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Digitalization, Internet & Energy Consumption 101

What answers are still missing and how can the global pandemic help study the digital phenomenon?

by

Alisa Chabanyuk

al7070ch-s@student.lu.se

This thesis attempts to study the linkages between the energy consumption, digitalization and internet expansion. Due to the ongoing global pandemic that served as a natural experiment, studying the potential impacts of telework and digital entertainment on energy consumption has become much easier and more urgent than ever, since both are growing rapidly, and no definitive answers on their impact are available. Designed on the grounded theory approach, this thesis strives to identify the existing research gaps in energy considerations for remote work and digital entertainment by conducting a thorough theoretical and secondary data analysis from before and during the pandemic in Sweden and Germany. It is suggested that contrary to the popular belief, the energy consumption associated with telework is mostly dependent on space utilization. Moreover, it is suggested that depending on the individual digital entertainment preferences, as exemplified on the case of Netflix viewership, the difference between on-site and digital entertainment individual energy consumption may differ and should be studied in-depth. To test these claims, I suggest two case study designs supplemented with a step-by-step methodological proposal.

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Table of Contents

List of Tables

List of Figures

1 Introduction

Many futurists and sci-fi novel writers envisioned the 21st-22nd century as a seemingly different world, operating on barely comprehensible technology and utilizing flying cars. While the modern cities still do not resemble these scenarios visually, the emergence of Internet has not only connected people in a way not previously predicted, but also helped induce many more innovations that make lives more efficient and automized.

At the same time, the modern world is also characterized by the environmental crisis, with many researchers trying to find a way for humans to operate within the planetary boundaries without sacrificing the level of comfort we have gotten used to. Consequently, the efficiency associated with digitalization and Internet is seen as an opportunity in battling climate change, although there are significant critiques, as discussed further in the thesis. Importantly, the main issue with addressing the effects of digitalization on the environment is the scope of the problem: how can it be quantified?

Considering that most of the CO2 emissions stem from the energy consumption (Kander, Malanima & Warde, 2013) – which, coincidentally happens to be the backbone of digital technology – this thesis will contribute to the relatively new stream of literature by proposing a method to study the link between the increasing penetration of digital technologies, Internet expansion, and the changes in energy consumption.

Studying the relationship has become slightly more possible due to the COVID-19 outbreak in the beginning of 2020. For instance, it has had a significant impact on both the consumption of energy and digital services: many had to switch to online modes of working, studying and interacting with friends and family, which was not as prevalent in the days before the outbreak. The comparable data already available from before and during the pandemic helps understand the effects of these developments on energy consumption and provides reasonable grounds to make hypotheses for further research. Thus, despite the undeniable tragedy associated with COVID-19, it helps create a natural experiment, and will be used as an instrument in creating a methodological proposal for when the data is available.

Due to the growing number of studies suggesting the potential transition to remote or hybrid working modes after the pandemic (e.g., O'Brien & Aliabadi, 2020; Barrero, Bloom & Davis, 2021), one of the primary concerns raised in this thesis is the effect of remote work on energy consumption. Furthermore, considering the continuous growth in popularity of digital entertainment services (Almeida et al, 2011), especially so with the quarantine restrictions in place (Cheshmehzangi, 2020), the thesis analyzes ways in which they can further affect the energy consumption. In this study, three channels of Internet-related energy consumption will be analyzed: end-device, data transmission, and data centers.

To understand the factors contributing to energy consumption during the pandemic, this thesis will compare two countries with similar energy systems and overall economic structure, as well as similarly high levels of digitization, that nonetheless had a different response to the COVID-19 pandemic (Hale et al, 2020) – Sweden (some restrictions in place) and Germany (quarantine in place).

It is important to consider, however, that the official lockdown stringency alone is not the sole contributor to people's decision to take precautionary measures. Thus, the discrepancy in pandemic response does not necessarily indicate a dramatic difference in people's mobility.

1.1 Research Question

Importantly, this thesis does not aim to compare the countries' pandemic response. Instead, the aim is to propose a way to study the impact of increased reliance on technology for work/study and leisure on energy consumption in Sweden and Germany by comparing the digital behavior before and during the pandemic. Thus, the related objectives are to understand the external (pandemic-related) and internal (behavior and socioeconomic status) factors that affect one's digital behavior and see how this variation can affect the energy consumption. The gathered insights are further used to contemplate whether working from home could help save energy in the future as well as find a way to compare the effects of digital entertainment consumption to those of going to entertainment centers. Consequently, the main questions read as follows:

- In what ways does the increased reliance on digital entertainment services and remote work in Sweden and Germany affect the energy consumption?
- What research gaps could be filled using these observations, and how?

In this study, three channels of Internet-related energy consumption will be analyzed: end-device, data transmission, and data centers. Due to the interdisciplinary nature of this thesis and limited data availability, I undertake a grounded theory approach in understanding the complex relationships involved in the process. This work can serve as a guide for further research in addressing the issue of climate change through digital transformations as well as help sustainability-driven companies make conscious decisions on their office status.

1.2 Outline of the thesis

At first, the thesis will look into the existing body of work surrounding the household energy consumption to compare the related behavioral patterns to those observed when quarantine restrictions are in place. In order to provide more context for the methodological proposal, the following chapter will look deeper into the overall energy trends and the household energy consumption during the pandemic.

The thesis continues by introducing the scarcely available body of literature that discusses the link between energy consumption, digitalization, and internet expansion. Furthermore, the chapter attempts to explain the nature of the seemingly paradoxical relationship between the energy efficiency improvements and the growing energy consumption. Afterwards, I look deeper into the aspects of digitalization considered in this study – entertainment and work – and see how both evolved throughout the COVID-19 pandemic in Germany and Sweden to hypothesize on the potential relationships with the currently available data. This chapter is set to provide ideas for the methodological proposal.

Although some statistical insights will be continuously presented throughout the thesis, chapter 3 covers the detailed energy consumption data for the platforms and devices analyzed in this thesis. This data is prepared to help researchers navigate the steps in the methodological proposal. Finally, the methodological proposal gathers the under-researched perspectives based on the presented theory and overview of data from Sweden and Germany. It provides a step-by-step explanation on how to prove or disprove the hypotheses made in this thesis, for which more data needs to be collected.

2 Theoretical Approach

Despite the scarcity of literature associated with the environmental and energy implications of digitalization, this chapter is set to link the existing research together and introduce sufficient grounds for further analysis. Based on the available material, research gaps are identified and suggested for study in the methodological proposal section.

2.1 Household energy consumption

To introduce the topic and try to identify the effect of digital solutions in the upcoming chapters of the thesis, it is important to understand the most important factors of household energy consumption before the global pandemic took place. This section will thus look at the behavioral patterns and contributing factors that affect the levels of energy consumed in residential areas.

According to Zhou & Yang (2015), the household energy consumption depends on an array of factors, with income levels, housing type, household size, energy prices, local climate and energy policies classified as objective, and attitudes to environmental conservation and self-awareness as subjective. Due to the possibility of high variation in all of the described variables, the behavioral patterns and the subsequent energy consumption largely vary. The authors explain that both the conscious and subconscious decision-making processes in energy consumption are further influenced by a set of intrapersonal, interpersonal and external conditions (Zhou & Yang, 2015). Interestingly, Frederiks et al (2015) point out the value-action gap in the individuals' self-reported energy-saving intentions and the outcome data and find that the financial considerations are not driving the behavioral shift either. In a way, such results indicate that most of the household energy consumption is predominantly an outcome of subconscious decisions and external factors.

Despite the growing availability of energy-saving appliances, Almeida et al (2011) found that the levels of residential electricity consumption in the EU have been growing steadily between 2001-2011, with approximately 2% increase annually. Partly, such growth was attributed to the rising levels of basic comfort and the subsequently preferred behaviors (Almeida et al, 2011). However, the authors discovered that it was only a minor contributing factor, as most of the increase in the electricity demand stemmed from the growing adoption of information technologies and digital entertainment (Almeida et al, 2011). The extent of such effect largely varies on the type of device used, with personal computers consuming double the energy used by laptops, on average. In this sense, considering the evolution of technology between the time of analysis and today, and the growing popularity of laptops over PCs, the effects of digital entertainment and work might be much lower than estimated in the study by Almeida et al (2011).

Moreover, as can be observed from Figure 1, the percent of European population owning a computer (invariably on the type) did not grow substantially since 2011, despite the growing availability of internet access at home. On one hand, it could indicate that the same age/income group is more likely to opt for computer ownership and utilize the benefits associated with internet adoption. On another hand, the growing amount of active mobile-broadband subscriptions that are available both at home and outside (depending on the broadband coverage quality in the region in question) could indicate that some of the users opt for using their portable devices instead. In addition to the rising quality of mobile internet in Europe, the growing functionality of smartphones observed in the past decade, including access to social media, e-commerce and online entertainment, could have reduced the necessity of owning a computer, especially if the workplace provides such utilities to the employees. Thus, the associated household energy consumption might have further decreased as the indirect effect of increased smartphone functionality coupled with higher coverage and better quality of broadband internet access.

