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Business Opportunities in Waste Heat Utilization in Norway

A new business research for the cloud data center pilot project at the Norwegian Center for Energy Transition Studies (NTRANS)

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Preface

This master thesis is a contribution to Statkraft's data center pilot project supported by User Case 2 of the Norwegian Center for Energy Transition Studies (NTRANS). NTRANS is researching the role of the energy system in the transition to a zero-emission society. NTRANS researches the development of environmentally friendly energy from a social science perspective, and in the interaction between technology and society. The research in NTRANS is building a knowledge base for the road to and the consequences of energy and climate change in Norway. NTRANS is working to understand how restructuring can give the business community opportunities for innovation and value creation.

NTRANS includes various User Cases to address current issues in close dialogue with user partners (experts and stakeholders). User Case 2 (UC2) is about green power and industry and it is chaired by SINTEF, which is one of Europe’s largest independent research organizations. UC2 deals with the potential of new renewable power production (focus on offshore wind power) and the attraction of new power-intensive industries, and possible interaction between them in Norway. There are two pilot projects in UC2. Statkraft is leading one of them. Statkraft is Europe’s largest producer of renewable energy and is proactive in the electrification of the economy. This master thesis was developed to provide a business model innovation perspective to the pilot data center project by Statkraft. The objective of this research is to feed the funnel of new business opportunities to create more value out of the utilization of waste heat from cloud data centers in Norway.

Keywords: *Cloud data centers, Waste heat utilization, District heating, Business model innovation, Strategic choice.*

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1. Introduction

1.1 Background

Modern society is going even more digital after the Covid-19 pandemic, and data centers are the backbone of the digital infrastructure. Data centers are mission-critical buildings to support the amount of data that is consumed daily for streaming and to use applications in the cloud. These buildings provide space, redundant power, cooling, security, and connectivity to technology tenants in sectors such as e-commerce, government agencies, health care, education, and gaming among others.

The data center industry is the world's fastest-growing, demand for data and digital services is growing exponentially and data center infrastructure must rise by 6-11% annually over the next decade to match growing usage. The global data center infrastructure market is projected to reach USD 230 billion in 2025 from USD 155 billion in 2019 (Globe Newswire, 2019).

The main concern in this industry is the environmental footprint. Nearly 75% of the world's greenhouse gas emissions are energy-related, and data centers are nearly 1% of the global electricity demand. Energy use will be determined by how the pace of energy efficiency gains offset the growing demand for data and digital services. The European Commission has set an ambitious target of climate neutrality by 2030 in the whole Information and Communications Technology (ICT) sector, which includes the data center industry (IEA, 2020a).

Norway has an advantageous position for this industry. Norway has the world's greenest data centers and was the first country to release a data center strategy aiming to be an attractive nation for data centers (Christensen, 2018; Green Mountain, 2020). Nowadays, there is a prospect to be among Europe's top five data centers markets by 2030. Apart from the policy and commitments, Norway has a robust grid with a surplus of renewable energy at the lowest prices in Europe. Thus, there is a strong value proposition for the world's top players in this industry to place their data centers in Norway (MTIF, 2018; Implement, 2020).

Data centers can be classified into three segment sizes, traditional data centers, cloud data centers, and hyperscale data centers. This research is focused on cloud data centers. Cloud data centers are growing the fastest due to edge computing driven by emerging technologies like the internet of things, artificial intelligence, virtual reality, blockchain, and 5G. Cloud data centers have power capacities in the range of tens of megawatts and should be substantially more efficient than they are today to achieve climate neutrality by 2030. The waste heat from data centers is one of the opportunities to reduce the environmental impacts, and particularly Norway's main opportunity to stay on top of the greenest data centers in the world.

Cloud data centers' waste heat is not only a technical challenge but a business opportunity from the circular economy perspective. Hence, there is a need to identify new business opportunities that could be developed in Norway to lead innovations and create more value out of using waste heat from cloud data centers.

1.2 Purpose and Research Question

The big companies operating data centers are leading the world's top corporate renewables procurement and the Nordic countries are competing to establish large data centers in their countries. Google and Facebook have established large data centers in Sweden, Denmark, and Finland. Still, Denmark is offering large and flat plots. And in Norway, Microsoft opened several data centers and Google bought a large plot of land from Statkraft in 2019.

Statkraft has decided to attract power-intensive industries, specifically data centers, and in that sense, they have been involved in the development of site plots for data centers in Norway. They find suitable plots and develop these in the form of regulations, power capacity and transmission line developments, and the like. Then, they sell the plots to large players for further development and use. An important motivation is to increase the power consumption in Norway, and thus increase value for Statkraft's power production.

The substantial energy needed by data centers is for cooling. A data center emits a lot of heat. The trend is that the data centers will be warmer and that there will be even more surplus heat.

Another trend has been that data centers are becoming larger and more energy-efficient. Hence, Statkraft has defined various research challenges within its data center pilot project. One of them is how to integrate waste heat from cloud data centers into Norwegian cities' energy systems. Statkraft also has several district heating businesses in Norway. These facts led them to research with the University of Stuttgart and SINTEF on the development of the data center industry in the future and the integration of waste heat; reliability studies of the Norwegian electric grid; advanced modeling for waste heat integration; and data center case studies in Norway.

As a complement, the objective of the present research is to identify new business opportunities to accelerate the integration of waste heat from cloud data centers into the city's energy system in Norway. Hence, our research question is as follows:

What new business opportunities around waste heat utilization could be developed to make Norway even more attractive for cloud data center investments?

The following four research questions pave the way to answer the main research question:

Q1: What are the economics, politics, environmental issues, and technology trends in the world's data center industry?, answered in chapter 2.

Q2: Which is an appropriate theoretical framework to identify business opportunities around the utilization of data center waste heat?, answered in chapter 3.

Q3: What is the prevalent business model of data center waste heat utilization in Europe?, answered in chapter 4.

Q4: Which financial sources could be used by Norwegian organizations for new ventures and innovations in waste heat utilization?, answered in section 5.2 after the discussion of the main research question.

We investigate these questions through literature research and a multiple case study of seven European exemplifications converging on waste heat utilization from data centers. Our results are presented in chapter 5, with a list of eight new business opportunities aimed to feed the knowledge base of User Case 2 by NTRANS. These business opportunities are believed to be plausible in Norway for developing a new competitive advantage that could lead this nation to become even more attractive for data center investments.

1.3 Assumptions

Based on the analysis of the competitive advantages for data centers in the Nordics by the Nordic Council of Ministers, it is assumed that current regulations ease the development of new business models in the waste heat utilization market in Norway and that those regulations do not impose substantial additional restrictions in Norway in comparison to other Nordic countries (Christensen et a., 2018).

For this research, a competitive advantage is about how the country's ecosystem eases the creation of value for users and business communities both greater than the costs and superior to their neighboring countries. And as such, the two fundamental means of achieving a competitive advantage are: to have structurally lower costs than its counterparts or to have differentiated products or services in ways that are so valued by users and the business community that in turn creates new revenue flows that covers the additional costs of differentiation (Johnson et al, 2018).

Since Norway was the first mover to release a data center strategy aiming to be an attractive nation for data centers and as it is mainly focused on lowering costs (MTIF, 2018), this study researches on uniqueness along some dimensions that could be sufficiently valued by the data center business community in such a way that it could turn into a new competitive advantage, which is referred herein as to develop a top innovation ecosystem on waste heat utilization in Norway. Thus, this research identifies new business opportunities in Norway to create such an ecosystem in waste heat utilization.

1.4 Structure

This thesis document comprises six chapters. The first chapter is the introduction. The second chapter is the descriptive framework of the data center industry. It sets the context for this study, and answers auxiliary research question Q1, starting from the world's economic perspective and nailing down to the specific advantages and opportunities for Norway. The third chapter answers the auxiliary research question Q2. It sets the theoretical foundation and presents the research design, covering the methodology and theories applied for the identification of the new business opportunities. The fourth chapter answers the auxiliary research question Q3. It contains the summary of the seven study cases and the business model assessment that were used as the exemplification of successful applications of data center waste heat integration into the city's energy system. Chapter five answers the auxiliary research question Q4, and the main research question. It lists eight new business opportunities that were identified by the research methodology described in chapter 3. Chapter 5 also includes proper support for our findings and the available funding sources to develop the new business opportunities by Norwegian firms. Finally, chapter six closes with our conclusions and recommendations to further research.

2. Context for Business Opportunities in Data Centers in Norway

This chapter consists of an overview of facts on the economics, politics, environmental issues, and technology trends in the data center industry. It summarizes the supply and demand metrics of the world's top data center markets, outlines its global concerns and the specifics on the Norwegian competitiveness for this industry. At the end of this chapter, there is a discussion on the strategic opportunities in Norway, which are based on the observed trends. Thus, this chapter is the context for both conducting the business model research and the identification of new business opportunities in Norway around the utilization of waste heat, mainly from cloud data centers.

2.1 An overview of data center economics

The data center industry is the world's fastest-growing, demand for data and digital services is expected to continue its exponential growth and double the global internet traffic by 2022 to 4.2 zettabytes per year (4.2 trillion gigabytes) (IEA, 2020a). The global number of data centers in 2021 is estimated at 7,2 million (Computerworld, 2017; Mlitz, 2021). Currently, the European data center markets are expanding at a faster growth pace than the United States markets. There are 605 MW, in aggregate, under construction in the five Europe Tier 1 data center markets and 375 MW in the United States Tier 1 data center markets, but in 2020, data center operators accelerated capital expenditures to fulfill leasing demand of 680+ MW in the United States and 200+ MW in Europe (Zhang, 2021a).

The outlook for the global power capacity of data centers is set to increase to above 80 GW by 2025 (Christensen, 2018). The spending on data center systems is expected to amount to USD 237 billion in 2021 (Gartner, 2021), where the global data center infrastructure market alone is projected to reach USD 230 billion in 2025 from USD 155 billion in 2019. McKinsey estimates spending on data center infrastructure must rise by 6-11% annually over the next decade to match growing usage. The global data center construction market is expected to grow from around USD 20 billion in 2018 to USD 32 billion by 2023 (Globe Newswire, 2019).

The data center markets are mainly segmented by data center type (enterprise and colocation data centers), corporations (owners/operators and main customers), region, and design type (traditional, cloud, hyperscale). Next, there is a description of each segmentation.

2.1.1 Market segmentation by data center type

There are principally two data center types: Enterprise data centers, and Colocation data centers. Data centers can be used and owned by the same enterprise or can be operated as a colocation data center, also known as Infrastructure as a Service (IaaS), where a third party provides and maintains infrastructure components on behalf of its customers (Statista, 2021).

In the colocation market, data centers provide space, redundant power, cooling, security, and connectivity to technology tenants. Colocation data centers can also be broadly classified into two main categories: retail data centers and wholesale data centers. Retail data centers are third-party organizations that are multi-tenant accessible, meaning that multiple businesses of any size or industry may house their equipment within the data center. Companies of all types and sizes from small and medium enterprises (SME) to fortune 500 firms use retail data centers. Customers of these facilities have small power requirements and require help to manage their equipment that resides in these data centers. On the other hand, wholesale data centers provide space, power, and cooling to run large-scale computing or storage deployments. Tenants of these facilities are large internet and cloud companies that own and operate their network equipment. Wholesale data centers lease space and power in larger capacities than retail data centers, and as such, they typically house fewer customers per facility. Some of the top data center providers are Equinix, Digital Realty, CyrusOne, CoreSite, QTS Realty Trust, ColonyCapital, and IronMountain. Most of them operate as a Real Estate Investment Trust (REIT). A REIT is a tax-efficient legal structure that distributes income to investors from the property they own (Dgtl Infra, 2021a; Greenstein, 2020; Zhang, 2021e).

2.1.2 Market segmentation by data center key players

Data Center key players are top data center providers, their main customers, and the top cloud service providers. The main customers of colocation data centers are the top cloud service providers and internet platforms, although they operate their own internet infrastructure as well. Up to this time in 2021, the top cloud service providers are Amazon Web Services (AWS), Microsoft Azure, Google Cloud, Alibaba Cloud, Oracle, IBM, and Tencent Cloud. AWS is by far the biggest cloud computing provider, with 33 % of the market, followed by Microsoft with 20 % of the market. AWS reported revenues of USD 35 billion in 2019 and USD 46 billion in 2020. On the other hand, the top firms in application markets and platforms are Facebook, Apple, Netflix, Tiktok, Uber, Twitter, Dropbox, Spotify, and Snapchat (Amazon, 2021; Dignan, 2021; Ratka, 2020; Zhang, 2021c; Statista, 2021).

