The Role of Data Centres and Energy Available to Support the Growing Smart Industry in Twente

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ABSTRACT
As traditional industries are becoming smart, their reliance on data centre services increases, leading to changes in the electricity demands of data centres and uncertainty in electricity supply. This thesis aims to synthesize the developments of the smart industry in Twente and the effects it has on data centre electricity needs and electricity supply. For that matter, insights from secondary sources and interviews with industry representatives, a data centre representative and an expert on the topic of data centre efficiencies were used to develop a system dynamics model. The model has two scenarios with predicted industry based on literature and industry representatives, to discover how the data centre electricity needs change until 2030, and whether the available electricity for data centres will suffice. When considering a single data centre, electricity shortages were discovered in the region of Twente until 2028 and 2029 depending on the industry's growth and the amount of electricity distributed to data centres. Considering all six data centres in the region, the electricity shortages are expected to continue beyond 2030. Thus, this thesis represents a blend of theoretical estimates about the industry's growth, data centres' electricity demands and available supply. Moreover, it informs the regional data centres, electricity suppliers and regulatory bodies about the electricity shortages and proposes solutions to cope with the shortages.

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Data centre, Electricity demand, Electricity supply, Twente, Smart industry, System dynamics

1. INTRODUCTION

Data centres, placed at the heart of the development of smart industries, represent a major consumer of electricity, with 200TWh in 2019 or 0.8% globally (IEA, 2020a). With the rise of smart technologies, the reliance on data centres has grown steadily, with some estimates suggesting that the percentage of electricity going to data centres can rise to 8% by 2030 (Andrae and Edler, 2015; Jones, 2018a).

The shifting trends towards the usage of data centres and their ever-increasing electricity consumption are noticeable in the Netherlands and affect all regions. Such developments are further highlighted in the reports of REOS and the Dutch DataCenter Association, putting emphasis on trends as centralizing and collocating of data centres (Dutch DataCenter Association, 2020; REOS, 2019), framing the energy efficiency amongst the top priorities (Dutch DataCenter Association, 2020).

Given the trends of IIot, blockchains ICT, growth of electricity usage of data centres is foreseen, although literature does not specifically agree upon the percentages (Morley et al., 2018). It is worth noting that when looking into historic data, the energy usage of data centres has slowed over the years, due to the major efficiency improvements in both hardware and software (IEA, 2020a), as well as the increased use of cloud and hyperscale data centres (Statista, 2021a). On the other hand, the reliance on data centres is increasing, suggesting that energy consumption will remain significant (IEA, 2020a).

According to the DDA, "(...), all Dutch Data centres together use 17.95PJ (2019)." (Dutch DataCenter Association, 2020, p.18). REOS recognizes the importance of data centres for the economic growth of the Netherlands and its regions (REOS, 2019). The importance of data centres for economic prosperity was proven by the COVID-19 crisis. Due to the large digital infrastructure in the Netherlands, part of which is the data centres, the online collaborations, working and learning went in most part smoothly (Dutch DataCentre Association, 2021). Since 2011, multiple roadmaps for digitalization, ICT and smart industry developments have been made (Larosse, 2017). Additionally, much focus is put on the regions' engagement with innovation and as such the digitalization of industries and creation of smart industries (Larosse, 2017). When looking at the region of Twente and its current largest manufacturing industries with potential for smart development, a few stand out: food, chemical and electronics (Bazen, 2019; Sijgers et al, 2006). Globally, the aforementioned industries become more dependent upon smart elements to achieve maximum efficiency and volumes.

As such, the need for electricity grows. Furthermore, there is significant movement towards the usage of green sources for electricity generation (RES Twente, 2020). According to the Dutch DataCenter Association, 86% of DDA members use green energy and an increase to 92% is expected (Dutch DataCenter Association, 2020), while LEAP aims at promoting a green and efficient society (Amsterdam Economic Board, n.d.). However, a challenge arises: simply, in the Netherlands, there is not enough renewable energy to supply the data centres (Dutch DataCentre Association, 2021).

In the Netherlands, REOS highlights the importance of RES (regionale energiestrategie) when it comes to the growth of data centres and the creation of networks for electricity (REOS, 2019). Considering the region of Twente, the greatest consumer of electricity represents the industry, while more and more emphasis is placed upon renewable sources of electricity, with a focus on increasing the sources until 2030 (RES Twente, 2020). Moreover, the Dutch DataCenter Association calls for the industry to aim to participate in the usage of green energy.

Given the global developments, national and regional initiatives for the Twente region, it becomes apparent that the need for stable electricity continues to grow for the usage of data centres as the smart industry develops, while significant emphasis is placed on sustainable sources of energy. Thus, the objective of this research is to explore how smart industry developments in Twente will affect the data centres and their electricity needs and match those needs.

Thus, the research question is: *How to synthesize the developments in the smart industry in Twente and forecast the data centres' energy needs?*

Further, this research aims to tackle the additional questions:

- What are the main smart industry developments in the food, chemicals, metal and electronics industries?
- How will the identified developments and volumes affect the use of data centres in the region of Twente?
- What are the main trends in data centres in the Netherlands affecting Twente?
- How will the capacity of data centres change in Twente?
- What are the electricity needs of data centres in Twente now and what are their estimated future needs?

Answering the research question incorporates theoretical estimates for industry developments and growths with estimates for data centre electricity needs by Koot and Wijnhoven (2021) in the context of Twente. It builds on the RES Twente (2020), CBS (2020), CBS (2021a) and CBS (2021b) estimates for electricity supply and data centre electricity consumption in respect of Twente. For practitioners, it may serve as a caution to data centres to secure their electricity supply while the region's supply catches up with their demands. Additionally, it calls for closer collaboration between electricity suppliers and regulatory bodies to address and cope with the potential electricity shortages.

2. THEORETICAL FRAMEWORK

2.1 Industry

Smart industry or industry 4.0 is: "(...) a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry 4.0, Cyber-Physical Systems (CPS) monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things (IoT), CPS communicates and cooperates with each other and humans in real time. Via the Internet of Services (IoS), both internal and cross organizational services are offered and utilized by participants of the value chain." (Hermann et al., 2016; Rossit et al., 2018, p. 3802). The developments encompassed by the smart industry have far-reaching implications for the value chains, altering the customer experience, production processes and facilities and the products themselves (Haverkort and Zimmermann, 2017). Amongst the advantages are improved and customized products and services, the creation of new products, as well as increased flexibility and adaptability, and efficiency in production and procurement processes (Haverkort and Zimmermann, 2017).

Due to the advantages the smart industry offers, industries across the world have opted for the adoption of smart elements.

Meanwhile, governments are acknowledging the economic and societal potential of smart industry and are putting forward plans and roadmaps to modernize their industries. Thus, in the Netherlands in 2018, the Smart Industry Implementatieagenda 2018-2021, was put forward, paving the way to widespread adoption and shift to smart industry practices (Smart Industry Implementatieagenda 2018-2021, 2018). Furthermore, the roadmap put forward the importance of creating regional Smart Industry Hubs, supporting entrepreneurs across the country's regions. The development of the regions is further acknowledged in various other roadmaps, as ICT Roadmap and Digital Agenda (Larosse, 2017). The region of Twente is characterized by a large array of manufacturing industries, encompassing amongst others, the chemicals industry, metal-electronics, food, materials, medical devices, defence and construction (Bazen, 2019; Sijgers et al., 2006). Because of the growing reliance on smart elements observed globally, this research will use the developments in the food, chemicals and electronics industries.

For instance, the food industry is becoming reliant on Fog- Cloud computing to achieve food quality (Bhatia and Ahanger, 2021), computer vision and AI for better productivity and more flexible processing (Kakani et al., 2020). To improve interoperability and data sharing in the food industry's supply chains, and quality, blockchain technology may further be utilized (Chopra, 2020). It is expected that by 2030, food production will increase by 4.6% globally (Statista, 2021b).

The chemicals industry is undergoing a similar transformation: the usage of IIoT is recognized for its connectivity, while to achieve improvements in production asset availability as well as performance, Big Data and analytics are being increasingly utilized (van Leeuw, 2018). Globally, the chemicals market is expected to grow 4.3% annually between 2020 and 2025, and 4.2% between 2025-2030 (Statista, 2021c).

Furthermore, the electronics industry is increasingly shifting towards automated production lines (Yang, 2018) and digital manufacturing (Dilberoglu et al., 2017). Additionally, the analogue pressing technologies being currently used are being substituted by digital control technologies (Yang, 2018). The industry recognizes the benefits brought by the effective use of cloud services, IoT, Big Data and Cloud computing, as well as the use of Autonomous robots and Additive manufacturing for new and customized products, with increased production speed and precision (Dilberoglu et al., 2017). The CAGR for the electronics market is 6% between 2021-2025 (Statista, 2021d).

2.2 Data centres and electricity needs

At the core of digitization, and thus, the smart industry are the data centres (Masanet et al. 2020). Koronen et al (2019) note that the efficiency of data centres can be split into three system levels - IT equipment efficiency, ancillary equipment efficiency and efficiency in computing management. Firstly, "IT equip- ment includes servers, storage devices and communica- tion networks that are directly involved in delivering the core functionalities of the data centre, i.e. the storage, processing and transmission of data." (Koronen et al. 2019, p. 132). Secondly, the ancillary equipment consists of the cooling system, power infrastructure, lighting, security and supporting equipment. (Koronen et al. 2019). The main efficiencies lay within the design of the cooling systems, as the optimization of airflow and using natural cooling sources (Koronen et al. 2019). Lastly, computing management can become more efficient (Koronen et al. 2019).

The three system levels of efficiency affect the data centre applications. The data centres have four main applications: servers, storage, network and infrastructure (Cisco, 2013; Masanet et al. 2020; Koot and Wijnhoven, 2021). The workloads that data centres' servers process, store and transmit, come from the application behaviours (Koot and Wijnhoven, 2021). In total, there are eight types of application behaviour, four consumer-oriented (search, social networking, video streaming and other consumer apps) and four business-oriented (cloud-ERP, business applications, databases, analytics, IoT, collaboration software and computations) (Koot and Wijnhoven, 2021).

The servers consume the most electricity in the data centres (Shehabi et al. 2018). Cisco (2018) noted that the global traffic of data centres will grow 25% yearly (CAGR), with cloud data centres growing by 27% yearly (CAGR). Due to Moore's law, by which efficiency in the improvements of computer capacity and energy performance due to decrease in transistor size, major efficiency improvements of computer capacity and energy efficiency the exponential growth of efficiency is achieved (Koronen et al., 2019). Although the continuation of Moore's law and the barriers of silicone-based chips have been brought under question (Andrae and Edler, 2015; Waldrop 2016), in the foreseeable future it is likely that it will continue (Koronen et al., 2019). The impact of the end of Moore's law would mean that the servers' electricity demand would increase further (Koot and Wijnhoven, 2021). Additionally, the electricity use per computation of an average volume server has decreased by a factor of four, due to the efficiency improvements in processors and idle power reductions (Masanet et al., 2020).

Second, networking is estimated to further increase (Koot and Wijnhoven, 2021). However, Koot and Wijnhoven (2021) note that while the efficiency of servers is increasing, and the costs of energy of data centres are declining, the traffic growth does not add greatly to the energy needs of data centres.

Third, the storage capacities will increase significantly (Koot and Wijnhoven, 2021). However, Koot and Wijnhoven (2021) further note that the electricity demand for storage will not be greatly affected by the increase in capacity. The reason for that is the utilization of more energy-efficient SSD devices (Koot and Wijnhoven, 2021). The reasons for the decrease are the efficiency gains of storage-drive density (Masanet et al, 2020).

Lastly, the infrastructure is defined as "(...) all data center energy needs that are not directly caused by server processing, storage, or network activities." (Koot and Wijnhoven, 2021, p.6). According to Masanet et al. (2020), the large decrease of energy use of the infrastructure of data centres offsets the growth of the IT devices energy use. In 2016, the PUE of traditional 2.10 and cloud 1.66 (Cisco, 2013; Koot and Wijnhoven, 2021).