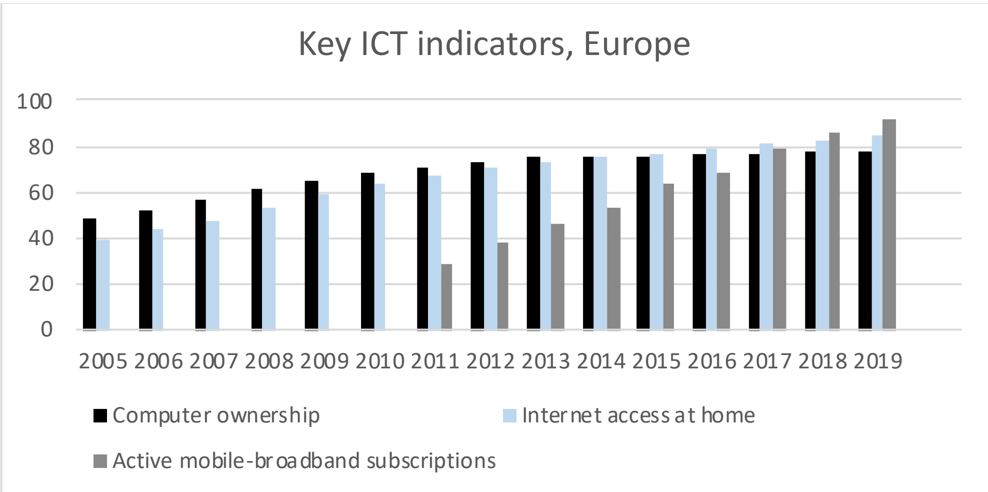


Figure 1. Some of the key ICT indicators in Europe, 2005-2020 (International Telecommunication Union, 2021).

On another hand, the growing use of mobile networks has negative implications outside of the household energy consumption: the electricity intensity of data transmission through such networks is significantly higher than that of fixed-line networks (Kamiya, 2020).

2.2 Energy trends during COVID-19

Due to the suffering international trade, decreased rate of industrial activity and lifestyle changes associated with the pandemic, the patterns of energy consumption changed significantly – one of the reasons behind the short-term drop in CO_2 emissions (Andreoni, 2021). In this chapter, the trends in overall energy consumption patterns as well as the consequences of decreased business activity in particular will be discussed.

2.2.1 Grand scale

According to Klemes et al (2020), the global pandemic has been significantly affecting the energy structure, demand, and the associated CO_2 emissions. On one hand, the temporary restrictions on mobility and the decreased scale of production in places with high quarantine stringency have led to significant alleviation of the local pollution levels (Klemens et al, 2020). In fact, according to Sovacool et al (2020), the strongest drivers of the decreased energy consumption stemmed from the restrictions on movement and travel, although the authors do not explicitly mention whether the effect is solely movement-related or whether the consequent decrease in industrial activity is considered. However, given the nature of temporary restrictions, it is highly questionable whether the positive effects will be long-term unless some changes are to be made. The evidence found by Aruga et al (2020) in India indicates that the energy consumption recuperates to the pre-lockdown levels relatively fast when the restrictions are eased, with higher-income regions taking less time for the recovery of energy consumption levels.

On another hand, the energy demand – leave alone the environmental footprint related to the production and disposal of masks, gloves and antiseptics, as well as their shipment – have all negatively contributed to the overall footprint (Klemens et al 2020). Moreover, the high energy-intensity of hospital facilities amplified by the increased demand for healthcare services and use of specific medical equipment (e.g., ventilators) during the pandemic, in addition to the construction of additional temporary hospital sites, have raised concerns regarding the energy sources and energy efficiency of built environment (Klemens et al 2020). Sovacool et al (2020) have reached a similar conclusion – the main lesson learnt from the COVID-19 pandemic so far with regards to the energy market is that it is currently unsustainable.

2.2.2 Household energy consumption

As pointed out by Cheshmehzangi (2020), household energy consumption during coronavirus – the main energy focus of this thesis – is one of the ongoing topics that has not been studied extensively yet, due to the obvious lack of data. Altogether, the residential energy demand includes in-house activities, such as heating, cooling, lighting, cooking and entertainment, and energy required to fuel the personal transportation. Depending on the restrictions in place, the mobility-related energy consumption decreases due to the closure of public transportation services, however, the personal footprint might increase if the mobility is still required and car use increases. The effect not only depends on the availability of mass transit, but also on the location of individual and the distances between key destinations, depending on the city size. Importantly, the tradeoffs also vary on the structure of urban mobility and the local preferences, with small cities more likely to opt for the use of bicycles, for example.

Based on the Google COVID-19 Community Trends (2021), both the Swedish and the German residents exhibited an overall downward trend for attendance of closed public locations, the degree of which is associated with both the lockdown stringency and the health-conscious behavior. Conversely, there was a rather steady increase in the amount of time spent at home - about 6.9 and 7.9 points from the baseline (median of January 3rd – February 6th, 2020), respectively – and a season-dependent preference for attending parks that, mobility set aside, do not require direct energy consumption.

Seeing the increase in time spent in residential areas, it is important to understand precisely what people tend to do when at home for prolonged periods of time. According to the study by Cheshmehzangi (2020), the evidence from China suggests that the pandemic has affected the people's behavior and the consequent energy consumption, in multiple ways: the locals tend to cook at home 40% more, as the result of restaurant closures, have an increased need for heating, cooling, and lighting, and exhibit higher electricity demand due to the growing interest in digital entertainment. Out of all circumstantial factors in the rising residential energy consumption, the author hypothesizes that entertainment could have long-lasting effects following a newly found habit for the local population. It is important to note that multiple factors play role in the people's behavior and energy consumption in the countries with sufficient rates of electrification and digital infrastructure: stringency of the local lockdown measures, climate, time of the year, and size of the household. Moreover, age, level of digital skills and income could explain one's lifestyle preferences both before and after lockdown.

According to Chen et al (2020), the electricity consumption patterns observed in New York during the pandemic illustrate that approximately half of all study participants reported higher usage of electricity but, in contrast to the pre-pandemic times, there are no morning/evening consumption peaks. In a way, most people consistently use a lot of electricity during the lockdown – a development that might affect the energy prices in the aftermath.

Overall, Bahmanyar et al (2020) claim that the electricity demand post-coronavirus decreased in countries with strict lockdown measures in place. While the household electricity consumption increased significantly, the closure of local businesses and the consequent decrease in electricity demand for commercial and industrial activities have had a much more prominent effect and completely absorbed the residential increases (Bahmanyar et al, 2020).

As previously mentioned, the energy consumption is expected to rebound relatively fast as the quarantine restrictions ease (Aruga et al, 2020). However, the authors also found that lower-income regions take longer time for the energy rebound to take place (Aruga et al, 2020). While this thesis focuses on the evidence from the developed countries, the latter finding has some implications for the analysis: people with lower income, even when businesses reopen, do not have as many resources to spend on the available goods and services, especially given the job losses associated with COVID-19. Thus, it is likely that those that suffered the most financial consequences during coronavirus – the lower income population, as suggested in Gustafsson & McCurdy (2020) - might not, for instance, cook less at home right when the crisis is over, as suggested in Cheshmehzangi (2020). It is also likely that those hit hardest by the pandemic will continue to use digital entertainment due to its relative cost-efficiency.

2.3 Digitalization, Internet and Energy

By discussing the scope of digitalization as a term, this chapter introduces its components and the way they are connected to energy consumption. Furthermore, distinction between the energy potential of digital solutions and their current impact is analyzed.

2.3.1 Digitalization

It is important to draw the line between digitalization and a seemingly interchangeable notion of digitization. According to Yoo (2010), the latter term applies to the solely technological perspective and covers the process of transforming information into the digital form. In other words, it is the definition of a process-related tool. Digitalization, on the other hand, refers to the consequences of digitization and its ability to re-establish the existing socio-technical relationship (Yoo, Y., 2010). Gobble (2018) expands on the proposed explanation by adding that digitalization deals with the use of digital technology for finding new ways and gaining higher rates of value generation.

According to Geels (2002), changes in the socio-technical regime involve adjustments and infrastructural developments from all actors involved in the process – policymakers, businesses, customers, and the society at large. Considering that digitalization and the rise of technology are one of the 5 megatrends re-shaping the world (PwC, 2016), it has already managed to redefine the socio-technical regime in multiple areas and services. However, it is important to note that these transformations are still in progress in many countries, due to the economy- and policy- related challenges that hinder the necessary infrastructural development. The rise in economic opportunities associated with digital revolution is thus bound to increase the between-country inequality and decrease the competitiveness of businesses from the developing nations (Kirton & Warren, 2018).