Table 2.1 lists the operational and financial metrics of the top seven data center REITs and table 2.2 the top seven data center non-REITs (Dgtl Infra, 2020; Greenstein, 2020; Zhang, 2021e). These tables show how big in terms of market capitalization are the top players of the colocation data center markets. They also present the number of data centers, power capacity, number of customers that they survey and the regions in which they operate.

Data Center REIT	Market Cap	Enterprise Value	Data centers	Power Capacity	Customers	Regions
Equinix	$ 54,5 bn	$ 65,5 bn	227	1 350 MW	10 000 +	26 countries
Digital Realty	$ 37,1 bn	$ 50,9 bn	291	1 847 MW	4 000 +	48 cities
CyrusOne	$ 7,9 bn	$ 10,8 bn	55	874 MW	944	USA and EU
CoreSite Realty	$ 4,8 bn	$ 6,5 bn	25	256 MW	1 350 +	USA
QTS Realty Trust	$ 3,8 bn	$ 6,1 bn	28	315 MW	1 200 +	USA and EU
Colony Capital	$ 3,0 bn	$ 15,8 bn	76	288 MW	3 100 +	USA and EU
Iron Mountain	$ 10,3 bn	$18,9 bn	15	130 MW	1 340 +	USA, EU, Asia

Table 2.1: Financial and operational metrics of top data center REITs

Equinix trades in NASDAQ (EQIX), which is the largest public data center REIT in the retail market with over USD 5 billion in revenue, 227 data centers, and 387 thousand interconnections, representing 1 350 MW of power capacity across 26 countries and supporting over ten thousand customers. The second-largest public data center REIT with USD 3 billion in revenue in 2018 is Digital Realty (NYSE: DLR). It operates in the wholesale market and has 291 data centers with 162 thousand interconnections representing 1847 MW of power capacity across 48 cities, supporting over four thousand customers.

Data Center non-REITs	Market Cap	Enterprise Value	Data centers	Power Capacity	Customers	Regions
Switch, Inc.	$ 3,4 bn	$ 4,7 bn	4	490 MW	950	USA
Cyxtera	$ 1,8 bn	$ 3,4 bn	61	245 MW	2 300 +	N.America, EU, Asia
GDS Holding	$ 17,1 bn	$ 19,7 bn	59	610 MW	673	China
21Vianet	$ 4,5 bn	$ 5,0 bn	54	200+ MW	6 000 +	China
Chindata	$ 6,8 bn	$ 6,9 bn	11	248 MW	-	China, India, Malaysia
NextDC Ltd	$ 3,5 bn	$ 3,5 bn	9	89 MW	1 465	Australia
Keppel DC	$ 3,2 bn	$ 3,9 bn	19	300 MW	90 +	S.Asia, Australia, EU

Table 2.2: Financial and operational metrics of top data center non-REITs

It can be observed that data center REITs have a greater market capitalization than non-REITs and operate mostly in the USA and Europe, and that data center non-REITs have a greater participation in the Asian market.

2.1.3 Market segmentation of data centers by the European region

In Europe, the tier 1 data center markets are Frankfurt, London, Amsterdam, Paris, and Dublin, which are referred to as the FLAP-D markets. Frankfurt as one of Europe's major financial and commercial hubs has strong power supply dynamics and network connectivity, which in turn has caused a higher level of data center demand and investment in the Frankfurt market. Overall Frankfurt has 425 MW of supply and the potential to develop another 585 MW of power capacity over the coming years. In 2020, Frankfurt leased 75 MW of power capacity which has been led by demand from hyper scale companies such as AWS, Google Cloud, Microsoft Azure, Oracle Cloud, IBM Cloud, SAP, and Alibaba Cloud. Beneficiaries of the leasing demand include data center providers Digital Realty, Equinix CyrusOne, and Iron Mountain, as well as private operators NTT and Global Switch. As an illustration of this, in June 2020 Iron Mountain pre-leased a 27 MW facility to Google Cloud on a 10-year lease term (Dgtl Infra, 2021b; Zhang, 2021d).

Market	Supply	Availability	Construction	Potential	Key leases tenants 2020
London	710 MW	175 MW	170 MW	400 MW	Azure, AWS
Frankfurt	425 MW	55 MW	235 MW	585 MW	AWS, Google
Amsterdam	390 MW	105 MW	70 MW	395 MW	Azure, IBM
Paris	210 MW	25 MW	75 MW	85 MW	Azure, AWS
Dublin	125 MW	10 MW	55 MW	135 MW	Azure, TikTok

Table 2.3: Power capacity of the top European data centers markets

London is the largest data center market in Europe and is supported by the London Internet Exchange (Linx), which is one of the largest internet exchange points in the world, connecting 900 members from over 80 countries. London has 710 MW of power supply and the potential to develop another 400 MW of power capacity with all the same cloud providers dominating the European markets. The power capacity of the FLAP-D markets is listed in table 2.3. Dublin's market is different from the other markets in Europe, it is largely dependent on American companies, specifically IT and internet companies, financial institutions and pharmaceutical companies that drive data center demand. Thus, Dublin has a significant amount of data centers being self-built by the end-users, like AWS, Facebook, and TickTock (Dgtl Infra, 2021b; Zhang, 2021d).

The Nordic region is pursuing becoming a global hub for data center investments. In the Nordic countries, the data center market is expected to attract an annual investment of between EUR 2 to

4.3 billion by 2025. This corresponds to an additional power capacity ranging between 280 to 580 MW per year (Christensen, 2018).

Norway is on the path to overcome the Paris' and Dublin's data center markets by 2030. Currently, Norway has a total installed capacity of 154 MW, and there is a potential to add up to 375 MW by 2030 (Implement, 2020). Green Mountain alone has nearly 100 MW power capacity with 100% renewable energy, making Green Mountain's the greenest data center in the world. They forecast growth of up to 200 MW within the next five years, with clients like Volkswagen Group, MasterCard, and international cloud providers (Europeanceo, 2020; Green Mountain, 2020). Microsoft has also opened several data centers in Norway. In addition, Google bought in 2019 a plot of land from Statkraft with an available capacity of up to 500 MW (Statkraft, 2020; The Explorer 2020).

2.1.4 Market segmentation by data center design type

Data centers can also be classified by design into three types: Traditional, Cloud, and Hyperscale data centers. Traditional small data centers, which demanded 41 TWh in 2020, normally have less than 1 MW of power capacity. Cloud data centers (non-hyperscale), which in 2020 demanded 73 TWh, have between 1 MW to 20 MW of power capacity, and can cost more than EUR 100 million each. And hyperscale data centers, which in 2020 demanded 76 TWh, normally have between 20 MW to 240 MW of power capacity and can cost several billion Euros (Greenstein, 2020; IEA, 2019; Implement, 2020).

There are data centers in almost every country, but cloud providers specifically build multisite regional setups with a range of zones to secure low latency and high reliability in the service, whereas most hyperscale data centers are located in three regions: North America (46%), Asia Pacific (30%), and Western Europe (19%) (Christensen, 2018; IEA, 2019).

Since 2010, it is decreasing the amount of "traditional" enterprise data centers shifting both to hyperscale and to cloud non-hyperscale data centers. Cloud services offer advantages to businesses, like reduced costs, increased automatic software updates, and ease of data access from different locations. This has led to continued growth in the cloud data center segment. Cloud data center construction growth is being driven by benefits provided by high-speed and lower latency. Latency is the time it takes for data to be transferred from its original source to its destination, and it is measured in milliseconds (Globe Newswire 2019; The Explorer 2020). In 2010, the small traditional data centers housed 79 % of the world's computing instances, and by 2018, 89 % of computing instances were hosted by cloud data centers, both hyperscale and smaller cloud computing facilities (Sverdlik, 2020).

2.2 Policy and required actions in the data center industry

The European Commission in February 2020 included a bold action in the *Digital Strategy* for the Information and Communications Technology (ICT) sector. It was to achieve climate neutrality by 2030, twenty years before the rest of the economy, under the claim that "Europe needs a digital sector that puts sustainability at its heart. The Commission will also consider measures to improve the energy efficiency and circular economy performance of the sector itself, from broadband networks to data centers and ICT devices.". This is a call for the industry to act and a promise of future initiatives to help the industry create a class of climate-neutral and highly energy-efficient data centers (Ballard, 2020a; IEA, 2020a).

Data centers are estimated to have the fastest-growing carbon footprint from across the whole ICT sector, mainly due to new businesses such as cloud computing and the rapid growth of the use of internet services (Acton et al., 2018). Data centers require vast amounts of electricity, the International Energy Agency (IEA) reported that in 2019 this industry consumed 200 TWh, nearly 1% of the global electricity demand. The energy use has been flat since 2015, while global internet traffic tripled and data center workload more than doubled. Electricity demand is expected to remain flat despite a trend of 60% increase in service demand, as it will continuously be offset by the ongoing efficiency improvements (IEA 2019; IEA, 2020a). In Europe by 2025, the total data center energy consumption is expected to increase 21% on 2018 levels, when data centers consumed 2.7 percent of all electricity in Europe (Ballard, 2020b). Whereas in Norway, the Norwegian Water Resources and Energy Directorate (NVE) expects a steady growth in power consumption from data centers in the future and estimates a consumption in Norway of between 4 and 14 TWh in 2040 (NVE, 2019).

As 75% of the world's greenhouse gas emissions are energy-related, the climate challenge is first and foremost an energy challenge. And as such, the two main concerns in the data center industry are the environmental footprint and power availability. ICT companies operating data centers are leading corporate renewables procurement, particularly through power purchase agreements (PPAs). In 2019, Google was the first in the list with 2 706 MW, Facebook was second with 1 111 MW, Amazon was third with 925 MW, Microsoft was fourth with 762 MW, and QTS Realty Trust was sixth with 544 MW. The fifth place was for BHP Group, the world's largest resources company, with 607 MW. IEA reported that all ICT companies account for about half of the 18,7 GW of global renewables procurement in 2019. Microsoft has been carbon neutral since 2012, runs on 100% renewable energy since 2014, and aims to be carbon negative by 2030, and by 2050 remove all the carbon the company has emitted since it was founded in 1975. Google and Apple purchased or generated enough renewable electricity to match 100% of their data center energy consumption since 2018. Recently, Google has set a long-term goal to source carbon-free energy on a "truly 24x7 basis". Data centers are paving a path that other energy-intensive industries could follow by integrating not only the latest technologies with renewables but by increasing efficiencies using artificial intelligence. Hence, the IEA reported that the data center is one of the few technologies "on target" to meet the *Sustainable Development Scenario*. Thus, it is expected a growing demand for greener power capacity and more efficient technologies for data centers to keep pace with the growing data demand. Estimates suggest that annual electricity demand from data centers could grow to 1 100 TWh by 2030 (IEA, 2019; IEA, 2020a; IEA, 2020c; Ratka, 2020).

IEA states that energy efficiency, demand response, and waste heat utilization can help minimize the impacts of data centers on the environment and the grid. The most significant opportunity to improve efficiency is at the cooling process as it frequently has the largest energy loss in the facility. Demand response helps as a complement to use more renewable capacity, as they can shift some energy-demanding tasks (data storage rearrangements and backups among others), and waste heat utilization contributes to decarbonize cities by reducing energy use from other sources to heat nearby commercial and residential buildings (Acton et al., 2018; IEA 2019; IEA 2020a).

2.3 The energy challenge of data centers in Europe

In Europe, data center energy consumption will reach 92,7 TWh in 2025, and cloud computing will be responsible for 60 percent of all that energy, nearly doubling its portion's size in 2018 (Ballard, 2020b). Energy demand from hyperscale data centers is growing ca. 12% yearly, while cloud data centers have a flat energy demand trend nonetheless, they are replacing the traditional small data centers. However, cloud data centers should be substantially more efficient than they are today to achieve climate neutrality by 2030.

2.3.1 Data center technology challenges for energy efficiency

Power usage effectiveness depends on the data center type. Hyperscale data centers are very efficient because they run at high capacity and can deliver greater work output with fewer servers, which means a high Power Usage Effectiveness (PUE). PUE is a measure of how efficiently a data center uses energy. For example, an hyperscale data center with a PUE value of 1,1 means that 0,1 kWh is used for cooling and other power provisions for every 1 kWh used for IT equipment (IEA, 2020a; IEA 2002b). PUE is a standard key performance indicator for data centers, however some authors argue that the PUE indicator is not suitable to identify the level of energy efficiency when heat reuse is implemented (Taddeo, 2017; Korhonen 2018).