When considering the total electricity use of data centres estimates differ, between 1,800TWh (Liu et al.2020), 8,000 TWh and 1,100TWh, worst- and best-case scenario respectively (Jones, 2018b; Ratka and Boshell, 2020). Lastly, Koot and Wijnhoven state: " (...) expect a combined growth of data center electricity needs of 286 TWh in 2016 up to 321 TWh in 2030, if today's technological and behavioral trends remain the same. The end of Moore's law results in a total of 658 TWh for 2030, and an increase of the global data centres'- share of electricity consumption from 1.15% in 2016 to 1.86% in 2030. The rise of Industrial IoT applications may consume a total of 364 TWh (about 1.03%) in 2030. Moore's law and IoT combined cause data center energy needs going up to 752 TWh in 2030, and about 2.13% of global electricity available." (Koot and Wijnhoven, 2021, p.10-11).

On the other hand, the reliance on edge computing, which brings the processing of data closer to the source itself (Jiang et al., 2019), is on the rise too (Statista, 2021e). Thus, "(...) edge computing paradigm can take some of the load off the central cloud data centers and migrate the tasks from cloud computing centers to network edge devices, reducing or even eliminating the processing workload at the central location." (Jiang et al., 2019, p.131544). According to IBM, 87% of industrial products and 83% of consumer products are expected to achieve an increase in operational responsiveness due to edge computing in the next five years, while decreasing their power consumption (IBM, n.d.). As such, some predict that by 2025, approximately 75% of data will be processed outside of the cloud or traditional and centralized data centres (van der Meulen, 2018), while other estimates suggested that by 2023, 50% of data will be processed outside of the core (Gill, 2020). Others argue that 50% of data will be processed outside of the data centres by 2022 (Rimol, 2019). Thus, when considering the growth of the smart industry and the effects it may have on data centres and electricity use, it

is crucial to take the edge computing advances and use into consideration.
In the Netherlands, almost all domestic data centres use green energy, which is in line with the promise that by 2030 all European data centres will be climate neutral (Dutch DataCentre Association, 2021). In 2019, 2.7% of the total electricity supplied via the Dutch electricity grid went to data centres (CBS, 2021b). Additionally, between 2017 and 2019, the amount supplied rose by 66% due to the creation of new data centres and the expansion of the existing ones (CBS, 2021b).
Twente currently houses primarily small and medium co-locating data centres (Equinix, 2021; InterDC, n.d.; Previder; n.d., REOS, 2019). The data centres and their sizes (m2), collocation possibilities, energy use and supply can be seen in Table 1. Data Centres in Twente.

Table 1. Data centres in Twente

Data Centre	Size (m2)	Collocation services	Green energy use (%)	Power supply
InterDC: Enschede Haven	119.8	✓	100	/
InterDC: Enschede Marssteden	74.3	✓	100	/
InterDC: Hengelo	127.9	✓	100	/
Previder: PDC1	11,000	✓	100	10MW
Previder: PDC2	2,500	✓	100	6MW
Equnix: EN1	1,200	✓	100	/

2.3 Electricity supply

Across the EU and the Netherlands, initiatives and plans are pushing forward the lowering of use of non-renewable sources of electricity, while encouraging the expansion of the supply of renewable ones.
In the 2020 report, RES Twente emphasises the usage of renewable energy for industry (RES Twente, 2020). In the report, it is noted that by 2030, Twente will generate approximately 1,5 TWh (1500 GWh) of renewable electricity. The electricity supply estimates in the region can be seen in table 2. Green energy supply in Twente in 2019 and 2030 (RES Twente 2020).

Table 2. Green energy supply in Twente in 2019 and 2030 (RES Twente, 2020)

Energy source	2019 (GWh/ year)	2030 (GWh/year)
Solar panels (roofs)	50	265
Solar panels (land)	66	500
Wind turbines	0	530
Unaccounted	0	205
Total	116	1500

However, in the foreseeable future, non-renewable energy sources will still be the main source of electricity in the Netherlands (CBS, 2021a; IEA 2020b). The non-renewable energy supply can be seen in table 3. Non-renewable energy supply (CBS, 2021a; CBS, 2021c). The supply in Twente was calculated by dividing the supply in the country by the number of energy regions as determined by the regional energy strategies. The yearly change of their use has been calculated based on data between 2017 and 2020 from CBS (2021a) and CBS (2021c).

Table 3. Non-renewable energy supply (CBS, 2021a; CBS, 2021c)

	Year	TPES (PJ)	TPES (TWh)	Twente supply (TWh)	Yearly change
Total coal and coal products	2017	385.1	106.97	3.57	-22.45%
	2018	346	96.11	3.20	
	2019	268.80	74.67	2.49	
	2020	179.60	49.89	1.66	
Total crude and petroleum products	2017	1,183.6	328.78	10.96	-3.65%
	2018	1,154.4	320.67	10.69	
	2019	1,105.8	307.17	10.24	
	2020	1,058.8	294.11	9.80	
Natural gas	2017	1,299.4	360.94	12.03	0.43%
	2018	1,286.7	357.42	11.91	
	2019	1,341.6	372.67	12.42	
	2020	1,316.2	365.61	12.19	
Other	2017	36.8	10.22	0.34	2.82%
	2018	39	10.83	0.36	
	2019	84.8	23.56	0.79	
	2020	40	11.11	0.37	

3. RESEARCH DESIGN

The literature search was conducted using Scopus, ScienceDirect, Web of Science, Mendeley and ResearchGate, with keywords and filtering the articles from years 2017-2021, by using keywords such as “smart developments AND food industry” or “data centres electricity use”. In the cases where too few results were showing, the filter for years was not used. To discover the specific developments and plans for Twente and the Netherlands, national and regional documents were used.
However, a lack of information was identified regarding the regional developments. Therefore, to find out how the global smart industry developments will reflect on the industry in Twente, and further, on the work of data centres in the region and the electricity supply, interviews were conducted.
The interviews were split into categories, depending on who was interviewed: companies, researchers and data centres. Splitting the interviews into separate categories was needed to further organize and present the results, while allow for structuring of the primary questions per area of interest.

To cover each industry of interest, at least one company of each will be interviewed. Thus, one from the food industry, two from the chemicals industry and one from electronics were interviewed. One data centre representative was interviewed to learn more about their capacities and prospects. Meanwhile, a researcher, and organizations as LEAP and the Dutch Data Center Association were contacted to gain more understanding about data centre developments and future expectations on the national level. In total, seven interviews were done. The primary set of questions asked per category of interviewees and their responses can be seen in Appendix A.

The interdependencies and interrelatedness of the smart industry, data centres and electricity needs in Twente will be represented with a system dynamics model with Insightmaker (Fortmann-Roe, 2014). The system dynamics model will allow for a better understanding of the relations within the industry, data centres and electricity supply, and the changes that may appear over the period of 10 years (Hjorth and Bagheri, 2006).

Additionally, besides the control results, with the creation of scenarios the possible directions in which the developments may manifest themselves will be represented (Tiberius, 2019). Two scenarios are created, based on the different industry growth predictions of the interviewees and the global expectations (Statista, 2021b; Statista, 2021c; Statista, 2021d). Furthermore, due to the uncertainty in the parameter values, sensitivity testing was done, to validate the model (Fortmann-Roe, 2014). The sensitivity analysis was run on the scenarios with 10,000 trials.

4. RESULTS

4.1 Interview insights

4.1.1 Industry developments

To discover the need for data centres in the region of Twente, employees from local companies were interviewed.

First, the food industry is experiencing a large transformation, not only due to the shift to smart industry practices but also in the customer demands. Therefore, the company interviewed aims to remain stable when it comes to growth prospects while recognizing that adapting to smart industry practices is necessary to keep its market share. From smart industry practices, the ERP systems, sensors and interfaces are a common ground, while automated production lines are not always possible, due to the century-old process of making some meat products. However, a few products are produced on fully automated lines and use robotics. The industry is facing major challenges when it comes to finding the appropriate personnel for both their production and maintenance. Therefore, adapting automated lines and sensors is a necessity for both substituting personnel, as well as satisfying the requirements for data collection set by the law. However, the volume of data stored is still too small compared to other industries. Thus, the growth of data collection leads the companies to explore the usage of data centres for the future, as storing increasing volumes of data locally becomes difficult. However, the distance between the data centres and the company remains a challenge due to the time needed for the information to pass from the machines to the data centres and back, potentially causing a loss of production time.

Another industry that was considered is the chemicals industry, in which smart industry practices are widespread and considered a necessity to realise the prosperity of the companies. Amongst the common elements between the companies interviewed are ERP systems and plans for automation on the production lines. Additionally, one of the companies reported using cloud services in their offices, while the other uses a transportation module, as well as separate software for machinery, data management, and numerous sensors and scanners on the machines. Meanwhile, companies are interested in adding more sensors, and software to automate their machinery and production lines. Companies use data centres for hosting their larger systems, such as ERP, and IT services, while smaller software, rely on their own, local servers. One of the main reasons for the limited data centre use is security concerns. Nonetheless, the importance of data centres for their operations and connectivity and speed is recognized. The companies are expecting about 5% yearly growth.

Lastly, the smart industry practices in the electronics industry are spreading beyond the automated lines and use of big data analytics, as identified from the literature. The amount of data that the companies are receiving and processing from their customers are ever-growing. However, due to the privacy, security and intellectual property concerns of the customers, relying on data centres and cloud services is proven to be a challenge; thus, the companies are relying on their own systems. Therefore, the companies from the electronics industry are highly hesitant about using data centres for now, due to the demands and concerns of their customers. For the future, as the shift to the smart industry progresses and the reliance on data will increase, data centres may be considered. However, that is highly dependent on the customers' demands and concerns. The company's growth is projected to steadily continue at approximately 20% yearly.

4.1.2 Data centre developments

The industry is taking an interest in data centres, so the data centre capacity growth come under question. An organization focusing on the data centres in the Netherlands was interviewed. The organization's expectation about the growth of capacity of data centres is 1 GW of extra capacity until 2030. The 1GW is considered a realistic scenario, since greater growth in capacity may be infeasible due to the need for grid expansion and technical people.

Furthermore, edge computing would not have a large influence on the local data centres in the Netherlands. There are two reasons for that: firstly, there are no real low latency use cases yet and secondly, the Netherlands has perfect connectivity towards data centres, cloud and hyper scales. Additionally, they noted that a connection <5ms is everywhere in the Netherlands. Unfortunately, any details about smart industry effects on the use of data centres are unknown.

The reliance on renewable energy sources is growing (Dutch Datacenter Association, 2021). For example, one data centre uses electricity from windmills in Rotterdam is used. Although solar panels are placed on the rooftops of the data centres, the amount of energy they produce is not enough to meet their demand. With contracting with electricity providers, their current supply is 10MW. To be able to match those 10MW, they would need two windmills on their own, whose installation is challenging. Data centres have an interest in participating in green initiatives since the customers' desire and encourage the use of renewable energy. Meanwhile, data centres have observed that energy consumption is slowly declining with improvements in the hardware. At the same time, the demand for data centres, especially cloud data centres, is growing. However, the traditional data centre services are still needed, primarily for ERP systems, or for specific customers for whom the cloud services are inappropriate, such as the government. It is noteworthy that the majority of data centres are concentrated in Amsterdam, thus redistribution of the customers throughout the Netherlands would be beneficial for maintaining electricity supply. However, additional support from national bodies is needed to realise such action.

4.1.3 Industry, data centres and electricity

There is a consensus that the demand for data centres and, with that electricity, will increase and thus presents a global problem.

Thus, there is a need for concentrating on the reduction of energy consumption, by utilizing different technologies, such as AI or photonics. However, a danger arises that the solutions may consume more electricity, than they create reductions. For example, AI itself consumes electricity, and thus, by using it to create reductions of electricity, it may lead to redistributing the electricity spending from the data centres to the AI.
When considering how much the electricity consumption will increase, the figures differ, with the interviewee suggesting about 8% of global electricity in 2030 will go to data centres; however, the figure is only an estimation and prediction and may be challenged. When considering the industry's side of the coin, it is apparent that opinions differ yet again. Some believe that the industry is trying to improve energy usage and has done, and the energy consumption will not increase dramatically. However, the industry should not be fully trusted. The true results or estimates of such developments cannot be known for now, due to the lack of concrete evidence when it comes to execution and use of the new technologies.

