericia data centre is one way in which Google supports sustainable digital services in Denmark. Further improvements to the overall sustainability of these

[20] See Google, (2020) Our data centers now work harder when the sun shines and wind blows (blog)
[21] Further information on energy efficiency is available in Copenhagen Economics (2019) Google's Hyperscale Data Centres and Infrastructure Ecosystem in Europe.
[22] Assuming that differences in energy use between Google's and average European data centres are due solely to overhead energy efficiency
[23] See Google (2019) Environmental report and Google (2011) Google's green computing: efficiency at scale.
[24] Eurostat data found in isoc_ci_eu_en2 (2018) and sbs_sc_sca_r2 (2017)
[25] Calculations assume that all the resulting new data centre activity is as energy efficient as Google's data centres (2011)
[26] Danish Energy Agency, Energy Statistics 2018

services are achieved through Google's energy procurement strategy. As noted previously, since 2017 Google has matched 100 per cent of the annual energy demand of its data centres and offices with purchases of renewable energy.[27] As part of this, Google has developed the largest portfolio worldwide of corporate renewable Power Purchase Agreements (PPA).

Via PPA deals, Google signs contracts with developers of renewable projects and supports the production of carbon free energy. Entering these transactions enables wind and solar farms to secure the financing they need to get built, something that is promoted by Google's intervention and commitment. In this way Google's operations in Denmark drive the development of new renewable energy assets.

In 2019, Google invested in the largest renewable energy purchase ever, consisting of 18 individual deals.[28] These deals include Google's first-ever PPAs in Denmark, totalling 167 MW of production capacity, namely:

- Næssundvej (25 MW – in operation) and Rødbyfjord (55 MW – completion due in 2021);[29]
- Gimming, Næstved and Nordjurs, for a total capacity of 87 MW (in operation).[30]

Case study analysis: Leading Danish power market players, enabling and driving the carbon transition

To understand the latest developments on renewable energy procurement and production in Denmark, we have conducted further research. We have focused on the energy developers and energy grid perspective on the role of PPAs and the functioning of the market for renewable energy – relying on the considerable expertise from Danish stakeholders. A key common finding across these case studies is that the financial certainty that a PPA provides for developers has emerged as a key driver for additional expansion of the Danish Renewable Energy sector. This insight stems from interviews carried out with leading players in the Danish power market, driving the carbon transition, which is a shared policy goal across Denmark and Europe.

Box 5 New renewable energy thanks to PPAs: developer Better Energy's views

Better Energy (BE) is a Danish renewable energy company focused on solar energy. It works together in the value chain as a vertically integrated player that designs, develops, engineers, finances, builds, operates and owns renewable power plants. The firm has not relied on public subsidies for the development of new projects since 2018 but has instead relied on PPAs to guarantee the stability needed.

"It is a historical turning point that it is now possible to install Solar PV without any financial aid"

This is possible due to a push from socially responsible companies realising that by demanding truly additional green energy, they can foster real change. According to BE, PPAs (absent subsidies) deliver "true additionality" in green energy projects. In turn, this has strengthened the

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27 Google (2020) Our data centers now work harder when the sun shines and wind blows.

28 See Google (2019): Our biggest renewable energy purchase ever.

29 Interview with Jonas Lau Forsberg Nihøj, Director of Energy Trade at European Energy, August 2020; https://europeanenergy.com/en/press-releases/2019/9/20/european-energy-signs-ppa-with-google;

30 Interview with Rasmus Lildholdt Kjær, CEO at Better Energy, August 2020; https://www.betterenergy.com/news/better-energy-has-signed-a-ppa-with-google/.

market. In some instances, PPAs with long-term conditions can today be signed (longer term PPAs span circa 10 years), which are an alternative for renewable energy producers and buyers to relying on spot market prices or traded power futures.

In BE's view, today, developing a new Solar PV project is not a mere question of price, but rather mainly a question of (un)certainty of future revenue stream. Thus, the key value of a PPA is not in the price obtained but in the guarantee of the revenue stream through a secured price and quantity of electricity over an extended period of time. This is similar to the concept of having an "anchor tenant" in place before initiating real estate development – it ensures just enough consistency and security of future income flows. Besides, price security is also important for the buyer.

Within renewables, alternative energy sources like wind and solar have different characteristics, while project Net Present Values (NPVs) are very site specific. Wind farms may generally reach a break-even point sooner than solar (an advantage for wind power), while solar farms may have generally longer lifetimes (an advantage for solar power). Thus, buyers have multiple advantageous options to seek renewable power.