The average PUE of a data center currently is 1,59. In the USA, the lowest PUE ratio of a data center provider is 1,23 by Switch Inc., which in addition uses 100% renewable energy (Zhang, 2021b), whereas, in Europe, Green Mountain has a PUE below 1,2 (Green Mountain, 2020). In 2020, a very low PUE of 1,07 was reported by David Rowe, CEO of Hydro66, a Swedish data center provider; and Mark Russinovich, Microsoft Azure CTO. This low PUE was achieved by cooling with the cold outside. For instance, Microsoft achieved a PUE of 1,07 or less, using a technology they tested at Project Natick (Scotland), which was a 5 MW data center inside a cylinder that was placed underwater, over the seafloor, benefiting from the cooling capacity of the surrounding water (Ballard, 2020a; Russinovich, 2020).

Taddeo studied the six state-of-art technologies for data center cooling and found that the global system efficiency is greatly dependent on the specific performance of the system's components. Consequently, data centers using old technologies for cooling can be retrofitted for efficiency, but it could cost 2 million Euros (Ballard, 2020a; IEA, 2020a; IEA 2002b; Taddeo, 2017).

2.3.2 Data center waste heat utilization

Waste heat reuse is one of the green strategies that are supporting the emergence of energy-efficient data centers. Waste heat reuse is a way to achieve the industrial circular economy by reuse of waste energy (Globe Newswire, 2019). The process of waste heat recovery (WHR) involves heat capturing from waste streams and its direct utilization, through its upgrading into a more useful temperature that can be used for the needs of the same site or exported to neighboring facilities or heat distribution networks. Conventional WHR requires a huge initial investment in equipment and infrastructures for the recovery and distribution of the heat (Bianchi et al., 2019; Yang et al., 2020).

The Global WHR market is expected to surpass EUR 65 billion by the end of 2021. In Europe, the theoretical WHR potential of low-temperature waste heat (< 100 °C) in the industry is nearly 470 TWh (Bianchi et al., 2019). Industrial waste heat recovery potential is still untapped due to the need for efficient and cost-effective technologies to recover heat losses and to reuse, upgrade or transform this heat for its valorization (Cordis, 2020). Europe leads the market related to WHR equipment with a 38% share of the global market, however, the Asia–Pacific region will surpass Europe as it has been experiencing a two-digit growth rate. In Europe, Germany owns more than 20% of the overall WHR potential, while Italy, France, and the UK are the second most relevant countries with a share for each close to 10%. Scandinavian or small member states as well as developing economies play a secondary role in the contribution to the whole WHR potential (Bianchi et al., 2019).

Data centers produce significant quantities of waste heat but at a relatively low temperature, yet there are some applications for the reuse of this energy. Where it is not possible to directly reuse this waste heat it can still be economical to use heat pumps to raise the temperature to a useful point to supply office, district, or other heating. This does not reduce the energy consumed by the data center itself but does offset the total energy overhead by potentially reducing energy use elsewhere. For example, heat pumps can use the waste heat and 1 MW of electricity to produce 4 MW of hot water at nearly 70 °C. The proximity to users of heat is key to ensure that waste heat is actually used given the high costs of new infrastructure. Other barriers to waste heat utilization are taxation on its use, technical challenges of getting sufficiently high temperatures, and contractual and legal challenges. For example in dealing with the technical challenges, data center operators and district heating suppliers need to work together on how to guarantee the delivery of heat to customers even if a data center is shut down (Acton et al., 2018; IEA, 2019; IEA, 2020a).

2.4 Norway's competitiveness in the data center industry

One of the key decisions in data center investments is site selection. Site selection for hyperscale and cloud data centers depends on a balance of four key factors, including access to a stable supply of cost-competitive electricity, preferably from renewable sources; favorable environmental conditions (e.g. low risk of natural hazards and cooler climates); strong connections to data infrastructure and networks; and, favorable regulatory and market conditions, including proximity to major markets, political stability, and low taxation (IEA, 2019).

Norway has a strong value proposition for the world's top players in the data center industry, especially for those who demand green power capacity. Norway's attractiveness relies on its 107% surplus of renewable energy at the lowest prices in Europe (below EUR 30 per MWh), the authorities' beneficial framework conditions (energy and property low taxes), favorable climate conditions (not only for cooling but no volcanoes, earthquakes, hurricanes, and sinkholes), good infrastructure, increasing connectivity and strong reputation of reliability; and additionally, Norway is a global leader in the digital economy (Christensen, 2018; Statkraft, 2020).

Furthermore, Norway ranks the worlds' number one in energy access and security by the world economic forum, second-best European country for Business, and fifth-happiest country in the world in 2020 by the UN. Connectivity is perhaps the most important area of improvement which is currently being addressed with the installation of 10 new subsea cables (Green Mountain, 2020).

In 2018, the Norwegian government released a data center strategy aiming to be an attractive nation for data centers and other data-centric industries (MTIF, 2018). Norway was the first country in the world of doing so (Green Mountain, 2020; The Explorer, 2020). This led to strong growth in new data center investments of NOK 2.7 billion in 2019 and 2020. And it is expected to create 11 thousand new jobs over the course of 5 years (Implement, 2020). District and Digitalisation Minister Linda Hofstad Helleland stated "We have good conditions to become an important data center region. The government has succeeded in facilitating important value creation in the districts. Now we want to invest even more". A new strategy will be released by June 2021 with new measures to further competence development in Norway, strengthening of data centers' business climate, and joint international efforts to attract foreign players (Datacenter forum, 2020).

Tor Kristian Gyland, CEO of Green Mountain, the biggest Norwegian data center company, states that Norwegian data centers are the world's greenest because of its abundant renewable hydropower and robust grid, but recognizes opportunities to improve energy efficiency and waste heat utilization (Europeanceo, 2020).

According to IEA, the incentive to reduce energy use is strong, as energy costs make up a significant share of ICT companies' operational expenditures, but Tina Bru, the Norwegian Minister of Energy, states that Norway's lowest energy prices lead to little incentive to use energy efficiently. Consequently, she is running amendments to the Energy Act on requirements for cost-benefit analysis that order data centers with a capacity of more than 2 MW to explore offering their waste heat to district heating systems. This cost-benefit analysis shall be submitted to the relevant authority for approval (IEA, 2020a; Judge, 2021). Luxemburg, another leader in these policies, chose an easier approach to control for private energy efficiency improvements but it is not specific on waste heat utilization. In Luxemburg, each and every energy-intensive industry player that receives cheaper electricity than average has to deliver a 1,5 % improvement in energy efficiency yearly (IEA, 2021a).

In line with that, Trygve Mellvang Tomren-Berg, general manager of Norsk Fjernvarme, argues that the utilization of waste heat from data centers will eventually become standard in Norway, as it will help to reduce the footprint of this power-intensive industry (Europower Energi, 2021).

The heat market in Norway is estimated at 53 TWh in 2017 and the district heating market accounts for about 4 % of the heat market serving nearly 211 000 citizens. The total installed heating capacity in Norway is 3,4 GW (Juhler, 2019).

Heidi Sørensen, Director of the Climate Agency Oslo, states that district heating plays an integral role in the Norwegian climate strategy and it is a link to the electrification policies, as it makes electricity available for other purposes and as a result, it is key for cutting Norwegian cities' climate emissions. In this regard, Kristiansand is looking to become the world's first fully electric region by 2030 (DHCities, 2021).

2.5 Final remarks on business opportunities in data centers in Norway

This chapter describes the social and economic trends, technology challenges, political and regulatory changes, and Norway's competitiveness in the cloud data center industry. It identified the major players, the investment drivers, and current challenges. It is noted that the cloud data center business is one of the world's fastest-growing industries and is concentrated in North America, Asia Pacific, and Western Europe. The Nordic region is becoming a global hub for data center investments. This is mainly due to the political decision to become data center nations and the Nordics' competitiveness to address the main challenges in this industry: low latency and environmental footprint. Cloud computing should be developed to match the rapidly growing demand of internet services driven by the emerging technologies (IoT, AI, VR, blockchain, and 5G), and data centers have the fastest growing carbon footprint across the whole ICT sector.

However, the data center industry is one of the few technologies “on target” to meet the *Sustainable Development Scenario* and should be climate neutral in Europe by 2030. This creates strategic business opportunities in the development of cloud computing technologies and solutions for the climate neutrality of data centers. As discussed in section 2.4, Norway is well-positioned for taking advantage of these opportunities.

3. Research Design and Theory

This chapter answers the auxiliary research question Q2: Which is an appropriate theoretical framework to identify business opportunities around the utilization of data center waste heat?. It presents the research design, covering the methodology, sampling, and data collection, data analysis, reliability, and validity.

For this research, a business opportunity is defined as a favorable set of circumstances that solves a real problem for customers, offers significant risk-adjusted profit potential, is potentially profitable over a reasonable time span, and is amenable to financing (Barringer et al., 2019; Harvard Entrepreneur's Handbook, 2018).

Hence, next, it is presented the way we set the theoretical foundation applied for the identification of the new business opportunities around the utilization of waste heat from data centers.

3.1 Methodology

This master's thesis is based on qualitative research carried out by two master students with majors in New Business Development; and Energy, Natural Resources, and the Environment, respectively. It is based on the theory of recognizing business opportunities by Barringer and Ireland (2019). We used a comparative multiple case study approach to explore innovations around data center waste heat utilization, with a special focus on the business models. A literature research was carried out within seven case studies representing a range of experiences in Europe.

As per Barringer et al (2019, chapter 2), there are three approaches to identify business opportunities, which are: observing trends, solving a problem, and finding gaps in the marketplace. The first approach is to observe the economic trends, social trends, technology advances, political action, and regulatory changes, and study how they create opportunities. This first approach was done in this research to answer auxiliary research question Q1 (see section

1.2) and the result is documented in chapter 2. The second approach is to recognize problems and find ways to solve them. Problems were recognized by observing the challenges that some entities are facing. This second approach was done in this research to answer the auxiliary research question Q3 by assessing the business models of seven cases of waste heat utilization from data centers in Europe. These results are documented in chapter 4. Finally, the third source of business opportunities is to find gaps in the marketplace. This refers to products that customers need or want that are not available in a particular location or are not available at all. For this third approach, we followed two of the proposed techniques for generating business ideas by Barringer et al (2019). They were focus groups, and library and internet research. Focus groups involved people who were familiar with business innovation both from entrepreneurial training programs and senior entrepreneurs of technology innovation. Focus groups were conducted applying the theory of strategic choices for new ventures by Gans, Scott, and Stern (2018), which is described in section 3.6. Subsequently, literature research was done to support the identified business ideas, in such a way that they can be regarded as business opportunities. This leads to answering the main research question, which is discussed in Chapter 5.

Next, we describe data collection and data analysis separately, although they occurred in parallel during the course of this research.

3.2 Sampling and data collection

Data collection was sampled and collected simultaneously in two different ways. The two approaches were focused on value creation out of data center waste heat utilization, on how value is currently being created, and how it could be created in the future, respectively. To identify how value is being created, we did a case study of recently documented exemplifications of waste heat utilization from cloud data centers in Europe (described in section 3.2.1). To identify how additional value could be created in the future, we did an opportunity recognition study with focus groups using a strategy framework for startups, which has been used to identify multiple new venture opportunities around the same business subject. In our study, it was specifically applied to waste heat utilization from cloud data centers (described in section 3.2.2). Next, it is described how we sampled and collected the data in each of the two approaches.

3.2.1 Case studies

In order to capture how value is created in the current business models, we collected data in terms of the nine building blocks of the business model canvas as per Osterwalder and Pigneur (2010). Our sampling of cases ensured that the business model captured is updated. We relied on the following selection criteria: (1) the sample can be regarded as a successful waste heat utilization case from a data center, (2) the sample case has recent reports and research literature in recognized journals, and (3) the sample case is from a European country leading data center investments. This resulted in a set of seven cases.

The data referred to in this analysis were obtained from secondary sources. Data was collected from academic journals, reports, newspapers, and numerous online sources. Data collection was carried out through a search process of information related to each case, considering only recent publications. The time frame for the data collection was 2018-2021. The raw data was then classified and processed to build a summary of the case study. The seven case studies are summarized in section 4.1.

3.2.2 New business opportunities recognition

To recognize new business opportunities, we collected primary data through focus groups in four workshops and secondary data by literature research based on the workshops' findings. We arranged workshops with focus groups as the primary method for collecting data because they provide a rich account of informants' experiences and knowledge (Hacklin, 2018). Workshops were structured based on the theoretical framework by Gans et al, described in section 3.6, and conducted via video conferencing with senior entrepreneurs and students being trained in entrepreneurship. Two workshops were done with a group of three senior entrepreneurs. Originally, it was planned only one workshop with this group, but after conducting follow-up discussions with them about Gans' framework, we did a second workshop with the same group, which helped participants to understand better the referenced framework and allowed us to identify more business opportunities. The other two workshops were done with two groups of students of two different entrepreneurial training programs. The workshop duration was typically one hour. Participants were identified and contacted through our personal contacts and using social networking. Participants belong to three different generations: fifteen people from iGen (18-26 years old), two millennials (27-41 years old), and three-generation X (42-56 years old). None of the participants had any specific experience in the data center industry but a spirit of new business seekers.