4.2 Model

4.2.1 Parameters

The insights from literature and interviews are used to find parameters for the industry growth expectations yearly until 2030. Since the industry recognizes that to remain competitive, greater reliance on the smart industry is necessary, thus industry's growth will affect the application use. Thus, the industry's growth, presented in table 4. Industry growth expectations is multiplied with the use of the applications.

Table 4. Industry yearly growth expectations

Industry	Interviewees' growth expectations of industry (yearly)	Global growth expectations of industry (yearly) (Statista 2021b; 2021c; 2021d)
Food	0.00%	4.60%
Chemicals	5.00%	4.20%
Electronics	20.00%	6.00%
Average	8.33%	4.93%

The data centre electricity needs stem from the workloads, coming from the use of applications (Koot and Wijnhoven, 2021). Ergo, the application workloads use affects the electricity consumption of the servers. Furthermore, the workloads affect the traffic of the data centre, and thus, affects the network electricity use (Koot and Wijnhoven, 2021). The applications' use influences the need for storage, and thus storage electricity use (Koot and Wijnhoven, 2021). Therefore, the applications are considered when calculating the electricity needs of the servers, network and storage. The model covers elements of randomness. Thus, the start of the end of Moore's law is a random year between 2016 and 2029, as well as the start of IoT impact. The workloads, storage and traffic also rely on randomness. Meanwhile, the cloud and traditional data centre services use is changing with different rates. Thus, the parameters for both are are considered. The data centre applications' parameters can be seen in table 5. Applications' parameters (CISCO, 2018; Koot and Wijnhoven, 2021) and table 6. Applications - Traditional and cloud (CISCO, 2018; Koot and Wijnhoven, 2021).

Table 5. Applications' parameters (CISCO, 2018; Koot and Wijnhoven, 2021)

Applications		Value	CAGR (%)
Application workload	Search	10	0.149
	Social	12	0.259
	Video	18	0.236
	Other	18	0.185
	ERP	57	0.186
	Data base	33	0.214
	Collaboration	48	0.144
	Compute	46	0.170

Table 6. Applications - traditional and cloud data centres (CISCO, 2018; Koot and Wijnhoven, 2021)

Applications		Value
Traditional data centre	Search	0.000
	Social	0.000
	Video	0.030
	Other	0.060
	ERP	0.240
	Database	0.260
	Collaboration	0.220
	Compute	0.170
Cloud data centre	Search	0.000
	Social	0.000
	Video	0.000
	Other	0.000
	ERP	0.480
	Database	0.450
	Collaboration	0.450
	Compute	0.430

The servers' electricity consumption is influenced by their productivity and power. Furthermore, there is a difference in the developments between the traditional and cloud data centres. The parameters for traditional and cloud productivity and power values as well as their CAGR are presented in table 7. Server parameters (CISCO, 2018; Koot and Wijnhoven, 2021; Masanet et al., 2020).

Table 7. Server parameters (CISCO, 2018; Koot and Wijnhoven, 2021; Masanet et al.; 2020)

Server		Value	CAGR (%)
Traditional	Productivity	2.4	0.096
	Power	230	0.036
Cloud	Producticity	8.8	0.084
	Power	303	-0.019

The network is split between external and internal. The external network energy consumption is dependent upon the traffic per workload of the different applications. The external network is influenced by the internal traffic and the traffic energy rate. The internal network electricity consumption is influenced by the server ports and power ports, which differ between traditional and cloud. The network parameters can be seen in table 8. Network parameters (CISCO, 2018; Koot and Wijnhoven, 2021).

Table 8. Network parameters (CISCO, 2018; Koot and Wijnhoven 2021)

Network		Value	CAGR (%)
External		77.6	0.051
Traffic per workload	Search	77.6	0.051
	Social	77.6	0.051
	Video	77.6	0.051
	Other	12.6	0.008
	ERP	12.6	0.008
	Data base	12.6	0.008
	Collaboration	12.6	0.008
	Compute	12.6	0.008
Internal traffic		0.754	-0.011
Traffic rate energy		0.06	-0.285
Internal			
Power ports	Traditional	1.71	-0.059
	Cloud	2.58	-0.095
Server ports		4.53	0.013

The infrastructure electricity needs originate from heating, lighting and alike components, specifically, the electricity needs of components other than servers, network or storage (Koot and Wijnhoven, 2021). It is measured with the power usage effectiveness (PUE), which differs between cloud and traditional data centres (Koot and Wijnhoven, 2021). The infrastructure parameters can be seen in table 9. Infrastructure parameters (CISCO, 2018; Koot and Wijnhoven, 2021).

Table 9. Infrastructure parameters (CISCO, 2018; Koot and Wijnhoven 2021)

Infrastructure		Value	CAGR (%)
PUE	Traditional	2.1	-0.01
	Cloud	1.66	-0.01

Lastly, the storage is influenced by the storage per workload by the different applications. Additionally, the driver capacity and storage power are shaped by the SSD and HDD drivers, whose use changes. The storage electricity consumption is further influenced by internal storage and HDD storage. The values and CAGR are shown in table 10. Storage parameters, and the infrastructure parameters (CISCO, 2018; Koot and Wijnhoven, 2021).

Table 10. Storage parameters (CISCO, 2018; Koot and Wijnhoven, 2021)

Storage		Value	CAGR (%)
Storage per workload	Search	2.3	0.103
	Social	2.42	0.088
	Video	2.67	0.097
	Other	2.39	0.092
	ERP	2.6	0.108
	Data base	3.88	0.076
	Collaboration	1.88	0.165
	Compute	3.35	0.096
Driver capacity	SSD	1.38	0.353
	HDD	3.78	0.27
Internal storage		0.285	-0.036
HDD storage		0.81	-0.029
Storage power	SSD	6	-0.023
	HDD	8.1	-0.053

The parameters from table 4 to table 10, are used in the model in order to calculate the data centre electricity needs. The complete model used for the simulation can be seen in Appendix B.

The electricity supply coming from both renewable and non-renewable sources is presented, using the parameters form in section 2.3 Electricity supply in table 2. Non-renewable energy supply (CBS, 2021a) and table 3. Green energy supply in Twente in 2019 and 2030 (RES Twente, 2020).

The electricity needs of data centres comes from the electricity demands of the servers, network, storage and infrastructure together, and consequently, the industry growth effects on each of them. Firstly, the applications part of the model uses the parameters from the workloads and the differences between cloud and traditional data centres and the IoT impact. Moreover, the industry's growth rates are included in the applications workload, in order to simulate the changes in the use of applications and their effects on the server's electricity usage. Thus, the servers are placed by the applications, with the developments in productivity and power. Since Moore's law affects the productivity of the servers, it is included by the server's productivity. The network is split between external and internal. The external network incorporates the traffic per workload and the influence of industry growth on it and the randomness, with the internal traffic and the traffic energy rate. The internal network incorporates the port power and server ports and their CAGRs. To represent the storage electricity use, firstly, the storage workload randomness and the storage per workload are considered. Additionally, the storage electricity use depends on internal storage, driver capacity, HDD storage and storage power. Thus, they are incorporated in the model in the storage portion. Lastly, on the infrastructure side, the PUE and the CAGR of PUE are included. Since, the servers, network, storage and infrastructure together create the electricity demands of data centres, and thus, their separate electricity needs are summed to find out the total data centre electricity needs. To find how the electricity needs of a data centre under the influence of industry will affect the supply, the electricity use of data centre is subtracted from the supply. A simplified version of the model is shown in figure 1. Model of industry effects on data centre electricity needs and electricity supply.

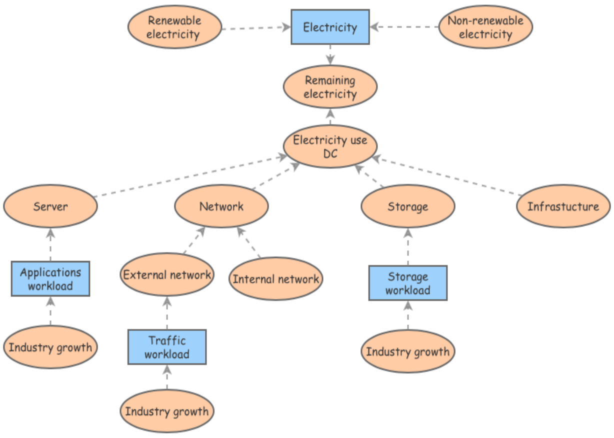

Figure 1. Model of industry effects on data centre electricity needs and electricity supply

4.2.2 Electricity supply simulation

The current electricity supply in Twente is 24.14TWh. From them, 0.1162TWh come from renewable sources, while 24.024TWh from non-renewable sources. By 2030, the electricity supply in Twente would reach 1654.5TWh. From them, 1402.9TWh would come from renewable sources such as solar on rooftops (590.8TWh), solar on land (808.2TWh), wind (1.9TWh) and unaccounted sources (2TWh). Additional 251.6TWh would come from non-renewable sources such as coal and coal products (17.7TWh), crude and petroleum products (99.7TWh), natural gas (130TWh) and other sources (4.2TWh). The simulation for electricity supply can be seen in figure 2 Electricity supply simulation results.

About 2.7% of the total electricity supplied by the grid in the Netherlands went to data centres in 2019, with 66% growth between 2017 and 2019 (CBS 2021b). Because of the efficiency gains in technology and the growing energy supply on one side, and the growing need for electricity on another, the percent of change is likely to change over time. Thus, if it is assumed that the 2.7% will remain constant by 2030 and that 2.7% also holds for the electricity supply in Twente going to data centres, from the 1,654.5TWh available in 2030, only 44.7TWh will go to data centres in the region. However, if the estimates of about 8% as mentioned by one of the interviewees, as well as literature (Andrae and Edler, 2015; Jones, 2018a; Koot and Wijnhoven, 2021), become true, 132.36TWh of the 1,654.5TWh produced in Twente, will go to the local data centres.

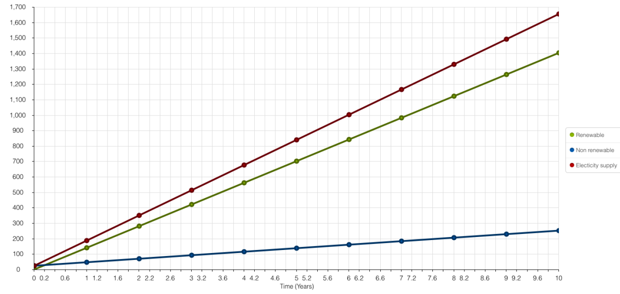

Figure 2. Electricity supply simulation results

4.2.3 Control simulation and sensitivity analysis

To observe the effects of industry growth, a control simulation is run without industry growth. The total electricity needs of data centres are expected to reach 84.3TWh by 2030. From them, 10.5TWh would go to servers in traditional and 11.9TWh in the cloud. The network electricity needs would be 34.6TWh and storage 3.2TWh. The infrastructure electricity needs would become 21.0TWh. The simulation results can be seen in figure 3. Control simulation results.

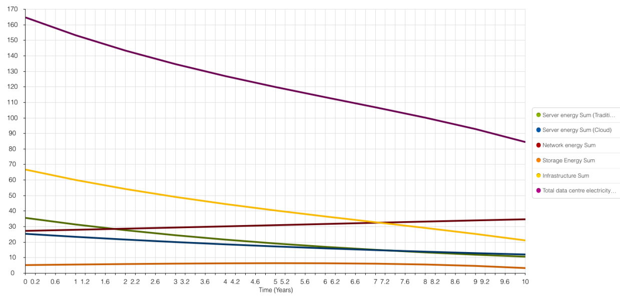

Figure 3. Control simulation results

With 2.7% of the electricity in Twente going to data centres, 39.65TWh of electricity shortage will happen in 2030, while with 8% of electricity going to data centres, by 2028, there will already be a surplus of 6.27TWh. In 2029, the surplus would reach 26.61TWh and 48.04TWh in 2030. Considering that the region has a total of six data centres currently, if the number remains constant to 2030, there will be 461.27TWh shortage with 2.7% of the electricity going to data centres in the region and 373.58TWh shortage with 8%. The result from the sensitivity analysis can be seen in figure 4. Control result sensitivity analysis. The median electricity consumption is 77.9TWh. In the 95% confidence region, for 2030, the lower value is 55.2TWh and the upper value is 108.7TWh. The exact figures and the 75% and 99% confidence regions can be seen in Appendix C.

