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Critical analysis of Green IT in Belgian data centres

Author: Nick Dewachter

Supervisor: Bernard Paque

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Abstract

The ICT sector has experienced exponential growth in the last decades through the Fourth Industrial Revolution. This evolution was accompanied by many positive and negative impacts on different levels: social, economic and environmental. One of the most recognisable impacts is the carbon footprint of data centre storage, especially from the hyperscale structures of cloud providers. The aim of this qualitative study was to better apprehend the modern global phenomenon of Green IT by analysing its development and integration in the data centres, on a national scale. Different field experts were interviewed to that end, based on the main Green IT aspects identified in the literature review. It was revealed Green IT deployment in Belgian data centres is slow and requires new tools to optimise implementation and improve market interactions. After extracting the relevant information by themes, the adaptability of a framework was verified, and Porter's five forces model was applied to better understand the underlying mechanisms of Green IT in the ICT sector. Several recommendations were elaborated to highlight improvement areas and guide field experts in future initiatives. Finally, the study limits were detailed as well as some future research leads.

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"The price of light is less than the cost of darkness"

– Arthur C. Nielsen,

Glossary

AI	Artificial Intelligence
AR	Augmented Reality
AWS	Amazon Web Services
AWEX	Agence Wallonne à l'exportation et aux investissements étrangers
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BATX	Baidu Alibaba Tencent Xiaomi
B2B	Business-to-business
B2C	Business-to-consumer
BREEAM	Building Research Establishment Environmental Assessment Method
C2C	Customer to customer
CAPEX	Capital Expenditure
COVID-19	Coronavirus Disease 2019
CPU	Computer Processing Unit
CRAC	Computer Room Air Conditioner
CRM	Customer Relationship Management
CSR	Corporate Social Responsibility
DCE	Data Centre Efficiency
DEEE	Déchets d'Equipement Electrique et Electronique
DPM	Dynamic power management
DRAM	Dynamic Random Access Memory
EOC	Environment Opportunistic Computing

EPEAT	Electronic Product Environmental Assessment Tool
EPR	Extended Producer Responsibility
ESG	Environmental, Social and Governance
EUC	End-User Computing
EV	Electric Vehicles
ExO	Exponential Organisation
FCC	Federal Communications Commission
FVER	Fixed-to-Variable Energy Ratio
GAFAM	Google Apple Facebook Amazon Microsoft
GDPR	General Data Protection Regulation
GHG	Greenhouse Gases
GPU	General Processing Unit
HDD	Hard disk drive
HPC	High-Performance Computer
HVAC	Heating Ventilation Air Conditioner
IaaS	Infrastructure as a Service
IBM	International Business Machines
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communications Technologies
IDC	International Data Corporation
IEA	International Energy Association

IoT	Internet of Things
IP	Internet Protocol
ISO	International Organisation for Standardisation
KaaS	Knowledge as a Service
KPI	Key Point Indicators
LTDH	Low-temperature District Heating
MS-DOS	Microsoft Disk Operating System
NATU	Netflix Airbnb Tesla Uber
NFV	Network Function Virtualisation
NGO	Non-Governmental Organisation
NOC	Networks Operations Centre
OPEX	Operational expenditures
PaaS	Platform as a Service
PCP	Professional Conversion Programmes
PDE	Power Density Efficiency
PUE	Power Usage Effectiveness
RAM	Random Access Memory
RCI	Rack Cooling Index
REE	Rare Earth Element
REC	Renewable Energy Certificate
RHI	Return Heat Index
ROI	Return on Investment
SaaS	Software as a Service
SCADA	Supervisory Control And Data Acquisition
SDDC	Sustainable Distributed Data Centre
SDG	Sustainable Development Goals
SDN	Software Defined Networks

SHI	Supply Heat Index
SIP	Session Initiation Protocol
SOC	Security Operation Centre
SSD	Solid-state Drive
sPUE	system Power Usage Effectiveness
TCI	Thermal Correlation Index
TCO	Total Cost of Ownership
TE	Thermodynamic Efficiency
UNCOPUOS	United Nations Committee on Peaceful Uses of Outer Space
UNOOSA	United Nations Office for Outer Space Affairs
USA	United States of America
UPS	Uninterruptible Power Supply
VM	Virtual Machine
VPN	Virtual Private Network
VR	Virtual Reality
WUE	Water Usage Effectiveness
XR	X reality

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Introduction

The Fourth Industrial Revolution has brought a technological development and deployment as never seen before and is remodelling our societies to this day. Besides the associated positive aspects, many new concerns were associated to this exponential growth considering how the triple bottom-line – a framework to measure performance based on three pillars (People, Planet, Profit) – was affected. The consequential risks and impacts were mitigated to a certain extent, but new ones also appeared.

The different new inventions and applications in the ICT sector (e.g. Internet of Things, Virtual Reality, blockchain, Artificial Intelligence, social media…) produce massive amounts of data hosted in data centres. This data storage comes with a power price that is not only financial but environmental, and progressively came under scrutiny of the public eye. As technological development is only set to evolve positively in the following years, how do the involved stakeholders respond to such a challenge? Green IT and, at a broader scope, Sustainable IT, were phenomena born as a result of this problematic. To better understand the processes and underlying mechanisms, this study aimed at analysing how thoroughly Green IT is integrated in Belgian data centres.

It hopes to raise awareness on a modern issue at different societal levels for readers with different technical backgrounds. The intended audience of the study, the field experts, are most concerned by the recommendations on how to increase efficiency gains through Green IT and optimise market interactions. Besides the literary contribution on a very contemporary phenomenon, the final objective of the study would be to increase Green IT considerations and efforts in market dynamics thus contributing in sustainably improving the sector.

Considering the extent and complexity of the issue at hand, the focus was set on the environmental aspects, at the expense of other aspects. The research was divided in three parts, each composed of several chapters: a theoretical analysis, an empirical analysis and a conclusion. The first part sets the context of the work by defining the ICT sector and stressing the triple bottom-line impacts associated to the global data demand growth. Next, the corresponding data management procedures and existing developed Green IT strategies for more efficiency. Finally, it was explored how different tech leaders of the ICT sector applied these Green IT efforts to better understand deployment in practice. Based on the identified challenges and strategies, the empirical analysis investigated how Belgian data centres introduced Green IT in their infrastructure. It was based on the interviews of a diverse panel composed of ten field experts and set in a territory at the heart of Europe, home of decisive continental institutions and organisms. After offering how Green IT inscribes itself in the data centre field, the potential sector optimisations were laid out and the compatibility of a framework for the specific Belgian environment was evaluated. In the third and last part, the recommendations and managerial implications are laid out and discussed. The study limits are exposed with interesting new leads of future research.

First part: Theoretical analysis

Chapter 1: The global data evolution in the ICT sector

1.1. What is the ICT sector?

Information and Communications Technologies are defined by (Biradovolu & Nag, 2019) as "*any product or service that stores, retrieves, manipulates, processes, transmits or receives information electronically in a digital form".* They identify different areas that bring opportunities and disruptions to the ICT landscape in:

1. *Services and Business Models*: immersive user experiences (AR/VR/XR), big data, social media, social marketing, crowdsourcing, e-commerce, etc.
2. *Mobile Networks*, using mobile broadbands (3G, 4G and upcoming 5G), enterprise mobility, end-user mobility and Telco mobility.
3. *Infrastructure and data centres*, which encompasses cloud computing, virtualization and all software, infrastructure and process services for data storage.
4. *Core Networks* such as IP ones, software defined networking, SIP trunking, network function virtualization, etc.
5. *Regulations* in the likes of competition or monopoly laws, net neutrality and data privacy topics.
6. *Technologies* like 3D printing, Internet of Things, Artificial Intelligence, Machine Learning, AR/VR/XR, etc.

The ICT industry has evolved exponentially in what has been defined as the Fourth Industrial Revolution, which was built on the three previous industry transformations. The First Industrial Revolution introduced steam-based machinery, the Second Industrial Revolution was powered by electrical inventions and the Third Industrial Revolution saw its dawn through a digital transformation of the world. Exponential Organisations played an important role in driving the latest revolution. These organisations are defined by (Ismail, 2014) as the ones "*whose impact (or output) is disproportionally large – at least 10x larger – compared to its peers because of the use of new organizational techniques that leverage accelerating technologies*". The GAFAM (Google Apple Facebook Amazon Microsoft), and more recent NATU (Netflix Airbnb Tesla Uber) and BATX (Baidu Alibaba Tencent Xiaomi) represent the ExOs of the tech industry. This new breed of companies relies on disruptive innovation using digitisation to conquer entire markets.

1.2. Data demand evolution

The six different areas cited in part 1.1 are indicating a trend of exponential growth. As the digital transformation of our societies comes with the burden of managing more data (the concept of big data), it is important to consider the energy consumptions associated and how the leaders in the ICT industry are positioning themselves to face these new challenges. With the urgency of the climate change effects, sustainable practices have gained more traction globally. After defining the data evolution, we will analyse how the prominent tech leaders are reacting and particularly in one of the more observable aspects, infrastructure and data centres.

The increase in data demand the world is experiencing can be defined along the lines of the four V's of big data: Volume, Variety, Velocity and Veracity. The first V stands for volume, constantly increasing through the diversity and popularity of new technologies and thus requiring appropriate management guidelines. The phenomenon is best illustrated through the sales of technological devices, as they are progressively becoming part of our everyday lives. As an example, a forecast by (Statistica, 2020) estimates there are 3.5 billion smartphone users in 2020, a number growing yearly. The International Energy Association estimated that Internet traffic will double towards 2022 and mobile Internet users will increase by 1.6 billion towards 2025 (see appendix 1). From the 33 Zettabytes – or 33,000,000,000,000 Gigabytes – produced data in 2018, an estimated 44 Zettabytes are expected to be produced in 2020 and 175 ZB in 2025 (Coughlin, 2018). IoT alone would represent around 79.4Zb of this production following a forecast from the International Data Corporation (IDC, 2019). They evaluate IoT connections should grow from 7.5 billion in 2018 to 41.6 billion in 2025. Even though different sources have different estimates, the numbers are all exponential, meaning data management will inevitably need to adapt to such growth.

The second V, of variety, represents the many forms in which data appears, as illustrated in part 1.1. PwC identified the eight essential technologies to look at for business over the next three to five years which are also expected to affect all facets of our daily lives (PwC, 2017): artificial intelligence, blockchain, virtual and augmented reality, internet of things, robotics, drones and 3D printing. These are all ICT and at times interact closely. For instance, artificial intelligence has been present as a processing method in computers, robots and drones. It can also be linked to translation hearing devices and sport equipment which adapts to the user's body for example. The Internet of things brings data to our everyday lives at home and in our means of transport up to entire neighbourhoods (Google's Sidewalk Lab's or Alibaba's City

Brain). Blockchain technology applications are still being unravelled and explored, one of the most popular being the use of cryptocurrencies (Bitcoins, Ethereum…), already hinting at future customer purchasing behaviours. Overall, new technologies are being developed everyday by start-ups and tech giants in technology clusters like the Silicon Valley in San Francisco or more upcoming technology hubs like the "Startup Nation" in Tel Aviv, Israel. They affect almost every aspect of our lives (interactive museums, switch from cinema to streaming platforms, virtual travelling and more) and companies that cannot follow these deep changes brought by ExOs are set for failure.

Larger and faster broadbands – 5G in mobile networks for instance – also facilitate the deployment of these inventions and increase data flow - and thus volume - and represent the V for velocity of data. These bring up debates on health and safety concerns as radiofrequencies have potential damaging physical effects on living beings (cancer, genetic modifications, cellular destruction, etc.). The International Commission on Non-Ionizing Radiation Protection has recently updated its recommendations (ICNIRP, 2020) to indicate there is no reason to believe these frequencies have negative side effects – and so has the World Health Organisation – but the lack of thorough and recent research has been criticised. Scientists, professors and students have mobilised against the deployment of the technology claiming a lack of verification and a precipitated roll out by the telecommunications industry. Further research might therefore be necessary to deliver more evidence supporting or infirming the cause. Opponents have therefore submitted an appeal to the European Union to halt deployment and start an independent scientific study investigating more deeply the effects of 5G. This is one of the more recent debates on social impacts data evolution can have.

The veracity of data, as the fourth and final pillar of big data, has many facets. An example can be the trend of buying followers on Instagram - pointed by the finger as "The Follower Factor" by the New York Times in 2018 - deteriorates trust and reduces transparency. Brands such as Unilever, are starting to identify and disapprove this specific strategy by not collaborating with suspected influencers (Unilever, 2018). Data consumers are exposed to incredible amounts of information at rapid rate which can misinform and distort data leading to deteriorated decision-making. For corporate users, IBM research has estimated poor data quality costs the United States around 3.1 trillion USD a year (IBM, 2016). The different impacts (social, economic, environmental) are discussed in later sections.

Derived demand

It needs to be pointed out at that the energy use of demanded data is a derived demand of which the data user tends to be unaware of. On the diagram below (Figure 1), it is illustrated how the different stakeholders (public instances, business organisations, individuals) of different industries require innovations which are supplied by ICT companies. They sell their products and services, defined through the 4Vs of big data, to satisfy the data demand of customers and clients. This derived data demand from the ICT sector brings, besides the positive aspects, negative impacts. Those impacts are classified on the diagram in economic, environmental and social. The generated carbon footprint of data centres or living conditions of rare earth metals mining workers are some examples of externalities stakeholders might be unaware of. This is hypothetically due to lack of communication strategies from ICT companies on the consequences of data use, especially concerning energy demands. This could well be a common phenomenon in speed innovation, where a lack of preventive measures and feasibility studies for competitive advantages brings consequences that companies need to solve. As the old saying goes, “an ounce of prevention if worth a pound of cure”. The final box on the diagram thus represents the new solutions and processes such as efficient data storage infrastructure needed to limit the impacts and leverage potential economic benefits. This study focuses on that last box, but further research might deepen understanding of communication strategies and sensibilisation of ICT users on the associated impacts.

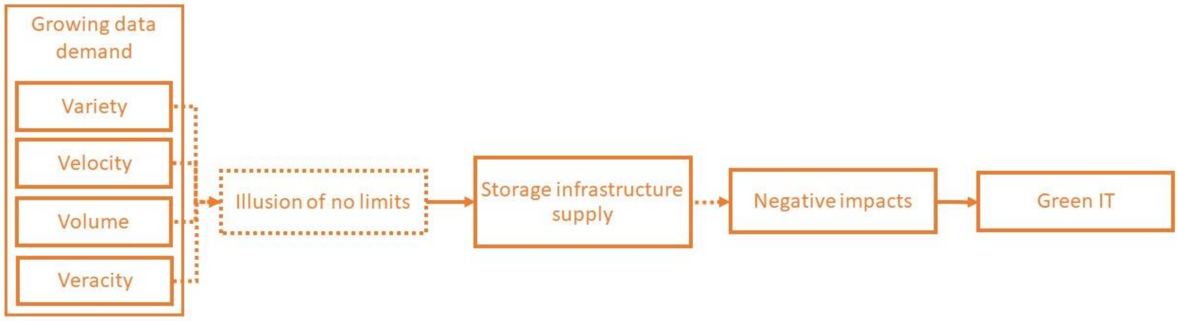

Figure 1: Derived demand (Dewachter, 2020)

1.2.1. Social, economic and environmental impacts

The following part illustrates the impacts on the triple bottom-line, which focuses on three pillars: People, Profit and Planet. Tables 1, 2 and 3 summarise the main points of each pillar.

Social impacts (People)

Our social structures and organisation have been affected by this new data demand growth in several ways. Physical and psychological risks are continuously being investigated and correlations established between, for example, magnetic waves causing cancer and altering cellular structure – as discussed in part 1.2 on velocity through 5G deployment – or between social media dependency and mental states. However, research requires time and hardly keeps the pace of new ICT development.

Besides the physical consequences of increased installed frequencies, psychological consequences and respect of ethical values have also raised concerns in the tech industry. New social behaviours seem to appear with excessive social media and online gaming addictions. Patterns have been suggested, drawn by the study of violent behaviours (terrorism, mass shootings, criminality) in relation to videogaming. Connections between depression, addictive substance consumption, gaming and sensibility have been subject to research. Furthermore, cyberbullying, isolation and suicide have been thought to be negative consequences of excessive data consumption causing depression, unhappiness and anxiety. An Origin study indicated 39% of Generation Z is ready to quit social media due to the experienced decrease in self-esteem. Tech companies (Facebook, Instagram, YouTube) have responded to these issues by offering new “wellbeing” sections (e.g. Google’s Digital Wellbeing initiative launched in May 2018) and time management features to limit unhealthy symptoms. In online videogaming, games and practices are being oriented towards more inclusivity between players. A report by (Wunderman Thompson, 2018) also raised the question of sexual discrimination and inequalities in machine learning systems. Think thanks and start-ups are hence exploring racial biases in data collection and sexism in the use of female voices for virtual personal assistants like Apple’s Siri, Amazon’s Alexa and Google Home. In the Big Tech playfield, the revenues of CEOs are also questioned and human right respect along the supply-chain (e.g. Amazon worker conditions or Apple in Asia). With information flowing at incredible speeds, new generations become increasingly aware of social and environmental issues and want to be able to trust companies for their transparency, empathy and authenticity. In the opposite case, they are exposed to an important reputational risk and consequential loss of customer base.

Information overload is another risk carried by increased data production. Continuous and excessive access to information has been thought to affect well-being and cloud decision-making in businesses. The possibility to replicate and multiply information available on thousands of platforms slows decision-making and decreases its quality but can also create attention deficit disorders. This brings losses to companies as the value of information received tends to be lower in certain cases and lose employee time. The issue of these interruptions is usually not considered a top priority by employers seeing as information has value and communication is important for a well-functioning society. Different software applications and filters (e.g. on mails) are still in development and could alleviate the problem (Hemp, 2009).

Next, data confidentiality and cybersecurity have been the fuel of many debates and scandals. With the emergence of new purchasing practices and companies willing to deliver hyper personalised services, data collection is at the forefront of defining target segments. However, in some cases companies have trespassed agreements, willingly or not, and data confidentiality has been breached. In the Facebook and Cambridge Analytica scandal, there have been accusations of using social media data to target certain profiles with political ads, biasing ballot objectivity. Similarly, the 2017 Equifax credit breach saw the personal information of hundreds of millions of people stolen due to a cyber-attack and the 2019 data leak Ecuador has also left user data of almost the entire population exposed in an unsecured database. Financial data, political ads targeting, government surveillance, e-commerce (marketing efforts, spams, personalised ads) are known examples illustrating the sensitivity of data and consequent importance of protecting consumer privacy and client confidentiality. In Europe, the General Data Protection (GDPR) was enforced to that end. Implemented in 2018, it authorises users to request access to their data stored by inline service providers and restrict the use made of their data by companies.