After the workshops, we collected additional secondary data, specifically related to the new business ideas identified not only in the seven case studies but extending our search to other cases. For each business opportunity, relevant academic articles, companies' reports, newspapers, and our case studies were revisited. Hence, our procedure of collecting data from both primary and secondary sources was iterated until saturation was reached and we got enough information to describe and support all business opportunities listed in chapter 5.

3.3 Data analysis

The data analysis followed a three-step approach. First, we wrote short narratives on how the exemplification cases were successfully integrating the waste heat from the data center into the city's energy system. Second, we described the business models in terms of the nine building blocks as per Osterwalder et al (2010). To do this, we developed an initial list of sub-elements for each building block, and then it was reviewed on each business model canvas and subsequently extended, refined, and condensed as data analysis proceeded. Third, we analyzed business model innovation by researching new entrepreneurial strategies and business model patterns. The business model description was performed by one author while the other did the new business recognition research. These findings were validated through discussion with two experts and literature research refinement by the two authors. These discussions are reported in every and each business opportunity listed in chapter 5. Experts and other participants are mentioned in the acknowledgment section.

3.4 Reliability and validity

This research followed a highly structured methodology to facilitate replication and thus to ensure reliability as emphasised by Saunders et al. (Saunders, 2019, section 5.11). As for the credibility of the obtained data, we consulted academic journals and internet information of credible sources. We took care to use data that is not obsolete, and we gave the most extreme significance to keep up that the information is the most recent one. So, we have taken information and data from ongoing articles, ideally distributed in 2019 and thereafter. On the other hand, we opted for a multiple case study design that allows us to analyze a variety of events and outcomes, examine patterns, and eliminate chance association.

For validity, we have compared the same sort of information from diverse sources. In the event that we found any discrepancy among the information collected from two distinctive sources, we have endeavored to compare it with other sources, after that, still not satisfied with regard to the sensible validity of the data, at that point we have not utilized that data for our consideration, but it only happened in one case.

3.5 Business model theory

The business model assessment performed in this study comprises a qualitative analysis that applies the business model rationale by Osterwalder and Pigneur (2010), which describes in nine building blocks how an organization creates, delivers, and captures value, as shown in the canvas model 3.1.

Osterwalder, Pigneur, Bernarda, and Smith (2014) states that the value proposition is the core of the business model as it refers to the value created for the customer. This business model rationale starts by understanding the customers through what jobs they need to be done, as well as the customer's pains and gains. A value map is then created by investigating how the product or service relieves pains and creates gains for the customers. By analyzing the value proposition and the customer segment of the business model, it can be identified opportunities to keep the value proposition aligned with customers' needs.

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Proposition</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">The network of suppliers and partners that make the business model work</td><td>The most important things the company must do to make its business model work</td><td rowspan="3">Products and services that create value for a specific customer segment</td><td>Relationships the company establishes with customer segments</td><td rowspan="3">Groups of people or organizations the company aims to reach and serve</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>The most important assets required to make the business model work</td><td>Ways to communicate and reach the customer segments to deliver the value proposition</td></tr>
</table>

Cost Structure	Revenue Streams
All costs incurred to operate the business model	The cash the company generates from each customer segment

Model 3.1: The Business Model Canvas by Osterwalder and Pigneur (2010)

Nielsen and Lund (2018) states that examining the alignment between value proposition and customer needs is the most recent research on business model innovation. However, they found in their business model research in the Nordics that a business model scalability study is required to assess the business growth capability. In this research, the first part of the business model analysis was done following the Osterwalder et al rationale, and the scalability study as per Nielsen et al is then recommended for further research.

3.6 Business model innovation theory

Many researchers in the energy domain look at business model innovation to find novel ways of creating and capturing value from digital technology (Loock, 2020). Business model innovation is mostly needed when there are structural changes in industries or when new ecosystems emerge. Scholars debate the merits of different business model innovation strategies. One stream of business model research advocates the operation of multiple, parallel, and partly even conflicting business models as a mechanism for hedging risks and opportunities. The alternative view suggests changing the primary business model to align with shifting demands (Hacklin, 2018).

Hacklin et al stated that several researchers in the last decade have shown that running separate business models in tandem is a way to diversify revenues and profits and thereby reducing risk. While others argued that running parallel business models is difficult and is often the leading cause for strategic failure. However, the practice of running a parallel secondary business model could solve this, as all the elements of the primary business model remain unchanged. The secondary business model provides a different customer value proposition to previously untapped customer segments via a new distribution channel. The low degree of integration provides protection against ‘contamination’ between the primary and secondary business models even though they might share some resources (Hacklin, 2018).

It has been acknowledged that industry-level factors such as technological developments impact business models (Korhonen, 2018; Hacklin, 2018). On one hand, Korhonen found that the business model dictates how energy efficiency can be approached when data center waste heat is used (Korhonen, 2018). And on the other hand, through digitalization, firms apply digital technologies to optimize existing business processes by allowing more efficient coordination between processes, or by creating additional customer value through enhancing user experiences. Additionally, emerging technologies are opening opportunities for the creation of new value for customers and it is leading to changes in consumer behavior and what customers are willing to pay for. Ventures with large native digital customer segments, such as the Nordics, are in a privileged position to take advantage of this trend (Christensen et a., 2018).

Correspondingly, digital transformation, defined as a change in how a venture employs digital technologies, is being used to develop new business models that help to create and capture more value. The digital transformation of business models enables ventures to scale faster, apply easily economics of scope, and also learn faster from the consumers. So that ventures are enabled to offer better and tailored customized products than their non-digital counterparts (Look, 2020).

The approaches discussed in this section represent different dimensions of the business models that can be referred to as strategic choices. These choices can be conveyed through the framework of four generic strategies by Gans, Scott and Stern (2018), which is described in the following section.

3.7 Strategic choices for new ventures

Gans et al. (2018) propose four strategic choices for new ventures, categorized along two dimensions: entrepreneur's attitudes toward incumbents (collaborate or compete), and attitudes toward innovation (build a moat or storm a hill). These four distinct strategies can guide decisions regarding customers, technology, identity, and competitive space. This framework is used to ideate new venture business opportunities. The reference strategies are based on the compass illustrated in Figure 3.1.

	Having a tight control over technology	**Quickly getting to the market**
Collaborate	**Intellectual Property**	**Value chain**
Compete	**Architectural**	**Disruption**

Figure 3.1: The entrepreneurial strategy compass by Gans et al. (2018)

Gans et al’s four generic strategies are intellectual property, value chain, architectural, and disruption. The intellectual property strategy consists of maintaining control of the innovation and finding a way to create value within the existing marketplace. The focus is on being an idea factory. The value chain strategy focuses on creating value for partners in the existing value chain, thus it executes quickly. The architectural strategy comprises the creation and control of a new value chain, often using a platform business. The control can also be done by protecting intellectual property. And the disruption strategy involves competing directly with incumbents. It embraces the command to take incumbents by surprise with fast execution.

This framework was the reference to structure the workshops for conducting the focus groups as described in the methodology section 3.1. Then the output, the identified business ideas, were used as the input for the literature research intended to support the new business opportunities.

4. Business Model of Data Center Waste Heat Utilization

In this chapter, we introduce exemplification cases of successful utilization of data center waste heat. We have chosen seven cases from six European countries following the sampling rationale described in section 3.2. The seven cases are from the following six countries: Finland, Denmark, Ireland, Netherlands, Sweden, and Norway. Through these case studies, we have tried to figure out how waste heat from data centers is utilized, as well as build the business model suggested by Osterwalder et al (2010) in section 3.5

4.1 Case studies

4.1.1 Case 1 - Yandex in Finland

Yandex, the Russian search engine which is the fourth largest search engine company in the world, and Nivos Oy, a Finish energy company, are working together in using waste heat as a by-product of a data center, in Mäntsälä, Finland. Yandex collects heat and sells it to Nivos Oy and then Nivos Oy sells it to the local community. Together with the local community, both Yandex and Nivoy Oy have benefited commercially from the project. Currently, the data center's excess heat is providing half the town's heat supply, and Mäntsälä's residents have seen their energy bills reduced by 12%. Carbon emissions produced by Nivos have also declined by 40% because the company can use the data center's recycled heat rather than energy generated from fossil fuels (Yandex, 2019).

Yandex has been transferring excess heat to Nivos since 2015 and started its second generation of heat recovery technology in November 2018 by introducing a new technology in one part of the facility which helped to recover 60-80% of excess heat, more than double the energy recycled from the first version. Yandex is expecting to reuse 90% of the facility's energy after applying the new technology throughout the rest of the data center (Yandex, 2019).

Yandex's success to some extent depends on its location. The manager of the Yandex data center in Mäntsälä, says the reason behind choosing this location: "Energy costs and reliability are extremely good. Finland has an educated workforce, and there are good communication channels to the authorities”. Socioeconomic and government stability also play an important role in his opinion (Cord, 2020).

Waste heat from the data center satisfies more than half of Mäntsälä’s heating needs, according to the Finnish innovation fund “Sitra”. Sitra estimates that if all new data centers which are opened or scheduled to open between 2018 and 2025 in all the Nordic countries were to recover their heat in this way, then the resulting emissions reductions would be the same as taking 500 000 cars off the road (Cord, 2020).

This exemplification case in Finland has been declared to be a win-win-win arrangement for all parties: Yandex data center benefits from offering the “recovered heat” to diminish the CO2 footprint, the locale district heating companies are capable to guarantee a steady, environmentally friendly, and cost-efficient energy source and the local inhabitants appreciate the consolation of reused energy at a lower price.

4.1.2 Case 2 - Facebook in Denmark

Facebook, in cooperation with Denmark's third-largest district heating company Fjernvarme Fyn, is providing heating to the Danish city, Odense. Facebook estimates that it will be able to donate 100 000 MWh of heat, which would otherwise have been wasted, to local communities through the district heating system (Edie, 2020).

Odense district heating system transmits water into Facebook's 50 000 square meter campus, where it is directed in insulated steel pipes to the roof of the data center, then it is passed through copper coils placed inside each of the data centers with a total of 176 cooling units. The water picks up low-temperature heat and is channeled back to Fjernvarme Fyn's heat pump facility. Fjernvarme Fyn then uses heat pumps to warm the water further making it hot enough to be valuable in the district heating system (Alley, 2020).

Since April 2020, the Odense data center has held a LEED (Leadership in Energy and Environmental Design) Gold certification and the social media company has committed itself to build efficient data centers and meet bold climate targets (Alley, 2020). Odense Mayor, Peter Rahbæk Juel said “It is amazing because every time we post pictures of our pets, family, and whatever on Facebook, it will produce heat that will heat up to almost 7,000 houses”. He further added that this was a “good, greenside effect” of building the facility near the city. Facebook says, in spite of the fact that none of the technology is novel, the combination of heat pumps and recycled data center energy will offer assistance to the city with its objective to stage out the utilization of coal by 2023. According to Facebook’s estimation, the data center will decrease Odense’s coal demand by up to 25 percent (Frost, 2020).

The data center started its operation in September 2019, and it is being expanded with a third server hall of approximately 30 000 square meters. Facebook’s supply of excess heat from the servers to the consumers of the district heating in Odense is growing as a result of the extension. Today, Facebook supplies excess heat from the data center to approx. 7000 households, and when the operation of hall 3 is to be completed, along with creating 900 new jobs, surplus heat will be able to meet the heat demand of 11 000 households in Odense (MFA, 2020).

To tout the reason behind choosing this location, Facebook energy specialist Lauren Edelman explained that the location for the data center was chosen because it was a place where this surplus heat could be used effectively: “The qualities that drew us to Odense include the ability to connect to a highly reliable Nordic electric grid with opportunities to add new sources of renewable energy, good access to fiber, and the talent needed to build and operate the data center” (Frost, 2020). Additionally, nearly 77% of the Danes are willing to change a number of different behaviors in order to live more sustainable lives. About half of them want to choose more sustainable energy sources but 26 % judged sustainability as too expensive (Bolius, 2019; Ridder, 2021).

4.1.3 Case 3 - Amazon in Ireland

Amazon Web Services (AWS) is building Ireland's first, custom-built sustainable solution to supply low-carbon heat to a developing Dublin suburb. The company is working with South

Dublin County Council to recycle heat from its data centers. Amazon will be using that heat for local community buildings in Ireland (Team, 2021).