The number of studies analyzing the link between digitalization and energy consumption is rather scarce. First of all, the scope of digitalization as a term varies across the existing literature. Second of all, it is even more complex to quantify, and since it is embedded in many of the operations nowadays, it is very difficult to isolate the effect digitalization has had on the energy consumption. Nevertheless, the existing literature provides some deeper insights into the nature of energy-saving technologies – a lot of which are associated with digitalization – and the final energy consumption. In this thesis, the indirect energy consumption required for the production of hardware, or "grey" energy, will not be focused on, due to the already broad nature of the study.

Overall, the scarcely available evidence is unanimous: while digitalization and internet development increase the energy efficiency, they lead to increased energy consumption by driving economic growth and, consequently, expanding the scope of economic activities (Ren et al, 2021; Lange et al, 2020). This paradox – known as the r*ebound* or *take-back* effect – has been a subject of many studies on energy development (Kander, Malanima & Warde, 2013). It is explained that we end up doing more (economic expansion) because the means (energy) become cheaper.

As summarized by Kander, Malanima & Warde (2013), there are three types of manifestation for the take-back effect: direct effects (being able to consume more because goods and services get cheaper), indirect effects (rising demand for complementary services), and scale effects (the saved resources are invested in expanding various economic activities). One of the following chapters is going to dig deeper into the origins of this paradox to not only explain why digitalization per se is not to blame for the increased energy consumption, but also to provide areas for improvement, so that the society can exploit the full benefits of new technology in the future.

2.3.2 Internet & Energy consumption

According to the International Energy Agency (2020), the internet traffic rose by nearly 40% worldwide in the beginning of the COVID-19 pandemic due to the mobility restrictions and the associated increase in demand for online entertainment services, telework, and social media. As Coroama & Hilty (2012) point out, it is crucial to make the distinction between the effects of Internet and end-devices to truly know the magnitude of the effects associated with data transmission through the network and data processing by the end device, separately. As illustrated in Figure 3, the end-device accounts for most of the energy consumed in the process of video streaming (IEA, 2020). Nevertheless, despite the relatively small share of energy consumption associated with data centers and transmission, the rising demand for online services poses certain pressures for improving the energy-efficiency of the existing facilities.

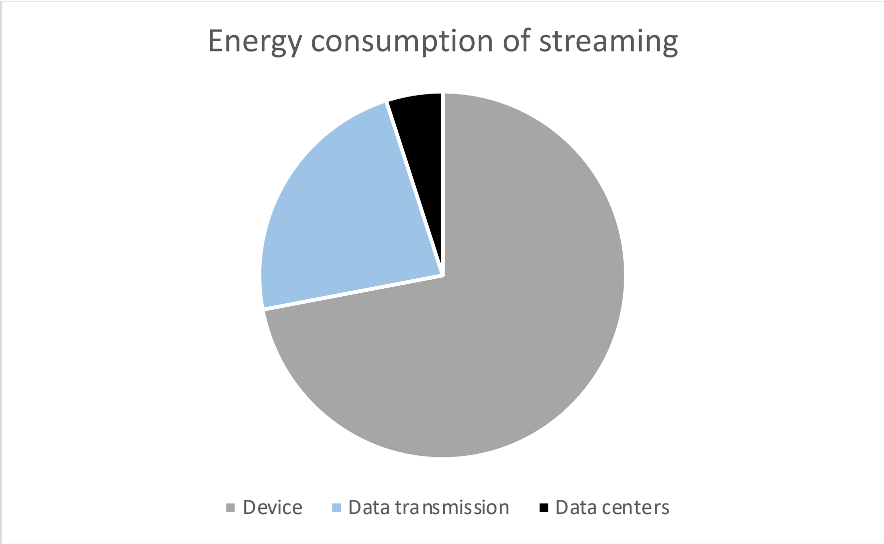


Figure 2. Share of energy consumed at different stages of data transmission while streaming (IEA, 2020)

Before narrowing the scope in the upcoming sections, it is important to mention that while Internet has given rise to innovations within energy-efficiency and increased environmental performance, it can be viewed as a tool. As any tool, it can be applied in ways beneficial to the society and the environment, and vice versa. Perhaps, the brightest and most recent example in this case is Bitcoin mining. For instance, in February 2021 it consumed more energy than Argentina and nearly as much as Sweden (Cambridge Bitcoin Electricity Consumption Index, 2021). However, following the tweet made by Elon Musk on the 13th of May pertaining to the environmental unfriendliness of the cryptocurrency, the price of Bitcoin fell steeply (Statista, 2021) and so did its energy consumption, now consuming only slightly more than the Netherlands (Cambridge Bitcoin Electricity Consumption Index, 2021). Although there is a clear irony in how the casual use of a social media platform by a person with high visibility damaged the performance of another internet-based service, this story points to a very interesting discovery. Not only do digitalization and the internet have way too many layers for someone to claim that they only benefit or only damage the progress made with regards to sustainability, but also the awareness on implications of different internet activities is low. Partly, the drop in Bitcoin prices indicates that, although widely discussed in the academic community, the information shared by Elon Musk was not as widely known in the general public. As an indirect effect of the Internet development, one might say that the social media channels have an impact on spreading both wrong and right information, with the latter giving a chance at reaching a wider public on issues associated with both sustainability and the responsible use of internet-enabled services as well.

As previously pointed out in in section 2.3.2, the rebound effect takes place from the consumer behavior perspective as well (Pihkola et al, 2018). For instance, the authors find that despite the significant energy efficiency gains observed with every new generation of cellular networks, the updated functionalities and scope of activities they allowed for led to dramatic increases in the data usage and the consequent energy consumption (Pihkola et al, 2018). Consequently, with the growing number of connected mobile devices, there is a need to educate the end-user on the environmental consequences of reckless data consumption (Pihkola et al, 2018), especially with the growing middle class globally (Statista, 2017) and the associated rise in purchasing power.

According to Hinton et al (2011), understanding of the sources of energy consumption within the Internet infrastructure is crucial in order to properly measure the energy consumption of the Internet. However, as pointed out by Anders (2020), the current research is highly biased due to the required scope of analysis and the consequent generalization, as well as disregard for factors such as disruptions, geographic variations and perceptual estimations of decreases in electricity intensity and increases in the amounts of data traffic. According to the author, the consumer ICT and Internet infrastructure are predicted to use even more electricity by 2030, with no current grounds to believe that the decoupling between the growing traffic and the energy consumption is to take place (Anders, 2020).

2.3.3 Origins of the paradox

In a way, the digitization practices are more environmentally friendly due to the associated efficiency. However, it is the way that digital tools are applied that raise concerns. In the classification by Geels (2002), major landscape developments, such as overall agendas and needs stemming from the past technological regimes, are thought to affect the course of further development and the technological niches that would succeed. It is unclear, however, whether the innovation directionality and the consequent way of technology integration – no matter the benevolent intentions of its researchers and developers – are more concerned with the environmental pressures or the associated economic gains.

A similarly confusing message can be observed in the *cleantech* sector. According to Caprotti (2011), the general myth about cleantech stems from the previously discussed directionality issue. In contrast to green tech – regulatory-driven technology development movement in the 20th century – the cleantech sector is market-driven (Caprotti, 2011). The author explains that the companies are providing a quick fix, treating some symptoms of the existing system and profiting off the market opportunity that the climate change provides (Caprotti, 2011). In this case, it is difficult to blame the company in greenwashing, as the complexity of socio-environmental challenges is not considered neither in their reporting initiatives nor in the nationwide assessments. The cleantech actors are considered to make truly great contributions if viewed in a narrow perspective but fuel the problem if viewed as a part of a complex system. At the same time, in this case the financial gains drive private sector innovation and R&D and if the market were to be de-incentivized, the society might not have been able to exploit some of the good technologies.

While one might think that the lucrative profits from innovation development became the major incentive following the rise of capitalist economies, such patterns can also be traced back in history. For instance, the famous Needham puzzle – question of why the scientific revolution happened in Europe and not China, where the innovation quest seemed to have started much earlier – is coherently explained by Snooks (2020) in the dynamic strategy theory. Due to China's isolation and the self-sustained family-multiplication strategy that only required basic technology, it was economically unattractive to change the strategy at the time, leading to low demand for science (Snooks, 2020). In contrast, the abundance of countries in Europe created high competition, and when the conquest and commerce strategies were exhausted (i.e., did not yield high gains anymore), technological change was thought to help the economies grow further and created demand for science (Snooks, 2020). The economic competition can also be mirrored to the ways national success is still compared globally – GDP, with no consideration for social or environmental outcomes. In this case, the modern scientists are faced with a big challenge: how can the long-term focus on economic power and market-driven innovation be transformed into the outcome- and life quality- based international competition?