This matter is expected to increasingly become a discussion topic as tech behemoths rushing towards offering banking services. While Amazon started working with J.P. Morgan, Apple approached Goldman Sachs and Google announced a partnership with Citigroup Inc. This would give them access to valuable data on money incomes and purchasing habits. On the political side of things, it has been noticed political parties are targeting ads towards specific publics forcing tech companies to change policies. Google for example, announced it would limit election targeting to general categories like age or postcode. Using AI for decision-making and recruiting – avoiding human biases – has also been a discussion topic. While it allows a certain objectivity, having important decisions on people lives being taken by algorithms is thought to bring unfairness and legal issues. Concerning commercial purposes and public surveillance, the different channels through which data is collected nowadays also diversifies. Facial recognition opportunities are being explored by businesses, but it has already backlashed in certain cases, reducing audience trust in the technology. Smart Cities, which would use omnipresent surveillance – hence facial recognition – spark debate on personal life privacy (Wunderman Thompson, 2018). While it would be seen as invasive in Western parts of the world, the introduction of it in public spheres has been thought to be more accepted in countries such as China. Although there is no national data protection standard to this date, the development of new laws and a framework resembling the GDPR are a positive indicator of change (Sheng, 2019).

Some suggested solutions for data privacy management are thus being tried out by organisations like Loomia and Snips, allowing consumers to have control over their data which they can exchange and even sell for blockchain rewards. Google for instance, has announced a new Password Checkup and set up a privacy engineering hub in Europe (Google Safety Engineering Centre). Microsoft on their side, built two data centres in Germany with the use of a data trustee intermediate (T-Systems International) to complicate data access for US law instances and other governmental instances and empower customers through control over their data (Dignan, 2020). They have, however, been accused of lacking transparency on sales figures. Another movement by the name MyData, an association of non-governmental organisations (NGOs) and actors around the world, promote user data privacy, organise conferences and forums to help people manage their data better (MyData Global, 2018). Overall, different organisations – including some ICT companies – are starting to realise the importance of regaining user trust by having a comprehensive review of their privacy settings. In the end, transparency and clarity are expected to be key in gaining customer and lawmakers' trust before introducing new processes of data collection.

Summary table of social impacts

Social impacts	Effects	Responses
Physical risks	- Magnetic waves (cancers) - Work conditions	- Extended research - Whistleblowing
Psychological risks	- Dependencies - Violent behaviours - Negative mental states	- Wellbeing sections - Time limits - Inclusivity promotion
Information overload	- Slower decision-making - Attention deficits - Need to disconnect	- Filters - Personalised experiences
Ethical risks	- Sexual discrimination - Racist biases - Pay inequalities - Working conditions	- AI objectivity - Whistleblowing - Blockchain applications
Data confidentiality	- Transparency on data usage - Data sensitivity	- Empower users - Quantify data value - Data trustee intermediate - Limit political ads - Regulations (GDPR)

Table 1: Social impacts (Dewachter, 2020)

Economic impacts (Profit)

The economic impact of increasing data is best illustrated through the associated material investments and consumer spending on new devices. Companies saw their business model switch from expensive CAPEX for material assets like infrastructure, storage, cooling systems to OPEX in a pay-as-you-go model for third parties that manage their data. Cloud-based technology is thus conceived as a service and the heavy burden of upfront cyclical infrastructure costs are transferred to the third-party. This leaves room for the company to invest more assets in innovation and explore new markets (business growth) but more importantly, offers more agility in operations. Instead of periodically buying hardware at occasional peak demands, which are soon excessive when demand drops, resources can be mobilised instantly without opportunity cost losses and inabilities to serve customers (Superloop, 2020). Besides the significant associated savings, the ability to do real-time planning and execute projects in 24 hours instead of having to wait several months to realise these projects is not easily quantified.

It is a positive externality that is often omitted and needs to be included to fully capture the value of cloud adoption.

Cloud Technology Partners gave some recommendations as to how best capture the value of transitioning to cloud use. They first suggest looking at the Return on Investment (ROI) before the Total Cost of Ownership (TCO) as the latter evaluates more the spending and savings than value created. Examples of different value drivers in the ROI are accelerated time to market, improved developer productivity, decreased provisioning time and more intangible benefits. Next, they advise to take soft savings (e.g. customer satisfaction, employee morale, etc.) and cost avoidance (e.g. impact on reputation) into account for more precision and clarity on gained value. A third recommendation is to break down the value of agility by determining the degree of company change (innovation in the market) over time, the company's ability to adapt to change over time (company culture), relative value of change and individual perspective of change (between leaders in departments). Overall, when looking at these elements contributing to value, cloud adoption becomes profitable (net payback analysis) sooner (Cloud Technology Partners, 2016).

A second important economic impact of increased data availability is how to conceive its value in the personal and professional sphere. With larger and more complex data sources, the risk of deteriorated data quality increases (Watts & Shankaranarayanan, 2009). IBM has estimated that poor data quality can cost companies up to 3.1 trillion USD yearly. Amongst all the considered data evaluation methods, (Wang & Wand, 1996) reported the four most cited data quality dimensions as accuracy, reliability, timeliness and relevance. In the corporate sphere, a study by (Haug, Zachariassen, & van Liempd, 2011) states that a multitude of negative consequences from poor data quality can be cited: less customer satisfaction, internal trust, increased running costs, inefficient decision-making processes, lower performance, lowered employee satisfaction job satisfaction, effects on organisational culture and operational costs (in detection and correction). They also report that measuring the exact extent of data costs is difficult to estimate with large error rates and unclear inaccuracy margins and that remedying this lack of research is not prioritised by decision-makers. Two recommendations that stand out are for businesses to "make greater use of the data they have stored" and "start measuring their data quality to the extents possible". This could allow organisations to optimise their data management to a satisfying level. In the personal sphere, data has increasingly been used by governments and corporations and has gained value to which users do not necessarily have access. The different recent scandals are progressively raising awareness on the risks and profit made from data exposure. Allowing people to regain control of their data, knowing how, why and where it is used and decide to sell or keep it, are areas of discussion raised in forums and conventions.

On top of these aspects, modifications in purchasing preferences and consumer expectations brings more data volume. Companies in every industry (e.g. news media, travel, retail, healthcare, real estate) that are unable to follow the curb on digitization and adapt offer to new demand of tech-savvy generations, are at risk of being economically unviable in years to come. Magazine paper newsstands lost 60% sales volume from 4.9 billion to 2 billion USD between 2007 and 2017 following (Forbes, 2018). The shift of new generation towards online content forces printing companies to rethink and adapt their channels. Similarly, the travel industry needs to evaluate new future demand affected by fast-flowing information (desire to disconnect, authentic experiences, wellness destinations, Instagram destinations). Consumers are aware of market competitors and choose accordingly, sometimes creating boycotting movement against disappointing services and building preferences according to what they read online. The appearance of entire new areas to invest in also reward the most reactive brands. The online videogaming industry (e.g. Fortnite and League of Legends) and streaming of players is set to be an industry worth 300 billion USD in 2025. It opens whole new opportunities for brands to collaborate and partner with star players live-streamed by hundreds of thousands of viewers. On the retail side, this information exchange also brings consumer-empowerment with brands involving consumers on how to improve different processes of products and services and supply-chains. Valuable intelligence and loyalty can be gained in this manner. Entire physical lifestyles are adapted to the connection between stores and ICT and can scale up to entire future neighbourhoods. In Ikea’s Space10 Urban Village Project announced in June 2019, rent payments, bike renting, equity investments, manage food delivery, schedules of community activities and laundry services all happen on an app. In the Chinese marketplace, apps form a complete virtual e-commerce ecosystem as communication, delivery, comparison sites, platforms, banking apps are interconnected to facilitate consumer experience.

Summary table of economic impacts

Economic impacts	Effects	Responses
Switch from CAPEX to OPEX	- Cost savings - Agility, innovation and growth	- Capture value (indicators, soft savings and agility)
Data quality	- Less customer satisfaction - Internal distrust - Increased running costs - Inefficient decision-making - Lower performance - Lower employee satisfaction - Effects organisational culture - Operational costs (detection/correction)	- Efficient use - Increased use - Empower users
Customer expectations	- Market share loss - Boycotting - Reputational risk	- Customer involvement - Adapt to market
New markets	- New purchasing methods - New investment areas (gaming) - Physical and virtual ecosystems	- Explore opportunities - Reactivity

Table 2: Economic impacts (Dewachter, 2020)

Environmental impacts (Planet)

In a world where consumers have more access to information, become aware of environmental issues and form preferences, they have new expectations as to how companies of any industry adapt to respect their values. Additionally, failure to do so can have multiplied and long-term economic repercussions (reputational risk and damage) on these businesses.

Data centres are very energy-consuming and need a constant source of power input that grows with the number of centres built. This allows estimations of carbon footprints associated with data ownership. As an illustration, one e-mail and its attachments can produce around 50 grams of carbon dioxide (Telia, 2019). Seeing as an estimated 281.1 billion e-mails were sent in 2018 and an estimated 306.4 billion e-mails are anticipated to be sent and received in 2020, the negative impact becomes clear (Statistica, 2019). This has motivated the development of new initiatives such as the Swedish company Doconomy’s Do Black credit card which functions until consumers’ purchases reach their monthly carbon footprint limit fixed by the

United Nations 2030 carbon reduction targets. This type of new tool can challenge consumption habits significantly by making users walk-the-talk.

Increased production of technological devices and strong demand for renewable energy have also brought new urgent environmental challenges like the necessity for rare metals as inputs with additional preoccupations of recycling at end-of-life. A Science Magazine article by (Sovacool, et al., 2020) identifies the metals in question as cadmium, copper, cobalt, lithium and rare earth elements (REEs) like neodymium and dysprosium with largest needs for lithium and cobalt. These components are transformed and used in the supply-chain processes of photovoltaic panels, wind turbines, electric vehicles motors, fuel cells and nuclear reactors. With the growing global demand for these low-carbon technologies, more of the inputs is needed while facing supply shortage and price volatility. Many sustainability issues have been detected in the extraction and smelting industries for these minerals: environmental degradation, adverse impacts to public health, marginalised communities and biodiversity damage. In the Democratic Republic of Congo, it has been reported that women and children work for hours without basic safety gear, for small wages (and less than men) putting their bodies at risk to toxic metals. The extraction has been known to deplete water resources (e.g. Chile) and affect local ecosystems or in general reject chemical pollution in the atmosphere (e.g. China). Some suggested recommendations to improve sustainability strategies for rare mineral prospects are to diversify mining enterprises, to identify and remedy the lack of transparency, explore new revenue streams (recycling and alternative technologies), include minerals in climate change planning and include ethical factors in locating mining locations (mapping, treaties for efficient governance). Inscribing REEs in the circular economy (market transparency and full lifecycle reporting) could thus, following the authors, yield important social and environmental benefits. These benefits can rise for example from extended use of materials, increased stakeholder trust, inspiration for market players, decreased pollution, positive spillovers or reduced supply-chain instability. In a model designed by (Hart & Milstein, 2003), four categories englobe these benefits: cost and risk reduction, reputation and legitimacy, innovation and repositioning and growth trajectory. These strongly depend however, as explained by (Bhattacharya, Sankar, & Korschun, 2011), on the quality of the reporting and associated perceptions.

Recycling was presented as a promising solution to extend product lifetimes and continual reuse of materials. It encompasses closed-loop circular economy supply-chains, metallurgy advancements, reverse logistics, waste separation, materials science, waste processing and advanced recycling. The application of these strategies could be motivated and eventually, enforced, through extended producer responsibility (EPR) shifting the focus from the user to the producer. This framework can introduce new market programs to offer designs that facilitate repair, reuse and recycling in a circular economy model perspective. Finally, space mining could in the longer-term also represent new streams of resources.

The importance of feasibility studies is best illustrated with the Starlink project of SpaceX satellites. The Federal Communications Commission has accepted the request to launch the network in March 2018. It is expected to be complete in 2027 with around 42,000 satellites. However, it has been pointed out the FCC has not completed any environmental impact assessment which is a requirement in the US for federal agencies, enforced by the National Environmental Policy Act of 1970 (McFall-Johnsen, 2020). This type of assessment is needed to evaluate the impacts satellites have on astronomy science, due to the brightness, and on radio astronomy, due to the increase in radio emissions. Another potential issue is the use of mercury fuel, which is cheaper and more efficient, but could cause physical damages which have not been studied in detail enough. Knowing that competitors Amazon, OneWeb and Telesat are planning similar satellite designs, the situation is expected to worsen in the future. Technology is in this case developed and deployed at greater speed than legal and environmental concerns and could have irreversible consequences that would only appear in the longer term. Studies have shown that further distance to Earth can limit the negative effects, but SpaceX and competitors set up or planned to set up their network at 550 kilometres, half of what was first announced (Williams, 2019). A study in the Cambridge University press (Losch, 2020) summarised the different externalities humans might encounter in space exploration such as space mining, space pollution (9,611 objects in outer space registered by (UNOOSA, 2020) see appendix 2), forward and backward contamination and space privatisation or commercialisation. It concludes that even though space exploration seems like the next “logical” step in human history, more clarity and legislation is needed to ensure processes and steps are done sustainably. Hence, the concept of “planetary sustainability” has been introduced and the eventual necessity to include planet considerations in Sustainable Development Goals (SDGs). So far, the long-term sustainability guidelines for outer Space have been redacted by the UNCOPUOS, but these are considered ‘soft laws’ and are not enforced.

Summary table of environmental impacts

Environmental impacts	Effects	Responses
Carbon footprint	- Energy demands - Heat/cooling management	- Inform and empower users - Efficient equipment - Efficient design
Rare earth elements use	- Scarcity - Environmental damage - Public health risks - Marginalised communities - Biodiversity damage	- Diversify mining enterprises - Improve transparency - New revenue streams - Planning - Ethical mapping - Producer accountability - Recycling/reusing - Space mining
Space exploration	- Observation perturbation - Radio perturbation - Mercury fuel - Space pollution - Space privatisation - Contamination	- More technical and feasibility pre-assessments - More legal guidelines (planetary sustainability)

Table 3: Environmental impacts (Dewachter, 2020)

1.2.2. External impacts

Data flow can also be disrupted by external impacts such as global diseases, terrorism and extreme weather events. The risk exposure (geographical location) and risk reduction or response strategies implemented determine how much business continuity can be affected and the impact on the organisations' reputation. The three main aspects are summarised below in bullet points and developed in detail in the appendices (see appendix 3).

i. Coronavirus Disease 2019 (COVID-19)

- Lack of real-time data accessibility on the phenomenon
- Data on power consumption was clouded by observable trends (e.g. season temperatures, oil price war between Russia and Saudi Arabia and national holidays)
- Decrease of power use due to factory closure

- Increased domestic Wi-Fi use (videoconferencing, online academic courses, video streaming and videogaming)
- Opportunities for videoconferencing platforms providers

ii. Extreme weather events

- Supply-chain disruption and danger for communities
- Mitigation by improved global weather forecasts detection systems from tech leaders
- Presence of disaster recovery experts in data centres to prevent disruption
- Prevention by solid centre construction at design stage (e.g. backup power, redundancies, water pump)

iii. Terrorism

- Direct physical terrorism with some buildings more at risk (e.g. airports, nuclear plants, data centres) mitigated by security measures
- Direct virtual terrorism (e.g. data theft, cyberterrorism…)
- Indirect terrorism through social media use

1.3. Data management

1.3.1. What is cloud computing?

Ranger S., (2018) described cloud computing in simple terms as "*the delivery of on-demand computing services – from application to storage and processing power – typically over the internet and on a pay-as-you-go model*". It allows for businesses to rent infrastructure from a cloud service provider and hereby avoiding expensive CAPEX and maintenance complexities. The providers on their side, can scale by offering similar services to multiple customers. These services range from online communication to video streaming and storage of video and photography content. The concept has evolved from time-sharing computer bureaus in the sixties to the application service providers, utility computing and grid computing in the late nineties and early 2000s to reach cloud computing at hyperscale and software as a service today.

It is therefore necessary to differentiate Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). The first offers all the fundamental blocks such as physical and virtual servers, storage and networking. It has been reported to facilitate innovation, speed up new services deployment and decrease maintenance costs at the constraints of companies needing the technical skills to manipulate the service and security concerns. The second, PaaS, adds to these first three blocks all the tools and software for developers to build applications in the likes of middleware, database management, operating systems and development tools. Finally, SaaS is the most familiar computing model to the user, accessed through a web browser or an app and bought per-user or per-seat. It has therefore been estimated that customer relationship management (field in which Salesforce is a large player) and enterprise resource management will represent up to 60% of the cloud application spending up to 2021.

Besides the saved costs on equipment and maintenance but also opportunity costs (having equipment not used in low demand periods), shifting to cloud computing also brings agility benefits that are not easily quantifiable and better skills and experience of the provider. However, it also means a provider can host a company and its rival(s), therefore hindering a potential competitive advantage. Then there is also the necessity of having an Internet connection, a growing realisation of talent and skills shortage and indications that ultimately, costs outweigh savings. An article by (ZDNet, 2017) explained companies have switched from migrating all applications to an app by app shift as unexpected migration costs rose. While it is more cost-effective for applications that have usage peak demands, it is not always for the application that have predictable demand patterns. Migration costs can include the need to rewrite application for better management in the cloud, the transition fees between systems, the incentives to retain talent or train people in data migration, software database license, performance issues after migration and latencies between on- and off-premises applications. When shifting from a “traditional” structure to cloud computing and make a business case for it, it is therefore necessary to consider costs for the existing infrastructure, for data centre operation, physical hardware (Computer Processing Unit (CPU), RAM, cores), storage, applications, people and intangible benefits. A careful analysis must be carried out beforehand of the benefits and disadvantages of both systems.

There are other considerations for cloud migration such as security – especially during the transition periods – increasing the development of cloud security tools and geographical location. The latter brings concerns for latency (distance to infrastructure), data sovereignty (e.g. US law enforcement access to data), regulation (e.g. China’s strict tech laws) and security (e.g. “digital fragmentation” is a barrier to globalisation as countries redact legislation for privacy and security). Three types of clouds can be identified – public, private and hybrid (mix of the two latter) – and the providers generally sector the centres close enough to each other in cloud computing regions or cloud computing availability zones. The preferred strategy is to have a multi-cloud hybrid cloud computing strategy. This is justified by reasons like not being locked with one vendor (as providers generally try to make their platform in a way that keeps clients from switching), avoiding shadow IT (being unaware by accident of the strategy because of different business units' decisions), increasing performance (less latencies), compliance (GDPR requires user data to be located in certain places) and providing resilience against outages.

The giant public cloud providers are Amazon Web Services, Microsoft's Azure, IBM, Google Cloud Platform and Alibaba Cloud followed by Fujitsu, Salesforce, Oracle, NTT and Rackspace Technology to name a few. Their strengths vary as Amazon Web Services (AWS) is mainly IaaS and PaaS while Microsoft focuses on SaaS but is progressively growing in the other two categories. Google is in between both, Oracle and IBM are mainly SaaS and infrastructure offerings and Salesforce is active in SaaS.