The new District Heating Scheme in Tallaght, South Dublin will at first warm 47 000 m^2 of public sector buildings as well as 3000 m^2 of commercial space and 135 affordable rental flats. During the first stage of the Tallaght District Heating Scheme, it is expected to save 1 500 tonnes of CO2 per annum, the equivalent of a 60 percent reduction in CO2 emissions. AWS under its broader sustainability commitments will provide recycled heat free of charge in a scheme that will further process the heat with heat pump technology, and then will be sold on to end-users at very low price by the district heating company, trading as Heatworks, Ireland's first publicly owned not-for-profit energy company (Team, 2021).

Fortum, an energy supply company with broad district-heating involvement all through Scandinavia and Eastern Europe, will carry out the plan, establishment, and operation of the network. The heat supplying will start before the end of 2021, with the first clients being the South Dublin County Council (SDCC) and the Tallaght campus of the Technological University Dublin. By 2024, the heat will moreover be provided to adjacent developments recently given planning permission, including affordable housing units and student accommodation (O'Sullivan, 2020).

The project is partly financed by the European Union's Heatnet program, promoting carbon reduction through district heating in Europe's northwest. It is additionally getting EUR 4,5 million from the Government's climate action fund and direct funding from SDCC (O'Sullivan, 2020).

According to Heatworks, the network's supply of low-cost, low-carbon heat is anticipated to pull in more creative businesses and development to Tallaght town center, and facilitate educational programs and start-up opportunities in renewable energy solutions, as well as helping to mitigate fuel poverty (O'Sullivan, 2020).

4.1.4 Case 4 - CyrusOne in Netherland

CyrusOne is a high-growth real estate investment trust specializing in the design, construction, and operation of more than 50 high-performance data centers worldwide. Municipality of Haarlem, Netherland, and the business park PolanenPark are joining forces to research capturing waste heat at its Amsterdam I data center. The heat re-use project will capture residual heat from the data center's water-cooling process, which will be fed into a new district heating network to heat 15 000 homes in the municipality (Fakhir, 2020).

Haarlem Municipality is planning to wean itself off of natural gas by 2040, so the municipality is searching for alternatives for heating homes and businesses. With the research into the use of residual heat, Haarlem is taking an important step in the advancement of a heat network in the area (SADC, 2020). The move came just months after the wider Amsterdam metropolitan zone lifted a year-long ban on new data center builds, after raising concerns about power usage (Moss, 2020).

CyrusOne will capture heat from its Amsterdam I data center at an average temperature of 30 °C. Since this temperature is too low to be directly used in a district heating network, which needs a water temperature of at least 70 °C, a mechanism is needed to raise the temperature of the water flowing into the system while lowering the temperature of the water returning to the data center, thus permitting maximum heat to be recovered. The heat pump technology does require electrical energy to operate, however, because it is only used to enhance the heat recovered from the data center, it is typically considered 400 % more efficient than directly heating the water with electricity. The data center's recovered heat can then be spread for a number of purposes, including commercial, recreational, and residential (CyrusOne, 2020).

The proposed method of achieving this is to use a heat pump to transfer heat from the water returning to the data center into the water flowing into the district heating network, thereby raising its temperature. To absorb heat, the refrigerant gas is extended, then compressed to release it. This allows heat to be transferred from one position to another and then, using a pipeline to take the waste heat to heat 15 000 homes in the municipality (SADC, 2020; CyrusOne, 2020).

4.1.5 Case 5 - Switch in Netherland

Switch is a global technology company whose core business is the design, construction, and operation of ultra-advanced data centers. Switch is planning to supply waste heat from its data center to local homes and businesses at a discounted price in the Netherlands. The company is supplanting gas generator units, already utilized to warm the company's office, and a neighboring property with heat exchangers that will offer heat from servers rather than utilizing natural gas (Swinhoe, 2021).

The company is expecting that 97 percent of the server heat will be captured and supplied to homes and workplaces, and clients getting heat this way will pick up a 20-30 percent markdown on their power costs. The Company's target is to heat over 2 000 homes and 2 large office buildings. The residual heat from the data center is also valuable for real estate developers because Netherland adopts the Nearly Energy Neutral Building rules, known as BENG (Swinhoe, 2021).

Since 2013, another data center in Amsterdam named Nikhef has been providing heat to nearly 800 homes in the 'Science Park II' complex. Within the coming year, the homes of the Science Stop I complex will also be connected, permitting another 720 student residences to be warmed by the Nikhef office. The Student housing agency is getting a subsidy for the project from the municipality of Amsterdam. The heating provided by the Nikhef data center implies that the student flats no longer need to use natural gas for their heating (HostingJournalist, 2019).

4.1.6 Case 6 - DigiPlex in Norway

Nordic data center operator Digiplex has signed an agreement that will use the waste heat from its facility in Ulven, Oslo, to warm 5 000 apartments in the city. The company will work with local district heating supplier Fortum Oslo Varme, which operates a 60-mile heat distribution system throughout Oslo to redistribute the heat generated by its data center, which is also powered by renewable energy.

Fortum Oslo Varme is already recovering energy from the sewage of Oslo, and by recovering the surplus heat from data centers, it will further increase the share of recovered heat in its production and strengthen Oslo's cycle-based energy system. The company claims that its data center in Oslo is already energy-efficient, but the ability to utilize surplus heat to heat homes and commercial buildings will help customers further reduce their environmental footprint (Donnelly, 2018).

District heating currently accounts for approximately 20 percent of Oslo’s heat demand, and with the heightened construction activity in the city as well as the ban on the use of fossil fuel for heating, substitutes for heating are expected to increase. Fortum Oslo will establish an energy production unit with associated heat pumps and pipelines on the site of DigiPlex in Oslo. Knut Inderhaug, Fortum Oslo Varme head of customer, declared that they are helping to create a more sustainable data center industry that can further contribute to cities and communities (Young, 2020).

4.1.7 Case 7 - Bahnhof in Sweden

Bahnhof is a Swedish internet service provider that delivers excess heat (and cooling) from two Bahnhof’s data centers: Bahnhof Thule and Bahnhof Pione, to Stockholm Exergi, a Stockholm's energy company. According to Stockholm Exergi, this has a number of advantages for both the district heating company and the business that supplies and sells surplus energy. Lower production costs are one advantage for Stockholm Exergi as incoming supplies replace more costly production. Benefits for the data center include revenue from energy sales that would otherwise be lost, increased utilization of the cooling system, and the possibility of greater system reliability.

Stockholm Exergi has a pricing model that is based on the network's energy demand. As a result, when demand is low, the price is low, and when demand is high, the price is high. During a cold day in the winter, the heat delivered can be worth ten times what it is on a normal day in the summer. As a result, the excess heat from the heat pumps is used in the district heating network primarily when the outside temperature is below 7 °C, which occurs approximately half of the year. Bahnhof reserves the right to deliver heat to Stockholm Exergi at any time, even though in the district heating network, there is always a need for heat (Celsius, 2020).

Bahnhof has invested a total of 5,3 million SEK (Approx 523,115 Euro) in the cooling system for the Thule data center, which includes three heat pumps, pipes, wiring, control systems, data collection, and installation. On the other hand, Exergi Stockholm has invested 2,6 million SEK for delivery pipes, Bahnhof has invested 3,5 million SEK in the Pionen Data Center cooling system and Stockholm Exergi has invested 1,3 million SEK for pipes (Celsius, 2020).

Stockholm is one of the few cities in the world where large-scale heat reuse from data centers is feasible because almost 90% of all buildings are connected to the district heating network. Stockholm Exergi is optimistic in their investment and values their intimate relationship with consumers, in such a way that Stockholm Exergi offers “Open District Heating" to encourage companies and businesses with excess heat that are located adjacent to their heating or cooling networks to sell energy, supplied in the form of warm water. They claim that it is the world’s first marketplace for excess heat. By recovering heat for the district heating network, the company creates a unique marketplace for trade-in excess heat. Stockholm Exergi’s investment in heat recovery is a key part of its efforts to create a sustainable city as it is estimated that by 2030, 100 percent of Stockholm’s district heating is to be generated from renewable and recovered energy (Open District Heating, 2018).

4.2 Analysis of the case studies

The prevalent business model of waste heat utilization is consistent across all seven case studies. There are more similarities than differences. The most noticeable differences are in four of the nine building blocks of the business model: Value proposition, customer segments, channels, and revenue stream. We assessed the business model using the framework by Osterwalder et al, as described in section 3.5.

Customer Segments: Out of seven cases, in six cases, data centers deliver their waste heat to a district heating company, and in just one case, the data center supplies heat directly to end-users.

Value proposition: It was observed that there are two values delivered: low-cost heat and reduced environmental footprint. The reduced environmental footprint value is obvious in every case, but the low-cost energy value is addressed just in three of the seven case studies. Table 4.1 illustrates the different emphases in the value proposition across the seven cases.

Case, Data center provider	Value Proposition Emphasis	
	Low-cost Energy	Circularity
Case-1, Yandex	✔	✔
Case-2, Facebook		✔
Case-3, Amazon	✔	✔
Case-4, CyrusOne		✔
Case-5, Switch	✔	✔
Case-6, Digiplex		✔
Case-7, Bahnhof		✔

✔ = Emphasis Blank = Nothing Mentioned

Table 4.1: Emphasis on the value proposition per case

There are disparities in environmental footprint reduction, but it is due to differences in the primary energy that is substituted. In some cases, it reduces the use of coal, while in others it substitutes the use of natural gas.

Channels: The differences in channels are due to distinct customer segments. In six cases, the channel is Business-to-Business (B2B), data centers directly transfer their waste heat to another corporate entity, four of which are district heating companies and two are energy companies. In one of the cases, they use the Business-to-Customer channel (B2C). Switch (Case 5) is supplying waste heat directly to end-users.

Revenue Stream: Except for Facebook and Amazon Case, in all other cases, revenue is earned through selling usable heat. As part of a larger commitment to sustainability, Facebook and Amazon provide it for free to a district heating provider, with the district heating firm generating income from the sale to consumers.

Table 4.2 highlights the differences and similarities found across the business model building blocks of the seven case studies.

Case studies *// business model block*	**Yandex Case-1**	**Facebook Case-2**	**Amazon Case-3**	**CyrusOne Case-4**	**Switch Case-5**	**Digiplex Case-6**	**Bahnhof Case-7**
Customer Segments	Energy company	District heating company			Local community	District heating company	Energy company
Value Proposition	Low-cost heat and reduced environmental footprint (See table 4.1)						
Channels	B2B				B2C	B2B	
Revenue Stream	Revenue for useable heat	Usable heat or free		Revenue for useable heat			
	Good reputation for energy circularity						
Key Resources	Waste heat and heat transfer technology						
Key Activities	Making waste heat (commercially) useable						
Key partners	Equipment manufacturer and technology providers						
Cost Structure	Investment in technology and operation/maintenance costs						

Table 4.2: Business model building blocks comparison of the seven case studies

The differences shown in table 4.2 can be associated with three different supply chains. These supply chains are used differently across the case studies and in two cases they used them in a mixed way. The supply chain system can be simplified to a single waste heat supplier, three possible waste heat distributors, and three heat consumer groups as illustrated in figure 4.1.

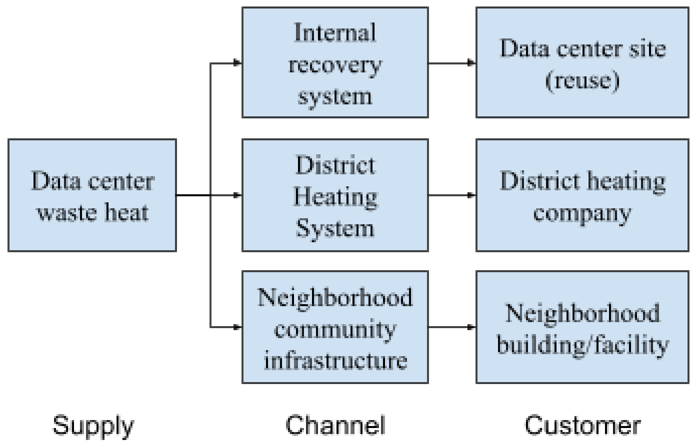

Figure 4.1: Supply chain system of waste heat utilization from data centers

Each supply chain has a different channel and customer segment. But all three supply chains could be used simultaneously in the same case. Next it is a reference to the operation of these supply chains into individual case studies.

- ➢ Data Center → Through internal recovery system → Data center own site

This is the scenario where the data center gathers heat for its own purpose. Switch data center (Case 5), for example, absorbs heat from its servers and uses it for its own corporate office.

- ➢ Data Center → Through district heating infrastructure → District heating company

It is the most common supply chain. The supplier is the data center, which is responsible for recycling the waste heat, and the distributors need to deliver the recovered heat to the end consumer and release the heat for consumers' use, such as neighborhood communities, schools, swimming pools, hospitals, and other enterprises.