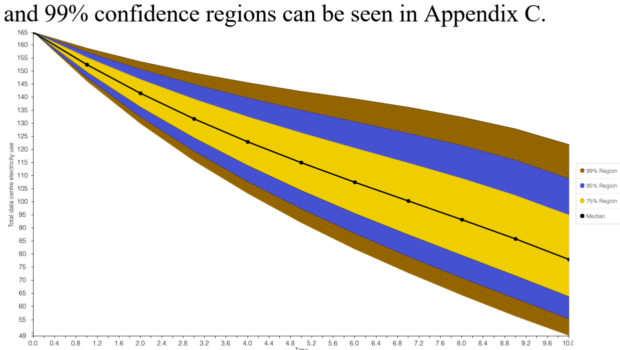

Figure 4. Control result sensitivity analysis.

4.3 Scenarios

4.3.1 Effects of literature estimates of industry growth

The first scenario is based on the literature's estimates of industry growth globally by Statista (2021b, 2021c, 2021d). With average industry growth of 4.93%, the electricity needs of data centres increases and becomes 96.1TWh. Since the industry growth would affect the use of applications, workloads and traffic, the servers, network and storage will consume more electricity. Thus, driven by the increased demand of electricity use of the servers, network and storage, the total needs for electricity of a data centre will increase. More precisely, 10.7TWh would be needed for the running of servers in traditional, while 12.0TWh for the cloud. The network would need 46.2TWh and storage 3.1TWh. Lastly, the infrastructure would require 21.1TWh. The simulation results can be observed in figure 5. Effects of growth according to literature. If the 2.7% of electricity supply remains to go to data centres nationally, based on the simulation, 51.43TWh of electricity will be lacking. Meanwhile, with 8% going to data centres, in 2029, there will be a surplus of 15.67TW and in 2030, 36.26TWh. The scenario observes the electricity needs of one data centre. When considering the six data centres in the region, with 2.7% of the electricity going to data centres, the shortage for 2030 will become 531.96TWh and with 8% it will reach 444.27TWh.

The sensitivity analysis shows that the median electricity consumption with industry growth of 4.88% is 83.8TWh. In the 95% confidence region, for 2030, the lower value is 59.2TWh and the upper value is 118.0TWh. In figure 6. Sensitivity analysis with literature growth estimates, the 99% and 75% confidence intervals can be observed. The exact figures can be seen in Appendix C.

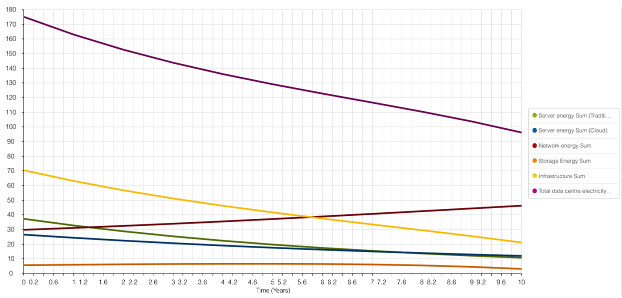

Figure 5. Effects of growth according to literature

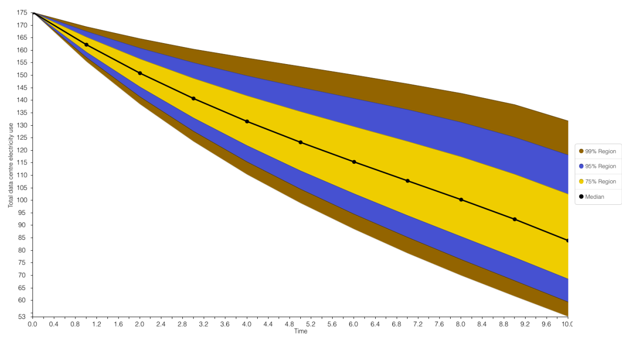

Figure 6. Sensitivity analysis with literature growth estimates

4.3.2 Effects of interviewees estimates of industry growth

The second scenario is based on the growth expectations of the interviewees, which averages 8.33%. With the industry growing 8.33% yearly, the total data centre electricity needs in 2030 would become 99.3TWh. The industry's growth would affect the applications workloads, and thus servers in traditional data centres would consume 11.8TWh, while in cloud 13.4TWh. The traffic would increase due to the growth in industry, leading the network to need 42.5TWh and storage will require 3.9TWh. Lastly, the infrastructure would need 24.0TWh. The simulation results can be seen in figure 7. Effects of growth according to interviewees. With 2.7% of electricity going to data centres, in 2030, there will be a shortage of 54.65TWh. If the percentage of electricity going to data centres becomes 8%, then a surplus of 9.94TWh and 33.04TWh will appear by 2029 and 2030 respectively. Since the region houses six data centres, the shortage by 2030 with 2.7% of electricity going to data centres will become 551.27TWh. With 8% of electricity going to data centres, the shortage will become 463.58TWh in 2030.

With 8.33% industry growth, the median electricity consumption is 87.7TWh. In the 95% confidence region, for 2030, the lower value is 62.2TWh and the upper value is 122.9TWh. The exact figures can be seen in Appendix C.

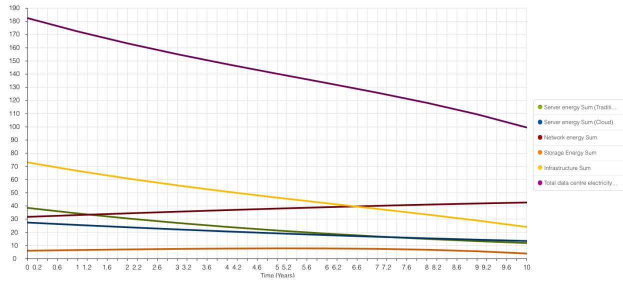

Figure 7. Effects of growth according to interviewees

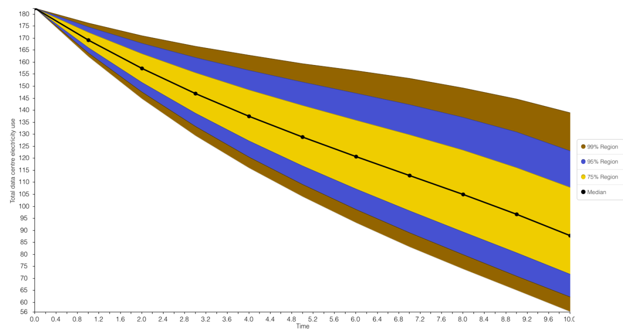

Figure 8. Sensitivity analysis with interviewees' growth estimates

4.3.3 Coping with energy shortages

Since the region of Twente may not be able to cope with the growing demand for electricity, reliable ways of coping with the shortages need to be discovered. Data centres are already using electricity from other parts of the country, while the government is offering grants and tax incentives for sustainable energy generation (Government of the Netherlands, n.d.). Additionally, the country relies on importing electricity from other countries, primarily Germany and Belgium with 20.4 billion kWh in 2019 total import (CBS, 2020). Meanwhile, the import numbers are declining, as domestic production increases (CBS, 2020).

Majority of data centres in the Netherlands are concentrated in Amsterdam and the surroundings, which causes additional concerns about the use and distribution of electricity affecting all of its regions. Thus, redistributing the data centres throughout the country may lessen the shortages occurring in the regions. To support such redistribution, the electricity supply will need to be levelled across the regions in the country, potentially leading to greater supply of electricity in the regions facing shortages.

The Netherlands is also exploring the development of a digitized energy system (IEA, 2020b). Such a system "(...) enables high shares of variable renewable generation, broad electrification of end-uses, co-ordination between networks for electricity and low-carbon gases, and innovative new energy services." (IEA 2020b, p.15). Additionally, for 2022, the new Energy law has been created to allow for demand-side response. The new law will lead to a more efficient energy system nationwide and greater flexibility (IEA, 2020b).

At the same time, the country is working on a Hydrogen strategy. The goal of the hydrogen strategy is to reinforce the flexibility of energy systems by building up production of hydrogen, storage and transport for renewable sources and seasonal energy storage (IEA, 2020b). Greater governmental support is needed to achieve the desired flexibility (IEA, 2020b). Moreover, regional laws need to be changed in order to allow for more windmills to be placed in Twente (RES Twente, 2020).

If developments such as the digitized energy system and the Hydrogen strategy become realised in the near future, the effects of electricity shortages in the region may become mitigated. However, since the results of the initiatives are currently unknown, it is not possible to estimate to what extent they will help in decreasing the electricity shortages in the region. Until significant progress is made with the digitized energy system and the hydrogen strategy, and the imports continue to decline, the most viable options seem to remain redistribution of the data centres and their customers and relying on electricity from other parts of the country.

5. DISCUSSION AND CONCLUSIONS

The shift to the use of smart industry practices creates greater demand for data centres, which in turn creates a greater need for stable electricity. National bodies such as the Dutch Data Centre Association are recognizing the importance of data centres for economic prosperity. Thus, synthesizing the industry's effect on data centre's electricity needs and the available supply becomes a crucial point in ensuring economic prosperity in the region.

Globally, traditional industries are becoming smart. Thus, the use of elements such as ERP systems, IoT, automated production lines, robotics, AI, Big Data and software is increasing across the food, chemicals and electronics industries (Bhatia and Ahanger, 2021; Dilberoglu et al., 2017; Kakani et al., 2020; van Leeuw, 2018; Yang, 2018). In Twente, the shift to the smart industry allows the industry to cope with the personnel shortages and regulatory demands for data collection. Consequently, when possible, regional companies are relying on smart elements such as software and ERP systems, while searching for opportunities to automate even greater parts of their production lines. Moreover, the industries are globally expected to grow 4.6% for food, 4.2% for chemicals and 6% for the electronics industry (Statista, 2021b; Statista 2021c; Statista 2021d). In Twente, the industries recognize that to remain competitive and achieve the desired stability for food, 5% growth for chemicals, 20% for electronics growth, the shift to the smart industry is necessary. The reliance on smart elements and consequently growth in volume increases their reliance on data centres.

The data centres are experiencing efficiency gains from both improvements in hardware and software as well as greater utilization of hyperscale data centres. However, their electricity needs are expected to continue growing (Jones, 2018a; Jones, 2018b; Koot and Wijnhoven, 2021; Liu et al., 2020; Ratka and Boshell, 2020). Nevertheless, due to the efficiency gains, the regional data centres report a slow decline in their electricity consumption.

The simulations confirm that the electricity demand will decrease over time of traditional and cloud data centres, confirming the findings from the interview, as well as Statista (2021a) and IEA (2020a); however, the figures differ. Yet, it contradicts some literature's predictions, for example from Liu et al. (2018), Andrae and Edler (2015), and Jones (2018b). The difference may be explained by the lack of hyperscale data centres in Twente and their omission from the model. However, the growing reliance of industry on data centres is expected to increase the electricity consumption of data centres.

Although there are both national and regional efforts for increasing the supply of electricity, especially from renewable sources, by 2030, the total supply will barely meet the needs of a single data centre in the region. Thus, in the foreseeable future, reliance on imported electricity will likely continue, unless there is a significant increase in electricity generation in Twente.

5.1 Theoretical implications

This thesis contributes to existing research by incorporating the work of Koot and Wijnhoven (2021) on data centre electricity needs within the context of industry growth expectation in Twente according to both literature and industry representatives. Furthermore, the thesis uses the theoretical expectations of electricity consumption of data centres to find the estimate how much of Twente's electricity will go to data centres. Moreover, it synthesizes the expected industry growths and their effects on the data centre industry needs in Twente, to simulate data centre electricity needs for 2030. It builds on the national data about electricity supply collected by CBS (2020) and CBS (2021a; 2021b; 2021c) to create predictions about the region of Twente. Lastly, it builds on the expected electricity supply set by RES Twente (2020) by adding the non-renewable electricity sources and examining the supply available in the region as a whole and for data centres.