The Klimapartnerskab (climate partnership) notes an aim to raise the current 31 TWh to 71 TWh, where new supply de facto needs to come from renewable power sources. The large potential here is for companies to drive this change. Indeed, without PPAs, BE does not see it possible for Denmark to reach a sufficient new renewable electricity production to meet the Danish policy aim of 70 % greenhouse gas reduction by 2030. PPAs will be an absolutely necessity in order to reach the 70% reduction target in Denmark, when it relies on 71 TWh green energy – otherwise the State has to take responsibility for the rest. In practice, company procurement is the only way to reach the goal: there is simply "not enough money in the Danish Budget Act" to drive the change through public subsidies.

Therefore, it is important to tackle barriers that impede the maximum potential of PPAs. First, lack of knowledge on PPAs is a barrier today – suggesting that thus education and information can play a valuable role. Second, legal complexity in establishing a PPA is an obstacle, especially for the smallest firms. Thus, it is key to define and promote "standard PPA deals", especially for SMEs.

"On this planet, we are only doing the green transition once, and one of the defining moments will be when the companies choose to be on the right side of the history – when they start entering into these PPAs"

Source: Interview with Rasmus Lildholdt Kjær, CEO at Better Energy, August 2020

Across Europe, Google has signed nearly 1,700 MW of PPAs with renewable energy developers, **making Google the largest corporate buyer of renewable energy** in Europe (it is nearly 5,500 MW globally, equivalent to a million rooftop solar panels).[31] As a result, it has been possible for every kilowatt hour of electricity consumed at Google data centres to be matched, on an annual basis, by a kilowatt hour of renewable energy from a wind or solar farm. Google's contracts have enabled investments in renewable energy projects across the world of over EUR 6 billion, including EUR 2.3 billion in Europe.

31 See Copenhagen Economics (2019) Google's Hyperscale Data Centres and Infrastructure Ecosystem in Europe.

Box 6 New renewable energy thanks to PPAs: developer European Energy's views

European Energy (EE) constructs wind and solar farms as well as venturing into large scale green energy storage – thus building solutions to climate change. It is currently developing and constructing parks in Denmark, Finland, Sweden, Germany, Italy, Brazil and Mexico.

According to EE, the Danish power market is well stocked with renewable energy to a degree that makes it unfeasible to engage in speculative projects, as without any form of price hedging these would be too risky to pass the business case and become a reality. Thus, all its recently initiated projects have been based on PPAs to provide certainty of the future income flow – i.e. hedging against future price volatility (which can be costly already today). Without this, EE would not be able to commit to a project. For example, the Google PPA made that renewable production project come to life – it was necessary for the Final Investment Decision (FID). All new projects are backed by PPAs.

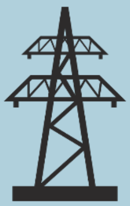
The market for PPAs has matured to a point where they are predominant drivers for additionality in the renewable energy sector – with the clients' demand playing the key role, compared to public subsidies. Since reliable and fixed off-take and prices over a long term are needed to secure financing for development of energy projects, the current and proposed future public subsidies systems can only contribute so much to the expansion of the sector. The reason is that the current subsidy system has minor effects on the price level (and volatility) and that the most important part for either support systems or PPAs are the impact on price stability.

PPAs deliver on that aspect, thus making the projects bankable, increasing the potential gearing (borrowing ratio set by the energy developer) and lowering the cost of borrowing and equity for the renewable energy developer (i.e. Weighted Average Cost of Capital, WACC). According to EE, there is still too little build-up of renewables in Denmark, while the current public subsidies system is not really applicable to EE or other small-scale developers. EE is confident to continue building renewable projects through good PPAs and sees PPAs as crucial for Denmark to reach a sufficient level of new renewable electricity production, so to fulfil the Danish policy aim of 70 % greenhouse gas reduction by 2030.

Source: Interview with Jonas Lau Forsberg Nihøj, Director of Energy Trade at European Energy, August 2020

Finally, we have sought a further expert the view from the perspective of the energy grid operations. In doing so, we have gathered additional detail on the functioning of energy markets, the role of renewable energy and prospective advances in the granularity provided via the renewable energy certificates and the incentives this may create towards a fuller green transition.

Box 7 The energy grid's role in facilitating the green transition: Energinet's views



Energinet owns, operates and develops the transmission systems for electricity and natural gas in Denmark. As a Transmission System Operator (TSO), it plays a fundamental systemic role overseeing the functioning of the electricity grid on behalf of the country. As a consequence, its role is pivotal in coordinating the integration of renewable energy sources. As discussed below, Energinet's endeavours to facilitate the tradability of renewable energy certificates fosters a healthy and efficient functioning of the market for renewable energy, thus furthering the country's sustainability aims.