These issues are widely addressed in sustainability studies and are referred to as weak sustainability practices, where the technological innovation is viewed as the quick-fix solution while doing "business as usual" (Heinrichs et al, 2016). Unfortunately, this has led to the rising confusion about the nature of technologies, with some studies (e.g., York & Clark, 2010) criticizing the near-obsession with its development and not treating them as improperly applied tools. Schot and Steinmuller (2018) address this issue and claim that the innovation systems currently in place – the same innovation systems that have led to the situation the world is faced with – are not designed to address the big challenges, but rather to create big opportunities, affecting the course of development and application of science and policy. Thus, no matter how good the environmental potential of a new technology might be, it is not likely to be prioritized over the associated gains due to the overall direction and consequent drivers of innovation. It is argued that the transition to strong sustainability practices is only possible following transformative change that would disrupt the existing markets and set new directions, or reasons, for developing innovation (Schot & Steinmuller, 2018). However, how would disrupting the market following one of the worst recessions in history affect the society? These are only some of the obstacles faced on the way to understanding the complexity of socio-environmental interactions.

Currently, digitalization simply mirrors the values and practices observed in the analogue times. Thus, its environmental potential is largely diminished and the very analysis on the link between digitalization and energy consumption is limited to the current scenario, which should not be taken at face value.

2.4 Entertainment

To start with, it is important to mention that entertainment could have various different meanings for different individuals, as, for the lack of a more scientific expression, different people find different things fun. In this chapter, various entertainment options will be explained. For instance, the thesis goes on to separate the popular options available outside of the house and those easily accessible from the convenience of one's apartment. The chapter serves as an introduction to understanding the energy consumption impacts of digital and on-site types of leisure activities.

2.4.1 Digital

As has been previously pointed out, digital entertainment has generally been on the rise in the European countries (Almeida et al, 2011), and the practice only grew more popular during the pandemic (Cheshmehzangi, 2020), playing an important role in the increases of household energy consumption. For instance, the components of digital entertainment analyzed in this thesis include video streaming services and online gaming platforms. Hinton et al (2011) found that the provision of video content specifically is the major driver of Internet expansion. In fact, the IEA (2020) claims that these entertainment services are predicted to constitute 87% of all consumer internet traffic in 2022, placing increasing demand on data center and network services.

Research suggests that the time spent on digital leisure and the associated likelihood of addiction seem to be strongly correlated with age (Mahendher & Hans, 2021), social environment and schedule flexibility, especially in terms of video gaming (Griffiths & Pontes, 2015). Due to the unique pandemic-related social circumstances, limited access to other entertainment options, and higher schedule flexibility for individuals working from home, the time spent on digital entertainment has increased (Cheshmehangi, 2020).

According to Cheshmehangi (2020), in-house entertainment nearly tripled during the strict quarantine measures but quickly recuperated to their pre-pandemic standard levels once the restrictions were eased in the analyzed Chinese province. While the author did not find statistically significant evidence to suggest that the popularity of digital entertainment is here to stay, the author is doubtful, as no-one is sure of whether the hybrid work modes and the associated amount of time spent at home could become the new norm (Cheshmehangi, 2020).

According to Mahendher & Hans (2021), only the Indian viewers tend to spend nearly 83% more time on such platforms as Amazon Prime, Netflix and Hotstar. While the time data is not available for Germany and Sweden, it is likely that users from both countries experienced at least some sort of increase, especially in Germany where the quarantine stringency has been higher throughout the pandemic. The search trends represented in Figure 3, indicate that the most popular movie streaming service in Europe (Wallach, 2021) – Netflix – was generally more popular in in Sweden before the pandemic, although Germany seems to have caught up following the global crisis.

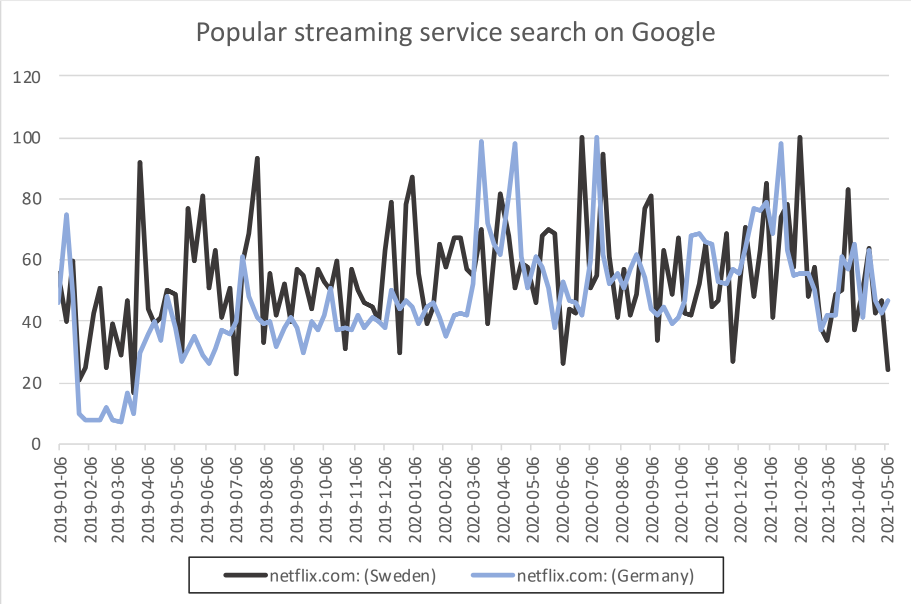


Figure 3.Netflix.com search popularity index in Sweden and Germany (Google Trends, 2021)

As can be observed in Figure 4, the difference between the pre-pandemic and the current interest in the streaming platform is more prominent in Germany – the popularity index increased by nearly 40%. This could indicate that the Swedish viewership is more likely to be connected to seasonal changes and the consequent willingness to go out rather than the quarantine.

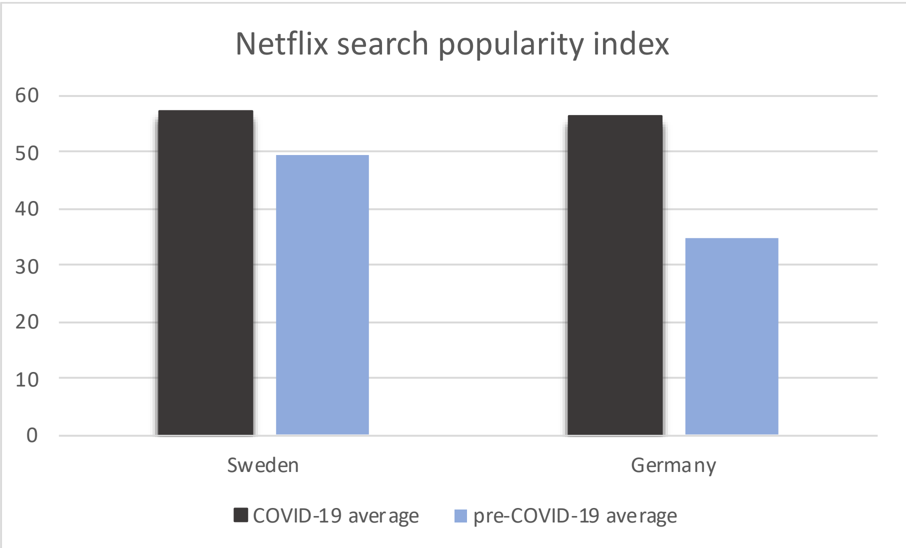


Figure 4.Netflix.com search popularity index, time-based averages for Sweden and Germany (Google Trends, 2021)

However, what is not captured in the graph is the time spent watching Netflix. Thus, the search popularity index is rather a proxy, as an individual may "google" Netflix once but spend significantly higher amounts of time on the platform, which results in the subsequent energy consumption.

As pointed out by Mahendher & Hans (2021), big streaming platforms like Netflix have put effort in increasing the availability of content. On one hand, the energy and resource efficiency has improved significantly since the times of DVD usage: no more CDs, no more DVD players have to be produced (Shehabi et al, 2014). In fact, it was found that the end-user devices were responsible for most of the energy consumption for both the footprint of DVD and streaming services (Shehabi et al, 2014). However, the scale is important: according to Pearce (2018), approximately one third of all internet traffic in North America was attributed to Netflix in 2016. Considering how much more data is generated each day, especially in the unforeseen circumstances such as the COVID-19 pandemic, a lot of power is required to support the data centers. Even back in 2016, they were responsible for the same amount of CO2 emissions as the airline industry (Pearce, 2018). At the same time, given the amount of information stored at these centers, they can be considered relatively energy efficient. As mentioned earlier in the thesis, only 5% of energy consumption during streaming is associated with data centers (IEA, 2020), which provides an interesting perspective for those skeptical of their efficiency.