Overall, cloud computing still has room for evolution and companies can be attracted either by the global digital transformation argument, which they can use as justification in their transformation, or by the cost savings argument. Analysis by (Gartner, 2019) have estimated that the worldwide public cloud service revenue will grow by 17% between 2019 and 2020 from 227.8 to 266.4 billion USD. In that market, SaaS is the largest segment and is expected to reach 116 billion USD of revenue due to subscription-based software. IaaS is expected to grow 24% yearly (largest growth in the market) and reach 50 billion USD in 2020 with the demand for modern applications and workloads. PaaS, like the two latter segments but to a smaller degree, has also grown more than expected by analysists. The (Synergy Research Group, 2020) on their side, estimate that 2019 spending on datacentre hardware and software reached 152 billion USD, up 2% from 2018.

1.3.2. What are data centres?

Considering the growing demand for data and the shift to cloud computing, infrastructure had to be built to host all the bytes that came with this revolution. The idea for an IT company is to collect a client's data in one place to facilitate data management through security, scalability, redundancy and constant availability. They can then manage the client's services from a networks operations centre (NOC), security through a security operation centre (SOC) and access infrastructure through a secure VPN connection which solves some problems of local expert scarcity. Even though around 2.3 trillion gigabytes need to be stored daily, there have also been notable efficiency gains over time. A recent blog article by a Google technical structure president, has indicated that between 2010 and 2018, computing with data centres has increased 550 percent while the energy consumed by centres has only increased 6 percent (Hölzle, 2020).

A data centre is defined by (Cisco Systems, 2020) as "*a physical facility that organisations use to house their critical applications and data*". They are composed essentially by routers, switches, firewalls, storage systems, services and application-delivery controllers. Facilities are also equipped with physical security (cameras, fire extinguishers, guards, controlled access), cooling installations of totally separate circuits and power emergency units (Uninterruptible Power Supply (UPS) and electrical generator units) and network connectivity. Connectivity is qualified as carrier-driven if set up based on supply, carrier-neutral if based on demand and if the provider also offers data centre services, the term carrier-hotel is used. Stress tests are carried out to verify the correct functioning of critical elements in the data centres. There are over 8 million data centres globally, of which at least 504 are hyperscale farms following an analyst firm (Sverdlik, 2019). They are categorised in four tiers (1 to 4) based on redundancies, batteries, generators and work downtime but can also be subdivided by type as enterprise data centres, managed services data centre, colocation data services and cloud data centres. As discussed in part 1.3.1, there was a first wave of internal data centres and IT teams in each company followed by a second wave that concentrated the data in pools off premises and the third wave characterised by a shift to cloud, hybrid-cloud and cloud-native.

A news report by (ConneXie, 2016) indicates that data management is still in a development phase that will meet important challenges. New equipment and the cloud form the future Zettabyte structure to complete our hyperconnected world. Some speculate that edge computing will be the next step. Our smartphones might then become the closest data centres (as expressed by (ConneXie, 2016), "*bring the centre to the data instead of the data to the centre*").

In 2016, Belgium had 37 data centres with a strong majority in the Flanders and Brussels as illustrated on the figure below. The green points illustrate carrier-neutral data centres with multiple telecom providers, yellow points are transit neutral data centres, red points indicate telecom-carrier private data centres, purple points are public cloud providers (e.g. Google) and blue points are data centres out of service. The report considered the top 10 most important Belgian centres as Antwerp DC, Belgacom Net Centre, Colt Technology Services, Datacentre Oostkamp, Interoute, Interxion, LCL, Level 3, Mobistar and NRB.

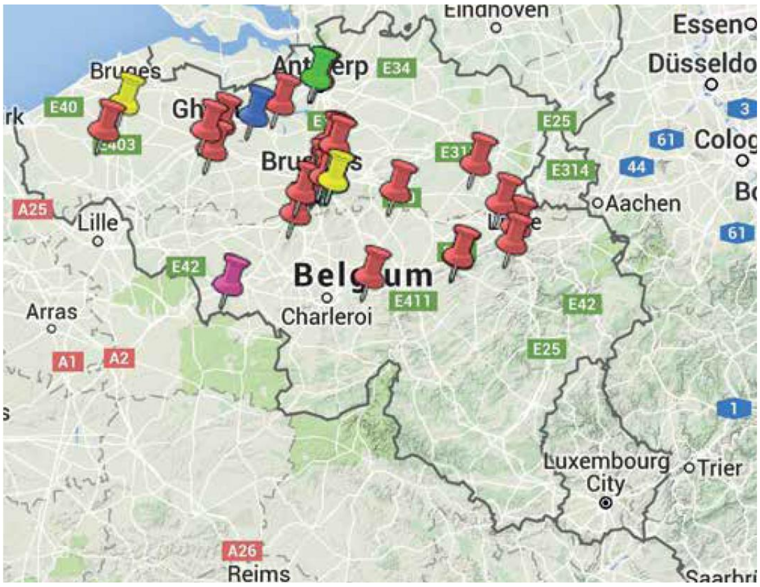

Figure 2: Belgian data centres (ConneXie, 2016)

The Walloon region would therefore like to attract more tech companies for the associated benefits (positive externalities such as job creation, modern image of the country as a digital hub, etc.). In that perspective, a campaign by (Wallonia Export-Investment Agency (AWEX), 2018) tries to attract data centres by setting forth six benefits in the region which are:

- Fast connectivity (e.g. optic fibre);
- Advantageous taxation;
- Competitive operating costs (low electricity prices but also accessibility);
- High-qualified workforce (universities and research centres proximity);
- Ideal weather conditions (rain/earthquakes);
- Numerous plots of land available (18 potential sites for tier 3 or 3+ centres in an area of 6 to 191 hectares).

These are some site selection criteria operators should consider, following the AWEX. (Engie Cofely , 2013) also identifies stable social conditions, absence of airports or nuclear plants nearby, risk of flooding and outside Seveso zones. A report by (ConneXie, 2016) has pointed at the reasons Belgium is not a top destination for data centre operator. They argued that the country is:

- Too small, as a minimum distance between tier 4 facilities needs to be of at least 50 kilometres;
- Too expensive energy-wise (costs and excessive taxes);
- Too unstable energy supply (break-out risks, old networks not adapted for renewable energy sources);
- Limited due to legal restrictions (multiple connections needed for a tier 4 centre and many construction regulations);
- Limited due to fiscal restrictions (investment profitability of 20 years at least);
- Lacking competition (Proximus prominence);
- Limited in connection points or "knots" to the European network (e.g. AMS-IX) besides Brussels.

The last point is justified in opposition to the Netherlands, where the Google data centre is situated close to the Internet sourcing cables coming from overseas.

Chapter 2: Green IT

2.1. What is sustainability in ICT?

The Brundtland report defined sustainable development as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (United Nations Brundtland Commission , 1987). Based on a collection of different article definitions, (Moore, Mascarenhas, Bain, & Straus, 2017) recognise that when defining sustainability, certain elements need to be detailed: the time period covered, the implemented strategies and/or program, the maintenance of observed behavioural change, the possibility for the program or behaviours to change in the future and the continuous benefits provided to individuals and the system in general. This study focuses on the sustainability aspects and especially the environmental axis.

Fujitsu has completed a benchmark of sustainability efforts that can be applied at a company-level looking at End User Computing (EUC), Equipment Lifecycle, Enterprise and Data Centre, Technology Enablement and Metrics and following a constructed index score (Fujitsu, 2014). Advice on how to improve each area is offered to guide individual companies in their path to more sustainability. For EUC, advice consisted, amongst others, in removing screen savers, print to tablets for less paper consumption, install power management software.

To improve Equipment Lifecycle, organisations were invited to discuss end-of-life take back policies with vendors, set up environmental standards (such as Electronic Product Environmental Assessment Tool (EPEAT)) internally and inform on the products components and future recycling. The report states that not only does managing products at the end of their lifecycle makes sense for ethical and compliance reasons (avoid reputational damage risks), there could also be many economic opportunities to explore e-waste management. Re-allocating existing resources can unravel hidden value for low to no cost. In the Enterprise and Data Centre category, the study suggested: light sensors for Data Halls, rack blanking panels for improved airflow, control internal and external (heat reflective roof paint) temperatures, increase chiller flow, use adjustable floor vents, repair leaks, implement under-floor pressure control systems, install aisle temperature containment and stay informed on guidelines (e.g. Green Grid). Next, the report mentions technology enablement, which considers how new technology can drive sustainability gains not only in the organisation but in society in general. Finally, the last area Metrics stresses the importance of measuring and monitoring costs and consumption, because, as the marketing Peter Drucker said: "*If you can't measure it, you can't improve it*". This allows clarity and accountability on financial and managerial levels but has not usually been the priority for businesses.

To increase sustainability in a company, the recommendations included using meters, creating a separate Green IT budget, calculating employee and organisation energy consumptions, measuring Power Usage Effectiveness (PUE), making managers accountable and defining benchmarks. Businesses need to analyse their processes and identify which areas could be digitised to save costs and increase efficiency (digitisation and automation have been identified as necessary ExO characteristics). This report by Fujitsu is a general overview of the many levels on which companies can act to become more sustainable.

2.2. What is Green IT?

Green computing is, following (Shuja, et al., 2017), a concept that implies resource efficiencies are maximised, re-used wherever possible, sustainable practices are adopted and green initiatives in other industries are supported with monitoring and management tools. They categorise the "green" cloud data centre technique operations in resource management with virtualisation (virtual machine migration), waste heat utilisation and renewable energy production for improved sustainability and resource scheduling with 'evolutionary' algorithms. The two latter can be redefined as reusing (waste) energy and reducing the use of energy.

The same article distinguishes best practices environmental-wise in the following emerging IT technologies: cloud computing, mobile computing, big data analytics, IoT and networks. Each of them presents challenges and solutions: green cloud computing, for instance, requires a considerable increase in renewable energy efficiency, storage mediums and Virtual Machine (VM) migrations with additional government incentives for green cloud providers and users. Mobile computing requires better battery resource usage which could happen by estimating operational costs (energy and execution time) and code storage location. For big data, where introducing efficient mechanisms can significantly impact the analytics making it highly desirable, more research is needed. In the case of IoT, the challenges to implement energy-efficient practices are the incomplete standardisation of IoT Architecture, the difficulty of redeploying exiting IoT infrastructure, the communication protocols and reliable connectivity and implementation of security and privacy algorithms (QoS). Finally, green networking could be possible either through Software Defined Networks or Network Function Virtualisation even though more research is needed as they are still in early stage of development.

Overall, the study concluded important endorsement by IT industries and IT empowered businesses to complement and prove the efficiency of the energy practices are needed. It gives us more insight on different existing procedures and their current development status. The following part will focus more on the main strategies recommended by (Shuja, et al., 2017): virtualisation, sustainability through renewable energy production and reusing energy and reducing energy use.

Virtualisation

The first category, virtualisation or VM migration, is a way to balance the mismatch between the data centre's workload demand and energy availability by migrating servers. As explained by (Shuja, et al., 2017), the two main challenges it answers are resource wastage and server overload. By using intelligent algorithms, it can automatically allocate energy efficiently. The original virtualisation layer consolidates the data centre through different backup techniques in the likes of backups and snapshots. It is now increasingly used for resource consolidation and energy optimisation by migrating servers in combinations hereby sparing unnecessary energy consumption. In inter-data centre use, network costs are reduced by data deduplication and compression techniques for long distance communications. In intra-data centre use, the network costs are reduced by grouping related VM for limited communications between servers. The virtualisation method could also be particularly appropriate for renewable energy allocation as their loads vary following time and geographic location. As an example, a solution being developed by Google, in partnership with Tomorrow, would forecast weather patterns to determine when to effectuate heavy workload tasks depending on renewable energy availability.

Data centre sustainability

Reusing (waste) energy

The different processes at the core of the data centre produce heat which can be released or recollected. It can be used internally, for example, to heat offices or externally in district heating. Data centre location, waste heat price and quality are the main factors in determining the potential use of heat for district heating. The solution is particularly adapted in the Northern countries where there is a strong demand for heat and where the cold environment presents perfect conditions to naturally cool data centres without need for energy. In 2015 for instance, Finland had 3.3% waste heat in district heating, while Sweden was at 8% in 2014. A study model has determined waste heat utilization saved 0.6% to 7.3% of operational costs in the used district heating system depending on the utilisation (18.7 to 58.5 MW). The profitability depends on which units are replaced in the system and might affect the electricity supply.

The issue that arises is that supply can fluctuate depending on the data centre contracts. While data centres heat unit production systems have a lifetime of 40 to 45 years, client contracts last one to five years. The more contracts district heating operators have, the more data, the more heat produced. District heating operators would therefore need to pool multiple data centres to satisfy their heat demand, which is not always possible. To buffer fluctuating demand, which can last between a few hours to months depending on the technique used, thermal storage could be a potential solution. For colder countries another alternative to district heating could be Low-Temperature District Heating (LTDH) networks. Overall temperatures in such a system are lower and the concept is to make consumers prosumers where they produce and consume heat. Coupled to LTDH there is the option of Environmentally Opportunistic Computing (EOC) which consists in modular servers integrated in office buildings and representing nodes to the system. It is also linked to reducing the energy use discussed in further sections. This would also facilitate thermal storage, more efficient with lower temperatures as there is less heat loss.

In a district heating system, temperatures vary around 75 to 120°C depending on outside temperature. With housing being better insulated, there is a lower energy demand, so district heating is striving for lower temperatures and can therefore be supplied with lower quality heat by data centres (usually below 85°). The question is therefore if waste heat is reliable enough to supply district heating. New solutions offered by start-ups such as QPinch (Borealis, 2018) can lift up waste heat to provide higher industrial heat using chemical processes (phosphoric acid), making cooling towers obsolete. This new solution was inspired by store and release processes of living cells. An article in the "*De Tijd*" newspaper claimed it could save thousands of metric tons of CO_2 and save from 10% to 30% on energy costs (operational costs and electricity use) depending on the sector (De Tijd, 2018). Finally, besides the fact that there needs to be an actual demand for heat, it has been determined an incentive – which can be economic or ethical – for heat providers and district heat operators to reuse their waste heat needs to be in place.

Renewable energy production

Another way for data centres to be more sustainable by implementing Green IT is to use renewable energy for their operations. The centres can produce their own renewable electricity on- or off- site as a direct input, which brings the challenge of balancing demand and supply following the weather conditions and time of day. Electricity storage options are limited, with hydrogen through electrolysis or fuel cell applications. Otherwise, they can also buy them from a third-party – usually off-site – if there is no space or time to build their own technologies. The green energy is thus bought from external providers (through green certificates, guarantees of origin or power purchase agreements) for a contract duration to offset their personal emissions and claim carbon neutrality. The renewable energy is therefore usually not pumped directly into the data centre, but into the grid. However, the centre is not always connected to the same grid, which has brought some questioning about how to best measure the actual effectiveness of Green IT. As the centres can buy renewable energy for one grid but use electricity unsustainably on another grid.

Reporting has therefore been put forward in several models and by several NGOs such as (Greenpeace, 2019) that have accused the lack of transparency in some ICT companies. The concept of 'Material Passport' has been introduced by (Salama & Kass, 2020) to more precisely trace data centre lifecycle.

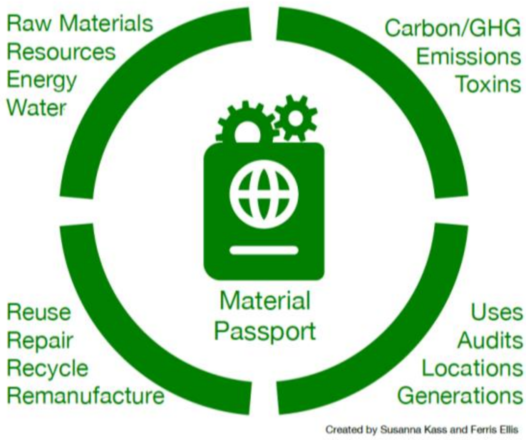

Figure 3: Material passport by (Salama & Kass, 2020)

It identifies four areas that are constantly monitored: inputs used (resources, energy, water and raw materials such as rare metals), environmental factors (carbon/GHG, emissions and toxicity), sustainability opportunities (reuse, repair, recycle and remanufacture) and verification tools (audits, uses, locations and generation). The objective of such a passport would be to fully capture value over multiple generations, maximise lifespan of used materials and reduce negative externalities. Moreover, due to its digital form, it would allow greater transparency and clarity for the owners on the different lifecycle stages of the centre: design, site selection, construction, operation, maintenance, growth and disassembly. The report concludes that the combination of this Material Passport with the three other axes of Sustainable Data Centre design, constant powering of renewable power and triple zero (carbon, emissions, waste), could inscribe data centres in a circular economy paradigm. It allows a more holistic view of Green IT in data centres – of which energy is one of the inputs – stressing other important elements in circular economy models such as monitoring, governance, advocacy, water usage, land impact, rare metal management and verification tools.

Reducing energy use

Using available resources more efficiently can mean performing more with the same energy amount or having the same performance using less energy. Even though Internet traffic and data centre workload is constantly growing, efficiency gains have stabilised global energy use at 1% to 1,5% which is around 200,000 GWh. (Kim & Lee, 2011) suggest different methods to improve energy use: reducing the power consumption of servers and equipment, modify the data centre's architecture (with location selection for additional benefits), smart use of cooling and heating equipment and efficient power management systems. The latter allows to dynamically switch on and off certain parts of the data centre following demands.

Despite impressive technology developments over the last decades, it is complicated for system resources to keep up with exponential data growth. It drives higher processing costs and data storage capacities, thus driving energy consumption and cooling requirements. To install less energy-intensive equipment versions, measurements and monitoring of several indicators are necessary. Basic storage systems can be rendered more efficient on a component-level, by improving the equipment technology and design (HDD, SSD, DRAM), or on a system-level, looking at data layout, movement and processing operations for example. Dynamic Power Management allows for components to function at different power modes (i.e. disks and memory chips spin at different speeds, processors at different frequencies…) and therefore save energy. Disks for instance, have different operating modes – active, idle or standby – that can affect power consumption. The challenge is to decide when to switch states without affecting performance at the expense of power saving. DPM can be installed at a hardware and/or software level even though the latter offers more flexibility. These components combined and multiplied can form a larger structure.

Generic data centre energy efficiency must be monitored by measuring the Power Usage Effectiveness (PUE), the data centre efficiency, system power usage effectiveness and fixed-to-variable energy ratio. These help to understand where inefficiencies are located and how to quantify the centres' performances. The most common indicator introduced by Green Grid consortium, the PUE, measures how much of total consumed energy by the data centre is allocated to IT equipment. The perfect score is thus 1 (and 1.6 is a good average score), meaning no energy is needed for cooling, lighting, power back up and so on. Despite the presence of these indicators, it must be pointed out that tech companies have different degrees of transparency which can complicate access to their data and thus compare different players. Amazon for example, has been criticised by Greenpeace for their lack of transparency (Greenpeace, 2019). Furthermore, it has been recommended to go further than power indicators and look at the Water Usage Efficiency (WUE), land impact, ocean ecosystem impact and airspace bandwidth. Google for instance, has been criticised in recent years for their excessive water usage in data centres.