5.2 Practical implications

This thesis is relevant beyond the theoretical context. With the electricity supply barely meeting the needs for a single data centre in Twente only after 2028, this thesis may warn regional data centres to strengthen their relationship with their electricity providers. By creating stronger relationships with their electricity providers, the regional data centres may secure their supply and continue operating smoothly even in times of shortages. Meanwhile, it spreads awareness to the growing use of data centres by industry, and thus brings awareness to data centres to address potential capacity increases.

Moreover, it informs the electricity suppliers and regulatory bodies about the electricity shortages from the supply designated to data centres in the region. This thesis urges the regulatory bodies and electricity suppliers to work closely with each other in order to achieve supply increases of electricity in the region of Twente, at least until they become sufficient to cover the needs of the region.

Furthermore, it informs the regional data centres and regional suppliers about potential solutions to the electricity shortage in the region, by suggesting continuous import of electricity from other parts of the country, while the regulation catches up with the developments in electricity supply.

6. LIMITATIONS & FUTURE RESEARCH

The model and the parameters used in the model originate from secondary sources, and therefore do not reflect the exact situation in Twente. The industry growth is estimated by only interviewing one company for both the food and electronics industry, while two for the chemicals industry and as such may not be representative of all companies and the industry in general. Lastly, no energy supplier agreed to an interview, and thus more information about coping with shortages and the timelines for increasing supply are not included.

Therefore, more research is needed to shed light on the electricity suppliers' side, to uncover the timelines in which more electricity will be available. Moreover, as the data centres' capacities and efficiency change over time, future research addressing the changes over time from primary data sources from the region may be beneficial for more accurate measurements of the electricity needs of data centres. Additionally, a larger sample size of industry representatives may bring forwards different growth rates and the use of different smart industry elements. This research may form the base for observing the effects of smart elements in other industries in the region. It may provide the foundation for future research on the electricity use of data centres in other regions of the Netherlands, and thus contribute to a better understanding of the electricity use of data centres, smart industry and electricity supply in the regions across the country.

7. ACKNOWLEDGEMENTS

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9. APPENDIX

Appendix A

<u>Interviews: Primary Questions and Answers:</u> General (Industry & Data Centres):

Table 11. Interview with researcher

Question	Rsearcher
Introduction	*Under the program there is a number of research lines all with look into way of reducing the energy consumption of data centers in their current being. So, we don't necessarily look into how yet , how the demand of the future will change, but the expectation is of course that the demand will increase because of all of these developments, including smart industry, increase demand and then that causes a problem for us a global community. And that's why we should focus on reducing the energy consumption of the data centres, so we can have different ways where we feel where we can contribute to that with AI which causes energy consumption by regenerating the heat and reusing the heat that has been generated, but also looking into the longer term at the new technologies that will not use so much technology, like photonics and neuromorphic computing and quantum computing. That of course doesn't answer any of your questions but it is what the research program is about. In AI, Bojana Rozhich is one of the more important researchers, one of the topics she will look into is also the energy efficiency of algorithms themselves. Because if you are not smart about that, your solution itself will consume more energy if you are not careful, then the energy reductions it can generate. She might me important to speak to and the people on her team. I focus a lot on industry and what industry is doing and recently an industrial roadmap that was published with industry themselves look into different developments that are important for them. I will see if I can dig that up. So, the european industrial technology roadmap, so the industry partners themselves look at what are the developments coming and what should we focus on, it might be interesting for you. There is quite some discussion on their view and how the developments are between edge and cloud. It can be helpful information. In that branch, that community, the Dutch Data centre organization, you probably have some of their documents. In Twente there is not a lot of big data centers, so there is a few. (...) And 4he industry of course has some interest in this topic. Not necessity the most sustainable interest, but they want to keep their industry alive. And also the Dutch Data centre association presents that. So, it is important to be aware of that positioning of this. And*

	if you read many articles about the prediction about the increase of energy consumption, that has been predicted for the upcoming 10 years, you can find a large variety of predictions. Some say it is not so much, don't worry, because as industry we do a lot to keep that down, so it will stay stable. And some say it will be 15 times as much as now in 10 years, so a horrible scenario. The truth is probably somewhere in between. And I think we are also largely in the drivers seat to make that as low as possible. Not just as industry, but us as users, the BMS faculty is looking at how we can influence users and how can we make them more aware, make us more aware of what we do, how can we influence policy makers in all of this. A lot of what we do will impact what that end figure will be for 2030. The algorithm energy, the algorithm design, software deign, data centre, ICT technology and so on and so forth. I think the question that you tick is a bit of it, You can't solve the whole thing. The industry view will also not only give you answers not only when it comes for smart industry.
Do you have any expectations, predictions, forecasts about how the demand for data centers will grow?	*There is quite some publications, I can send you a few, the predictions. None of these give you the same figure and that's the challenging bit. Everybody agrees that demand will go up, everybody agrees that energy demand will go up, the opinions differ a bit about how much can the industry do to keep that down, but with whoever you speak you will not get the same figure. So, I usually say it's 8%, in 2018 it was 1% of global energy demand that came from data centers, and in 2030 it will be 8%. People can challenge me on that of course because I can't guarantee that it will be that, some say it will be 10%, some say it will be 3%. They all might be right or wrong, I can be equally right or wrong as the people who say it will be 50%. I can't predict that, I don't have the calculations to underpin that. I just see a lot of publications that are in this bandwidth. And I also don't trust the industry who say we will keep it low, so it will only be 2%. So I really, do not believe that they can manage that. Also, because that the data centre industry itself is quite torn up into smaller bits, strange business model, but also the technology they drive is often the surrounding technology. So, data centers you have these ICT equipment and servers and for the big data centers often that is equipment for other parties. For example, Equinix, a big company, they have 250 data centers across the globe, they are quite a big player, but all of these, they own the building the cooling system, they own the lighting, but the ICT equipment is owned by their customers, so they offer their customers the space to put their ICT equipment in. That is their business model. So, they are in charge of how much energy this building takes, how much the cooling takes, that's what they manage. But they don't manage in any way the consumption of these ICT equipment.*

	So, who owns that energy consumption- their customer. But with that, customer is a whole array of us using the equipment - of using Netflix of doing our online meetings, and so on. So nobody is really driving that down.
Are there any specific developments (such as AI, regenerating heat etc.)?How probable is it that the energy consumption will be lowered in the next years?	*Now I cannot say that yet. For instance, the photonics technology the same question came. If we could remove some of the electronics and replace it wby photonics chips for example, how much energy will be saved. We don't know that yet. I cannot answer the questions. And therefore I find it very difficult to believe the industry if they say we can keep it to a same level. They have some quite some efforts in the past and that is the data that we can see, they simply extrapolate that and say, well based on this, for the future we think we can do this. But, I think that at some point there is a limit to that, because of the model, because of having optimized the building management quite a bit, but there is more in there, but that is not as much as in the past.*
Do you have any past data about how did some efficiency developments in the past influence the electricity consumption now?	*I will have to dig in my files to send you some of the relevant information. Maybe they are not detailed, but there should be some information. Also, I think that the data centre association should be able to give some insights on that. There is a lot of European and national information, I don't know how we can give you the region.*

Table 12. Interview with food industry representative

Question	IT manager of a company in food industry
Which smart industry elements (for example, IIoT, Big Data analytics, cloud) are you currently using in your operations?	*Let me start with explaining a little bit about (company name) and then we come to this topic and then you will understand my answers. (Company name) is family company, family owned. 500 minion euros revenue and around 60 000 people. We have, in the Netherlands 5 plants and one office. We also have plants, three plants in the UK, and 2 in the US. But, I am responsible for the plants in the Netherlands. We have been making food, especially meat products, ambient meat products. So, products that can stay out of the refrigerator for a long time and we have been doing that for many many years. And with the recent mergers, the last 3 years, we now also produce soup and sauces. We are not only focusing on meat anymore, but also on vegetable based products and all of our meat products are available in vegan and vegetarian version, going with trends that everyone wants to be vegetarian. The process of making canned meat is a very old process. It has been the same for almost 100 years. So, we buy meat, we don't slaughter cattle ourselves. We buy standardized meat, we cut it in pieces and we put some ingredients into it, put it in*

	a can and heat it label it an it's ready. You can have it in a can for 3-5 years, because it sheared so much that it is sterilized, so there are no bacteria anymore and you can eat it. Because the process is already the same for the past 100 years, our main machines are also quite old. So, most of the machines are separated. So, if you look at the process, then you receive meat, you cut it in pieces, you mix it with ingredients, salt, pepper, things like that, and then you put t in a shape. Those are the main steps. For most of the meat products, those steps are separate. It's not a long industrial process, where you put some meat somewhere and at the end there will be cans. There is a lot of manual labour in between those steps. Those machines are quite expensive, so they are not replaced quite often, and almost none of them has an IP connection. So, they have the SKARA, the user interface to run the machine and collect all the data, but it is all for here and now for this moment and not for long term analytics. And that's quite different from other types of industry that you have here in Twente. When you look at the dairy and the Bolletje, with the beschuit, that is different. That is more long production lines, where they have a lot of connections between and they check within the line the work. This is not the case with meat productions. The only exception is the knackworst. That is the only exception, where we have a production line, where we put in meat, cut it and it is completely automated and then you have a pallet full of cans of boxes with cans. Due to that type of production, which we cannot change easily, we do not have that much data. And we are in the middle right now of trying to find out how can we find more data, or capture the data which is already there but is not intended for analytics, so that we can have big data. So for your question about data analytics, no, we don't have big data. We capture a lot of information within out manufacturing system, because we are required by law to do so, we have to protect the food safety and things like that, so we know exactly what we are doing. But the data is very limited in volume. I just asked one of my colleague how large our manufacturing system is, but then you are talking about 300GB of data, which is not much. And we have 5 locations, so 5 manufacturing systems, so 1.5 TB of production data, which is still not that much, if I compare it to the dairy producers and the things they are step ahead of us, where they have fully automated their production lines and they have much more robotics and things like that. We do have robotics and we do have some type of sensors, but it is still very early in the early stages.
Do you have plans to adopt more or other smart industry elements?	*A lot. Because we are facing two issues or more or less the same issue. The issue is people. There are not many Dutch people who would like to work in a factory anymore. People who are working with us are*

	some Dutch but the most are coming from Poland, Hungary and the Eastern Europe countries, and even those countries are not having the highest standard of living, they are not willing to come to the Netherlands and work in a factory anymore. We have to get our people from farther away, so that is hard. We are depending a lot on people, we would like to remove the dependency on people, and we want what is very normal in the dairy industry, that we enter a product in the system and pick we want to make this type of sausage and all the machines know what to do and we collect the data while producing and check for differences in what the norm and the case is. The second thing is also people - the technical people, the people who maintain the machines. Technical people in the Netherlands is even worse, that there are not that many and if you need them, they cost a lot of money. So, downtime of our systems are quite expensive, because we don't have the people and also our suppliers don't have that many people anymore and it takes a long time to get those people, so, location and to repair the machine. So, we also are looking very much into prediction what will need maintain, to prevent the downtime. And to predict that we need information. Now, the maintenance people predict it themselves, based on experience, expertise and this like that. So, that is one of the areas where we are looking to how we can do that. But, there are constraints - the old machines. There is a lot of variety in the machines we have and we cannot connect it to one system, so if we find a connection with one type of machine and we can use it in all locations, so it makes it hard. We are quite struggling with that right now. But our intention and our goal for the next three years is to find a system where we connect all our variety of machines, collect all the information, so we can make predictions on maintenance and connect that layer to our management and factory, so we can say we produce this article and the machine knows what to do. And that is for an IT department quite hard, who are very much focused on the inside. We have our servers locally, because the machinery is developed that you cannot centralize the servers. I cannot use a data centre right now because the data centres are too far away. There is a lot of latency between the servers and machinery that the machinery will slow done based on the latency and you need many hotdogs per minute to be successful and we need speed. We cannot achieve speed with over one connection. So, we have the data centres that are at locations right now, that are hyper conference hardware, like on box with the servers and come all at one. It is all still locally. So, the security is quite tight, because we don't need connectivity. Most of the people in the company don't have connectivity to the outside world or internet and people like me who have access to it, and people who do, don't have access to the production network. We