As to gaming, another major entertainment service available online, this thesis looks at Steam – videogame digital distribution platform that acts as an intermediary between game developers and the players. Steam is the leading platform for PC gaming (Clement, 2021) that experienced a significant rise in the number of concurrent users due to the pandemic with increase from 95 million in 2019 to over 24 million in 2020 (Clement, 2021). As represented in Figure 5, both Sweden and Germany experienced a moderate increase in the service's

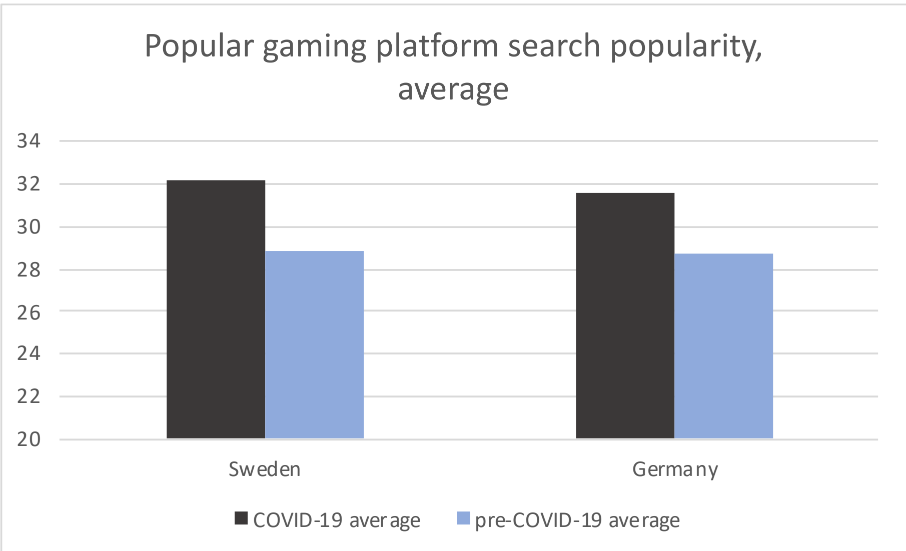


Figure 5. Steam search popularity index, timespan-based averages for Sweden and Germany (Google trends, 2021)

search popularity. Based on the data, the average figures for both countries before the pandemic were nearly similar, although the platform search popularity rose slightly more in Sweden. On another hand, Steam (2021) indicates that Sweden and Germany constituted 0.8% and 4.5% of the overall traffic on the platform *in the past seven days*, respectively. However, multiple factors play a role in a country's share of traffic on the platform, including a considerable difference in population size of the two countries.

According to Mills et al (2019), gaming behavior is as important for the regulation of energy use as the conscious choice of more efficient hardware. For instance, there is a considerable difference between the energy consumption of cloud and online gaming, as well as the chosen standard of resolution (Mills et al, 2019). It is estimated that an average user spent 1.4 hours a day on gaming in 2018, the streaming range of which ranges from 0.1 Gb/h for online gaming to 6.75 Gb/h + for cloud gaming (Mills et al, 2019), both of which are available on Steam.

It is important to mention that the individual energy consumption largely depends on one's behavior, as a unique mix of smartphone/laptop/PC usage, characteristics and the type of network connection are involved. Moreover, the preferred types of leisure and its resolution all play a role in the final outcome. Thus, it would be too ambitious to even begin to analyze gaming practices in this thesis. While it is still hypothesized that the energy consumption associated with this type of digital entertainment would be lower in the aggregate measures than the use of entertainment facilities (mobility included), this assumption does not have enough grounds nor data to be developed further.

However, as also indicated in Mills et al (2019) more gaming-related research is needed in order to properly assess the growing burden of digital entertainment services on Internet expansion and the consequent data consumption. While Netflix can serve as an indication of one side of online leisure, it is not enough to estimate the full effects of such developments. Additionally, one could analyze the demand for consoles and social media to paint at least a relatively comprehensive view of the most popular digital entertainment services, their demand, and their energy efficiency.

2.4.2 On-site Entertainment

Following the definition of entertainment presented earlier in the thesis, it is apparent that, depending on the individual and particular occasion, leisure can take place anywhere, ranging from the previously discussed personal apartments to live music venues, cinemas, and malls, to name a few. Evidently, the various activities, their scope and audience capacity, as well as the corresponding infrastructure require significantly different energy inputs. In this case, it would be incorrect to compare the relatively narrow scope of digital entertainment analyzed in this thesis to all types of leisure activities available out there, simply because their range is seemingly unlimited to the wants of even the smallest, niche, groups. Due to the all-encompassing nature of malls today, where retailers are located alongside cinemas, restaurants and arcades, this thesis will suggest a way to compare the individual's share in the associated energy consumption with that of movie streaming.

For instance, according to Talpade & Haynes (1997), at the time of the study, about a third of all mall visitors engaged in the offered entertainment services. Importantly, this group of people also tend to spend more time at the mall (Talpade & Haynes, 1997). In a more recent study, Wiriyani (2018) finds that 50% of those surveyed went to a mall for leisure and entertainment services or without a particular reason in mind – to walk around. With both studies in mind, half of all mall visitors were likely to spend considerable amounts of time at the premises.

For example, Figure 6 represents average energy intensities of malls in different countries across the world. In the supplied bar graph, it can be seen that the energy intensities are not largely different in all localities, except Hong Kong. It is important to mention, however, that depending on the local cultural preferences, the intensities may vary in other countries not represented in this study. For comparison, Wu et al (2020) find that the average energy intensity of office buildings in Shanghai was 107 kW h/(m2·a).

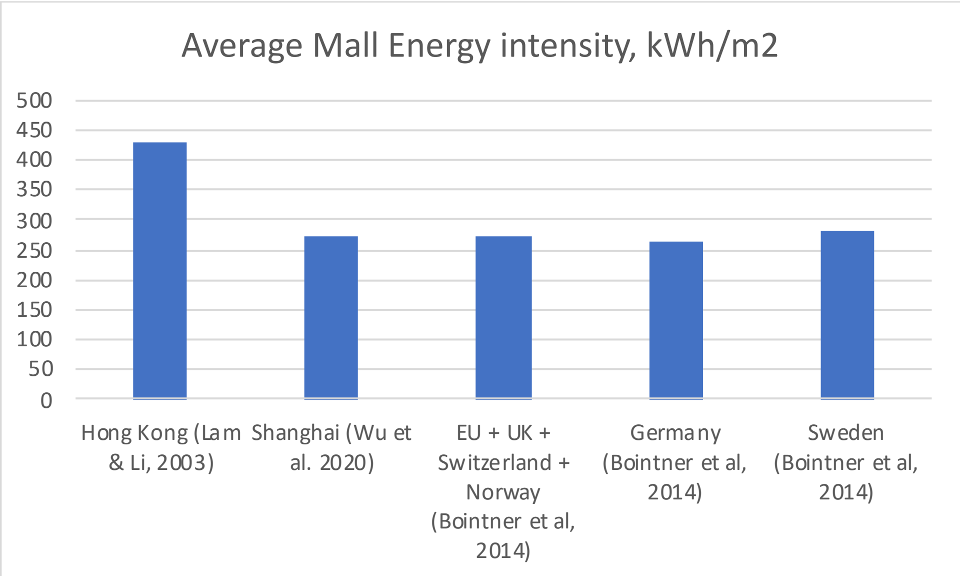


Figure 6. Average evergy use intensity in malls across the world

Wang & Han (2016) stress the impact of ICT development on the retail sector that, although not analyzed in this thesis, has led to a decrease in mall attendance for shopping purposes due to the availability of e-commerce. While it is unclear whether e-commerce leads to higher rates of impulse purchasing – discussion of such impacts on energy consumption is avoided for clarity reasons – malls, as they are known today, might become the thing of the past and with that, buildings with some of the highest rates of energy consumption might not have as much pressure on our resources in the future.

2.5 Remote Work

As previously mentioned, digitalization is disproportionally targeting countries with a relatively strong economic performance, creating potential issues for the future of economic development (Kirton & Warren, 2018). Relatedly, the economic losses associated with the global pandemic have been alleviated with the help of established digital infrastructure in the West: it was possible to keep operating most businesses and educating the future workforce without endangering lives of the locals. It was found, however, that those working in the knowledge economy and coincidentally those of higher income, were more likely to have the possibility to work remotely, disproportionately affecting essential workers, many of which (doctors being the exception) were already at more risk of losing their job (Gustafsson & McCurdy, 2020). As Alipour, Falck & Schuller (2020) refer to Mergener (2020), "jobs that can be done from home are typically distinguished by a high content of cognitive, non-manual tasks, such as working with a computer, researching, developing and gathering information".

In addition to the already existing economic gap, many residents of the developing countries were not able to get access to the same resources. It is even more so concerning, since even despite the benefits associated with digitalization in the global North, the forced closure of production sites as well as financial and COVID-related limitations on the consumption of services resulted in the worst recession since WW2 globally (World Bank, 2020). This indicates the urgent need to develop proper infrastructure and increase the level of technological competence in countries and districts where rates of digital penetration are lagging behind.

The reports indicate that even within the European Union, there is a high variation in different countries, sectors, occupations and the level of digital skills, at least when addressing the telework experiences (European Commission, 2020). It is claimed that only a handful of sectors, including IT, knowledge-intense services and administrative and support services were actively using telework solutions before the pandemic, as the trends within the EU suggest (European Commission, 2020). In both Sweden and Germany, the pandemic did not seem to cause unprecedented changes in the percentage of people using internet to place calls (Figure 7), although the presented data does not assess the purpose or frequency of the calls, which would be expected to increase during the pandemic.