Several state-of-the-art data centre architectures – all symmetric structures – like the balanced tree, fat-tree or Clos technology, BCube and DCell were investigated by (Kim & Lee, 2011). They then tested a new structure (usually asymmetric, scale-free network) based on biological plant cell features named Scafida. The benefits of the latter are scalability and flexibility which would potentially be useful for data centres. By looking at servers and switches, where symmetric structures could engorge much less servers than asymmetric designs, they concluded that power consumption was lower for the scale-free designs. Another explored structure that could present energy efficiencies by the authors are nano data centres. These would work on a peer-to-peer model, dissipating heat by their repartition and a reduced intra-network traffic because of colocation. NRB suggested some architecture optimisations for energy efficiency: cold corridors to avoid temperature mixtures, adaptive lighting (that consumes 50% less), grids on floors (more efficient than tiles with holes) and special cable tunnels to avoid cold air loss.

Cooling and heating systems are part of the most energy-consuming elements in a centre. The two main conditioning systems are the Heating Ventilation Air Conditioner (HVAC) and Computer Room Air Conditioner (CRAC). Replacing this infrastructure represented consequential expenses but is now considered before construction in new facilities. The main HVAC metrics to determine cooling efficiency are the Thermal Correlation Index, the Rack Cooling Index, the Supply Heat Index and Return Heat Index, the Power Density Efficiency and the Thermodynamic Efficiency. These indicators help define which improvements are needed. Some models have been developed to place workloads in a thermal-aware context allowing a better control of heat and less use of cooling facilities. External location can also play a role as cooler countries allow the use of outside temperatures for cooling in the centres. This has the benefit of reducing the need for cooling systems. A study by (Wahlroos, Pärssinen, Manner, & Syri, 2016) in Finland, concluded total energy consumption increases when outside temperatures increase. More recently, in 2013 and 2018, Microsoft carried out experiments to determine underwater data storage opportunities which also benefit from the cool underwater environment.

The last technique is the development of resource scheduling using ‘evolutionary’ algorithms that intelligently allocate energy. ‘Evolutionary’ as this AI process is based on biological evolution: reproduction, selection, recombination and mutation. This method sets in place an autonomic resource management framework that uses predictive models, scenario-running to balance power and performance. This method switches off network elements that are unnecessary to save power by having less units consume energy including the cooling facilities (less activity, less heat, less need for cooling). Tests by network-wide power manager ElasticTree, resulted in a 60% power consumption saving by managing network traffic efficiently. VMFlow through virtualisation considered topology and traffic for even better results (Kim & Lee, 2011). The Green500 ranks supercomputers by energy-efficiency (calculating the computers performance on energy consumption). In 2019, the top three included a new Fujitsu prototype, followed by PEZY Computing system also used in Japan and at last an IBM Power System AiMOS used in New York. Five other systems in the top 10 are designed by IBM Power Systems (The Green500, 2019).

In a combination of virtualisation and 'evolutionary' algorithms, the concept of EOC, defined by (Go, 2010) as "*sustainable computing technology that complements existing efficiency improvements at the application, operating system and hardware levels*" has seen the light of day. It creates heat where needed, uses cooling where available, utilises energy where it is less expensive to use, to minimise overall organisation energy costs. A prototype – the Green Cloud – has been tried out at the University of Notre Dame in 2010, where heat was moved from a 'Sustainable Distributed Data Centre' near a greenhouse in cold weather and services were migrated to balance heat in hot weather. EOC architectures have economic and environmental benefits by moving workload across geographically separated physical systems based on price of power variations and available free cooling sources.

To conclude this part, three main strategies have been developed and combined to increase efficiency and performance of data centres (see Table 4). This has stabilised the facilities' energy use levels over time despite the data demand growth witnessed. However, if the needs of electricity keep increasing, data centre emissions might surpass the aviation sector currently responsible for 2% of human-generated carbon annually. Some potential new complications might arise such as the unknown efficiency profiles of smaller chips, the downsizing limit of these chips or the migration of data centres closer to the users. The latter is a trend predicting the digital transformation, growing urbanisation and mass migrations will push data centres closer to the user for better and faster connectivity. The potential benefits of this proximity with users is facility of e-waste management (recollecting rare metals, cost savings on recycling) and better district heating opportunities.

Summary table of Green IT strategies

Applications	**Virtualisation**	**Reusing energy**	**Renewable energy use**	**Reducing energy**

Hardware	- Grouping VM (intra)	- Heat reuse	- Onsite
			- Offsite: RECs and PPAs
				- Equipment efficiency
				  - Components (DPM)
				  - System
				  - Centre architecture
				- Cooling

Software	- Backups - Data deduplication (inter) - Compression (inter)	- EOC	- AI balancing	- Component DPM - EOC
Challenges	- Sustainability of deduplication	- Contracts - Location - Waste heat price - Waste heat quality	- Load balancing - Transparency	- Efficiency limits - Downsizing limits - Transparency - Shortcuts
Opportunities	- AI applications	- LTDH prosumers - Thermal storage - New solutions - Incentives	- Electricity storage - Material passport	- Centre location - Scafida - Nano DCs - REE management - Monitoring (indicators)

Table 4: Summary table Green IT strategies (Dewachter, 2020)

2.3. Green IT for tech leaders

In part 2.1, tech leaders have been cited throughout different parts because of their continuous innovation and prominence in the ICT sector. The next part will take a closer look at some of the tech leaders to identify how, in practice, they have implemented Green IT. The main points are summarised (see Table 5) and additional general descriptions of the leaders are available in the appendices (see appendix 5).

While Google Cloud platform, AWS and Microsoft Azure offer infrastructure as a service, IBM, Dell Technologies, Hewlett-Packard Enterprise and VMware are active in multi-cloud deployments. Salesforce, Adobe, Workday are in software as a service, SAP and Oracle represent infrastructure- and database-as-a-service. To compete, data acquisition and pulling in companies to grasp for shares on the market are of prime importance; which explains these actors entering new markets and prospecting new ways to collect data. The different ICT technologies cited in part 1.1 such as IoT, AI, edge computing and service quality (serverless and/or managed services) are expected to be differentiators amongst competitors. It must be pointed out that, in contrast to these companies acquiring data, there is a different paradigm in favour of open data access. As explained by (Hossain, Dwivedi, & Rana, 2015), this recent movement originated in the United States and the United Kingdom in 2009 and presents two currents of thought. The first is in favour of using open data information for economic purposes through innovation while the second is more motivated by increasing societal transparency. Even though most of the open data seems to come from public instances, other fields like sciences, culture and economics also share data on many topics. It comes under many forms such as pictures, satellite photography, maps, medical data and so forth. Some of the challenges linked to the phenomenon in recent years have been to define a legal framework for privacy concerns, identify necessary processes to follow for a successful model integration, linked trust risks in political contexts and build the economic model incentivising businesses to share their data. As a global trend, it is believed to be developed and explored in years to come.

Google

The first tech leader Google owns 21 data centres of which five are in Europe: St-Ghislain (Belgium), Dublin (Ireland), Hamina (Finland), Fredericia (Denmark) and Eemshaven (Netherlands) for a total worth of 3.2 billion EUR (Google, 2020). The average PUE for these centres was scored 1.11 in 2018. The Belgian Saint-Ghislain centre has a 2.8 MW solar and an advanced evaporative cooling system based on grey water, collected from the nearby industrial canal and purified onsite. Upcoming investments were announced to further develop infrastructure. It has been running since 2009 in a location chosen because of a right combination of energy infrastructure and developable land (AWEX, 2019).

In Green IT, the company reached operation carbon-neutrality in 2007 and matched 100% of their electricity with renewable sources in 2017. To achieve these goals, they have invested over 2.5 billion USD globally in Power Purchase Agreements (or PPAs, see appendix 6), making them the largest corporate buyer of renewable energy (Ambrose, 2020). This represents 5475 MW of renewable energy of which over 3,700 MW is already functioning with an increase of 40% from 2018 to 2019 (Pichai, 2019). In comparison, the second place went to the tech giant Facebook who owned 1100 MW (see appendix 7). In 2018, the tech giant diverted 87% of waste from landfills and 19% of used components were refurbished.

Besides being the most important purchaser of renewable energy, Google is continuously innovating and reinventing its systems to use energy more efficiently. In 2019, they have announced developing a new carbon-intelligent computing platform with their partner Tomorrow that will allocate more efficiently renewable energy (Radovanovic, 2020). Less urgent and heavy tasks will therefore be completed at peak loads, when there is more wind and solar energy available. By combining Tomorrow's weather forecasts for the next day and Google's internal forecasts on power resource needs, they can establish hour-by-hour use of the available energy. Future perspectives are to shift time and location use between data centres in the most intelligent and sustainable way. More detailed report on the precise functioning of the mentioned system are expected for the end of 2020. Other collaborations include Solar Freeze, Everimpact and Ellipsis.earth all backed up under the Google for Startups Accelerator on the Sustainable Development Goals (Brandt & Matias, 2020) project. The tech giant is also working on improving supply-chain sustainability in projects such as Flex or Gold Circuit Electronics to adopt ISO50001 certifications, energy-saving initiatives and training workshops. Additionally, they are exploring blockchain opportunities for end-to-end mineral traceability working with different stakeholders (NGOs, Minespider, Minsur) to limit child labour and not fuel conflicts at extraction zones. Future initiatives include more efforts towards reusing rare earth metals in hard disk drives (HDDs), better collaboration across partners and suppliers for sufficient access to renewable energy, GHG emissions reductions and inspire other companies (Google, 2020).

Artificial intelligence also holds an important place in Google's innovation leads and is a strategy for the organisation to differentiate from competitors Microsoft and Amazon. They strive to apply AI in all facets of the organisation from projects for biodiversity conservation to data centres energy savings (cooling, lighting and energy savings through virtualisation). The company also calls on organisations to submit AI projects with social aim that are then financially supported by Google.org, coached by Google's AI experts and consulting from Google Cloud. Machine learning has shed light on the opportunities of increased renewable technologies performance and brought about the new project forecasting weather patterns. Finally, even though many new applications are being pointed out, some have been defined at high-risk and require additional precautions and warranty such as in the medical field or transportation.

In April 2020 however, they have been pointed out by Bloomberg to consume consequential amounts of water in the United States, despite the remarkable efforts for their carbon footprint (Sattiraju, 2020). They have reported how the company has received the public authorisation to use one million gallons[1] of water daily in Arizona, while citizens are asked to consume water responsibly (in comparison, a daily use of 120 gallons). The company considered its consumption proprietary use secret and used legal battles to protect its information. In 2019, they requested 2.3 billion water gallons for data centres in three states, mostly for cooling infrastructure. The Bloomberg article goes on to give the example of Red Oak, in Texas, where the tech giant has requested 1.46 billion gallons of water for 2021 while the town already needs 15 billion for different uses (residential, agriculture and so on) and there is a growing demand for water. These new pressures are forecasted to worsen as droughts are expected to be more recurrent in the future, due to climate change. In 2019, Google has already sparked debate in Berkeley, South Carolina where the company received a permit to tap similar amounts of groundwater while a local public water utility – Mount Pleasant Waters – was asked to reduce by 57% its aquifer water use in the four years to come. They are planning on setting up a new centre in Mesa, Arizona, where water of the Colorado river is used even though there are also concerns for future drought of the river. Google uses its water for evaporative cooling, which requires less energy than water (the cheaper input), to cool its processing units like the CRAC. Despite the company's justification that reducing their energy consumption also reduces water use, some experts say the relation is more of a trade-off.

[1] One US liquid gallon represents around 3.785 litres (Wight Hat Ltd., 2018)

Despite these arising issues, Google started searching for alternatives such as industrial water in Belgium, air cooling in Ireland and seawater use in Finland instead of using drinking water and draining local supplies. The article also mentions a potential water credit system which in Mesa, but information is incomplete. However, switching water sources is not always possible in all data centre locations. This apparent choice to be made between economic development and sustainability is one to be considered carefully and there is a need for clarity, accountability and transparency for all stakeholders involved to avoid potential backlashes.

Amazon

The seven main areas in Amazon's sustainability report are: Sustainable Operations, Packaging and Products, Social Responsibility, Employees and Communities, Sustainability in the Cloud, Tech for Good and Governance. These efforts are in line with the company's objectives to achieve 80% renewable energy by 2024, and net zero carbon by 2040. Concerning renewable energy use for Sustainable Operations, Amazon owns over 1,900MW of renewable power (5.3TWh of production annually) in PPAs of which 21 are large-scale solar and wind projects and over 50 solar rooftops. More recently, they announced plans to build 149MW and 50MW farms in Sevilla and Zaragoza respectively. The Sevilla farm is set to power AWS data centres and logistics. Two other projects in Illinois and Virginia are also to see the light of day at 180MW each for a yearly production of 400GWh annually (Molinar, 2019).

Besides owning renewable energy infrastructure, the Amazon has solar rooftops on its fulfilment centres, works on reduced packaging waste (Frustration-Free Packaging program), better packaging (Ship In Own Container program), sustainable offices and buildings (lighting, composting, energy consumption, green roofs, district heating from data centre and building materials), sustainable transportation and several investments in circular economy (Closed Loop Fund for recycling projects). Along those lines, Amazon has also announced in 2019 it hoped to reach carbon neutrality for half its shipments by 2030 in a program named "Shipment Zero". Efforts include looking for alternative transport methods (drones, small autonomous cars), electrifying the fleet, maximizing fleet efficiency (routes, wheels, speed) and working with industry partners for a faster transition to a low-carbon future. In the sustainable infrastructure category, the tech giant has progressively started producing its own components along the supply-chain (servers, storage, network fibres) and electrical substations to limit cloud costs.

Greenpeace however, accused the company for not achieving its objectives and a lack of transparency – concerning size, scale and solar rooftops, and compared to competitors Microsoft and Facebook – which has been rejected by Amazon who claimed data inaccuracies (Perez, 2019). It is not clear how many data centres the tech giant owns even though a recent Wikileaks claims there are 63 data centres worldwide. In the US East Coast, which has been an important host to hyperscale data centres, Greenpeace blasted the giant for increasing its activity to 1,689MW while maintaining 132MW of renewable power (12%) and therefore not living up to its commitment of 100% renewable electricity. They added that no deadline has been detailed by the leader for that commitment of 2014.

Microsoft

The three main points Microsoft reports working on are: transparency, clean energy infrastructure and investments in research. Energy commitments are to improve the energy mix, maintain their carbon neutrality, ensure green certificates are not counted double, invest in new technologies and support public policies. From 2007 to 2012, Microsoft used a global internal carbon fee model as an incentive to reduce emissions and purchased green certificates to achieve 100% carbon neutrality by 2014. In 2016, they started looking more into renewable electricity (roughly 44% of their power was at that time from renewable sources) as they vowed to power half their data centres by renewables for the end of 2018 and reach 60% in the next decade (Smith, 2019). In 2017 they stroke a deal with General Electrics to power their cloud computing the next 15 years through the PPA of a 37MW wind farm. It is situated in the outskirts of Dublin where Amazon and Google also have centres as the region wishes to develop economic activity and boost digital innovation locally. Later that same year, a purchase was also made for a 180MW onshore Vattenfall wind farm in the Netherlands particularly interesting as it could procure energy for their data centre in the area. In 2018 the company also signed its third deal for a 60MW solar farm by Sunseap in Singapore for the next 20 years (Shu, 2018). By 2019 they owned over 800MW worth of renewable energy worldwide and made new commitments at the beginning of January 2020 to become carbon negative in 2030 and remove the equivalent of all carbon emitted since their foundation in 1975. This would happen by increasing the carbon fee and investing in more projects and technologies that reduce emissions by improved efficiency and carbon capture. A 1 billion USD fund has been announced to that end.

One of the Green IT innovative research topics at Microsoft are underwater data centres (Lardinois, 2018). In 2018 project Natick was deployed to evaluate the possibility of locating data centres at the bottom of the ocean. The benefits of this potential location are accessibility (many cities are located close to the oceans), close energy sources (offshore wind farm energy) and surrounding temperature (the cooling of the underwater environment). It would allow the company to save on cooling infrastructure and offer better service (competitive advantage). After a low-scale experiment in 2013 in the Pacific, which they claim had positive results (no consequent temperature changes in the water, wildlife acclimated and no consequent noise pollution), they launched phase 2 in the Orkney islands, close to the European Marine Energy Centre. The main challenge for this project is maintenance, which would be impossible and explains the presence of nitrogen in the container size vessel to prevent corrosion.

Another research area are gas data centres which would be fuelled by biogas and use fuel cells in the process to power the centres (Belady & Sean, 2017). This would eliminate all the intermediates from the power station, therefore reducing losses along the way, increasing reliability and saving costs. Microsoft has been partnering with Cummins and McKinstry on the project in Seattle. The technology could potentially be used for other players in the energy sector and more waste collection opportunities are being explored (e.g. fuel cell heat for cooling or extra power). More recently, in April 2020, the tech company has declared developing a project named “Planetary Computer” that supposedly would use global aggregated environmental data to look at how to improve planetary health (Etherington, 2020).

International Business Machines

The main areas of focus for IBM are sustainable building (especially through IoT), green data centres and counselling other companies on sustainability initiatives. The first area taps into how IoT can make the client’s buildings more flexible (IBM IoT, 2016). This can happen through: better energy consumption monitoring, increased security (improved detection), space optimisation (patterns), personalisation (voice command), lease management, building maintenance, construction management (modelling), new leasing models (e.g. rent offices by the hour), affect well-being and health with better lighting and create an ecosystem of best practices between buildings. The second area strives to accompany customers in their journey to render infrastructure and services more efficient and less energy consuming. The third part is to help at a macro level to modify systems such as traffic flows, water management, smart grids, by combining the efforts of organisations to change industries and government actions.

IBM owns 60 data centres on 19 countries with an average PUE of their data centres – consuming 59% of their electricity – at 1.76. Their 2018 goals for the future are increasing renewable electricity use from 39.5% (part from the grid energy mix and part of it separated) to 55% by 2025 and reaching a 40% drop of their 2005 baseline carbon emission levels (in 2018 they were at 32.2%). In IBM's 2018 Environmental Report, the company claims to have saved 3.3% on total energy, reduced water usage by 0.4% (down from 6.6% in 2016) and to have recycled 89.5% of their non-hazardous waste (up from 85.9% in 2014) and 51.3% of their hazardous waste. From the latter, 29.6% was incinerated, 11.7% went to landfills and 6.4% was subjected to "other treatments". IBM manufactured four of the eight most efficient supercomputers on the Green500 list allowing them to use energy more responsibly. They claim to evaluate materials to determine their chemical footprint and the storage equipment is optimised in compression and deduplication.