- ➢ Data Center → Through neighborhood´s infrastructure → Neighborhood facilities

In this supply chain, waste heat from the data center is distributed to the nearby buildings or offices via the local community infrastructure like in the Switch case. Nikhef data center supplies waste heat to a nearby student housing.

In conclusion, in terms of the business model construct it is observed that there is a prevalent business model of data center waste heat integration into a city's energy system. The most significant changes across the seven case studies are: the price of waste heat, and three different supply chains. Therefore, there is an opportunity to develop differentiation advantages in order to be more competitive.

4.3 Description of the prevalent business model of data center waste heat utilization in Europe

The model 4.1 shows the prevalent business model of the case studies using the canvas model by Osterwalder and Pigneur (2010). It is observed that the core is the recovery value of the waste heat and the fact that utilization of waste heat is considered circularity of green energy because it does not require additional resources. Next is a description of the building blocks of the prevalent business that successfully makes use of the data center waste heat.

4.3.1 Customer Segments

As illustrated in figure 4.1, there are three types of customer segments: Local district heating operators, neighborhood home and office building owners, and data center own building (reuse). A data center can serve one or several customers. For example, Yandex data center provides heat to Finish energy company Nivos Oy in Mäntsälä, Finland; Amazon data center in Dublin is expecting to supply heat to adjacent buildings by 2024 and Switch data center in Netherland uses heat to warm its company's offices.

4.3.2 Value Proposition

Waste Heat currently has two value propositions, namely low-cost heat and energy circularity, however, there is more emphasis on the reduction of environmental footprint than on low-cost heat, as indicated in Table 4.1. This could imply that the importance of waste heat currently stems from its green and circular nature more than its low cost. This picture could change in the future if waste heat utilization from data centers can be transformed into a profitable industry.

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Proposition</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">Equipment manufacturers (Server, Heat Pump, Cooling)</td><td>Making waste heat useable</td><td rowspan="3">Low-cost heat, and energy circularity</td><td>Sustainability, Being circular</td><td rowspan="3">Local district heating company.
Neighborhood buildings.
Own data center site.</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>Waste heat, Infrastructure</td><td>B2B and Direct to customers</td></tr>
<tr><th colspan="3">Cost Structure</th><th colspan="2">Revenue Streams</th></tr>
<tr><td colspan="3">Capex: Infrastructure, technology
Opex: Operation and maintenance</td><td colspan="2">Revenue for useable heat and a good reputation for energy circularity</td></tr>
</table>

Model 4.1: Typical business model canvas of data center waste heat utilization

4.3.3 Channels

The delivery channel is mainly business to business (B2B), just in one case there is a plan to have a business to customers channel (B2C). Hence, there are two ways that a data center communicates with and reaches its customers to deliver the value proposition. In the B2B channel, waste heat producers make a contract with a district heating operator or energy company. Thus, as per the contract, the data center supplies heat to the district heating operator, and then the operator delivers the heat to the end-user. Alternatively, in just one of the cases, it is expected to use B2C, where the data center directly supplies heat to the end-users.

4.3.4 Customer Relationships

Most customers are attracted to waste heat use due to sustainability considerations. For example, in the Amazon case, during the first stage of the Tallaght District Heating Scheme, it is expected to save 1 500 tonnes of carbon per annum, the equivalent of a 60 percent reduction in carbon emissions. Additionally, waste heat has replaced coal in the Facebook case, and natural gas in the Switch case. It has been possible due to waste heat sustainable attributes, which have great bonding with customers who value this.

4.3.5 Revenue Stream

It consisted of revenues for usable heat and a good reputation for energy circularity. Revenue comes from selling commercially usable waste heat to the customer (district heating company or neighborhood building). The end-user could be a home, swimming pool, spa or any other user of heat. The price of waste heat energy could be lower than traditional energy, resulting in decreased energy bills for waste heat consumers. For example, Switch supplies waste heat from its data center to local homes and businesses at a discounted price. However, the price of waste heat may not be fixed all year round. In the Bahnhof case, Stockholm Exergi has a pricing mechanism based on the network's energy demand. As a result, when there is low demand, the price is low, and when there is a high demand, the price is high. In this case, on a winter day, the heat delivered can be worth ten times what it is on an average summer day. Facebook and Amazon opted for a different pricing strategy; they are delivering data center waste heat for free to a district heating company.

4.3.6 Key Resources

Waste heat is the main key resource, and the second one is the technology for absorption, transmission, and distribution of the heat. The amount of waste energy resources is normally significant. For example, in the Yandex case, the data center's excess heat is providing half the local town heat supply. Regarding the technology, there is a substantial difference among types of cooling technologies. For instance, in air-cooled data centers, waste heat can generally be captured between 25 °C and 35 °C, while liquid cooling would allow capturing waste heat at between 50 to 60 °C. Due to the more efficient heat transfer of liquid compared to air, the temperature of the circulating liquid can be higher, and therefore the waste heat can be captured with higher quality. The higher the temperature, the better for business, because higher temperature heat may be utilized directly in district heating without incurring any additional costs for heat pumps and other technologies.

4.3.7 Key activities

The waste heat captured from the data center is not readily usable for commercial purposes. In most cases, the main reason for not utilizing the waste heat is the low quality of heat. Capturing waste heat is usually below 85 °C, hence temperatures are too low for many applications especially for district heating, so it requires further methods and processes to exploit it. Thus, the main activity to make this business model viable is to transform waste heat into a commercially usable one.

4.3.8 Key partners

To capture and make usable the heat from a data center it is required to partner servers, cooling systems, and a heat pump. These types of equipment come into action in different phases and for different purposes during the whole business process. For example, heat pumps can be used in data centers to produce the cooling energy for the server room; but in addition, they can be used to improve the quality of heat up to 95 °C and above, which would allow heat to be utilized in many other processes. Success and profitability of waste heat utilization to some extent depend on the quality and servicing of these types of equipment. So, equipment manufactures, and servicing companies are the key providers and partners for the waste heat utilization business.

4.3.9 Cost Structure

The waste heat utilization business requires a significant capital expenditure (Capex) for the installation of equipment and infrastructure for capturing and distributing heat. The data center mostly covers the expense of additional equipment required for heat capture and maintenance, whereas the district heating company or energy company bears the cost of equipment needed to transfer the heat and its maintenance. For example, in the Bahnhof case, Bahnhof for the Thule data center has invested a total of 5,3 million SEK (523 thousand Euro) for heat pumps, pipes, wiring, control systems, data collection, and installation, whereas the energy company, Exergi Stockholm, invested 2,6 million SEK for delivery pipes. The capital expenditure is normally too high that makes this business not viable for many applications and conditions. As a result, profitability is the main challenge of this business.

4.4 Final remarks on the prevalent business model of waste heat utilization

This chapter describes and assesses the business model as per Osterwalder et al. (2010) for seven cases of waste heat utilization from data centers in Europe. We observed that all the business models are roughly the same. The main remarks are a low profit business and differences in customer segments and their respective channels. The prevalent business model is shown in the canvas Model 4.1. Although no significant differences were found among the cases, the studied business models may vary in the future depending on the needs (policies and regulations) and incentives for data centers. For example, Digiplex (Case 6) is currently selling waste heat to a district heating firm, but in the future, if realized to be more profitable, it may sell waste heat directly to home consumers. In conclusion, we can shorten the current business challenges to low profitability and differentiation.

5. Business Opportunities in Waste Heat Utilization in Norway

Norway is about to embark on a difficult journey of fundamental transformation. Norway currently has large revenues from the oil and gas sector, but they are expected to fall in the years ahead. At the same time, population growth is expected, and the standard of living to be maintained. It is probably not necessary to fully compensate for all the revenues from the petroleum sector, because Norway has had large surpluses in the economy for a number of years. However, it cannot be expected that Norway will continue to build up funds to the same extent based on other types of activity. Nevertheless, there will be a need for the development of new businesses.

Data centers are the world's fastest-growing industry, which is energy-intensive and mandated to be carbon neutral by 2030 in Europe. Norway has an advantage compared to many other countries in terms of renewable power resources, natural cooling, and in addition, is determined to be a data center nation. Not only that, Norway is also leading in its ambition to reduce greenhouse emissions. Consequently, Tina Bru, Norwegian Minister of Energy, is leading a policy upgrade so that data centers shall utilize their surplus heat. This proposal sets stricter requirements than the current European Union (EU) directive does (Judge, 2021).

In October 2019, jointly with the European Union and Iceland, Norway decided to work together to reduce greenhouse gas emissions by at least 40% by 2030 compared to 1990. But then, Norway revised and expanded its nationally defined commitment (NDC) under the Paris Agreement on February 7, 2020, agreeing to reduce emissions by at least 50% and up to 55% by 2030 relative to 1990 levels. Nonetheless, it is expected to stretch NDC targets even more in the future (Ballard, 2020a; IEA, 2020a).

Data centers are already expected to be carbon neutral by 2030 in Europe. Reaching net-zero by 2050 requires further rapid deployment of available technologies and widespread use of new technologies yet to come to the market. As per IEA, in 2050 almost half of the CO2 reductions come from matured technologies and the other half from technologies that are currently at the demonstration or prototype phase (IEA, 2021b).

5.1 Business opportunities in waste heat utilization in Norway

This section lists eight new business opportunities in waste heat utilization in Norway that were identified following the research design described in chapter 3. These business opportunities have the potential to develop an innovation ecosystem that would create even more value out of waste heat utilization. Supporting the development of this ecosystem would create a new competitive advantage in Norway to attract more investments in cloud data centers. These business opportunities could also accelerate the reduction of greenhouse emissions by the integration of data center waste heat into the city's energy system.

As per the methodology, described in section 3.1, the results of the business model research reported in chapter 4 led to identifying the challenges on which the search for new business opportunities should focus; low profitability and differentiation. These challenges, along with the observed opportunities discussed in section 2.5: development of cloud computing technologies and solutions for the climate neutrality of data centers, fueled the workshops and subsequent analysis to recognize new business opportunities in waste heat utilization from cloud data centers in Norway. Appendix A shows the structure of the workshops (powerpoint presentation - in spanish) and figure 5.1 illustrates the findings after the workshop analysis following the theory by Gans et al, as described in section 3.7.

Intellectual Property	**Value chain**
5.1.1 Equipment innovations 5.1.2 New digital solutions	5.1.3 Specialized services for WHR 5.1.4 New applications for waste heat
Architectural	**Disruption**
5.1.5 New distribution networks 5.1.6 New e-commerce platforms	5.1.7 Heat attributes market 5.1.8 New financial products

Figure 5.1: Recognized business opportunities mapped in the strategy compass by Gans et al.

The recognized business opportunities are discussed in the next sections. Each business opportunity is endorsed by evidence of recent research or investments in the referred innovations, and a remark about the particular circumstances that makes it a plausible business opportunity in Norway.

5.1.1 Equipment innovations for waste heat utilization

It refers to the technological development of equipment and systems for waste heat utilization and energy efficiency in data centers. It demands developing an ecosystem for innovation and improvement of technologies like heat pumps, and solutions for processor efficiency, reductions in idle power, increments in storage drive density, and slowing server growth, among others. From this list, heat pumps are one of the key solutions in the road map to net-zero by 2050. In 2020, heat pumps delivered 7% of the world's energy demand for heating and it is expected to grow to 20% by 2030 and to 55% by 2050 (IEA, 2021b). New equipment technologies are also being developed to use waste heat for electricity production. For example, Heat Power, an energy technology developed by the Climeon company in Sweden, generates electricity from low-temperature heat. This enables the use of excess heat not only from cloud data centers but in a variety of other industrial processes (Becker, 2020). The development of the required capabilities to innovate in these technologies and take them to the next level of core technologies can be achieved by private and public partnerships where the industry works together with the government (IEA, 2021a). A reference case is Denmark, which has established climate partnerships with world-leading engineering and technology firms to cooperate in the development of technological innovations for the climate transition. The policy and regulations by the Danish government are partnered with private investments for competitive future-oriented technologies (IEA, 2021a). The recovery potential of waste heat is still untapped due to the need for efficient and cost-effective technologies to recover heat losses and to reuse, upgrade or transform this heat for its valorization (Cordis, 2020). Europe leads the waste heat recovery equipment market with a 38% share of the global market, but the Asia-Pacific region is experiencing a higher growth rate (Bianchi et al., 2019).