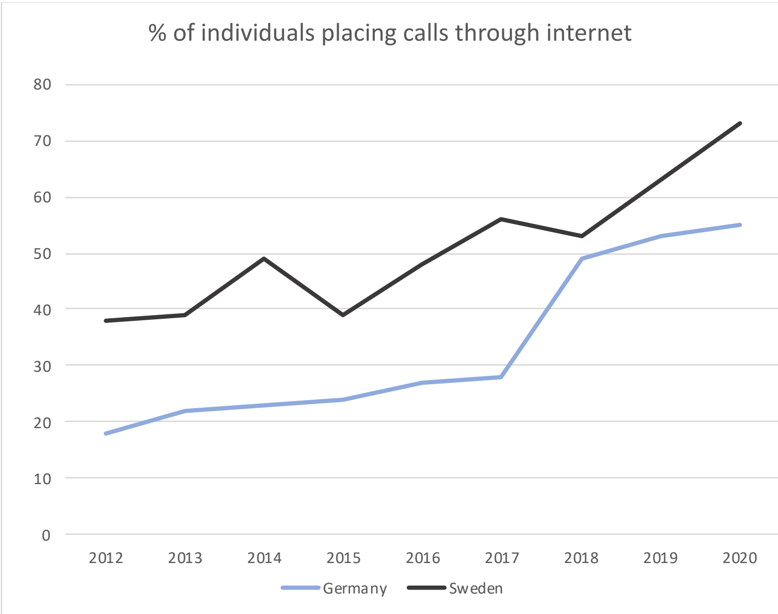
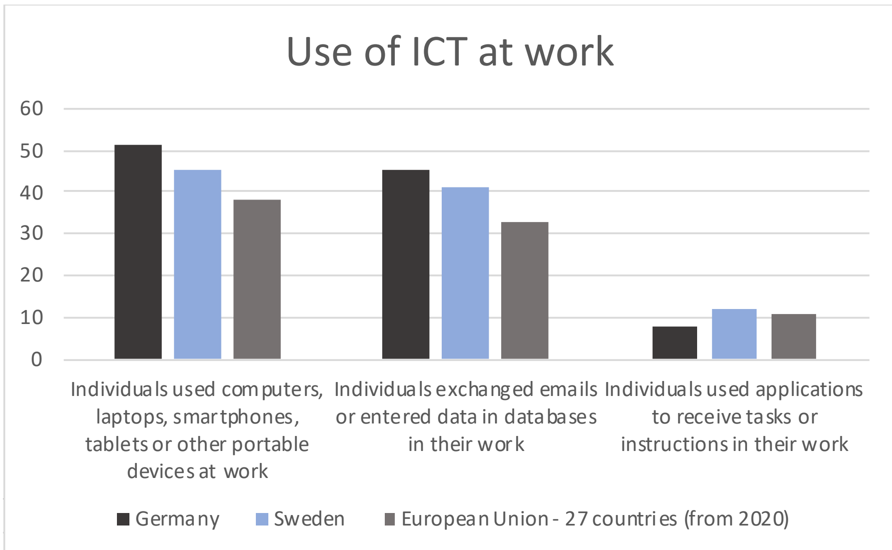


Figure 7.Percentage of individuals in Sweden and Germany using internet for telephoning or video calls, 2012-2020 (Eurostat, 2020)

This thesis argues that in highly digitized countries, such as Sweden and Germany, digital technology was already highly integrated and continuously used in workplaces, and the most significant change that took place during the pandemic was digital coordination of teams and meetings. For instance, the data suggests that back in 2018, both Sweden and the Germany had levels of ICT integration at work higher than the EU average (Figure 8). Especially considering the share of population employed at the previously described sectors with high digitalization potential, the levels of ICT usage at work have already been substantial, although the latter indicator (individuals used applications to receive tasks or instructions in



their work) has likely dramatically increased over the course of the pandemic. In this case, it is likely that the computation-associated energy consumption simply shifted from offices to the households until further notice.

As further illustrated in Figure 9, a reasonable share of employees in both the public and private sector in Sweden were working remotely before the pandemic – 18% and 27% respectively. During the pandemic, the percentage of public sector staff working from home doubled, while the percentage of private sector staff working from home reached 47%. Unfortunately, similar data is so far unavailable for Germany. However, data from the Google COVID-19 Community Trends (2021) briefly discussed earlier in the thesis indicates that the workplace attendance was significantly lower in Germany – a decrease of around 22.2% – compared to the baseline from before the pandemic.

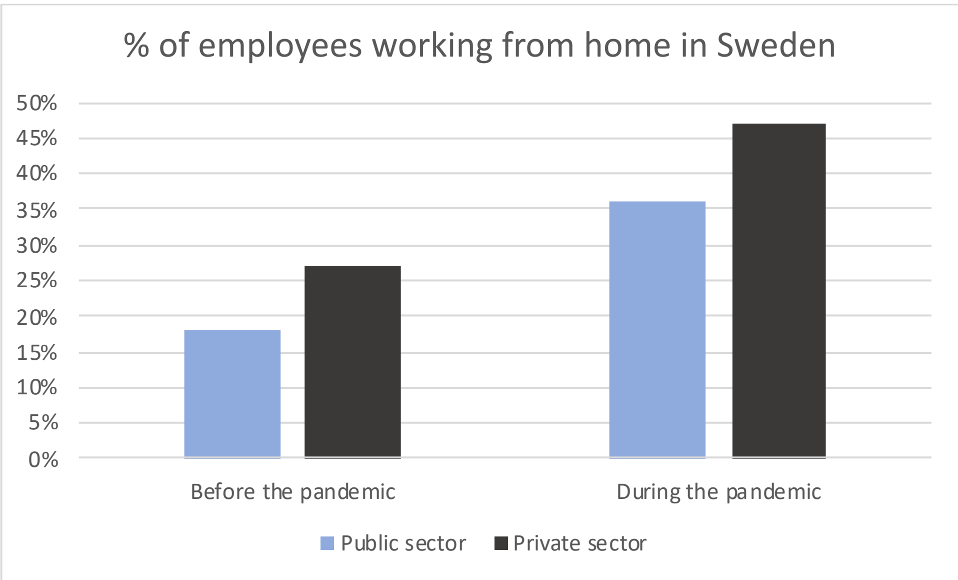


Figure 9. Share of employees working from home in Sweden, by sector (Statista, 2021)

According to a study from 2017, e-work increases the ICT greenhouse gas emission abatement potential mainly by reducing the need for owning an office, as the space utilization is generally low, while the energy consumption of office buildings tends to be high (Hilty & Bieser, 2017). However, the effect depends on the type and size of household, as well as the number of residents. For instance, Cicala (2020) points out that big suburban houses are generally less energy-efficient than offices, although they normally require more resources for mobility.

Previously, other authors have pointed out some of the benefits associated with remote work. The obvious one, namely the reduced need for conference-related travels, has been widely discussed but not quantified until 2012. For instance, while videoconferences tend to host a larger number of participants, having positive implications on the employees, they also tend to save 37% and 50% in mobility-related GHG emissions, as especially the long-haul flights consume a lot of fuel (Coroama et al, 2012; O'Brien & Aliabadi, 2020).

While videoconferencing was known of before, the pandemic has obviously affected its popularity so far through restrictions on travel, not by personal choice. However, how many people are satisfied with the associated flexibility and efficiency? Would telework prompt significant preference changes with regards to business travel and office-based employment after the pandemic? Or would the social withdrawal factor prompt many to revert to the office?

Importantly, Zoom – the most popular telework software at the moment– is now so engraved in our daily lives that "zooming" with someone has become a part of the active colloquial vocabulary – something previously attributed to only a few applications and tech giants, such as Skype (personal interactions rather than work) and Google. As illustrated in Figure 10, Zoom has only gained popularity during the pandemic, as it gives companies (and universities) an opportunity to host large meetings with high efficiency, which was not in

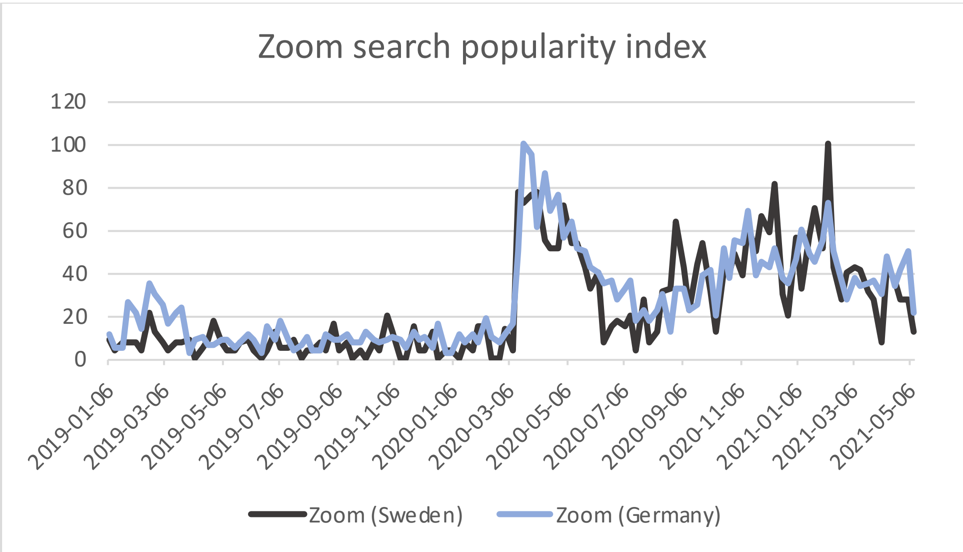


Figure 10. Zoom search popularity index, Jan 2019-May 2021 (Google trends, 2021)

urgent demand before the quarantine measures. As a cloud-based videoconferencing service, Zoom tends to consume a considerable amount of energy, the range of which depends on the number of call participants, the number of participants with a camera on, and resolution settings (Zoom, 2021).