The company has had several other sustainability – other than Green IT in infrastructure – initiatives and projects over the years (Whitehurst, 2020): AI to fight human traffic with the Traffik Analysis Hub (IBM, 2019), blockchain to improve food supply-chains (TechCrunch, 2019), global big data collection with the IBM PAIRS GEOSCOPE and an unmanned AI ship to fight pollution, unsustainable fishing practices, impact on species and habitat degradation (Stanford-Clark, 2020). Overall, IBM has a strong focus on advising and collaborating with their stakeholders (suppliers, customers, clients) and supply-chains to have impacts on different scales. They look for new ways to apply new technology such as AI, 5G, IoT or blockchain for more sustainability.

Salesforce

The tech leader considers the environment a main stakeholder and operates following the Sustainable Development Guidelines. They have kept carbon emissions per transaction at a similar level despite a much higher level of operations, monitor office space electricity consumption and reduce it wherever possible and offset the emissions of organised events like the Dreamforce conference (Salesforce, 2020). There are many aspects considered in the company's "Stakeholder Impact Report". On a corporate side: governance, data privacy, data security, supplier sustainability, supplier diversity and supply-chain responsibility. On the environmental side, there is: the sustainability cloud, the 1 trillion trees project, climate policy advocacy, renewable energy use, energy mix, tracking emissions, internal price carbon, sustainable workplaces and employee investment. At the social level, they act on improving their culture, attracting, training and forming talent, philanthropy actions, equality objectives and the Pledge 1% model. The latter is one of the unique and original strategies they follow which consists in companies pledging from the start to give one percent of their resources – equity, time, product – for a more sustainable world. Another interesting endeavour is the Salesforce Sustainability Cloud which helps companies track their sustainability efforts. The app monitors if sustainability objectives are reached, where there are carbon emissions and how much renewable energy is used. It facilitates initiatives by giving a broad picture of areas that need to be improved (TechCrunch, 2019).

The tech behemoth indicates having consumed 659 GWh of electricity in the fiscal year 2020, a 31 GWh growth from the previous years. Their data centres consumed 90% of that electricity, scored an average PUE of 1.39 and collected 164 million gallons of water. They announce having purchased enough renewable energy to offset 63% and set an objective to power 100% of their activities sustainably by 2022. The exact amount of renewable energy owned by Salesforce is unavailable in the 2019 Stakeholder Impact Report or 2018 Salesforce Clean Energy Strategy report. They report however that 61.7 GWh of the fiscal year 2020 electricity consumed was renewable electricity, 32.9 GWh was hydroelectricity and 152.3 GWh nuclear. Additionally, they want to ensure 50% of their suppliers to set targets by 2025, that all new offices after 2020 receive Net Zero carbon certifications, increase the internal carbon price, invest 10 million USD in entrepreneurial projects and start-ups and overall stay committed to their promises (Salesforce, 2020).

Alibaba

Greenpeace has attributed a first-ever clean energy scorecard (see appendix 8) for the Chinese tech industry analysing the 15 biggest independent and cloud computing data centre companies (Greenpeace, 2020). The different criteria they graded were Energy Transparency, Energy Efficiency and Carbon reduction, Renewable Energy Performance (only score worth 40 points instead of 20) and Government & Industry Influence. Alibaba came in second with a score of 60 out of 100, Chindata, an independent data centre provider, came in first at 80 and lower scores included cloud computing companies Tencent at 52 and Jindong set at 12. Chindata earned its score by their status of first China-based data centre operator to set a goal for 100% renewable energy use in December 2020 combining “big data and new energy”. Alibaba owns one data centre powered significantly by renewable energy through rooftop solar panels, green certificates and renewable energy purchases. While they score higher on renewable energy power, they have a lower score in energy transparency as they do not disclose electricity consumption of the infrastructure. This is the opposite of its competitor Tencent, which has high transparency about its energy use but lower efforts. Overall, scores were low as in 2018, Chinese internet data centres were powered at 73% by coal – the main contributor in greenhouse gas emissions – and despite recent progress, the operators are still behind schedule compared to global peers (16 global tech firms like Google and Apple set their objectives in 2017). An example of the progress being made is the government introducing regulations in 2019, requiring companies to purchase a percentage of renewable energy in their portfolio but also encouraging them to have PUE targets and to purchase green power certificates. The conclusion of the Clean Cloud report was for Chinese data centre providers to set up objectives as ambitious as their growth, disclose their information and data for more transparency and intensively scale up their efforts to deploy more clean energy.

On their website, the Alibaba group has claimed to contribute sustainably by offering job opportunities, supporting rural development, poverty-relieving programs, environmental and charitable contributions. The seven Environmental Social and Governance (ESG) focus points were: corporate governance, intellectual property rights protection, cybersecurity, data protection, human capital, social impact and environmental impact. Considering the latter, which is the focus of the study, the tech giant has 21 data centre regions and 63 availability zones (each composed of one or multiple scattered data centres) and is increasingly procuring renewable energy to offset the emissions. As an example, in 2019, they purchased 140 GWh of energy in Zhangjiakou, Hebei province from the energy market. Alibaba’s sustainability report for 2018 cited two examples of achieved results: their Qiandao Lake and the Zhangjiakou data centres. The first uses the local water source to reduce CO^2 emissions by 300,000 tons yearly and achieve an average PUE of 1.17. The latter uses wind power to entirely power the centre in renewable energy with a PUE of 1.25, a 4% efficiency increase and 59% drop in energy used for cooling. Other initiatives of the report included working with Cainiao on replacing 50% of their packaging with 100% eco-responsible materials and the Ant Forest program, which allows

Alipay users to collect "green points" to plant trees in Northern China (conjunctly with Ant Financials).

Summary table of tech leaders' Green IT initiatives

	Data centres	Renewables capacity	Objectives	Initiatives	Issues
Google	21	5475MW (2700MW active)	24x7x365 carbon neutral, Supply-chains optimisation	Tomorrow & REE traceability	Water usage
Amazon	38	1900MW	80% RES by 2024 Carbon neutral by 2040	District heating	Achieving objectives & transparency
Microsoft	> 100 locations	800MW	Carbon negative by 2030	Underwater DC, carbon fee, fuel cells/biogas	Transparency in sales figures
IBM	22	39,5% of electricity	55% renewables use & 40% carbon reduction by 2025	Components end-of-cycle	Speed of transition
Salesforce	9	63% of electricity	100% renewables by 2022 Zero carbon by 2050	Sustainability Cloud & internal carbon price	Transparency details
Alibaba	21	Not specified	Not specified	Use wind towers for air-cooling	Speed of transition & transparency

Table 5: Summary table of tech leaders' Green IT initiatives (Dewachter, 2020)

Collecting the information, it can be observed all six tech giants are progressively realising the impacts they have on the planet and the consequent need for more sustainability on all levels of operation. They are at different stages of developments in their efforts and levels of transparency on their data. In 2017, a scorecard by Greenpeace intended to verify if commitments were respected and followed by the IT companies (see appendix 9). The evaluation criteria were Energy Transparency, Renewable Energy Commitment, Energy Efficiency, Renewable Procurement and Advocacy. Of the six selected tech leaders, Google positioned first with an A score followed by a B score for Microsoft and Salesforce, a C score for AWS and IBM and finally a D score for Alibaba. Google and Salesforce were also amongst the first to commit towards 100% renewable energy use. Over the period of 2010 to 2016, Google has clearly purchased most contracts followed by AWS, Microsoft and Salesforce, in that order. The main identified obstacles were a lack of transparency (for competitive reasons) and a lack of access to renewable supply. Furthermore, the report claimed the tendency of some companies to use shortcuts to reach their commitments, therefore undermining the leaders genuinely realising renewable efforts. The most recurrent shortcuts identified by Greenpeace were unbundled Renewable Energy Certificates (RECs), overreaching claims (grids), lack of transparency in reporting and redefining renewables (Greenpeace International, 2017).

Second part: Empirical analysis

Chapter 1: Methodology

The objective of this study was to evaluate Belgium's data centres performance in Green IT as perceived by ICT market actors. The first part (literary review) allowed a thorough understanding of the origins of the Green IT phenomenon as well as developing awareness of its existence. The work presented a deductive structure by qualifying the Belgium Green IT environment based on the identified global Green IT environment (types of initiatives, obstacles, enablers) from the literary review. The Green IT phenomenon is, however, very recent and still evolving. New elements are expected to appear progressively over time as the situation evolves.

1.1. Qualitative exploratory inductive methodology

This study follows a qualitative methodology understood as "research that produces descriptive data – people's own written or spoken words and behaviour", described by (Taylor, Bogdan, & DeVault, 2016). Collected data is based on field expert interviews and aims at understanding a phenomenon in a field according to their perceptions, opinions and experience.

The exploratory aspect of the methodology is justified by the objective of exploring little known phenomena in order to unravel new ideas or hypotheses as described by (Evrard, et al., 2009). Green IT was understood in the first part as a very modern phenomenon. Considering the even more recent introduction of the Green IT Belgium organism in the country, there seemed to be an opportunity for relevant research to be made on a national scale.

The inductive quality of the work is reflected in the process of detecting useful elements to answer the research question by analysing data going from the specific to the general to extract meaning as explained by (Blais & Martineau, 2006). In this study, it is expected that the views, perceptions and expectations of different field experts could point out determining factors such as obstacles, enablers, strategies and initiatives of the Belgian Green IT evolution in data centres.

1.2. Data collection method: Semi-directive interviews

To analyse Belgium's Green IT state, different actors in the Belgian ICT sector have been questioned in semi-directive interviews. These interviewees were chosen to investigate one problem from several angles, collecting diverse insights and perspectives to better understand the phenomenon and offering one representation of it. This is based on the principle of diversity, as introduced by (Roussel & Wacheux, 2005). The interviewees were selected by first identifying the major Belgian cloud providers. Next, data centre managers (different types of data centres), then the representant of Green IT Belgium and finally, engineers and consultants were solicited. Contacts were established mainly through the LinkedIn channel, e-mail, telephone call and videocall on Teams. Some of the participants were contacted at a later stage to confirm some statements or define the preferred degree of confidentiality.

The number of interviewees was determined by theoretical and semantic saturation and depended on participation willingness. Out of the 40 contacts established, 15 answered positively and 10 effectively participated. These ten interviewees occupied current positions as data centre managers (university, third-party facilities, pharmaceutical company, green energy park), Green IT consultants, operations managers, sales manager and telecommunications head of engineering. It must be pointed out, that most of the participants had field experience from over 10 years up to over 25 years in different other sectors (such as banking) or locations, sometimes overseas. The data centre sites were in Antwerp, Ghent, Brussels, Zeeland, Oostkamp, Braine-l'Alleud or Gembloux-Lessines and ranged in size from 2000 m² to several hundreds of square meters. The type of data centre varied from large centre, to colocation providers, colocation customers and private data centre. The ESG scores of the organisations were verified on the CSRHub website (see appendix 10) to get a broad idea on their Corporate Social Responsibility (CSR) integration. As a certified B Corporation, the tool unites 691 sources from ESG analyst raters, crowd and government sources and NGOs and scores companies based on 12 criteria. Out of the ten organisations, five were on the website and scored between 85 and 92 out of 100 which are all in the "High" category.

Every participant suggested or accepted having the interview through the online videoconference channels Teams or Google Meet mostly for purposes of availability and speed of communication, but also due to the exceptional conditions of social distancing caused by the COVID-19 pandemic. All discussed topics were the personal views of the participants and cannot be, under any circumstance, associated to their employing organisations. One participant explicitly requested to retain anonymity for his organisation and himself. They were thus placed under the Chatham House Rule, which is understood on the official site (Chatham House, 2020) as follows: "*When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed*". The interview questions (see appendix 11) were based on the previously identified model of (Salama & Kass, 2020), Key Point Indicators (KPIs) and tech leaders' Green IT initiatives.

1.3. Data collection: Terrain

The research terrain for this study was situated in Belgium and was chosen for different reasons. Firstly, the recent introduction of Green IT Belgium in 2019 – while it already existed in France, the Netherlands and Switzerland – seemed to indicate that the Green IT phenomenon was at an early stage of development which made room for relevant, new and useful analysis. Secondly, as reported by (Eurostat, 2019), Belgium's population is composed by one of the largest proportions of employed ICT specialists. These are defined by the website as "persons who have the ability to develop, operate and maintain ICT systems and for whom ICTs constitute the main part of their job". It is estimated 4.8% of the employed population are ICT specialists and the country positions 7th out of the 28 European countries. Thirdly, an interesting feature of the country is the presence of 37 data centres to date of which most are set in the Flanders and Brussels. Furthermore, the interest of tech leader Google has shown for the country with one data centre in St-Ghislain can be examined to understand if potential new entrants might appear and if their processes can be inscribed in Green IT. Fourthly, being home to the European Commission, European Parliament and the Council of the European Union, Brussels is considered the "capital of Europe". It is therefore the scene of discussions and policy preparation such as the EU Code of Conduct on Data Centre Energy Efficiency prepared by the Joint Research Centre of the European Commission. Finally, the proximity of the researcher and the terrain allowed for deeper investigation and easier communication with interviewees. The familiarity of spoken languages for instance, facilitated a more open, clear and complete dialogue.

1.4. Qualitative data analysis: thematic analysis

To analyse the performance of Belgium in the Green IT data centre environment, a qualitative methodology defined by and translated on the software DeepL as "*a discursive process of reformulation, explicitation or theorisation of experiences, testimonies or phenomena. The logic at work is part of the discovery and the construction of meaning.*" has been followed. In order to do so, the thematic analysis used was inspired by (Gavard-Perrett, Gotteland, Haon, & Jollibert, 2012). The analysis of the interviews consisted in categorising the similarities and discrepancies for each question expressed by the different field experts. The model of (Salama & Kass, 2020) was then verified against the information to determine its usefulness as a tool for Belgian data centres. The analysis generated different recommendations, built awareness, unravelled limitations and exposed guidelines for further research.

Chapter 2: Interviews analysis

2.1. Belgian ICT sector

Throughout the interviews, there was a consensus that ICT development in Belgium has been slow or slacking, especially compared to neighbouring (Netherlands, France, Germany and Great Britain) or larger countries (United States of America, Japan). Compared to close neighbours, some justifications for Belgium's latency were the use of old equipment in data centres and strict laws and regulations complicating construction. In line with the argument of old equipment use, one expert explained Belgium experienced a slow deployment of fibre – with many copper connections still used – reducing broadband. While the neighbouring cities like Frankfurt, Amsterdam, London and Paris are major Internet connections, Belgium was described by (Trulmont, 2020) as a transit point in these Internet traffic patterns. The growth of 5G, IoT, scientific computing but also the COVID-19 case – 40 to 50% more broadband traffic following one speaker – were mentioned. Finally, Belgium was said to have lower engineering capabilities than larger countries.

On a national scale, firstly, the lack of competition between energy suppliers (Electrabel and Elia) was cited once as a factor complicating sector development. Secondly, inflexible regulations for energy production complicate grid injection and cogeneration opportunities for individuals and organisations alike. Thirdly, the difficulty to attract large investments in network, infrastructure and data centres was mentioned, as many larger banks and corporations try to keep servers close to the heart of operations (Dutch and French groups). On the data centre side, two experts pointed out that there are not many large data centres. Besides the large infrastructure of Google, there are mostly smaller centres which have different needs in redundancy, audits and norms and for which it was harder to receive credits. There has been a lack of development with similar equipment being used for decades.

Part of the participants have however shared positive perspectives for the country's ICT evolution. There are still some initiatives happening, with several start-ups showing entrepreneurship. Two of the interviewees also acknowledged that a smaller geographic scale can facilitate technology deployment (apps and transport). At last, the upcoming Green Deal of the European Commission is thought to enable more development by deploying more measures and better enforcement of regulations.

2.2. Belgian Green IT in data centres: perceptions

Green IT can be induced at different levels: in non-ICT businesses using IT, in ICT businesses that use private or hybrid cloud and public cloud providers for whom the data centre is the core business. Even though Green IT was a familiar concept for all the experts, it was necessary at times to specify which Green IT was discussed. This occasional confusion might indicate a need for clearer distinction and definition. This is how the “Sustainable IT” concept was introduced by two interviewees, which has a broader scope that goes beyond environment and includes more societal concerns.

The experts agreed Belgian data centres were also slacking on the Green IT side even though there were signs of improvement and new future perspectives. It appears Green IT in data centres is a very recent phenomenon in Belgium for which awareness and implementation are progressively growing. Besides some larger players like LCL, Proximus and Interxion as well as the Google hyperscale centre, it was acknowledged that Belgian data centres were mostly small. One expert explained Green IT came after operational cost reduction and continuity of service even though (Biesen, 2020) explained investigating into Green IT could decrease energy use by 30% and increase performance by 10% to 20%. Belgian data centres are seen by half of the participants as using old equipment and poor system design. There have been small improvements and replacements, which are costly and complicated due to the credit accessibility, but there is generally a business-as-usual approach to be observed.

The main identified obstacles to Green IT deployment were:

Figure 4: Identified obstacles to Green IT (Dewachter,2020)

1) Costs of equipment replacement

The most recurrent obstacle was the costs associated with improving or renewing equipment. Air-cooling was cited by (Biesen, 2020) as an example of technique losing energy and electricity across the value chain. He explained how energy is lost through duplication (dividing the energy available) or dense servers with smaller component sizes (more energy requirements for cooling). He suggested liquid cooling as a first solution, but also - with four other interviewees – exploring the software-side. These solutions could save on material costs (maintenance and investment) and optimise equipment use by allowing to turn off machines or use idle states. Compatibility between equipment and the application and duration of licenses (shorter, more flexible licenses as an idea) must then be considered.

2) Restrictive legislation

For a good number of the experts, the issue of unclear national legislation was an important obstacle to developing Green IT projects. According to (Roefs, 2020), certain laws complicate the development of microgrids and intelligent grids. Next, it was mentioned how cogeneration and renewable energy grid injection were also regulated. This deters the possibility of “load shaving” where the centre could store and sell energy depending on prices of the grid. Moreover, compared to the Netherlands, there are no required minimum standards on new centre construction. Although it was believed new centres are usually designed more efficiently at the start, there seemed more progress could be made even if it meant being inspired by neighbours. Five experts pointed out that realised efficiency gains are mostly motivated by economic incentives (energy bills, equipment purchases, maintenance, marketing). One of them explained that cloud providers are still developing and growing and might reach saturation at which point they will focus on optimisations. Environmental benefits are simply secondary considerations and are misused at times for marketing purposes closely associated to greenwashing. This seemed to indicate an information distortion or a misunderstanding of the benefits of performance gains through improved efficiency. Another expert mentioned a lack of political support and national coordination in Belgium which could facilitate the deployment of Green IT.

3) Stakeholder awareness

Another strong obstacle identified on the Belgian data centre environment was the lack of internal communication and deployment of opportunities/initiatives. This responsibility is not only at the data centre level, but also from the end user perspective, who is unaware of data use impacts. One interviewee working more on the sales side reported clients do not ask how green the IT is and one colocation client reported no information was given on objectives or initiatives happening at that level.