	see that we cannot save all the data that we need on our own servers. We have some calculations that we expect to have data growth f about 15 000%. Based upon that we throw away a lot of the information passing through the machines and that we don't collect it, and it is finished because it is there only for the moment on the screen to see what is happening. So we expect that we will need external data centres and cloud data centres, because we don't want to build something on our own. And we need to find a way that we can connect the outside world to our own and protective environment. *I think we can do. Because that is even necessary. If you look to get stable we need the current plants and due to the covid- 19 situation, our products are very required and we have a lot of production right now. And to keep this stable we need our plants and people we have right now and people are getting harder and harder to get and that's a threat that we need to counter with robotics and analytics and more or less industry 4.0 things that we can connect our machines to our data and that is necessary to do. The same with the technical people, if I look at the prospects that some companies do see how many technical people are there, then it's getting less and less. So we also need to do something there to maintain the stable. Otherwise we can sell a lot but we cannot produce.*
How much data centre services are you currently using?	*We are required to use them. We cannot have that much data on our own servers. We need a data lake or something on one of the platforms, like Azure or Amazon and also they have all that type of tools that are required for machine learning and analytics which is much easier to get out of the cloud than think about it and buy something on our own. That new world that we are designing and we are trying to build will be a cloud based world.*
What are your growth expectations for the future 5 to 10 years?	*If I look at the data what we have right now, I can give you some figures. We have 5 production systems and 1.5 TB of production data. That is quite stable all years, we have our ERP systems, which is 3 TB and data warehouse of 1.5 TB, and those systems grow with about 10% each year. The business as a whole. That is a difficult question, because we cannot predicts how many sausages you can buy, It depends on the market. As a whole, I think we will be stable. We will not have much growth and we will be stable. What we see in Europe, the market of canned meat is getting smaller because people are getting into vegetables and have enough money to buy real meat and not canned meat. On the other hand, we export to about 110 countries across the world and there are countries that are growing very fast and there you start to see that they earn just enough money to buy this type of canned meat and for them canned meat is a luxury item. For example, in Africa, and Middle*

	East where many people are born and have not that many refrigerators and we see that the growth in that kind of countries is larger than the growth in Europe. On the other hand, the growth of vegetarian products is growing but not that fast. In percentages, it is about 20-30%, in normal values it is very small compared to meat products. I think there will be changes and shifts within our portfolio products, but on a whole I think we will be more or less the same.
How much data centre services do you think you will need to realise and support your growth? Would you considering using a collocating one or one for your own company?	*Never one on our own, no. My IT team is quite small and there is no need to do that type of work on your own. To give you an idea, when I started here 7 years ago, I found a company without email and internet. It's hard to understand that a company can work without email today, but even 7 years ago was quite hard to understand. So, we went to a situation where we were quite behind the normal situation, to a situation where we were in the need, and we moved directly to office 365. My technical people thought it will be good idea to have our own service, but I explained that nobody can do that better than somebody who has to do it in book and do it for very large scale. Microsoft can run it much better than my own people.That is the same with data centres, you can run your own one, but when I look at what we need to do at a normal level, we can never achieve what is done in the normal data centers. We would always share and that's also a better thing because then you can utilize your resources in a much better way then buying things on your own.*

Table 13. Interview with chemical industry representatives

Question	Manager Marketing & Operations of a company in the chemicals industry	Manager Finance & IT of a company in the chemicals industry
Which smart industry elements (for example, IIoT, Big Data analytics, cloud) are you currently using in your operations?	*We are currently using cloud functionality in the office, the factory mainly works locally and is system wise separated from the office (in the light of cyber security).*	*Data service - we have big systems that we are using, of course, ERP system, our administration system, but there is also logistics in it, warehousing, procurement, sales and so, and a lot of additions, and transportations. Then we have add ons on this, for example, I don't know if it's smart, but we have a transportation module. This has a direct link with a lot of companies, for example, if you want to ship something to Spain, then we get a real update of what's available, what are the costs, so there is an interface with another kind of software. For our factory system, it's more machinery software, that*

		is steering the machines, behind that we have OSIsoft from the US, the by-systems, that retrieves all the data from all the machines, the heat, the temperature, the pressure, etc. With this data base we can make different kind of queries and look if we produce something out of specification, so it was not a good production and we can look back in the data and look where it went wrong, not enough raw materials, not enough hydrogen etc. So, this is all what we have. It's not .. I don't know what is exactly smart, but this is what we have. Do you have any examples of what you mean what is smart? *So, cloud we don't use it, we store always local, or in European headquarters or in Malaysia, so it is a little bit separated. We have a lot of sensors on the machines, and that is then feeding our data bases to look what happened. We are also adding a lot of sensors, mainly for sustainability. For our energy consumption, because we use a lot of energy, a lot of gas. We use more than I think 10000 houses, we are big consumer. We only have a certain limit of data - we know which building, we have 100 buildings, so which building are using it. But in the buildings are different pumps and machines. So, now we are investing for more scanners to look where is the real energy consumption. But, that is now, the last one year what we are starting on, because we need to do something about sustainability. We are looking to go for a European data centre, but in the future, between 3-5 years because we are just starting with the kind of people to organize it. That is in the future, because we have some issues, since a lot of data is still stored in Malaysia, we have some speed issues. It is not that quick always. And it is maintained by Malaysia, so they have different working hours, so they are at the end of the day, and we are just starting. For european we have the same timeline and quicker data and it is*

		easier to communicate with them and make changes. With Malaysia, it's a different culture and it takes time and energy to make some changes. That's one of the reasons why, and then, European data centre, I think it will go to Germany, to be honest, needs to be set up.
Do you have plans to adopt more or other smart industry elements?	*We consider a new ERP-system which enables us to streamline a number of processes. We are also considering to (semi-) automate certain industrial processes to run 24/7*	*So, what I said, we have 7 factories, everybody wants something for their own kind of smart elements. And now, we are in the phase when we are sitting all together, once a month, to look what are the needs of every company and to look do we have time and money to invest in smart elements. For now, we are doing some smaller things. We have the transport module and some other factories do not have it, so they want to implement it in upcoming years. To be honest, of the companies, we are the little bit more modern, maybe not good to say, but we see that we don't have a lot of practices, but they have a lot to be on a certain baseline, then we can grow. What we really want to have is, a little bit specific. Every day we have three shifts that are working 8 hours, three teams of 8 hours. The data and information that needs to be shared between these teams is in Excel, so it is old-school, so to say. And we have an advanced software that is called Shiftconnecor that can connect all the data from the production machines and make a dashboard, so when a new team enters can see this is going on, you need to watch out for this, and all kinds of special things. No factory in Europe is still there, so now this is the biggest project we want to introduce and then look where the data is stored - is it every separate or in one database. So, that is one of the bigger things we want to do. And what I said, other factories need first to do additional things . We have a weighbridge, so when there is a truck entering we weight it, and when it goes out of the*

		factory we weight it again, and then we know how much chemicals they have and this is just now printed on paper and we want to interface it with our system. So, then you will just see it in the system, for example this is 1000kgs and is also ordered by the customer and then we just send an invoice and then it's checked. This kind of things, but this is in the coming two years. *We just renewed our servers and data bases; half a year ago, they were 12 years old, and we renewed everything, so I think that will take us 7-10 years, and from then on I don't think they will be replaced, but we will go more to centralized Europe data base.*
How much data centre services are you currently using?	*Mainly for IT and hosting services*	*Main things are locally stored. What we have is our main system ASP, an European system that is stored in Malaysia. That is a system that is used in also Asia and Europe, and that is one system that every factory has. SO, this data is stored there. We have some small data centers in Switzerland, our European headquarters, but that is really small, with some smaller software packages and I think that the rest is locally stored. So, If i say in percentage, if the ASP is 50% and is in Malaysia, then 5% is stored in data centers in Switzerlands and the rest 45% is still stored in Delden. But it depends how big the systems are.*
What are your growth expectations for the future 5 to 10 years? Do your believe that adapting more smart elements within the production processes will allow you to continue with those growth expectations? What about your production volumes now and in the future?	*We expect to double our turnover (12Mln) in the next 10 years.*	*I think the last, you can also see in the newspapers, it's pretty busy. A lot of requests from a lot of companies, we still have spare capacity. From my view, for only Delden, we make five year budget, I think we will grow 20-25% in the upcoming , so, 5% every year in the upcoming 5 years. We have the figures, now for this year, we predicted we will sell 44 million liters of chemicals, so 44, and we expect them, next year, 50 million. We have some bigger projects and it takes long time to get new*

		customers, but we have them, we call it in the pipeline, in the first year, we have some projects on machines that are not really running full. For next year, we will have 50 million liters of chemicals. But, we do specialties also. We have another factories in Rotterdam, and they produce 200 minion liters, but for less value. They do continued production, but in Delden we do batch production, smaller batches and smaller quantities. *I think it will help, and also needed. At the end, if you want to grow and get these volumes, you need to hire a lot fo additional people and that is not the way forward. and that is not the way forward. we have the same kind of people, work smarter, more data, more automation, so, to produce more quantities, so what we want to do, we have some manual handled, you push a button and it goes, so we have some machines that are fully automatic, where you are by the computer, type in and you can do it. And for the upcoming year we will invest 1 million to more automatization and some hardware for the machines so they can act on themselves. With this, we want to avoid growing with people, with more employees.*
How much data centre services do you think you will need to realise and support your growth? Would you considering using a collocating one or one for your own company?	*That is hard to say, 'data centre services' is quite an abstract term. We do however expect to become more and more reliant on data centers, given that as we grow our data flow will further increase.*	*At he end to be honest, where it is stored is for the engineers, and not a key thing, more for the IT departments what is the most efficient way and the most centralized. So, what I think, after long time, 3-5 years, we will store many parts on European level. And use the same data, in the background it will change. I think we are still in the discussion point for now. If it is safe, it is safe, to be honest, so, that is not on the discussion yet.*

Table 14. Interview with electronics industry representative

Question	Managing Director of a company in the electronics industry

Which smart industry elements (for example, IIoT, Big Data analytics, cloud) are you currently using in your operations?	*I believe there is a lot of data transmitted from customers to us for every product we produce in here. So, part of the bulk, the development material has a lot of information that we need to transmit and transfer. That's the first stage actually, and our operations and our production, we have a highly automated process, which also needs a lot of storage. At this time we are having the storage capacity all internal, built internally. So, we don't need a data centre yet. But maybe in the future. It has to do with the security issue, where we have some customers in the defense industry that don't like those kinds of stuff, actually data centres. But, there are two stages in the process. So, the first stage is the orientation, where a lot of data is sent by our customers to us, and secondly, in the production, the second stage, where we transfer and process a lot of data. Cloud services are not very common yet, because of the fact I mentioned before, many customers do not really appreciate that in electronics because of security issues, intellectual property issues and that's why in general we built our own system. It wasn't the most cost effective, but it's the demand of our customers.*
Do you have plans to adopt more or other smart industry elements?	*Yes, we do. Specifically, I just started a project with Saxion University on augmented reality, implementing augmented reality technology. Secondly, I have discussions with my supplier of our pick and place, a highly automated pick and place machine from Japan, from a Japanese supplier. I am talking with those guys on several topics about how to automate any further processes and last, but not least, is focus on the handcraft* part *of the company. There I am also looking for opportunities to automate. That's not really making a lot of progress now, but the other two yes; it's really a challenge at the moment.*
How much data centre services are you currently using?	*Still, independent from everyone. So, we don't make use of data centres yet. I can imagine that it may be the case in the next period of time. I am not sure if we are allowed to do it.*
What are your growth expectations for the future 5 to 10 years? Do your believe that adapting more smart elements within the production processes will allow you to continue with those growth expectations? What about your production volumes now and in the future?	*To be honest, I bought this company two years ago, as a management buy-in and the only goal for me is growth and I believe it will be 10-20% a year. Up to now, we achieved that goal, so I believe that 20% for now per year, I hope I can get it to a level and can build new premises.* *That's hard to say- you need to be competitive, and when you adapt fast new technology it gives you the opportunity to grow, even faster than you expected. It depends on a lot of factors, and I can't predict the future, more than two years from now.* *The difficult point is that we don't actually count the number of products. It is between 50 000 and 100 000 pisces a year. My objective and the company goal is to grow it triple this number, within the next five years. For your understanding. 2021 is really an interesting year, since we have a very high growth rate at the moment, coming from 2020, it was really slowing down because of Covid. But, now it's ramping up really fast. We now have a growth rate of approximately 50% this year. I am really encouraged*

	about 2022.
How much data centre services do you think you will need to realise and support your growth? Would you considering using a collocating one or one for your own company?	*The last option, I believe the last option is what we prefer. The point is that we deliver services by assembling piece by piece and we don't have our own product. So, customers will have certain needs for how they process everything. Therefore, we can't decide ourselves. We need to have commitment and approval from our customers for this kinds of topics.*