These trends are particularly important due to the potentially long-lasting implications of the telework models. Especially due to the global pandemic and the ongoing transition towards knowledge-based economies in times of climate change, working from home is expected to only rise in popularity (O'Brien & Aliabadi, 2020). Similarly, Barrero, Bloom & Davis (2021) claim that the "big social experiment" in shape of the pandemic indicates that working from home is going to transform the future of employment. For instance, it was found and supported by multiple other studies that the labor productivity actually increased in the work-from-home scenarios (Barrero, Bloom & Davis, 2021)). Similarly, according to the data collection initiative from the University of Essex in the UK (2020), nearly 90% of all people surveyed reported either higher self-perceived productivity levels or those similar to work in their normal office environment. In contrast to around 3% of people who thought to have much less done during the pandemic, over 30% of people indicated significant productivity increases (University of Essex, 2020). According to Barrero, Bloom & Davis (2021), the re-optimization of work structure post-pandemic is expected to result in 5% productivity growth. Due to the overwhelming amount of evidence that despite the initial hesitations, working from home does positively affect the productivity levels, companies might consider the financial benefits associated with letting go of the office space.

3 Data & Methods

This section covers an array of data and simple calculations required before proceeding with the methodological proposal. Importantly, the data is prepared for use in further studies suggested in chapter 4, with a step-by-step explanation of its origins and effects. Since formulas for all calculations are provided, the estimates used in this chapter are to be updated with more case-specific figures if such are collected.

3.1 Entertainment

In order to provide adequate grounds for the analysis suggested in chapter 4, the available data is presented, formulas are derived and finally estimates for individual energy consumption are calculated based on the entertainment preference.

Importantly, methods similar to those described in 3.1.1 can be applied to other streaming services, depending on the scope of the study performed. Although this study and the consequent methodological proposal are focused on Sweden and Germany, similar logic can be followed when analyzing other countries, with consideration for the case-specific characteristics such as the pandemic-related restrictions.

3.1.1 Netflix

In order to estimate the average energy consumption of viewing Netflix per hour, information on the type of resolution and the consequent data consumption are needed, in addition to the device specifications. Importantly, depending on the video quality, the amount of transmitted data can largely vary, as represented in Table 1.

Table 1. Maximum data usage per hour of streaming, by resolution (Netflix, 2021)

Basic video quality	~0.3Gb/h
Standard video quality	~0.7Gb/h
Standard definition (SD)	~1Gb/h
High definition (HD)	~3Gb/h
Ultra-high definition (4k)	~7Gb/h

According to Aslan et al (2018), the energy intensity of data transmission is halved every 2 years. Given the intensity of 0.06kWh/GB in 2015 (Aslan et al, 2018), the estimated figure for

2019 is 0.015kWh/GB for fixed-line internet connection. For mobile internet, the consumption is estimated at 0.1kWh/GB in 2019 (Pihkola et al, 2018). Figure 11 was compiled to represent the variance in energy intensity of streaming using the available figures. As can be observed, the difference is especially evident in videos with higher resolution – HD and Ultra-HD – that are also associated with the use of devices with larger screens and, consequently, higher energy consumption.

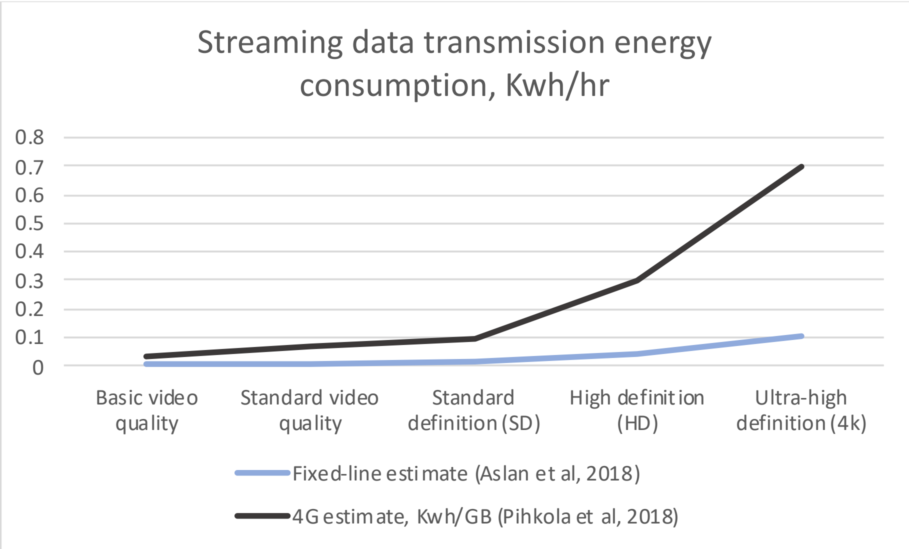


Figure 11. Estimated Netflix streaming data transmission energy consumption by network type and resolution

Although all of the analyzed studies use data-based energy-intensity measures (e.g., Aslan et al, 2018; Pihkola et al, 2018; Mills et al, 2019), the IEA (2020) refers to the recent findings that claim it is more appropriate to use time-based energy intensity values instead. However, considering that the validity of the studies referred to in the updated method could not be confirmed, this thesis will focus on the existing approach. According to the IEA (2020), additional 0.001 Kwh/h of device power is consumed while streaming on the phone, 0.022 Kwh/h – on laptop, and 0.120 Kwh/h – on TV (adjusted to comfortable resolution needed for average device size), and mere 0.002 Kwh/GB are attributed to the data centers.

In order to estimate the individual energy consumption associated with Netflix viewership, the following formula is suggested:

$$Individual\ Netflix\ energy\ consumption = \left(data\ usage\ of\ the\ chosen\ resolution\,\frac{GB}{hr} * \left(data\ transmission\,\frac{kWh}{GB} + data\ centers\,\frac{kWh}{GB}\right) + device\ energy\ consumption\,\frac{kWh}{hr}\right) * time$$

Following the suggested formula and the presented data, the estimated individual energy consumption per hour of streaming Netflix is estimated for different preferences and scenarios. The results of my calculations are presented in Table 2.

Table 2. Estimated individual energy consumption per hour of streaming

Scenario	Fixed-line connection, kWh/hr used	4G connection, kWh/hr used
Individual streaming Netflix on TV (Ultra HD assumed)	0.239	
Individual streaming Netflix on laptop (HD assumed)	0.073	
Individual streaming Netflix on smartphone (SD assumed)	0.018	0.103

As the IEA (2020) refer to Netflix (2020), 70% of viewers watch Netflix on TV, 15% - on laptops, 10% - on tablets, and 5% - on smartphones. Considering that there is no available data on energy intensity of tablets while streaming videos and that most tablets do not support Ultra HD resolution with the maximum capacity of playing HD (Netflix, 2021), they will be added to the share of laptop users, who also tend to watch high-definition videos.

Based on the number of daily active users in Sweden in 2019 and 2020 (Statista, 2021) and the estimated total amount of users for both years (Moody, 2020), it was calculated that approximately 10% of users streamed movies from Netflix daily. Although there was an increase in the number of daily viewers, it is associated with the growing number of subscriptions in 2020 and did not affect the share per se. The monthly data was averaged for time span before and after restrictions took place, as found in Hale et al (2020).

Considering that there is no available data on energy intensity of tablets while streaming videos and that most tablets do not support Ultra HD resolution with the maximum capacity of playing HD offered on Netflix mobile apps (Netflix, 2021), they will be added to the share of laptop users, who also tend to watch high-definition videos. Given that the similar statistics for Germany was not available, the country will not be used for a comparison in this segment, as tougher lockdown stringency measures could be associated with a different viewership rate.

The average amount of time spent watching Netflix rose from 2 hours per day in 2019 (IEA, 2020) to 3.2 hours per day in 2021 (Dean, 2021) due to the global pandemic. Although the figures may vary for different countries given the varying quarantine stringency measures, no further information is available on a regional basis. Thus, these figures are used for further comparison and estimation.

Table 3.Estimations of daily Netflix-related energy consumption for different groups of viewers in Sweden.