4) Lack of transparency

Two experts working closely with organisations using IT or owning data centres also reported the limited use and misuse of indicators. The PUE is the main indicator used, but like any statistic, interpretations can be very subjective and lead to greenwashing. Not only is there a risk of indicator misuse, but a lack of homogeneity complicates comparison and thus improvement: as the previously stated expression by Peter Drucker, "*If you can't measure it, you can't improve it*". In the scope of data centres, ISO standards, TCO and EPEAT were qualified by (Vergueynst, 2020) as quite representative but there is a voluntary approach. He stated the need for a clear, common and transparent framework to evaluate centres and which could evolve over time to become more precise and complete.

5) Country's situation

Two experts explained the side-line position Belgium occupies by missing out on cross-initiatives, large investments, Internet traffic points and hard accessibility to renewables complicating Green IT implementation. Not being on the forefront of Internet hubs and limited energy opportunities, but also lacking a political driver behind Green IT hinders Belgium's capabilities for Green IT deployment.

6) Technology development

One expert mentioned the problem of buffer battery storage for fluctuating electricity from renewable sources. This could help balance the fluctuating supply of energy to ensure continuity of data centre service and is not yet available at that scale.

Despite mainly negative perceptions, there have been more efforts over the last 10 years. Green IT Belgium was launched in 2019 with the initial objective to consult firms on their IT processes (like greenIT.fr in France). The founder explained his desire to move towards a more non-lucrative and associative structure (inspired by the "*Institut du Numérique Responsable*" in France). The organism would strive to improve the dissemination of information and to offer training more in the scope of Sustainable IT. The entry procedure would also differ: instead of simply joining – there were already 3, 4 members in 2020 – new members would need to sign a chart and stand in front of an ethical committee to deter greenwashing. The objective would be to increase awareness and help communicate best practices. Additionally, the organisation is expecting to occupy a guarantee position in the frame of the Green Deal project. Next, there was the Euro Green IT effort that became FuturoCité, a collaboration between Microsoft, IBM and the Walloon Region that fell off due to misconceptions of objectives. Furthermore, there were different start-ups (e.g. around Kristof de Spiegeleer in Ghent) and some initiatives from big private companies but as providers, consultants, engineers. These efforts were a good sign, but not considered as really pushing for change. For larger centres like hyperscale data centres, four experts determined it was easier to achieve efficiency gains especially when the same standard equipment is used for all clients. One expert expressed large data centres are also more subject to requirements as they receive more media visibility.

Figure 5: Identified recommendations for Green IT obstacles (Dewachter, 2020)

Out of the discussions, some positive aspects were cited as future Green IT enablers. The first, liquid cooling, was said to have a better technical and business argument (lower TCO and TLC). The second grouped some suggestions: offer flexible software licenses, measure sustainable code, optimise application use and introduce sustainability scores for websites. The last would be a framework harmonising measurement tools and standards on a country- or continent- level, as mentioned by four participants. An example of such a framework is the

Building Research Establishment Environmental Assessment Method (BREEAM). The Green Deal could contribute in the application of the framework.

In conclusion, the interviewed panel described Belgium as being late in ICT and Green IT development. When looking at the different arguments of AWEX and ConneXie in part 1.3.2, the interviewees seemed to mostly support the image of inadequate environment for data centre evolution and even more for Green IT implementation. Some initiatives have taken place which have not been very successful, and some are still happening. The most promising solution perspectives perceived by the interviewees were software opportunities, the definition of a methodology or shared framework that could enforce standards more intensively (potentially with the Green Deal) but also increase clarity and transparency in monitoring performance.

2.3. Belgian Green IT in data centres: inputs

Renewable electricity access

As explained in the theoretical part, electricity is an important input for data centres and is largely consumed by the many servers in the racks of the data centre. Providing renewable electricity was identified as an important Green IT objective to that end. In Belgium however, it is generally sourced from the grid, with a backup generator to ensure continuity. (Coppee, 2020) even expressed diesel generators were used as main power source (for their reliability) and accounted for around 40% of the centre's carbon footprint.

There seemed to be a shared view that there is access to green energy, but it is usually not produced locally and purchased through PPAs. One expert specified that buying green energy is not a problem, but there is a lack of awareness on transport and distribution costs as well as environmental impact. This again stresses the problem of end user awareness and transparency, supported by a second field expert. The two most recurrent problems were the space availability (especially in Flanders) and compatibility (appropriate terrain and weather conditions) for setting up renewables.

The use of renewable energy has been identified as a new criterion for site selection. Data centres constantly consume large amounts of electricity, making them an ideal customer for renewable operators. But in Belgium, the purchase of a large field for a solar farm was said not to be profitable enough. Additionally, as (Biesen, 2020) explained, knowing the energy supply of renewables is variable. He used the example of onshore windfarms that have a load of around

20% (higher for offshore) which cannot supply a data centre that has a constant need for electricity. There are not enough electricity storage opportunities of that scale to buffer the energy. Moreover, the use of renewables is complicated when considering the administrative restrictions linked with building renewable energy sources. One example shared by (Coppee, 2020) was a 1MW limit for solar farm projects, which is insufficient. Considering the energy needs of the centres. A different interviewee explained the energy billing was chaotic and changing constantly with expensive connections to the grid.

In a Belgian university, (Roefs, 2020) explained how they try to show the example by using renewable energy sources just as global tech leaders. Advocating for renewable energy use can thus be done by buying contracts, hereby creating a dynamic market. The United States of America (USA) were used as an example by two other experts of how sharing consumptions and needs in ESG reports can motivate market dynamics. But based on the research in the first parts, this was not the case for all the tech leaders as some were criticised for their lack of transparency (Amazon in the USA and Alibaba in China). However, increasing renewable energy infrastructure production impacts a market where batteries and smart cars need the same scarce rare metal inputs. This also brings back the debate on the need for nuclear energy considering the scarcity of rare metals. Finally, two interviewees suggested exploring future promising renewable technologies such as hydrogen, local hydroelectricity and biomass.

Components and raw materials

The different equipment in data centres have an expiration date and adequate strategies can avoid losses (technical and economical) and increase a centre's sustainability. Talking to the experts, one of the ten precisely cited the different Sustainable IT and Green IT projects in the Flanders and Wallonia. Usually, data centres had partner companies that collect "used" equipment under contracts, but some donate their equipment to universities and schools directly. The equipment would sometimes still be functional (the warranty ends) but represented a risk in supporting critical infrastructure or had confidential data on hard drives. Concerning electrical, electronical devices and REE collection, the cited organisations and projects in order of recurrence were: Umicore, Recupel, Close the Gap, WordLoop, A Smart World, Connex, Cereo, Out Of Use, Digital For Use and Future Proof. All these programs and organisations were not relevant for data centres, as some are mostly about Sustainable IT and collect personal devices. For data centres, the most known seemed to be Recupel, Close The Gap and Umicore.

It seemed that most interviewees considered the responsibility for equipment generally lied on the supplier-side (Hewlett-Packard and Dell cited) and there was more awareness – and transparency – for efforts on a component-level, than for the raw materials (and their toxicity). For larger cloud providers, it was considered easier to replace equipment if they produce their own. One data centre manager observed there is a lack of interest from managers because of the time and human resources investment needed. For (Roefs, 2020), one reason were the warranties extensions expensive cost, saying: "*it makes more sense to buy a new machine that will do the same amount of work with less energy or do more work with the same amount of energy"*.

Next, a different speaker explained that there was at least some regulation on these matters in Belgium, the "*Déchets d'Equipement Electrique et Electronique (DEEE)*". In other countries, besides the US and China that have versions of the DEEE, he affirmed there were less restrictions and more greenwashing. It was mentioned several times that equipment was sent overseas to Africa, sometimes in the frame of exchange programs to create circularity, but sometimes there was no follow-up. This introduced the main problem: the traceability of the machines. The interviewee working most closely with initiatives of the kind concluded that even though the different mentioned programs were a remarkable start, there is always a shortage in traceability once the machine is fragmented. Even at the level of the programs, there was some opacity on the details of the supply-chain. Overall, it seemed that even though there were different initiatives, mostly on the component-side, they seemed imperfect (transparency, traceability and respect of contracts) and were not all familiar to the experts interviewed.

Besides partnering with other organisations, strategies that were mentioned were to use less, but more efficient equipment producing more heat due to denser servers, to donate computers to schools and universities, extend lifecycles (10 years) in simpler applications and make infrastructure accessible to retrieve data (instead of buying more). Blockchain was identified in the literature part as a potential solution and could solve the problem by improving the monitoring of the whole supply-chain. Sustainable labels and demands for the contracts from clients to include end-of-lifecycle management have also been mentioned to be potential strong drivers for change in the area of material management. Finally, a solid marketing and image campaign can help build more awareness on the different programs or shed light on a strong state initiative.

Water usage

The question of water usage in data centres and specifically, in Belgium, rose from critics on Google's water management in the USA. The different exchanges lead to the belief that there is some knowledge, which is mostly on the technical side, but not much. Water usage was less discussed than other topics either due to a lack of knowledge or a lack of willingness. In both cases, it could reflect an issue to be addressed: awareness or transparency.

The interviewees worked for different organisations that used water in different proportions, meaning their understanding of the technical intricacies varied. As explained by (Biesen, 2020), water is used in data centres in two ways: as a transport medium and in cooling technology. The first is cheap as water can be recycled, while the other can be more complicated to handle. The WUE indicator was recognised by most interviewees but considered to different degrees. In the data centre where rainwater is collected for instance, the WUE was not really looked at. The manager of the centre where canal water is used reported everything is closely monitored (water temperature, water quality and electricity consumption), with the help of a Supervisory Control And Data Acquisition (SCADA) system to comply with city regulations. Yet, another expert specified the impact on the canal water is not understood fully. The design standards followed by two interviewees in their data centres were from the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), defining the adequate aisle and corridor temperatures and humidification degrees. Both hoped for an increase in tolerated temperatures to facilitate free cooling - using outside air – and exploring district heating possibilities.

An important point that was made by two experts was the importance of looking at different indicators in a holistic manner, as having a positive impact on one area can result in a negative impact on another area. For instance, increasing cycles for cooling can increase the need for chemicals to clean the water which brings the question of the safety of these chemicals and their toxicity. These chemicals reduce maintenance and costs by avoiding the purchase of additional infrastructure. But one of the experts considered data quality on water impact was unreliable and for companies to modify their activities, the impacts must be clearly understood. There seemed to be a lack of interest or regard for water usage while the impact can be quite important on communities as seen in the theoretical part.

Summary tables

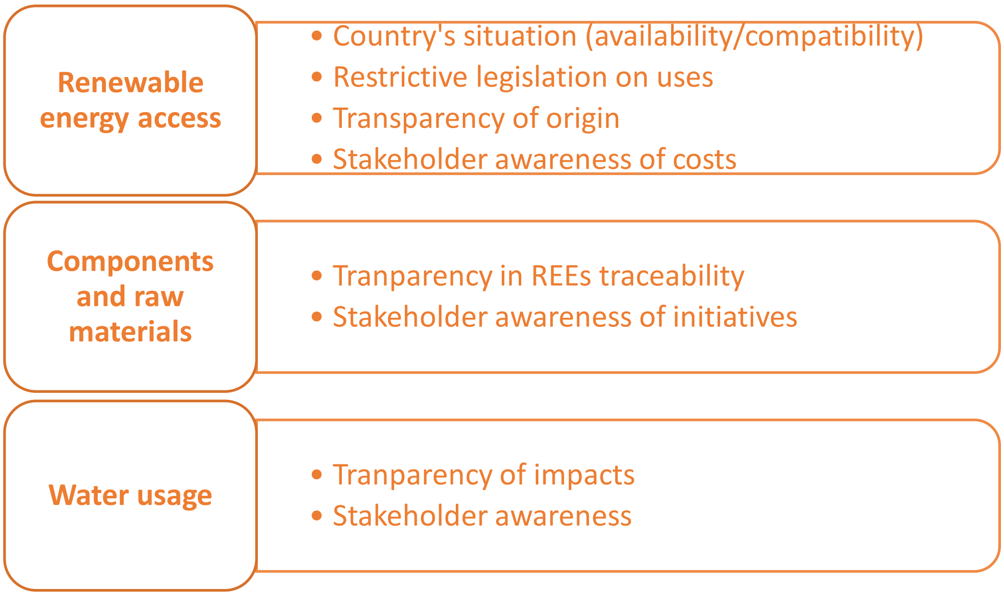

Figure 6: Identified obstacles inputs (Dewachter, 2020)

Figure 7: Identified recommendations inputs (Dewachter, 2020)

2.4. Belgian Green IT in data centres: outputs

The different inputs determine the degree of output emissions. The necessity to improve processes was stressed by (Trulmont, 2020) and a few other experts because of the increased compliance expectations, especially in the business-to-business (B2B) market, as clients increasingly demand independent audits to verify their partners.

Architecture and design

Concerning the internal design and architecture, the equipment is positioned or used in ways that can more effectively manage the heat. On the material side, it depends on the server occupying the racks, the technology used to cool the racks and the architecture of the racks that allow for a better airflow in the building. In the case of hardware used, the first idea mentioned by half of the respondents is to look for the less consuming hardware following the space occupied. The components were described as the most intensive energy-consumer so improvements on this side can leverage efficiency gains. This also depends on the brand of the equipment in the data centre. Where a large GAFAM or hyperscale structure can use the same equipment, a colocation provider has different clients with their own equipment needing different degrees of management. The compatibility of the hardware for the application also needs to be evaluated, as explained by (Biesen, 2020). Some companies do not consider if the used equipment is adapted to the application which brings time losses and additional costs. This was supported by an engineer who explained that the cost of the adequate hardware can help guide selection choices.

Over time, it was said that the allowed temperatures in racks grew from less than 20 degrees to 27 degrees and some of the participants hoped for an even higher limit around 35° (for free cooling similarly to Engie Cofely's data centre). As mentioned in the perceptions of Belgian Green IT, even though there is still some progress to be made on the infrastructure-side, the interviewees identified more opportunities on the software-side. Suggestions included sustainable code, more application of idle states (DPM), website sustainability labels and monitor consumption per task (e.g. transaction, email). It seemed the technique by default was air conditioning using fans and was slowly turning to liquid cooling. The latter was described as expensive (chemicals, material), but allowed a longer equipment lifecycle and lower TCO.

The disposition of racks inside the centres is also considered. It depends on the cooling equipment for efficiency and is thought to be better in hyperscale structures. One centre had a structure bringing cold air from the outside through the CRAC in the hot and cold aisles or corridors and exchange it with the heat. That specific centre did not use enclosed aisles to reduce energy use and heat losses. While common practice used to cool the entire centre, it is also possible to focus on the most heated areas of the aisles. As demonstrated by (Dubois, 2020), it is possible to identify and focus cooling on the areas in the aisles where heat was released using thermal imaging. If the heat is to be reused, it is important to consider potential projects around the centre and the need for heat pumps, an additional investment.

Virtualisation

As expressed by the experts and managers, virtualisation was used by all for some time (10, 20 years). It allows energy and cost savings by buying less equipment and maintenance - up to 30% or 40% over the whole value-chain - while ensuring continuity. This flexibility not only optimises the cost, but the location. It allows to move servers to locations that are colder and need less energy for cooling. On a smaller scale, it was said it was less profitable to virtualise as there will not be any impactful efficiency benefits. In large data centres, they sometimes access meta-data – enormous amounts of information on information as is the case with Google – which needs to be stored. According to (Trulmont, 2020), automatically filtering the relevant data and moving it on less energy-hungry long-term storage systems – instead of fast SSDs – while monitoring gains and losses in speed and energy-use, might be an interesting lead. In a good portion of the discussions, economic incentives were the main motivations for organisations; reactivity and speed being preferred over energy-saving slower idle states. In the UGhent University, where 3000 machines are virtualised, a big software-as-a-setup allows automatic on and off powering following utilisation rate except for the High-Performance Computers (HPCs) that are active constantly and work with queues.

District heating

Once the heat is produced and collected it is usually at a low-temperature and needs to be heated with heat pumps to bring it from 30-45 degrees to 80 or more. It can also be transported through liquid cooling as it is a better carrier. One specific project (Roefs, 2020) described was the Green Energy Park. The location uses bidirectional electricity flow from the UPS to do load shaving by extracting and injecting electricity on the grid following prices. Electrical vehicles are used as transport, but also energy storage for load shaving and centre heat is used for a biofield. This could be a typical example of functional system that maximizes the use of energy. The interviewees were not all aware of projects, but the ones mentioned were (by order of recurrence in discussions):

- Buildings (ING bank, university Ghent, schools Zeeland, Google offices, apartments), either by one large centre or a structure with smaller decentralised centres under apartments.
- Biofield/biomass/greenhouses, using an exchanger. An example that was cited was having heat for a greenhouse in the summer and for buildings in the winter.
- Swimming pools, with the constraints of timing (heat availability and pool use) and water vaporisation (bad business case). One case in Mechelen, Belgium.

It was justified by (Trulmont, 2020) that district heating is not a site selection criterion, especially for large data centres which are usually situated outside high-density areas. When there is an opportunity to use district heating, it may be by chance or in the frame of a CSR communication strategy. This explains that there are not many projects of reusing heat, it is not a priority. Two of the respondents explained that few of the projects are concretely implemented as managers do not wish to take the risk of manipulating critical infrastructure. There needs to be a strong business case for it (ROI) but also a collective desire to see more projects happen. Additionally, (Coppee, 2020) specified that a demand of around 8000 hours of heat needs to be satisfied and this challenges again the "synchronisation", balancing demand and supply.

Summary tables

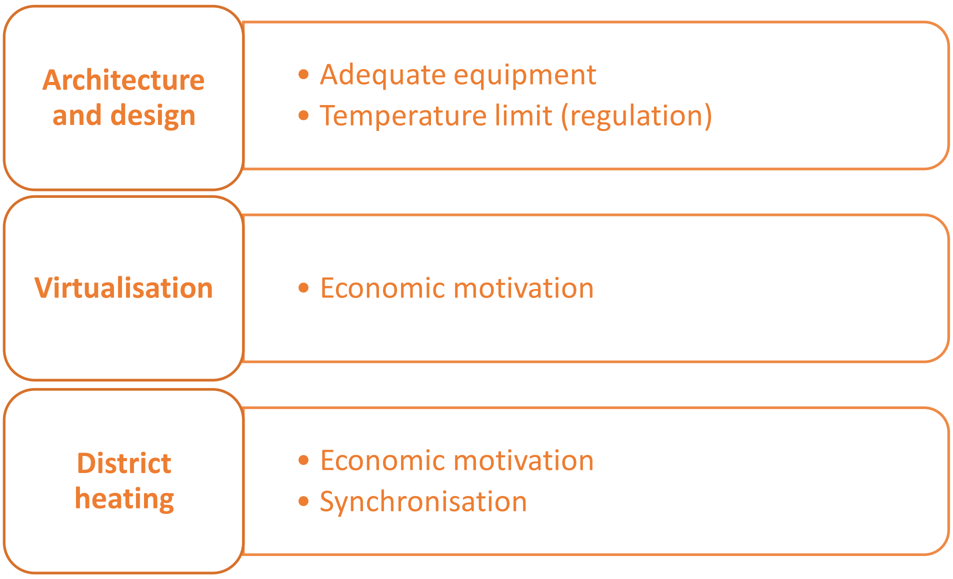

Figure 8: Identified obstacles outputs (Dewachter, 2020)

Figure 9: Identified recommendations outputs (Dewachter, 2020)

2.5. Belgian Green IT in data centres: concerns and future strategies

Transparency

The main concern that is questioned through the first questions of the third part of the interviews is transparency and the partnership or communication strategies to improve it. Transparency in the data centre sector is perceived as close to non-existent by most of the interviewees (nine out of ten with one not questioned). When initiatives are set forward, it is perceived either as a marketing effort or a necessity to gain a competitive advantage. It is not seen as a genuine effort to improve environmental impacts. There is generally an economic motive behind to satisfy stakeholders' demands or attract new customers.