While a TSO does not have a specific monitoring role on the market for PPAs, it is aware of an increasing trend in the number of agreements entered. While the bigger picture is still emerging, Energinet expects that the increased demand for green energy increases production – after all, that is how markets usually work.

A Guarantee of Origin (GO or GoO) is a standardised tracking instrument defined in article 15 of the EU Directive 2009/28/EC. It labels electricity from renewable sources to provide evidence and information to electricity customers on the source of their energy. A GO can be traded and when a firm buys a GO, the GO then gets cancelled in the electronic certificate registry, that makes it possible to track ownership and ensure that each GO is only sold once, thus without double counting.

However, GOs have built-in inconsistencies given that GOs are only denominated so to indicate the month and year in which the electricity was generated (rather than the hour), then GOs from solar PV can be used in the middle of the night.

For this reason – and as sought by energy users – Energinet is currently working on enhancing its Guarantee of Origin (GO) programme via new "Granular Guarantees of Origin (GGOs). This entails Energinet using production and consumption stats to issue GGOs denominated to specify which production hour and date they refer to. Besides, the system will rely on a blockchain "ledger" for added reliability and verifiability.

This will make it easier for a broad range of companies, whether those running data centres or any power-to-x producers, to ensure and document their progress in matching their specific energy consumption pattern to the renewable energy production (which is by nature fluctuating). Thus, GGOs will support energy users in their aim to maximise additionality of green PPAs, as well as aim to improve further the transparency of the Danish power sector.

The effect of GGOs is complex and systemic. Currently, renewable energy still fundamentally depends on the weather. For many times of the day/month/year, from an energy system-wide perspective, the marginal production is still fossil (e.g. coal) based. GGOs and hour-by-hour matching give rise to a question: If the producer, with which the energy buyer has a PPA with GGOs, does not produce (enough) energy at a given hour, what is an energy user to do? One option may be to look for alternative renewable supply options that deliver the relevant time profile, if available. A further option may be to shift consumption in time, insofar as possible. Over time, this can drive change in the market, both via the supply- and the demand-side. The wider socio-economic beneficial effects of take-up of GGOs by corporate energy users could include:

- Supply-side: foster greater room and incentives for other (less weather dependent) forms of green energy such as hydropower, biogas or power storage solutions
- Demand-side: induce energy demand to adapt so to reflect the time periods when the marginal production is renewable, i.e. move more consumption to when there is overproduction of green energy – thus improving the generation mix.
- Achieve regulatory aims as to guarantees of green energy in e.g. P-to-X and hydrogen projects.

Source: Interview with Nicolas Bernhardi, Business Developer at Energinet, August 2020

6 CLOSING REMARKS: A MULTI-SECTOR POLICY APPROACH TO REAP DENMARK'S AND EUROPE'S DIGITAL INFRASTRUCTURES' OPPORTUNITY

To conclude this study, we turn back and reflect on what, as economists, we have learned as part of this research journey and what related elements could be of socio-economic and policy interest. On this basis, our September 2019 study has highlighted exploratory suggestions on what to research and discuss further.

First, environmental considerations are top of the current agenda across Europe and achieving these will depend on vision, as well as attention to detail. Regulatory impediments can block or delay the private sector's role in fostering the green transition via smart procurement of renewables. National divergence in regulatory conditions and best practices can discourage efficient PPA procurement across Europe. The latter is key to satisfy the internet users' demand for digital services to be underpinned by green ICT, as firms and citizens transform their consumption from physical (and its energy inputs) to digital products and processes (and their energy inputs).

Second, the development of pan-European digital infrastructures involves a lot of nitty-gritty at the national and local level. This includes electricity network capacity, telecom infrastructure provision, educational systems delivering up to date technical skills – as well as traditional matters such as efficient planning and permitting processes.

Last, the topic of digital infrastructures is inherently multi-disciplinary. Just as the private sector (Google is a case in point) brings together experts from different specialisations to develop and make use of infrastructures – it is very relevant for national policy makers to come together, interact, and collaborate to ensure a timely and sustainable infrastructure development supporting the digital transformation. It follows that a combination of sectoral expertise and public policy processes (areas such as education, employment, energy, environment, planning, telecoms) are key to design in theory and ensure in practice, virtuous framework conditions for the development of digital infrastructures such as those analysed in this study.

Note on Covid-19: Our calculations are based on information (public statistics such Eurostat, as well as Google expenditure data) made prior to the recent Covid-19 pandemic. While the overall method, relying on Eurostat input-output tables, remains a relevant basis to assess economy-wide effects of investments, future research may shed light on any changes in patterns of economic activity across value chains. This will rely on any updates from national statistics, as they gather retrospectively information about economic activity.

Disclaimer: the reports are Copenhagen Economics analysis based inter alia on Google publicly available investment announcements.

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