5.1.2 New digital solutions for energy efficiency

This opportunity is about the development of software solutions for energy efficiency, including the optimization of waste heat utilization systems. For example, Google has developed a solution called DeepMind AI that provides operational recommendations to turn the cooling system on or off, and in that way, it has reduced the energy used in one data center site by 15%. With the integration of IoT devices and machine learning algorithms it can further optimize the power usage, and as flexibility is more valued and compensated in the Nordic power markets, engaging in demand-side management can further decrease the cost of ownership of a data center. Data centers can ramp up or down their power usage based on price signals, could reduce peak power demand during times with limited renewables generation, and conversely, consume more power during times of excess renewables generation. For instance, Google designed a system for their hyperscale data centers to shift the timing of many non-urgent computation tasks, like creating new filter features, processing videos or adding new words to Google Translate, to when low-carbon power sources are most plentiful (Ratka, 2020; IEA, 2020a; IEA, 2020b). In this way, data centers can use more renewable energy, but a negative side effect is lack of uniformity in waste heat supply. Hence it is becoming even more complex the optimal operation of the system, which needs new digital solutions for optimal operation of both the data center energy system and the heat distribution systems.

RheinEnergie, a Cologne-based energy firm in Germany, used the Siedlungs Management software, an intelligent management system software, to minimize energy and heat usage, increasing the self-sufficiency of the Stegerwaldsiedlung neighborhood (16 buildings). This software was retrofitted in the GrowSmarter project, a 25 million Euro Horizon 2020 lighthouse project in which Barcelona, Stockholm, and Cologne showcase 12 smart solutions to support growth and sustainability in Europe. The software manages the performance of 41 heat pumps, peak-load district heating, and 16 batteries. Simultaneously, the system predicts and optimizes energy consumption for the next 36 hours, with updates every 15 minutes (EC, 2020). As heat pumps and district heating is and will be an essential part of waste heat utilization, then demand for such software solutions is expected to grow exponentially. The Energy Management System

(EMS) market is expected to increase at a compound annual growth rate (CAGR) of 18,8 percent from USD 32,41 billion in 2016 to USD 76,75 billion by 2021 (MRF, 2021). In 2020, there were 180 million heat pump units installed, by 2030 there will be 600 million units and 1,8 billion units by 2050 (IEA, 2021b).

5.1.3 Specialized services for low-temperature waste heat utilization

Consulting and engineering services for low-temperature waste heat utilization is a growing business opportunity. There are many firms providing specialized services for high-temperature applications in a wide range of industries. In Norway, Norsk Energi provides a total solution for the implementation of energy recovery projects, both in large industrial facilities and small businesses, including utilization of heat for district heating and electricity generation (NorskEnergi, 2021). On the other hand, low-temperature applications have an untapped potential of 470 TWh (Bianchi et al., 2029). In this regard, ElectraTherm by BITZER Group in Georgia, United States, has developed a waste heat recovery solution utilizing an organic cycle along with proprietary technologies to turn low-temperature heat (as low as 70°C) into power (up to 125 kW). ElectraTherm's technologies produce renewable electricity at a low energy price due to the consumption of no additional fuels (ET, 2021).

The stringent requirements to reduce the carbon footprint is expected to be the major driving factor in the global waste heat recovery (WHR) market. The global waste heat recovery market was worth USD 54,3 billion in 2019 and it is predicted to increase at an 8,8 percent compound annual growth rate (CAGR) from 2020 to 2027 (Grandviewresearch, 2020).

5.1.4 New applications for low-temperature waste heat

As referred to in the previous sections, extending the use of data center waste heat is a trend in Europe. The Nordic countries are taking the lead. For instance in Denmark, which has one of the world's largest district heat markets with 132 PJ in 2019, the district heating is used in 18 different industries, including applications in human health, manufacturing, education, accommodation, and food services among others (StatisticsDenmark, 2020a, 2020b). Another example is Finland, where 54 % of the residential buildings are heated by a district heating system and 10,5 % of that energy comes from waste heat (Energiateollisuus, 2020a, 2020b).

According to Wahlroos et al, possible use of waste heat can be drying biomass, preheating water, water desalination, and electricity production (Wahlroos et al, 2017a). Yale School of the Environment reported that air conditioners and fans currently use around 10% of global capacity, and demand is expected to triple by 2050. Waste heat can also be used for cooling through absorption coolers that use the energy from heat instead of electrically driven compression to condense a refrigerant. This technology is matured and is currently used for absorption refrigerators in recreational vehicles, and trigeneration power plants to make usable electricity, heat, and cooling all at once (Jones, 2018).

Organic data center (ODC) is a technology, currently under research, for synergies between IT and agriculture. It combines the operation of a data center and a greenhouse given their compatible thermal and operation requirements. Greenhouses and data centers can be easily combined in order to increase the overall efficiency of the system. For this purpose, warm air can be directly extracted into a greenhouse system. Excess fresh air can then be used in order to adjust the temperature and relative humidity (Karnama, 2019).

Low-Temperature District Heating (LTDH) could be another bright application of low-temperature waste heat from data centers. According to Wahlroos et al., if the supply water temperatures are less than 50 Celsius, waste heat from Data Centers could be directly fed to the Low-Temperature District Heating (LTDH) network without the use of a heat pump, particularly from Data Centers with modern cooling technologies that allow for high waste heat recovery efficiencies (Wahlroos, 2017b).

Low-Temperature District Heating (LTDH) provides opportunities for both the supply side and the demand side, especially in buildings that need only low temperatures for space heating. The utilization of lower temperatures decreases losses in pipelines and can increment the efficiency of the whole energy chains in the District Heating system. Moreover, they can also use plastic piping, which is less expensive than traditional District Heating metal-based pipes (Schmidt et al. 2017)

5.1.5 New distribution networks for waste heat

It refers to the creation of new distribution networks for waste heat, so that those who have waste heat could use the network to deliver energy to on-demand consumers. For example, Yang et al. concluded in a case study in 2020 that mobile waste heat recovery is more cost-effective than the conventional pipeline network because building an energy pipeline is rather expensive and also due to unstable waste heat quality and scattered recovery and discharge destinations. Thus, a mobile heating vehicle could be the best solution in some cases. However, mobile networks depend on the opportunities discussed in 5.1 and 5.2. First, developing the technology to improve the heat recovery efficiency of the mobile supply chain, so that discharge temperature and heat preservation can effectively reduce the cost to make it profitable; and second, the optimization of the distribution routes to ensure the effective distribution within the energy supply distances (Yang et al., 2020).

5.1.6 New commercialization architectures for waste heat

It consists of a new platform for commercialization of waste heat such as open district heating, where both producer and buyer of waste heat can sell and buy heat. Whereas the wholesale and retail trade is commonly the largest user of district heat, there are multiple platforms for waste heat commercialization. For example, Open District Heating in Sweden is a solution available for data centers, retailers, and other companies that produce surplus heat and want to sell it on an open marketplace. The point of Open District Heating is to increase heating and cooling plant performance by allowing energy transfers from factories with excess heat to the local district heating network. For example, the district heating supplier Stockholm Exergi collects surplus heat from organizations connected to its district heating or cooling grids for the market price. After its inception in 2014, Open District Heating has seen an increase in the number of surplus heat producers connecting to the grid. Currently, more than 30 data centers in Stockholm are connected to the district heating and cooling networks (Sivengårdngård, 2020).

5.1.7 New markets for heat attributes

This business opportunity is about using heat attributes by providing a heat certificate of origin. It is a replication of the Guarantees of Origin (GO) that applies today for electricity. The GO system is working as expected. According to the latest figures from the Association of Issuing Bodies (AIB), the supply of GOs continues to outpace demand through 2020 (Patel, 2021).

Consumers are opting for environmentally friendly goods and are willing to support circularity, it is particularly true for the Nordic countries. For example in Finland, the use of recycled resources, and the reduction of environmental impacts are regarded as the most significant indices of good business behavior by Finnish people. Almost 75,000 Helsinki locals are using recycled heat. The concept of recycling in energy usage is still relatively new to the general population, but recycling heat sends a clear message of environmental accountability (Helen, 2021).

In the Netherlands, the residual heat from Orgaworld's fermentation plant has a GO, proving that the heat supplied is entirely sustainable (Richter, 2020). In Norway, Statkraft has a wide range of GO certifications from various technologies such as hydro, wind, and solar, both from its own power plants and from its several power purchase agreements (PPAs). The same product can be offered for waste heat from various sources. GOs for heat in Norway are currently under revision. The revision includes a working group looking at including (district) heating and cooling into the European GO system (StandardNorge, 2021; Statkraft, 2021).

5.1.8 New financial products for the waste heat utilization market

A healthy financial sector is critical not only for economic stability and security but also a driving force behind reform in other industries. The financial sector's contribution is vital for every country to flourish in its transition to a low-carbon future. Globally, it has been estimated that achieving the UN's Sustainable Development Goals presents annual business opportunities equivalent to USD 12 trillion (FinansNorge, 2018).

The financial industry may benefit from the Sustainable Development Goals by greening the bond market, providing products that encourage climate-smart behavior, incorporating climate into the credit process, and incorporating climate factors into residential and commercial mortgages. SpareBank 1 Boligkreditt, for example, launched the world's first green-covered bond backed by energy-efficient residential property in 2018. SpareBank 1 plans to issue Green Bonds in order to contribute to fulfilling the rising demand from investors in ecologically friendly initiatives, as well as to fulfill society's goal of minimizing global warming (Sparebank1, 2020). Green bond issuance is expected to rise by 30% to $350 billion in the coming year. Green bonds are estimated to account for more than half of the overall sustainable bond issuance volume in 2021. The yearly new issuance volume should surpass $1 trillion in around two to three years (Pratsch, 2021).

Investment in energy efficiency initiatives is also low due to financial institutions' aversion to risk. Loans for these projects are returned with anticipated energy savings, which raises the perceived risk of investments. The banks' risk aversion has a knock-on impact since a lack of investment from other corporations makes energy efficiency initiatives appear riskier. Insurance-based processes, on the other hand, might provide a solution. Energy Savings Insurance(ESI) is one such technique. This safeguards investments in energy efficiency initiatives by ensuring the energy savings that an appliance is intended to offer for a small to medium-sized business (SME). The Inter-American Development Bank (IDB) has adopted this strategy in collaboration with FIRA, Mexico's national development bank, for a trial project in Mexico. In Latin America, the ESI plan intends to attract investments ranging from $10 to $100 billion in energy efficiency. According to the Asian Development Bank Institute, the ESI program offers a "impressively complete approach to market derisking." ESI is now being implemented in the EU and throughout Latin America, and it has the potential to revolutionize the future of energy efficiency (Ucl, 2021).

5.2 Funding sources available to develop new business opportunities by Norwegian firms

Europe has the world's biggest funding sources for research and development of technology and innovations. They are aimed to foster Europe's competitiveness and to stay upfront with the world's top technology advancements. Next, there is a list of the most well-known funding sources that could be used by Norwegian ventures to accelerate the development of new solutions and businesses to create more value out of the data center waste heat utilization. The following funding sources offer grants or low-interest loans for specific calls on European objectives, most of them related to the energy transition issue, and specifically where innovation projects on waste heat utilization could apply for funding support.

5.2.1 Horizon Europe

It is the world's largest funding program for research and innovation. It is the next edition of Horizon 2020 for the period 2021-2027. It has an indicative budget of nearly EUR 100 billion, of which 35% will be allocated to addressing the challenges of climate change, supporting policies for the transition to a low carbon economy, and the protection of the environment. Its specific terms are still under negotiation and the first calls are expected to be launched in early May 2021. The specific program that addresses European industrial competitiveness is Pilar II, cluster 4: Digital, Industry & Space with a budget of around EUR 13 billion (Horizon Europe, 2021).

5.2.2 Innovation Fund

The Innovation Fund is one of the world's largest funding programs for innovation and development of low-carbon technologies with around EUR 10 billion of support over 2020-2030. The goal is to help businesses invest in clean energy and industry to boost economic growth, create local future-proof jobs and reinforce European technological leadership on a global scale. It aids with up to 60% of the additional costs linked to innovation, aimed at projects related to innovative low-carbon technologies and processes in energy-intensive industries; innovative renewable energy generation projects, energy storage projects, and cross-cutting projects for innovative low-carbon solutions (Innovation fund, 2019).

5.2.3 European Green Deal

The Green Deal and the recovery plan for Europe prioritized energy efficiency as a key means of the clean energy transition to achieve the decarbonization objective by 2050 (IEA, 2021a). The European Green Deal has a budget of EUR 1 billion intended for pilot applications, demonstration projects, innovative products, and other innovations in the value chain, contributing to a green and digital recovery from the pandemic caused by Covid- 19. From the eight thematic areas, the fourth one, energy, and resource-efficient buildings, is the available call for innovations in the energy system of data centers. It specifically considers measures to improve the energy efficiency and circular economy performance of data centers (European Commission, 2019; European Green Deal, 2020).