The use of indicators to communicate energy consumption figures or Green IT performance was described by six out of ten respondents as "unclear". They expressed that, like all indicators, it can be used and interpreted in different ways, especially the PUE. It has been criticised by two experts as only representing a specific moment in time (in opposition to an annual view) and not showing the real performance following centre occupation (inverse relation as high occupation meaning lower PUE, which is usually the one used in marketing strategies). Another example by (Dubois, 2020) was the classification of nuclear energy as "green energy" as it is carbon-free technology, without capturing other risks of disasters and pollution.

When there are Green IT or Sustainable IT efforts from organisations, (Vergueynst, 2020) explained it is either motivated by customers and clients, top management or employees. The first case was illustrated through projects with Microsoft to improve Outlook, Teams and Microsoft Office. The second case was L'Oréal, where management had showed genuine interest to improve their IT while it was not their core business. This brings some advantages by attracting young talent seeking meaning and creating a responsible company culture. The third case, which is increasingly frequent in his experience, is seeing more employees assist to webinars and conferences and push internally for company-level efforts. Customers can thus help push for more transparency but following two respondents, there is not much demand for it. One of them explained there needs to be an incentive or perceived utility for them to act or choose providers accordingly and to that end, he needs to understand the labels or indicators that he's showed. This means more clarity, completeness, awareness and harmonisation in the market so they can understand, trust and compare market players. On the other side, for the customer to be a "responsible digital citizen", he also has a part of responsibility to inform and be involved.

To push for more transparency from ICT companies, identified opportunities include more applied legislation (without influence of big companies like Electrabel as explained by (Biesen, 2020)), more advocacy from large players and presence of a guiding association like ICT Netherlands or Green IT Belgium to help harmonise a uniform verification approach. The Green Deal was again cited as a potential Green IT enabler, setting requirements to follow.

Market interactions

Interactions between ICT companies and other companies can happen in order to share knowledge or processes in order to increase best practices of Green IT in the environment. These could take the form of acquisitions, mergers or partnerships like appealing to a third-party to increase assurance and verification for better transparency and customer trust. The interviewees were asked which interactions they had witnessed in Belgium over the time of their experience in the field.

Concerning acquisitions and mergers, none were identified in the Belgian context. A possible explanation put forward by one interviewee was the lack of a dynamic ICT ecosystem in Belgium (in opposition to the Netherlands or places like the Silicon Valley). Concerning collaborations or partnerships for assurance, data centres seem to refer to ISO standards as the most adapted and most understandable for the wider public. The three mentioned were the ISO50600, ISO27001 and ISO50001 (for coloproviders and large players) and came from three different experts. A different participant indicated not using any evaluation except for tiering, ASHRAE and the requirements in the Code of Conduct of the European Commission (despite having to pay for it). A fifth engineering speaker explained verification was mostly for security reasons. The reference varied considerably amongst respondents indicating a lack of shared approach and a different degree of investment.

Once more there were expectations for a state implication in the Green Deal. As explained by (Vergueynst, 2020), new regulations could not only verify the hardware but also the chemicals used, metals, software and even end-users to evaluate the impact of an online service. Europe could then have a competitive advantage compared to the USA (slowed down by the current political status) and Asia, which are less concerned with Green IT except for deals with Europe. According to him, European start-ups could gain a significant competitive advantage as an early market adopter.

This could also solve an issue (Biesen, 2020) mentioned about standards not covering the entire value-chain. Internally, a lack of coordination between departments (sales, energy and IT) complicates implementation of solid standards at organisation-level. He exposed the difficulty of changing people's habits from the inside mostly through efficient communication. Monetary bonus for every applied efficiency gain and appropriate governance were cited as two important drivers. Some recommendations include convincing top management, setting objectives, defining KPIs for monitoring and appointing a Green IT manager. There must be some supervision (with decision grid), as individual efforts can be applied in the wrong way, without impact or deterred by another department. An approach that is used by companies in France is a self-assessment of best practices in IT which is scored from bronze to gold. Then an external audit by a company such as Veritas or the "*Société Générale de Surveillance*" can provide assurance to receive a label by a certified company. It is called a "responsible numeric label" and a similar approach could be adopted for data centres.

Fuel cells and underwater data centre

Participants were then questioned about their perceptions on recent experiments in the data centre field by large players. First off, fuel cells were considered by four interviewees in different projects (e.g. Drogenbos and Energy Park) and are discussed in the field, but the technology is not deemed on point. Considering the energy needs of centres and the level fuel cells can provide, it is not adapted enough for this specific use. Additionally, it can also represent a liability for service continuity and has an important price tag associated for purchase and maintenance (every 6 months). According to (Coppee, 2020), the use of lead batteries in dynamic UPSs is still common even though it comes with a high environmental footprint and higher maintenance cost. Being a proven technology, it can ensure continuity. For him, there needs to be a financial driver, a profitability to be made for it to gain leverage. Another obstacle observed by (Biesen, 2020), is the politics behind such technology as large energy companies such as Shell in the Netherlands or Electrabel in Belgium buy the patents for competitive reasons. However, three of the speakers estimated there are opportunities to be explored in the future but some more research and development is needed. As of now, there is an initiative named Watt4Ever recycling Electric Vehicles (EV) batteries and considering uses for data centres. Similarly, hydrogen opportunities are also being explored to serve as a buffer electricity storage, which could considerably optimise the fluctuating load of renewable technologies.

Microsoft's underwater data centres were overall considered an interesting idea, but it would be hard to put into practice, especially at a large scale. Interviewed experts were sceptic or critic (public relations stunt, not all issues might have been communicated) about the impacts on the ecosystem and the associated maintenance complications. The impact was also compared with data centres using canal water for cooling, as there supposedly is an impact which must be evaluated more thoroughly. The experiment was identified by two participants as part of a recent trend in the sector of complete data centre automation to nullify interventions. Next, following two other experts, the reaction of clients and customers must be carefully considered, and the safety of new innovations must always be proved or verified. Other arguments against the idea were the risk of combining water and electronics as well as displacing the problem away instead of finding a use for the heat. Instead, different solutions were put forward as more promising, such as water cooling (submerged racks in oil because of hyperconverged servers which are very dense and hard to cool) and edge computing. The latter was a recurrent topic in different questions and appeared as a promising solution which had been described in the theory part but was not studied in detail. It brings up a debate on which trend will prevail in the future between large hyperscale data centres and edge computing.

Future perspectives

As a final question in the interviews, participants were asked to share their predictions on future trends and most promising endeavours to come. As a result, some recurrent topics were identified. On the hardware-side, liquid cooling was considered a major step that will most likely happen according to three interviewees. One of them explained it would occur as load has been rising over the last 10 years and will continue to do so. It allows to get close to the medium (RAM or CPU) and facilitates heat reuse. He explained liquids could be of any kind, it would still be a better transport channel than air. Another member of the group of three also suggested the lead of racks be submerged in oil. Besides these improvements, there was also a reminder of opportunities to be explored on the software-side. Some of the interviewees also specified new forms of storage could optimise the use of renewables such as wind and solar using hydrogen, fuel cells while nuclear and fossil fuels (backup generators) will always have a role in the meantime to ensure continuity.

An important challenge that will have to be overcome is to reconcile the economic aspect and environmental aspect as the first always has priority as mentioned by three respondents which were quite sceptic on the topic. It is the classic approach to first satisfy profits for shareholders before considering all stakeholders involved in an organisation. This responsibility lies not only in the camp of the organisation but users also have a part to play as, what (Claes, 2020) defined, a “responsible digital citizen”. He added new forms of contracts – in the likes of existing green lease contracts – between service providers and users could be imagined with the objective of creating a win-win situation, which is not the case today in the data centre field. The concept would be to switch from paying per energy consumed in space used (where it is not in the provider's benefit to reduce energy used) to longer contracts where the user pays for lower carbon footprint and receives a bonus from the service provider. One party is more aware, involved and motivated by the bonus while the second party can enjoy a long-term contractual relationship while being held more accountable.

Next, a prediction shared among three interviewees was the rise of decentralisation through edge computing and centralisation with a move to the cloud. There is a discussion about the fact that one might prevail or a mix of both shall happen. Centralisation is already growing but with the evolution of IoT, 5G and scientific computing (academic and healthcare sector use cases), the use of micro data centres might gain support. Even though bandwidth and network gains were not negligible, (Coppee, 2020) specified installing equipment in communities – in a similar way as Latesys does – could bring security concerns (e.g. theft, vandalism, data security). He also explained optic fibre has performance and speed limits and that edge computing could reduce latency. This was mitigated by a telecom engineer who explained that latency gains are not very relevant for Belgium due to the country's small size on a global scale. In the case micro data centres are implemented, he added migration costs must be opposed in the switch from less energy-consuming smartphone CPUs to saved costs of energy-hungry data centres Intel CPUs.

Finally, on a national and international level, two respondents estimated more coordination and collaboration was required for a successful development of Green IT in data centres. In Belgium, (Trulmont, 2020) believed a stronger political guidance is needed to implement better infrastructure requirements and policies. On a regional and urban level, he determined more collaboration should take the place of the currently separated competitive approach. Furthermore, (Dubois, 2020) also called for more standardisation, to stop large companies from simply migrating to other countries with less regulations. According to (Vergueynst, 2020), efforts of neighbour countries (e.g. France), the arrival of the Green Deal and future evolution of Green IT Belgium will bring more state investment.

Summary tables

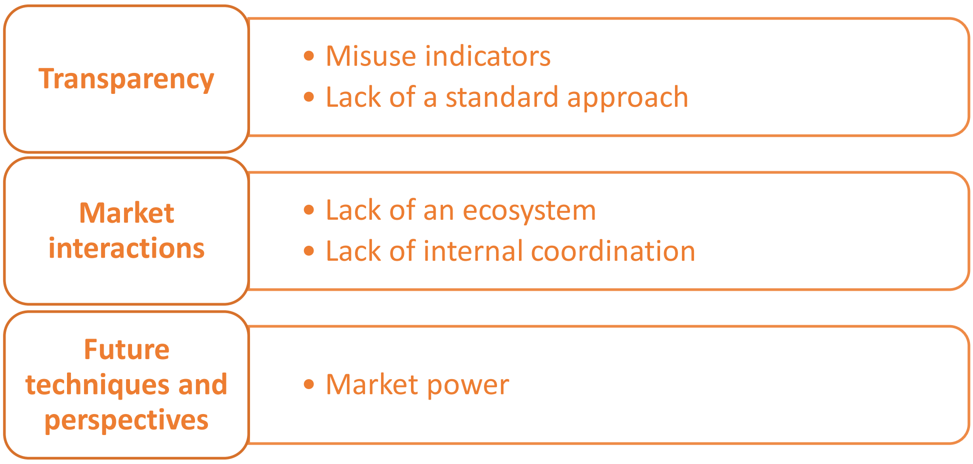

Figure 11: Identified obstacles future perspectives and concerns (Dewachter, 2020)

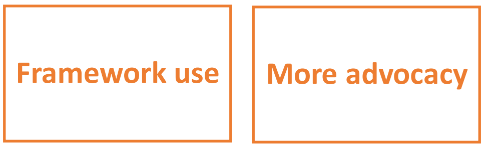

Figure 10: Identified recommendations future strategies and concerns (Dewachter, 2020)

Chapter 3: Data analysis

3.1. Framework analysis

As the interviews were based on the framework of (Salama & Kass, 2020), it can be determined how Belgium performs on the different axes and thus if and on which points the model would be applicable and useful to Belgian data centres.

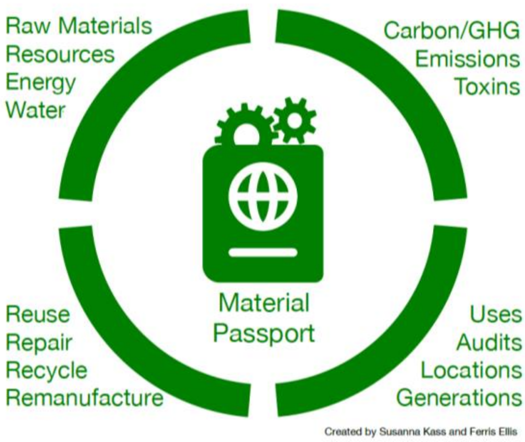

Figure 12: Material passport by (Salama & Kass, 2020)

Sustainable Data Centre design

Concerning the internal design of data centres, it was made clear the Belgian data centre market is relatively limited and old equipment is widespread. For the smaller size centres, it was expensive to replace or improve infrastructure and there seemed to be a lack of initiative. Liquid cooling was identified as one of the major future trends by the group of respondents. The possibility to cool specific parts of the racks – with thermal mapping for example – could gain importance as server densification due to more small efficient components creates more heat which air-cooling can hardly dissipate. Although there have been efforts on the infrastructure-side, the real field of growth was said to be software applications. Solutions like sustainable code, idle states (i.e. DPM), website sustainability labels and communication on consumption per transaction were cited as examples. For colocation providers, the task seemed to be perceived as more difficult as they host different equipment with different needs. But understanding and measuring the state of hardware is the first step in finding solutions.

For the external design and site selection, the interviewees did recognise that new data centres now consider access to renewables as a selection criterion and are generally built more efficiently from the design stage. District heating opportunities on the other hand, were not seen as an important site selection factor and legislation was viewed as an obstacle for cogeneration projects or renewable energy production. What was imagined as a possible strong incentive was a harmonised approach in regulations and requirements that extends to the monitoring level. To measure and compare performance in efficiency, transparent shared indicators should be considered with filters deterring misuse (as seen at times with the PUE, the most used indicator).

The framework could help in the understanding of best practices at design level (e.g. BREEAM and harmonisation of requirements from the European level. When applied to the Belgian context, elements like site selection considerations and different methods to reduce misuse of indicators can be set into motion. We could imagine locating heat demand, water source and renewable energy mapping on a national scale to support organisations in locating their centres. The importance of pre-assessments has been stressed in part 1.2.1 and from the discussions it still appears to be a point that needs thorough consideration in early stages. This would allow new centres to be efficient early on. The development of Green IT Belgium and the Green Deal offer positive prospects to enforce these requirements, but demand state involvement.

100% renewable energy

When considering access to renewable energy sources, the analysis of expert's perceptions revealed the main obstacles were space availability, space compatibility, restrictive billing and regulations, lack of advocacy and user awareness (transparency). In addition to these points we can raise the issues of energy fluctuation, the need for buffers (hydrogen, batteries) as well as the price of energy. Fuelling only renewable electricity to data centres is not impossible in Belgium but requires efforts from multiple parties. Large organisations need to set an example by creating demand for renewables, advocating for the technologies. This could incentivise the market towards more research on buffer storage and new solutions like hydroelectricity on water canals. Belgian data centres of different sizes and types could share information on consumption and production so there is a better understanding of the demand that needs to be satisfied. Stakeholders like the government could then adapt legislation, reduce costs and make it more flexible for organisations to act. More openness and completeness of information could thus potentially mobilise the data centre field (coordinated by an association). This is not an easy task in practice but a tool like the model of (Salama & Kass, 2020) could standardise monitoring and increase transparency, which was also an issue identified for tech leaders as much as the smaller data centres. In turn, these smaller centres – which are most present on the Belgian market – can then compare amongst themselves and start a constructive competition, ideally sharing best practices to improve the overall field.

Triple zero (carbon, emissions, waste)

Nullifying all data centre outputs intertwines with using renewable energy, optimising data centre design, components and the workload using software. It brings back the Green IT guidelines of the theoretical part: virtualisation, reducing the use of energy (components), renewable energy use or reusing energy (heat). The main motivations behind reducing emissions for organisations were perceived as economical before environmental.

One of the recurrent topics was finding a solution for backup diesel generators and efficient heat management. Additionally, components at end-of-lifecycle, raw materials and toxic materials (chemicals used to cleanse the water used for cooling or the batteries) should be considered. Although there are different projects, not all actors are aware of them and the transparency of traceability could be pushed further. The rise of temperature in wastewater from cooling is an important emission to be considered. In the case of underwater data centre experiments, concerns for ecosystems were raised and interviewees hinted it was impossible there were no impacts. In Belgium there are two data centres using canal water: Google in St-Ghislain and Smals in Brussels. The use of water for Google was understood as being a top-notch initiative whereas it was hinted that the heat impact of the Smals data centre on the canal was not understood sufficiently. It was however declared everything was monitored following state requirements for use.

Employees, top management, “responsible digital citizen, the state and involved associations could also push for Green IT at a company-level. The framework should thus be applicable for the different stakeholders to understand, communicate and identify areas of improvement.

Monitoring

Following the perceptions of the experts, more transparency and standardisation could certainly be useful in the field. The material passport of the model strives to monitor and measure these four points:

1. Inputs used (resources, energy, water and raw materials such as rare metals)
2. Environmental factors (carbon/GHG, emissions and toxicity)
3. Sustainability opportunities (reuse, repair, recycle and remanufacture)
4. Verification tools (audits, uses, locations and generation)

On the first point, it was understood the PUE was the main indicator used for energy use and not always in an accurate or honest manner. Water usage was said to be monitored and satisfy environmental requirements, although it was said the impacts are not understood precisely enough. More traceability of total component supply-chains was also viewed as desirable despite different existing initiatives (which still have some flaws once hardware is atomised). On the end of the ICT company, more contractual requirements can be demanded from component suppliers. An extended lifecycle of components by imagining new recycling patterns and reuses (more donations or simpler applications) could help further limit material use without risking service continuity. To that end, blockchain applications to retrace lifecycles of components and raw materials could be explored by start-ups and motivated by associations like the Green IT Belgium project.

In the second point, there is not much monitoring on the environmental impacts of the centres except when there is an economic incentive to do so. Reducing carbon emissions was a reality, sometimes cited as mostly for public communication reasons, and the toxicity of batteries and metals was realised by some interviewees, but only until it was in the hands of the partner. Concerning chemicals for water use (purification), there were no mentions on the toxicity they represent.