Table 15. Interview with organization

Question	Managing Director of organization
What are the efficiency developments of data centres?	*Sent a document: Dutch Datacenter Association. Data Centers and Duurzaamheid (2021).*
What effects will those developments have on the capacity and energy consumption (in terms of kWh, MWh, TWh)?	*Sent a document:Dutch Datacenter Association. Data Centers and Duurzaamheid (2021).*
What are the effects of such developments on businesses using data centres for their operations?	*Sent a document: Dutch Datacenter Association. Data Centers and Duurzaamheid (2021).*
How will the data centre services consumption change as a result of the efficiency developments?	*Sent a document:Dutch Datacenter Association. Data Centers and Duurzaamheid (2021).*
How did the smart industry growth in the past affect the data centres work and capacity in the Netherlands?	*Could not answer - do not collect such data*
What are the expectations, predictions and forecasts for growth of data centres used for the future five or ten years, and the energy consumption that may come with it?	*There have been some report about the future growth for 2030. A realistic scenario is one 1 GW of extra capacity in NL in 2030. Any more would also become unrealistic as we are waiting on the expansion of the grid, need for technical people to accomodate this.*
Do you have any insights into whether the advancements of edge computing affected the data centres used in the Netherlands?	*Edge computing in terms of local data centers will not have a huge effect in NL. There are 1 no real low latency use cases yet and 2 in NL we have perfect connectivity towards DataCenters/Cloud/Hyperscales. Connection <5ms is everywhere in NL. By the way, if the Dutch data center density was taken as a standard and combining that with the EU goal of 10.000 Edge data centers spread over Europe, Europe should aim for 25.000 edge data centers.*
Do you follow the data centre use by the different industry sectors? If yes, what are the industries reliant most on data centres?	*The Tech/Cloud sector has been traditionally and are still the biggest industry. With digitization every industry is picking up. IDC says we are at 60% of global GDP digitized so you can say than more half of the industries are online. Banking sector is one of the most online sectors. Below a figure we made in 2016 with research we did how far industries are in the transformation. (Additionally, provided a graph with more details per industry)*

Table 16. Interview with data centre representative

Question	Key Accountmanager of a data centre
How did the data centre use change as a result of the growth of the smart industry within the past five years?	*Smart industry is a difficult definition for me. Because we have a mix of traditional companies in our data centers, companies which use racks. But we have a fair amount in our own cloud proposition which is also hosted in the data centre and what we see is a real explosive growth in cloud in our data centers. So, what we see, you are familiar with the data centers we have, we have two data centers both in Hengelo, and we see something in the last years a pretty steep growth in data centers in Hengelo which we have, But, I don't have a strict link with smart industry. Actually, I have a lot of customers which are in smart industry but they also build something smart things build in their software for monitoring. But, I think that 80% of their business is traditional and 20% of their business is typical more smart industry. So, we see it but I don't know whether that growth is attached to smart industry. Definitely there is a lot of interest in IoT and in how connecting IoT, performances IoT, but how in percent that is affecting our energy need in the data centers, I don't have figures.*
How did the energy consumption of data centres change?	*I will upload some information. What we see is a steep growth of energy. What we did when we started 10 years ago, we have about 10MG of power supply. That's a future question, if energy consumption is rising and it is, we have enough energy- that's important. There is no shortage of energy here in Twente. That's the technical side. But what we did is that we invested in green buildings and green energy. We used the energy from windmills from the coast of Rotterdam so that's 100% green energy, Dutch green energy. When we build PDC1, the largest data centre, we have a BREEM certificate. We build the building 8 years ago, and we have the first and the second data centre to receive BREEM certificate excellent in the data centers. That's what we did - a green building with green energy. Are you familiar with the code of conduct? The code of conduct is interesting, because it is an European idea and it defines on I think about 50 questions how energy consumption should be decided and improved. I can share you the picture of it. You see bar diagram, so what you see is that 70% of the measures are already in place in our data centers. That's a study for a customer we did, but it is good to know that 70% of the measures in the code of conduct are in use by Previder. Then we have the PUE, defines if we use 100% power, we need 10, 15 or 20% overhead imposed to keep the systems running for servicing the data centers. The PUE is about 1.2 or 1.25 and the WUE (water use effectiveness) is actual figure. In the news was the water usage from the Microsoft and*

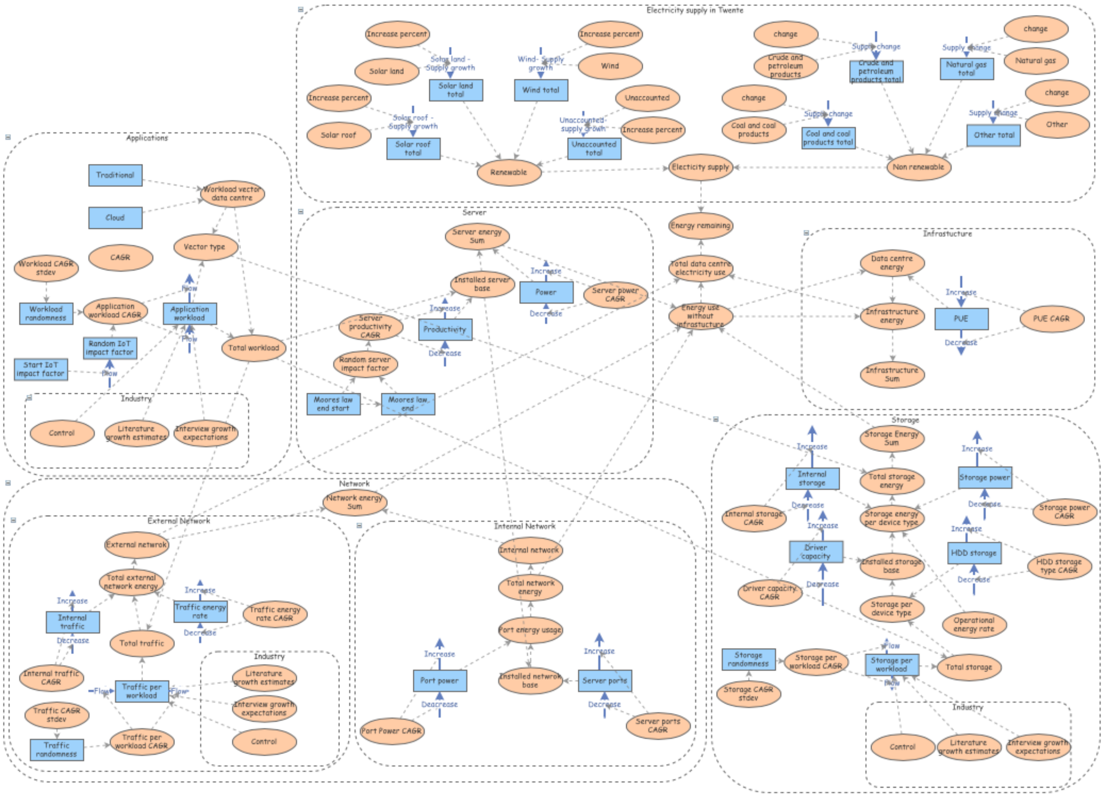
	Google in the north of the Netherlands, where you have some different cooling techniques of the data centers, so you can blow water in the air for cooling, which causes you to need a lot of water for that. What we do is that we use some extra energy for cooling, but the energy is 100% green, it comes from windmills. We have water usage effectiveness of near 0, because we don't use water for cooling. Having that said, means that I think that the measures we have in place for our data centers we have enough power that we use, and that will suffice the need for future power in I think also in smart industries. I will share some documents and links. Expo business part is about durability and it is interesting to read. The second one is the Odin, the mother company of Previder, and you can download the pdf and you can see our initiatives of doing green business. It is not only power supply, but also electric cars, solar panels on the roofs, windmills, about waste and how to handle waste, it is all in that document. The third one is about this topic and last one about green with quite some information in that. Someone approach us about how to handle air flow in data centre and are we ready. No, we are not ready- we are investigating all kinds of possibilities to decrease power usage by optimizing applications, optimizing data bases and seeing that with customers. Having green initiatives and service is an initiative. How much power there is I don't know to be honest, but there are quite some initiatives on our side, because we have customers from Government and they want us to do it and to start initiatives and decrease power usage.
What are the expectations, predictions and forecasts for growth of the data centre use for the future five or ten years?	*I think it should grow somewhere between 50 and 100%, and that is data centre cloud business. I've been in the data centre business 12 years, and the growth is steep especially in cloud. It's growing very very much. Traditional data centers still have customers, for example, government and defense which have their own regulations. Public cloud is not a good offer for them. What we see is that we have a lot of customers with traditional ERP and the life time of traditional ERP is between 7 and 10 years. I think there are still a lot of customers who have those kind of applications, but I expect them to move to the cloud somewhere between now and 10 years. What we see is a steady growth of?, so I have a very big installed base of software developers as customers and they are building faster applications and they are hosting them in our data centers traditional in a rack, so they buy hardware, and we deliver it, install it and manage it, but that's also charged, but customers having their own applications is vanishing in somewhere I think between 0 and 10 years. And we have a passport for which is the next step for software development. What we see is that traditional data centre is changing, it has customers, but more software developers building traditional applications, but also for smart industry. Yearly growth*

	is hard to predict. We are traditional company and growth is between 10-20% each year, but I have no specific information about data centers. But, what we see is a steady growth in cloud data centre, but that is in general. The growth figures in Twente are different than in Amsterdam, and that's a double digit growth every year. That's because people come from abroad, they come to Amsterdam, do their job and have a weekend there and go back. They don't go to the other data centers in the Netherlands and Amsterdam is promoting that very well, and the Dutch Data Centre Association is promoting that very well too. So, if we are talking about data centers in the Netherlands for people from abroad, it means that 9/10 cases hosting is in Amsterdam. But, I think they should consider placing their data in other data centers because public infrastructure is very good in the Netherlands, within one or two hours you are in any corner of the Netherlands. They speak English and German very well, power supply is good, infrastructure, internet is good. There is no specific reason to host in Amsterdam as far as I am concerned.
What are the energy usage estimates for servers, infrastructure, storage and network? How do you expect them to change in the future (in for instance 2030)?	*We see energy uses is becoming less. Take a look at storage. Storage is changing- we had the SAS drives which tingles, rotating, now it is all SSD. So, what you see is that if we had a unit of fire, we call it a fire and we can see the next level of innovation uses less energy. The situation is that we do not have one file, we have two and three, the extra growth we have means we use more energy. The energy consumption is specific to device and is decreasing. That's what we see in networking and in compute. Last year we had a nice case, we bought a hardware with specific green power, Intel Prox, but what showed out is that here was a superior performance penalty when it was activated. Which you see is that the technique is there, but the people from software developments and application, well, we need the best performance for our customers. So, software developers are not busy with what is the energy consumption of the application. But, i think that writing the application in a smart way, I think it uses less energy. And if you have a traditional data centre, at the end of the month you get an energy bill and you can see the amount. But, if you use cloud, you get a CPU or gigabyte of storage sent in your bill, you don't see your power usage. So, there is no concern with the developers about the power usage. That's the difficult part. What we see is that the hardware is becoming more and more efficient, but we need more hardware to meet the demands of customers. That's not specific but that is what we see in real life. We see is that the only figure we have is the power usage effective, so that's the overhead and I see the overhead is decreasing slightly, switching the of kind overhead would bring a few percent. Another interesting thing is the climate. When we have a year that is very warm, is then we use*