5.2.4 Innovation Norway

Innovation Norway provides grants and loans to Norwegian companies. Innovation Norway's total framework amounts to NOK 7 billion. Grants are reserved for innovation projects with international growth potential, high technical risk, and considerable socio-economic benefit. They are commonly linked to environmental technology and innovation. Whereas innovation loans are offered to all industries to finance up to 50% of the capital requirement and can be used for commercialization of new solutions, strengthening of working capital, restructuring, development, growth, and internationalization (Innovation Norway, 2020b, 2020c).

5.2.5 Enova

The *Norges Forskningsråd* (Research Council of Norway), Innovation Norway, and Enova are the three most important instruments for energy and climate technology in Norway. *Norges Forskningsråd* is to support the development of completely new technologies, Innovation Norway is to support the development of new products or solutions, and Enova to support the use of new and innovative energy or climate technology in full scale. Enova works to promote Norway's transition to a low emission society by bringing the key solutions out in the market and contributing to new energy and climate technologies. In 2020, Enova's funding commitments totalled about NOK 3.3 billion, distributed across 3 852 projects. Enova also approved grants for more than 9 000 measures, a subsidy that reimburses homeowners for parts of their expenses for investing in energy-smart solutions in the home (Enova, 2021).

5.2.6 InnovFin energy demonstration projects

It is a financing mechanism of the European Investment Bank (EIB), through loans, loan guarantees, or equity-type financing, normally between EUR 7.5 million and EUR 75 million, for innovation projects in the field of energy system transformation, including renewable energy technologies, energy storage, and smart energy systems, to help them make the leap from demonstration to commercialization. In May 2020, a credit line of EUR 90 million was opened in Norway, 70% of this is earmarked for Climate Action projects (EIB, 2020).

5.2.7 InvestEU

It is a new EU instrument that offers guarantees in order to mobilize public and private financing for strategic investments. It will cover the period 2021-2027 and will bring together several currently available EU financial instruments under one umbrella. It will mobilize public and private investments through a guarantee from the EU budget of EUR 38 billion, to support investment projects of financial partners such as the EIB Group, strengthening their risk absorption capacity. The budget guarantee is divided into 4 areas: sustainable infrastructure; research, innovation, and digitization; SMEs, and social investment. Historically, Norway has got 26 funded projects, one of those was in 2012 for a new fiber-optic broadband link on the Swedish-Norwegian border, owing commercial operators have shown little interest in developing fiber-optic broadband networks because of their remoteness, sparse population, and consequent lack of profitability (investEU, 2021).

5.2.8 Connecting Europe Facility

It is a financing mechanism for infrastructure projects in the energy, transport, and digital services sectors. In the energy sector, this financing mechanism is directly related to ensuring the security of supply or supporting the large-scale deployment of energy from renewable sources. In the 2020 call, EUR 979.6 million were made available to finance projects of common interest that pursued, among others; end energy isolation, increase the security of supply in the EU, contribute environmental protection and sustainable development through the integration of renewable energies and the development of smart energy grids, and other objectives related to the objectives of the Green Deal. In 2012, a Norwegian project was financed through this mechanism for doing studies and preparatory activities leading to investment decisions for the construction of a high-voltage, direct current (HVDC) interconnection between Norway and the United Kingdom (INEA, 2020). This mechanism could be used if data center waste heat is integrated into the development of smart energy grids.

5.2.9 The EEA and Norway Grants

The EEA and Norway Grants cover areas ranging from climate change and energy to innovation and sustainable business development and have a budget of EUR 2.8 billion for the period 2014-2021. It's aimed to reduce economic and social disparities and to strengthen bilateral relations with 16 EU countries in Central and Southern Europe and the Baltics. Norwegian companies can be paid as project partners to activities taking place in the different EEA and Norway Grants partner countries (Innovation Norway, 2020a).

5.2.10 Next Generation EU

It is a new recovery instrument endowed with EUR 750 billion, to make the post-Covid-19 Europe greener, more digital, more resilient, and better fit for the current and forthcoming challenges. These funds will be deployed through new mechanisms or by reinforcing and increasing the funding of existing mechanisms, such as Horizon Europe (with EUR 5 billion), InvestEU (with EUR 5.6 billion), or the Just Transition Fund -JTF (with EUR 10 billion). But

Norway can not apply for the JTF because it is allocated to the 27 EU members only (Recovery plan for Europe, 2021).

5.3 Final remarks on business opportunities and available funding

In this chapter, we discussed eight business opportunities for creating more value out of waste heat utilization in Norway. They are based on the strategic opportunities for data centers in Norway, as discussed in section 2.5, and the current challenges in this business, as discussed in 4.4. The eight business opportunities are mapped out in the compass of strategic choices for new ventures by Gans and et al (see Figure 5.1). To support each business opportunity, both primary and secondary sources were iterated until saturation was reached to have enough information to describe and support all business opportunities listed in section 5.1. In section 5.2, we included a research report of the funding sources that Norwegian firms could use to fund innovation projects on waste heat utilization or energy efficiency solutions for data centers. As discussed in chapter 2, Norway is well positioned to take advantage of these business opportunities to have differentiated products and services, so that they are so valued by users and the business community that in turn creates new revenue flows that covers the additional costs of differentiation. Based on the assumption described in 1.3, building an ecosystem composed with these products and services in Norway could create a new competitive advantage to attract more investments in data centers.

6. Conclusions and further research

6.1 Conclusions

The purpose of this research was to recognize new business opportunities around the utilization of waste heat in Norway. These opportunities are assumed to create a differentiation advantage in the aim to make Norway even more attractive for cloud data center investments. In this research, we analyzed the business models of data center waste heat integration into the city's energy system of seven exemplification cases from six European countries. To identify the new business opportunities, we followed recent and recognized theories on business model innovation and strategic choices for new ventures. We identified eight business opportunities to create more value out of waste heat utilization. These business opportunities are strategic choices for the business community and do not benefit exclusively the cloud data center business. Hence, they demand synergies among different agents to actually develop the new business models. It is noted that a new competitive advantage for attracting cloud data center investments to Norway could be developed by establishing an innovation ecosystem fueled with the capitalization of the identified business opportunities.

6.2 Further research

We recommend this research to be followed by the development of business cases of selected business opportunities from section 5.1 in the current data center pilot project by Statkraft, and taking advantage of the available funding sources to Norwegian firms. We propose to follow a world’s top reference in business schools for the opportunity evaluation and a Nordics reference for business model growth capability assessment. Hence, opportunity evaluation as per the Entrepreneur’s Handbook by the Harvard Business Review (2018), and business models scalability as per Nielsen and Lund (2018). Scalability refers to the business model’s ability to expand output on demand when resources are added and discuss business attributes that do not constrain the venture’s potential by physical or material assets.

Thus the referred business cases should answer the following questions: will it deliver a significant profit?, will it last?, will it be competitive?, will the risk-to-return relationship be attractive?, and is it more or less attractive than the other opportunities?. Additionally, the business cases should assess the following five patterns by which ventures can achieve scalability: *platform-based business model*, *leveraging the work of partners*, *adding new distribution channels*, *shifting capital requirements to partners*, and *exploring ways to work around traditional capacity constraints*.

The referred business cases are to be amenable to multiple financing sources because they are ICT innovations and related to the circular economy. In section 5.2 we listed recognized funding sources available for Norwegian firms to finance innovation projects related to waste heat utilization and energy efficiency in data centers. Those funding sources offer grants or low-interest loans and can be used for different scopes and levels of technology maturity. Most of the calls are already open or coming in early June 2021. However, there will still come additional calls this year and in 2022 at least. We think it is plausible to use these financial resources to further assess the potential of the business opportunities by studying the business cases and investigating the impact on the respective ecosystem's ability to create and capture value, as well as changes in its financial performance.

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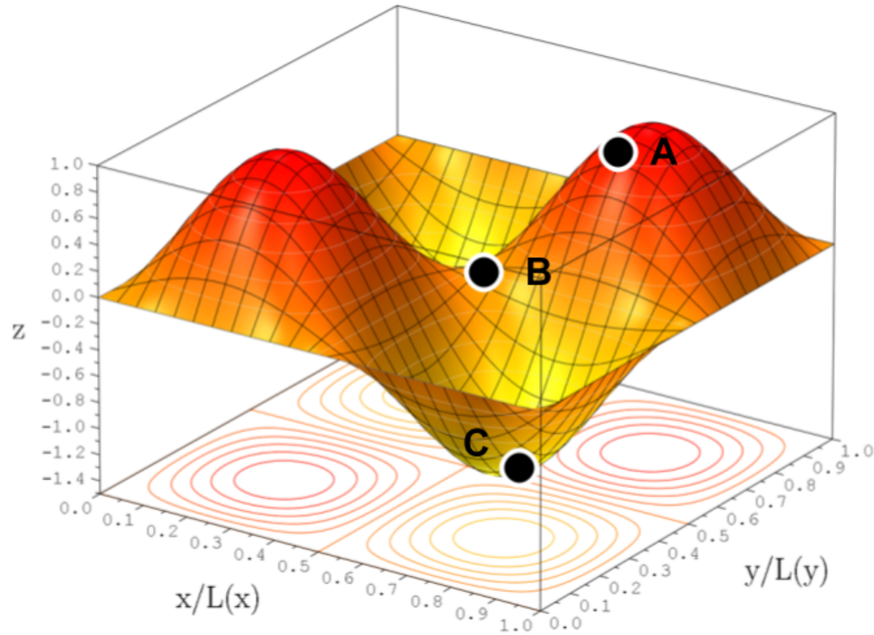
Appendix - Workshop presentation for recognition of business opportunities by focus groups (in spanish)



¿Por qué es importante?

Problema: en el afán de entrar al mercado el emprendimiento arranca con la primer estrategia plausible que se identifica y como resultado de esto se acaba perdiendo con el segundo o tercero que entra al mercado con la misma idea pero con estrategias superiores.

¿Por qué pasa?: se hacen compromisos estratégicos para avanzar que limitan la habilidad de pivotear más adelante.

Solución: articular múltiples versiones de estrategias y enfocarse en la que mayor se alinea con los valores y motivaciones de los fundadores.

Estrategia de emprendimiento:
El ejemplo y el caso para aprender

RapidSOS

Desarrolló una tecnología para reportar la ubicación precisa del celular a los sistemas de emergencia

Eco-Calor

Tiene la oportunidad de aprovechar agua tibia desperdiciada (40 °C)

Imagen tomada de: https://www.saskpower.com/

Estrategia RapidSOS- Respuesta a la emergencia

	Colaborar	Competir
Control tecnológico	**PI: Mantener control de la innovación y encontrar la forma de crear valor dentro del mercado existente.**	**Arquitectura: crear nueva cadena de valor**
Rápido al mercado	**Cadena de valor: Crear valor para participantes de cadena valor existente**	**Disrupción: competir directamente con incumbentes, sorprendiendolos**

PI: Dueño del IP y trabajar con Motorola…

Cadena Valor: aliarse con aseguradoras (pagan las ambulancias), producto podría ser App

Plataforma: reemplazar el sistema emergencia actual

Disrupción: desarrollo para epilépticos y luego escalar

Gans et al (2018) strategy for startups, Harvard Business Review

Estrategia de emprendimiento para oportunidad de aprovechar **agua tibia** (40 °C) **desperdiciada** por la industria

	Colaborar	**Competir**
Control tecnológico	1.Desarrollar una tecnología para reducción/detección de pérdidas (pe. químico mantiene-tibia, detector de pérdidas en tubería, software optimiza-operación) y aplicación a través de distribuidores del agua tibia	3.Crear red de distribución para agua tibia, quienes tienen el desperdicio podrían usar la red para vender a usuarios interesados. 4.Crear plataforma e-commerce para mercado de agua tibia.
Rápido al mercado	2.Consultoría y servicios de ingeniería para que los actores de la cadena puedan ejecutar proyectos que aprovechen el agua tibia desperdiciada	5.Crear mini-mercado para los atributos del calor, quienes quieren ser “cero-emisiones” compran los certificados de uso de energía “reciclada”. Luego escalar el mercado.

Business opportunities from data center waste heat

	Having a tight control over technology	**Quickly getting to the market**
Collaborate	(1) Technological development and innovation of energy efficient equipment for waste heat utilization. (2) Development of software solutions for optimization of waste heat utilization systems.	(3) Consulting and engineering services on data center waste heat utilization (4) Developing other internal and external uses for data center waste heat
Compete	(5) Create a distribution network for warm water, those who have the waste could use the network to sell to interested users. (6) Create an e-commerce platform for the waste heat market.	(7) Create a market for heat attributes, those who want to be “circular” buy the “recycled” energy use certificates. Then scale the market.

29 Mar 2021