For the four R strategies, each have been cited at least once for the component management, less so for rare earth metals. Moreover, understanding of the project partner's activities were not very elaborate (one out of ten interviewees explained in detail the different projects and differences amongst them) and traceability at later stages was barely known. There were no specific partnerships to share knowledge or best practices but mainly to sell or give away old equipment which is usually still functional but represents a liability to critical infrastructure. Appropriate legislative and political support, more advocacy and guidance for harmonisation on used methods were identified as main recommendations. The strategies could also influence site selection considerations, by locating close to places where they can be applied.

Concerning verification tools, ISO standards are used, but the ones experts cited varied, some mentioned ASHRAE standards but there was not a clear shared recognised framework that could accurately report information. This is indispensable to foster stakeholder awareness and in turn, bring action. As explained in the theoretical part of this study, the objective of this material passport would be to fully capture value over multiple generations, maximise lifespan of used materials and reduce negative externalities. Moreover, due to its digital form, it would allow greater transparency and clarity for the owners on the different lifecycle stages of the centre: design, site selection, construction, operation, maintenance, growth and disassembly. Participation in the Code of Conduct was voluntary, and no specific external assurance was mentioned, although one expert did notify clients are progressively using their own audits.

In conclusion, the model of (Salama & Kass, 2020) allows a very holistic view of the data centre. Its application could push companies into further investigating how stakeholders and supply-chain partners understand and respect the values of the organisation. Furthermore, the framework could increase transparency and potentially create a constructive competition for more sustainability among market players. It is an example of how organisations can standardise requirements of new centres but needs to be enforced by external assurances or international organisms to avoid voluntary use of tools and interpretation of guidelines. It must be pointed out however, that the potential evolution towards edge computing and decentralisation might shift data centre monitoring entirely and thus the conception of a framework.

3.2. Porter's five forces

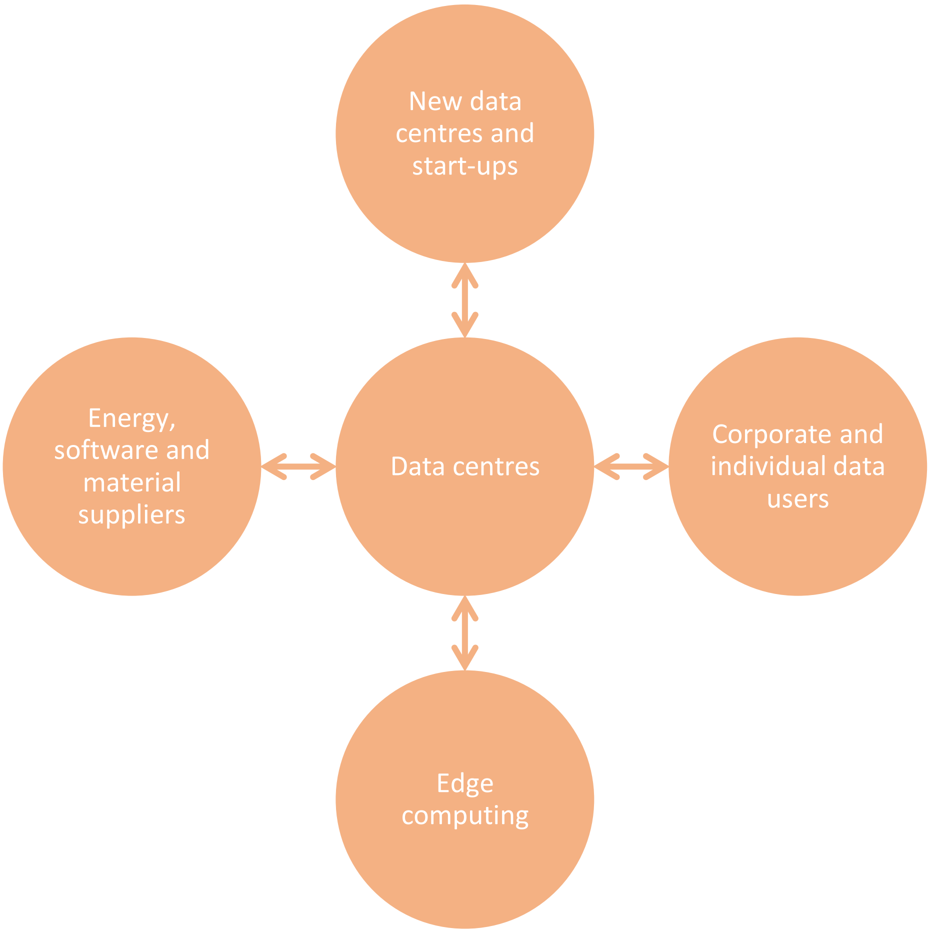

Figure 13: Porter's five forces model (Dewachter, 2020)

To understand the market interactions between the different actors implicated in the Green IT phenomenon of the Belgian data centre market, the Porter's five forces model was used.

In the market, there was a low rivalry between all the Belgian data centres at different stages of Green IT implementation. There are 37 competitors, quite diverse, which were defined as mostly "smaller" centres except for Google. There was a strong consensus that the large hyperscale player had the market advantage in energy efficiency by its size and use of standard equipment. An important exit barrier to switch towards a more sustainable IT management was the equipment replacement costs. It was determined more appropriate to ensure efficient energy consumption in early design stages of the building. For companies that wish to switch from private to public cloud there were gains to be made in the long-term. At a national level, the side-line innovation position of Belgium in Europe that was understood from the research, affected competitors in deploying the most efficient components. In the ICT sector, it was important to "pull in" users and find ways to increase brand loyalty. This also appeared in the research as close attention is paid to customer requirements, but Green IT was then mostly considered as a marketing effort instead of a genuine effort that could help forge more trust towards the company. It was not seen as a strategy to diversify from competitors but rather one to fulfil customer expectations.

There is a strong probability for new data centres to enter the sector considering the data use increase that was determined in the first part of the study and in several interviews. Moreover, these new centres could be designed more efficiently from the start (e.g. Engie Cofely and Energy Park), they might be located closer to district heating opportunities and use alternative renewable energy solutions (e.g. fuel cells, hydrogen). This would make them considerable competitors. When entering the market of "green data centres", there are equipment investments to be made and economies of scale depending on their size. It was clearly a competitive advantage for larger players for example when virtualising machines. On the other hand, there are also important barriers to market entry: constraining legislation for district heating projects, renewable energy grid injection and farm size limits. These barriers are problematic as an increase in the number of more efficient data centres is desirable to create more rivalry and advocacy for Green IT in the field. The expected Green Deal is set to represent a new barrier with more rigorous requirements from new entrants. The use of an innovative software (virtualisation, blockchain) or components can distinguish new entrants from the competition. Data users will switch to a more sustainable competitor if he is aware and understands the benefits of Green IT processes and willing to act on it. With the right communication channels, users can trust and become loyal to the ICT organisation that stores their data.

The data centre customers are the different organisations and individuals using the data and unconsciously creating the derived demand for energy described in the first part. On the side of individuals, the "responsible digital citizen" concept was introduced in the interviews. The idea is to increase user awareness of his personal consumption – per transaction, mail, task, streaming – in energy and associated carbon footprint. A similar initiative mentioned previously that pushes customers to walk-the-talk was Doconomy's "Do Black" credit card; stopping purchases after a certain carbon footprint. At company-level, initiatives can be pushed from different levels: customers and clients, top management, employees and external associations. From the discussions, it seemed clients can make demands from the colocation provider for example by conducting audits. Companies can be more proactive by maximising transparency on energy use and supply-chains (e.g. REEs, water usage, types of renewables used), using clear, unbiased, shared indicators and recognised labels. This would not only help the organisation situate which areas can be impacted, but it can help customers compare the offer on the market and show an authentic desire to have a positive impact. In turn stakeholder trust can be gained (attract and retain talent, respect company values). Clients might compare competitors on several factors. The level of personalisation and continuity of service assurance were mentioned. It was said colocation centres hosting different servers provided higher service personalisation level while more efficient standard service was provided by hyperscale cloud providers. Considering the importance given to client satisfaction, especially corporate clients (B2B), it seems their bargaining power is quite strong.

The substitute threat for data centres – and applied Green IT initiatives – would be a substitution in model from centralisation to decentralisation. While centralisation is currently the most common practice, experts identified edge computing as a real possibility in the future considering new technologies (EVs and IoT). Although an interviewee explained the debate always goes from side to the other, in practice a mix of both – in a similar way as a balance between private and public cloud – could be imagined. The deployment of Green IT in this new model (inputs and outputs) would be entirely different. Current centres that would switch would face consequential costs as an exit barrier, while it could be a market opportunity for new entrants to explore. Data users' – especially businesses – decisions would be influenced following order of priority considering data security, continuity and speed of service. On a global scale, for a small country like Belgium, it was not mentioned as an important challenge. Switching models would also affect suppliers and supply-chains. As smaller renewable energy sources are required, the price and regulations to buy large farms disappears. As local stakeholders of communities would be more involved integrating the centres in the system, better accountability could increase transparency. The use of water would be facilitated, with smaller water streams being used but with more visibility on impacts (as seen with Google facing legal problems with cities in the USA). Components would still be the same, but the circularity strategies would require more transport and distribution channels – and thus pollution – except if materials are reused, recycled, remanufactured and repaired locally.

District heating would be extremely facilitated by this proximity to use the heat in large buildings (banks, schools, stations, pools) or greenhouses from local farmers but the challenge in balancing supply and demand would remain. Models such as the energy parc, sourcing the heat to different places following season demand could be the most promising. In conclusion, a complete switch to edge computing would have a strong impact, but it seems it should only be moderate seeing as a mix of both seems more likely.

In this case, the suppliers would represent the different partners that supply data centres with their inputs in materials, software and energy. The bargaining power was relatively low. For three centres, water was supplied by rainwater or canals and for others it was generally a water tank that was reused, sometimes with the use of a chemical. There were some state requirements to fulfil before using canal water but there seemed to be doubt about the impact measurement. VMWare was cited several times as the software used, but very few information was given on these suppliers. Different partnerships were identified for component recycling and reuse at end-of-lifecycle, although there were traceability issues after a certain point in the product's decomposition. The same goes for rare metals, where there is an important verification process of the suppliers' supply-chain sustainability to be made (e.g. stop child labour, avoid war zones, stop mining toxic exposure, support local communities). The return policies can be discussed with suppliers, components can be designed more to be recuperated and blockchain applications could explore supply-chain processes monitoring. These are areas where new entrants (start-ups) or competitors could gain competitive advantages, especially if the right communication strategies can convince data users to prefer centres with responsible supply-chains. Electricity was provided by the grid (with PPAs for renewable electricity) and diesel backup generators. The renewable energy market is still at development stage and solutions for alternative renewables (e.g. hydrogen, hydroelectricity on rivers, fuel cells) and large-scale buffer energy storage are still being researched. As service continuity must be ensured, there is not much supplier choice and grid connection with backup generators are mostly used to satisfy the steady energy demand of centres. Furthermore, it was determined by two research participants that large energy suppliers such as Engie Electrabel have high market power managing the network and even representing a barrier to entry for start-ups with new technologies. From the interviews, it therefore seemed suppliers have moderate to high bargaining power energy supply.

Third part: Conclusion

Chapter 1: Recommendations

The interviews shed light on several recommendations – as perceived by field experts – which can be reviewed and completed.

First, promising technological development (components, liquid cooling, renewable technologies, buffer storage) is expected to improve energy efficiency. However, some solutions are already available and considering the rate of ICT development, new efficient solutions are bound to be discovered. It seems market perceptions are that Green IT efforts are either not a priority or destined for larger data centres that can afford them. Seeing as equipment in Belgian data centres is old and brings important inefficiencies, there is an urgent need to replace equipment and integrate new solutions. To overcome the associated high costs, they must first be considered differently and not measured following classic financial methods. New ways to measure long-term value and translating positive social and environmental impacts in financial terms should therefore be considered and applied.

Secondly, for private clouds in organisations, accountable management should be designed, clear energy reduction objectives should be set based on quality information (data demand forecasts, standard requirements and filtering the essential data to be stored). A separated Green IT budget can be prepared, and a Green IT manager appointed. Information is key in Green IT deployment. As many centres follow different methodologies (e.g. indicators, standards, communication) and are not accountable to any particular organism (e.g. voluntary participation to the EU Code of Conduct), there is a need for a structured framework setting requirements on all aspects of the centre and validated by a recognised institution. The material passport can be an inspiration to monitor and report on energy use. It could in turn reduce the opacity in the field increasing stakeholder awareness and initiating more action from them.

Thirdly, system-level efforts should be examined to create a Belgian "Green IT ecosystem". More collaborations between data centres in the field and members of the supply-chain (upstream and downstream) should thus take place. Green lease contracts can inspire the development of new billing mechanisms and communication strategies should be elaborated with most used apps and sites to increase user awareness of their data consumption through apps. Software opportunities like sustainable coding or blockchain must be researched and determined how they could fit business processes. Labels for websites can increase their accountability and provide even more information to users. Cradle-to-cradle strategies should be discussed with component suppliers to identify e-waste opportunities and contracts should bind both parties. Large data centres should go beyond their individual role and become a market advocate for Green IT deployment. This would happen not only by having an exemplary role but working with other data centres to transform the field. Their leader position should be used to share innovative technology, suppliers and even invest into replacing equipment. Similarly, large energy suppliers can play a more proactive role by looking at renewable energy strategies for the centres, creating cross-initiatives in the market and identifying heating opportunities. Coordination between public and private institutions can facilitate the introduction of Green IT initiatives by assigning loans and reviewing laws. Belgian legislation should be reconsidered for a sector as dynamic and evolving as the ICT. It could enforce the use of the framework requirements and define more strict minimum requirements for data centre construction.

Chapter 2: Study conclusions

The study aimed at exploring how Belgium's Green IT performance was in data centres by looking at obstacles, enablers and future strategies. The theoretical approach consisted in understanding the global data demand in the ICT sector and its impacts before introducing the concept of Green IT and illustrating how global cloud providers applied it in their processes. The empirical research consisted in a qualitative exploratory inductive methodology where field experts of different positions were interviewed to define the phenomenon on a Belgian scale. The model of (Salama & Kass, 2020) was used as inspiration for interview conduction and its adaptability to the Belgian environment was analysed. At last, Porter's five forces model was used to get a broad view of the sector and the interactions between them.

2.1. **Results summary**

In conclusion, it was determined from the interviews that Green IT implementation in Belgium was slow and had room to develop and evolve. The interviewees shed light on different obstacles and enablers which were grouped in five main recurring themes: transparency, legislation, stakeholder awareness, technological development and country situation. The themes are closely interrelated and interact (e.g. more awareness can help increase transparency). When analysing tech leaders globally, some of the themes also appeared as a challenge they faced while other challenges mostly concerned the specific Belgian environment. Seeing as similar problems are encountered in different parts of the world – especially concerning transparency – and the fact that economic motives are usually prioritised over environmental concerns, Belgium could lead by example taking a proactive advocate role at the heart of Europe.

The main recommendation of the study would be the design and application of a harmonised framework applied at a national or European scale. This framework would set minimum requirements for the centres with clear and complete guidelines – enforced by legislative mechanisms – on how to monitor clearly defined indicators. It would offer a holistic view of any data centre while indicating details on each aspect hereby increasing understanding, awareness and transparency of the actors in the field. A shared tool of this type facilitates coordinated action from different stakeholders at different levels: state and government, organisations and users. They all hold a part of responsibility and better understanding of the problem is needed to help solve it. For example, companies could work more with their partners and suppliers in designing data centre equipment adapted for reuse or to push traceability further. Furthermore, financial support mechanisms can be directed towards the most urgent cases of material replacement as the long-term value would be acknowledged. Hence, sharing a standard tool could create a Green IT ecosystem with larger players leading by example, constructive competition and increased interactions along the value chain.

2.2. Literary contribution

This study inscribes itself in a literature that is not very developed and helps get a broad view of Green IT in Belgian data centres. Increases in data demand and the associated impacts are modern phenomena that are expected to evolve even more in the future. Considering the speed of innovation in the ICT sector and the Fourth Industrial Revolution, new developments are to be expected. The contribution of this study is to raise awareness and understanding of an issue that is not regarded as a priority in the sector.

Data centres only represent a fraction of ICT developments in a similar way that Belgium represents a small portion of the European or global territory. Furthermore, there are many ways to consider a phenomenon and its aspects. This study also represented the state of a field at a point in time which is bound to evolve. It sets the basis for more detailed and thorough research considering the many factors involved in data centre Green IT. For experts in the field, it can be used as a contribution towards building a harmonised framework, point out flaws and solutions for their own infrastructure and expose some projects and standards used in Belgium for inspiration. For future students researching on similar topics, it can introduce an unfamiliar field in a structured way or offer new leads for future research.

2.3. Study limits and future research leads

Some limits to the research were future paradigm shifts that can considerably affect predictions and considerations especially in a dynamic sector like ICT. As was mentioned with the debate between centralisation or decentralisation, the entire structure and perceptions of data centres can be modified, and part of the research could be rendered irrelevant. Research could also have been pushed further by increasing the number and diversity of participants. Some larger Belgian data centre operators have not been included in the study, which might have unravelled interesting facts or perceptions of the field.

Considering the study in a holistic perspective while having identified the limits, some future research leads can be highlighted. Firstly, the topic of edge computing, which is still at development stage can be investigated at the national level. In a qualitative approach, different experts can be interviewed to better understand in the debate between centralisation and decentralisation what are the characteristics of both and what would a complete switch to edge computing mean for the sector. Secondly, the impacts of external events on data demand and management, can be further analysed to evaluate response mechanisms and their efficiency. The exceptional situation of the 2020 pandemic has yet to reveal new literature to which interesting contributions on efficient prevention methods can be added. In this context, the role of disaster recovery data centres and emergency generators or batteries can be explored. Thirdly, further research on best practices for communication with stakeholders – and especially the user as “responsible digital citizen” – on their data consumption and how to efficiently raise awareness to reduce data use could lead to many new insights. In parallel, different indicators and associated reporting channels can be evaluated to optimise monitoring and reporting in data centres. Fourthly, a more thorough investigation at the European scale could unravel the intricacies of system-level coordination. This might identify the obstacles and enablers of data centre management planning and regulation as well as the effects of recent developments such as the European Commission Green Deal. Another research lead could be data value and how users could become prosumers. There are different strategies, some of which were mentioned in the study (e.g. blockchain), that can be explored to determine the best way for users to make companies accountable and transparent on how user data is manipulated. A model can be imagined valuing the user data, protecting his privacy and channels to communicate on the matter. Finally, the recommendations can be reviewed and updated as the ICT sector is constantly changing at a fast pace: new initiatives, companies, hardware, software, country policies. Complementing the study with a more quantitative analysis of the specific efforts each data centre applies could help set up an action plan on the shorter term.

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