	(inaudible), so that means when the temperature below 16 degrees, we can cool with the air. But if it is above that, we need extra power to do the cooling of the data centre. And that has a larger effect than all the initiatives in hardware. If I look at the figures, it's the PUE is more or less the same since the beginning of our data centers, so if I need to get an exact answer to your question, there is not a measurable difference in energy savings because of different devices. What is also very interesting is also the water usage effectiveness. Because the bigger data centers use drinking water for their cooling systems and it's very interesting topic to look at. It's not only about the power, but also how the data centre business is run (...). In total, it is minor. What also is minor, we have a big data centre and we have the roof filled with solar panels but in total, they do not produce enough energy to support the data centres. And it is not changing very much.
How will you cope with the growing electricity needs while supply is not keeping up with your demand?	*If you look at the data centre industry in the Netherlands, I think that 60-70% of growth is in Amsterdam and 80% of the growth are American company. The DDA does not say that in this report that are the actual figures. We are, private owned company and I think there are three private owned companies and that's a concern for the future. As for now, we have enough, and contract with energy companies but it is like a stock market, using power. And I think we are planing for plants of our own windmills but that's a difficult discussion because you can't build a mill of 200m height in our back yard and that's really an issue. The concentration of the data centers is a really big issue. All the American companies come to Amsterdam, and Previder is somewhere in the reporting column of edge data centres, on the edge of the Netherlands. I think it should spread the data centers more throughout the Netherlands, I think energy consumption and the dependency on energy is easier to manage, than the large concentration in Amsterdam. Because if you have an issue in Amsterdam with power, you have a world-wide issue, and you can spread the energy use throughout the Netherlands, with windmills and solar. But, solar is not an issue here. We have 10MW of energy and we will need 2 windmills at least of 200m height, but it doesn't always blow wind in the air, so we can't rely on them. So, you still are dependent on traditional, coal, gas to deliver energy to our data centers.*

Appendix B

Figure 9. Insightmaker model used for simulation



Appendix C

Simulation & sensitivity analysis results

Control

Table 17. Control simulation results for data centre electricity needs

Control simulation : Data centre electricity needs						
Time	Server energy Sum (Traditional)	Server energy Sum (Cloud)	Network energy Sum	Storage energy Sum	Infrastructure Sum	Total data centre electricity use
0	35.5	25.2	27.1	5.1	66.6	164.6
1	31.2	23.3	27.8	5.4	59.9	153.1
2	27.5	21.5	28.5	5.8	54.1	143.2
3	24.3	19.9	29.3	6.0	49.0	134.5
4	21.5	18.4	30.0	6.2	44.4	126.8
5	19.0	17.1	30.8	6.3	40.2	119.8
6	16.8	15.9	31.6	6.3	36.4	113.2
7	14.9	14.7	32.3	6.0	32.7	106.7
8	13.3	13.7	33.1	5.5	29.0	100.0
9	11.8	12.8	33.9	4.6	25.2	92.7
10	10.5	11.9	34.6	3.2	21.0	84.3

Table 18. Control simulation sensitivity analysis

Control simulation: Sensitivity analysis							
Time	99% Lower	99% Upper	95% Lower	95% Upper	75% Lower	75% Upper	Median
0	164.6	164.6	164.6	164.6	164.6	164.6	164.6
1	145.9	158.6	147.3	157.1	149.4	155.1	152.3
2	129.6	153.4	132.3	150.5	136.1	146.7	141.3
3	115.4	149.1	119.2	144.7	124.3	139.2	131.6
4	103.0	145.4	107.6	139.6	113.8	132.4	122.8
5	91.8	142.1	97.3	134.9	104.2	126.3	114.9
6	81.8	139.2	87.8	130.5	95.5	120.5	107.4
7	72.7	136.0	79.0	126.1	87.3	114.8	100.2
8	64.2	132.3	70.8	121.4	79.5	108.9	93.1
9	56.1	127.8	63.0	115.8	71.7	102.4	85.8
10	48.8	121.8	55.2	108.7	63.7	94.9	77.9

Simulation: Literature

Table 19. Literature industry growth estimates simulation results for data centre electricity needs

Literature industry growth estimates simulation: Data centre electricity needs						
Time	Server energy Sum (Traditional)	Server energy Sum (Cloud)	Network Energy Sum	Storage Energy Sum	Infrastructure Energy Sum	Total data centre electricity use
0	37.2	26.5	29.8	5.6	70.3	175.0
1	32.7	24.3	31.0	5.9	63.0	162.9
2	28.7	22.4	32.4	6.2	56.7	152.6
3	25.3	20.6	33.9	6.4	51.1	143.7
4	22.3	19.0	35.5	6.5	46.1	135.9
5	19.7	17.5	37.1	6.6	41.6	129.0
6	17.4	16.2	38.8	6.4	37.4	122.7
7	15.4	15.0	40.6	6.1	33.4	116.5
8	13.6	13.9	42.5	5.5	29.4	110.3
9	12.1	12.9	44.3	4.5	25.4	103.7
10	10.7	12.0	46.2	3.1	21.1	96.1

Table 20. Literature industry growth estimates simulation sensitivity analysis

Literature industry growth estimates simulation: Sensitivity analysis							
Time	99% Lower	99% Upper	95% Lower	95% Upper	75% Lower	75% Upper	Median
0	175.0	175.0	175.0	175.0	175.0	175.0	175.0
1	155.3	169.3	157.0	167.4	159.1	165.1	162.1
2	138.3	164.5	141.3	160.7	145.2	156.4	150.7
3	123.4	160.3	127.5	154.9	132.8	148.6	140.6
4	110.2	156.8	115.3	149.7	121.8	141.7	131.4
5	98.7	153.4	104.4	145.0	111.7	135.3	123.1
6	88.3	150.0	94.4	140.6	102.5	129.4	115.3
7	78.7	146.5	85.1	136.2	93.8	123.5	107.7
8	69.8	142.7	76.3	131.1	85.4	117.3	100.2
9	61.5	138.1	67.8	125.1	77.0	110.3	92.3
10	53.4	131.6	59.2	118.0	68.4	102.4	83.8

Simulation: Interviewee expectations

Table 21. Interviewees' industry growth estimates simulation results for data centre electricity needs

Interviewees' industry growth estimates simulation: Data centre electricity needs						
Time	Server energy Sum (Traditional)	Server energy Sum (Cloud)	Network energy Sum	Storage Energy Sum	Infrastructure Sum	Total data centre electricity use
0	38.4	27.3	31.6	6.0	72.9	182.3
1	34.2	25.5	33.0	6.5	66.5	172.2
2	30.4	23.8	34.3	6.9	60.7	163.1
3	27.0	22.1	35.6	7.3	55.5	154.9
4	24.0	20.6	36.8	7.6	50.7	147.3
5	21.3	19.1	37.9	7.8	46.2	140.1
6	18.9	17.8	39.0	7.7	41.9	133.0
7	16.8	16.5	40.0	7.4	37.7	125.8
8	14.9	15.4	40.9	6.7	33.4	118.0
9	13.2	14.3	41.8	5.6	28.9	109.4
10	11.8	13.4	42.5	3.9	24.0	99.3

Table 22. Interviewees' industry growth estimates simulation sensitivity analysis

Interviewees' industry growth estimates simulation: Sensitivity analysis							
Time	99% Lower	99% Upper	95% Lower	95% Upper	75% Lower	75% Upper	Median
0.0	182.3	182.3	182.3	182.3	182.3	182.3	182.3
1.0	162.1	176.1	163.7	174.5	165.8	172.2	169.0
2.0	144.6	170.9	147.4	167.7	151.4	163.3	157.3
3.0	129.2	166.5	133.1	161.8	138.6	155.4	146.8
4.0	115.8	162.8	120.4	156.4	127.1	148.3	137.3
5.0	103.9	159.2	109.0	151.6	116.7	141.8	128.7
6.0	93.0	156.3	98.6	146.9	107.1	135.7	120.6
7.0	83.0	153.1	88.9	142.2	98.0	129.6	112.7
8.0	73.8	149.1	79.8	136.9	89.2	123.2	104.8
9.0	64.9	144.5	70.8	130.8	80.5	115.9	96.6
10.0	56.0	138.8	62.2	122.9	71.6	107.7	87.7

Electricity supply – Shortages and Surpluses

Table 23. Data centre electricity needs, supply and amount of electricity available to data centres to use

	Data centre electricity needs				Supply of electricity going to DC	
	Control	Literature	Interviewees	Supply full	2.70%	8%
2020	164.6	175.0	182.3	24.14	0.65	1.93
2021	153.1	162.9	172.2	187.18	5.05	14.97
2022	143.2	152.6	163.1	350.22	9.46	28.02
2023	134.5	143.7	154.9	513.26	13.86	41.06
2024	126.8	135.9	147.3	676.30	18.26	54.10
2025	119.8	129.0	140.1	839.34	22.66	67.15
2026	113.2	122.7	133.0	1002.38	27.06	80.19
2027	106.7	116.5	125.8	1165.42	31.47	93.23
2028	100.0	110.3	118.0	1328.45	35.87	106.28
2029	92.7	103.7	109.4	1491.49	40.27	119.32
2030	84.3	96.1	99.3	1654.53	44.67	132.36

Table 24. Electricity shortages and surpluses occurring with 2.7% and 8% of electricity going to data centres, with the electricity needs of a data centre without industry growth

Control			
2.7% to DC	2.7% to 6 DCs	8% to DC	8% to 6 DCs
-163.93	-986.85	-162.65	-985.57
-148.09	-913.80	-138.17	-903.88
-133.75	-849.78	-115.19	-831.22
-120.65	-793.18	-93.45	-765.98
-108.52	-742.43	-72.68	-706.58
-97.10	-695.90	-52.61	-651.42
-86.10	-651.94	-32.98	-598.81
-75.23	-608.71	-13.46	-546.94
-64.14	-564.17	6.27	-493.76
-52.43	-515.96	26.61	-436.91
-39.65	-461.27	48.04	-373.58

Table 25. Electricity shortages and surpluses occurring with 2.7% and 8% of electricity going to data centres, with the electricity needs of a data centre with industry growth according to literature (Statista, 2021b; Statista, 2021c; Statista; 2021c)

Literature			
2.7% to DC	2.7% to 6 DCs	8% to DC	8% to 6 DCs
-174.33	-1049.26	-173.05	-1047.99
-157.86	-972.45	-147.94	-962.53
-143.14	-906.10	-124.58	-887.54
-129.84	-848.35	-102.64	-821.15
-117.68	-797.40	-81.84	-761.56
-106.37	-751.52	-61.88	-707.03
-95.60	-708.93	-42.47	-655.80
-85.07	-667.78	-23.31	-606.01
-74.46	-626.08	-4.05	-555.68
-63.38	-581.64	15.67	-502.59
-51.43	-531.96	36.26	-444.27

Table 26. Electricity shortages and surpluses occurring with 2.7% and 8% of electricity going to data centres, with the electricity needs of a data centre with industry growth according to interviewees estimates

Interviews			
2.7% to DC	2.7% to 6 DCs	8% to DC	8% to 6 DCs
-181.63	-1093.03	-180.35	-1091.75
-167.15	-1028.17	-157.23	-1018.25
-153.69	-969.39	-135.12	-950.83
-141.05	-915.59	-113.85	-888.38
-129.04	-865.52	-93.19	-829.67
-117.42	-817.82	-72.93	-773.33
-105.94	-770.94	-52.81	-717.81
-94.30	-723.11	-32.53	-661.34
-82.16	-672.27	-11.75	-601.87
-69.10	-615.98	9.94	-536.93
-54.65	-551.27	33.04	-463.58