Pre-pandemic			
Device type	TV (Ultra HD)	Laptop (HD)	Smartphone (SD)
Estimated no. of daily viewers	160995.2556	57498.3056	114996.611
Daily energy consumption, kWh	76955.73216	8394.75261	4139.878
Pandemic			
Device type	TV (Ultra HD)	Laptop (HD)	Smartphone (SD)
Estimated no. of daily viewers	173371.73	61918.475	123836.95
Daily energy consumption, kWh	132594.6991	14464.1558	7133.00832

Based on the results obtained in Table 2 and the suggested formula, Table 3 was compiled. Although tempting to calculate the share of energy consumption attributed to Netflix viewership with the average daily energy consumption in Sweden before and during the pandemic, it is nearly impossible to know where the data is consumed and frequently cannot be attributed to only one country in question.

3.1.2 Malls

According to the International Council of Shopping Centers (2015), around 83% of the US population visited a mall minimum once a week, and an astonishing share of 20% - more than 10 times a week. However, similar data is not available for Sweden and Germany. Moreover, the local urban environment is largely different in both countries: most of the European countries have multiple small towns scattered across resulting in a relatively small density of population, especially so in Sweden. Since malls need to secure a reasonable foot traffic to generate profit, it is unlikely that they would be placed in small towns located far away from each other. Thus, the absolute numbers for mall attendance are assumed to be lower for such countries, although the share relative to population and size of the center might be similar, which additionally depends on the local culture and consumption practices.

The Table 4 was compiled to represent the classification of shopping center sizes in Europe, as defined in ICSC (2005).

Table 4.Mall size classification (ICSC, 2005)

Very large	80,000 m² +
Large	40,000 – 79,999 m²
Medium	20,000 – 39,999 m²
Small	5,000 – 19,999 m²

As Bointner et al (2014) refer to the ICSC (2005), the predominant number of shopping centers in Sweden are classified as small, in contrast to Germany, where the lion share of all malls is medium to large size. This could potentially be linked to the population factors and culture, as described above. For instance, the number of metropolitan areas (where theoretically speaking malls would be located) is significantly different for the two countries: only 3 in Sweden and 11 in Germany.

According to Bointner et al (2014), the average energy intensity of malls is estimated at 265kWh/m² for Germany and 280kWh/m² for Sweden. As this is a measure derived from annual energy consumption, both were divided by 365 to illustrate the average daily lower and upper limits for the energy consumption of predominant malls sizes in the two countries in Figure 12.

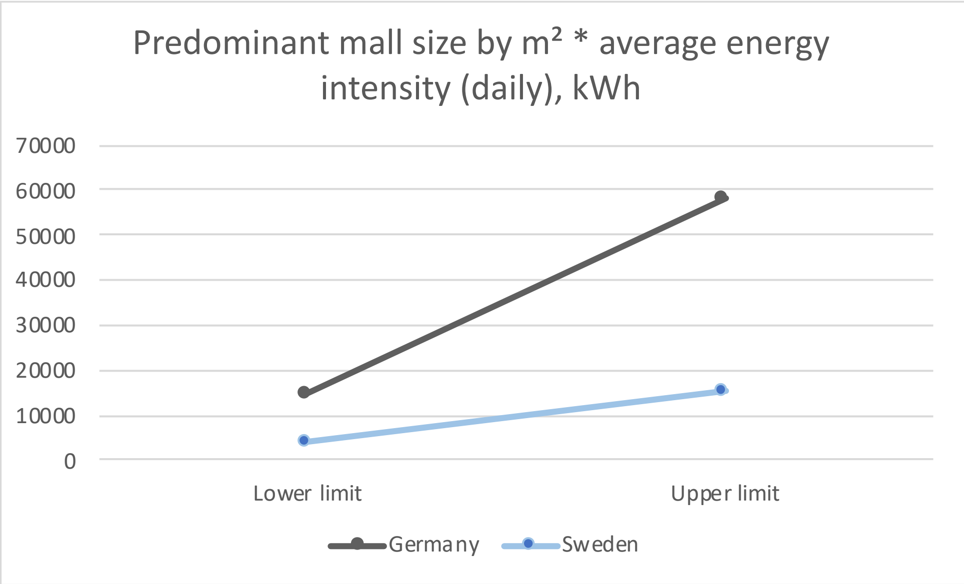


Figure 12. Average daily energy consumption for the predominant mall sizes in Germany and Sweden

Invariably on the number of "passersbys", shoppers, and individuals seeking entertainment, the average energy consumption of malls does not change significantly: a cinema with capacity to accommodate 100 people would still screen the movie for 2. Thus, the individual contribution in the mall's energy consumption depends on the amount of people who visited the venue the same day and the amount of time they spent inside. In a way, it is similar to the individual choice of taking a train over a plane flight, when possible, even if the plane is still likely to accommodate customers to its full capacity, especially on popular routes. Similarly, in bigger malls, it is unlikely that the foot traffic reaches unreasonably low amounts. Despite the variance associated with energy consumption of different malls, depending on their size, services offered and, importantly, the design, "averages" can be derived. Moreover, looking at energy intensity, rather than energy consumption, can account for the building size variation that depends on the local population and demand.

Although no data is currently available to immediately compare the individual share (responsibility) in energy consumption of the malls, the following formula can be used for such calculations:

$$Individual\ share\ of\ energy\ consumption = \frac{mall\ size * energy\ use\ intensity/8760}{number\ of\ daily\ visitors} * time\ ,$$

where the annual measure of energy use intensity is transformed into an hourly measure through division by the number of days per year and hours per day. Of course, this is a largely simplified formula that does not account for the individual service preferences within the mall that, in contrast to airplanes, have a larger variation in the individual behavior. However, it is unlikely that one will be able to ever estimate every possible scenario in buildings with varying types of entertainment offered and varying types of individuals partaking based on their own preferences.

3.2 Remote Work

As represented in Table 5, the recommended bandwidth for Zoom calls varies on the number of call participants, the chosen resolution, and additionally, the number of people who have their cameras on during the call. Importantly, the up/down measurement stands for the amount of data transmitted while continuously uploading and downloading the live video. If only one measure is presented in the table, the amount of data for both videocall streaming directions is the same.

Table 5.Estimated data transmission during different types of Zoom calls (Zoom, 2021; own calculations)

For one-on-one video calls		Converted to GBps	Converted to GB/hr
High-quality (HQ)	600kbps (up/down)	0.000075 (up/down)	0.27 (up/down)
720p HD	1.2Mbps (up/down)	0.00015 (up/down)	0.54 (up/down)
1080p HD	3.8Mbps/3Mbps (up/down)	0.000475/0.000375 (up/down)	1.71/1.35 (up/down)
For group video calls		**Converted to GBps**	**Converted to GB/hr**
High-quality (HQ)	1.0Mbps/600kbps (up/down)	0.000125/0.000075 (up/down)	0.45/0.27 (up/down)
720p HD	2.6Mbps/1.8Mbps (up/down)	0.000325/0.000225 (up/down)	1.17/0.81 (up/down)
1080p HD	3.8Mbps/3.0Mbps (up/down)	0.000475/0.000375 (up/down)	1.71/1.35 (up/down)

In order to apply the data-based energy intensity method presented in the previous section, the variables were first converted into GBps, where 1kbps=0.000008GBps and 1Mbps=0.000125GBps. Then, the hourly data consumption in GBs was derived by simply multiplying the result by 3600 (number of seconds in one hour).

For now, there is no data available on the preferred type of device used to access Zoom. Since applied in the work environment, it is assumed that most corporate customers access the platform through its laptop version. In this case, the data introduced in the previous section will be used, with 0.022 Kwh/h laptop energy consumption and 0.015 kWh/GB energy intensity of data transmission using fixed-line internet connection (Aslan et al, 2018). However, based on the theory presented in the chapter 2.5 (Remote Work), it was hypothesized that in countries with high digitalization and internet penetration levels, such as Sweden and Germany, the share of the labor force that was able to work remotely (i.e., knowledge intense services) was already using computers at the workplace. Since the length of the working hours remained the same before and after the pandemic, the hourly device energy consumption is avoided from the comparison suggested in the methodological proposal section. Finally, the lower and upper limits (negative and positive scenario) of energy-intensity are be used to calculate the data-related energy consumption of 1 hour of Zoom call for each of the specified parameters, following the formula:

$$Energy\ consumption = (data\ uploaded + data\ downloaded) * energy\ intensity$$

The calculation results can be observed in Table 5. While the number of participants affects the hourly energy consumption involved in data transmission, the figures were not available. The provided calculations were based on Zoom's recommendations, indicating that the results in Table 5 would represent the rule of thumb for different types of video resolution.

Table 6. Zoom data transmission energy consumption

For one-on-one video calls	
Resolution	kWh/hr
High-quality (HQ)	0.0081
720p HD	0.0162
1080p HD	0.0459
For group video calls	
Resolution	kWh/hr
High-quality (HQ)	0.0108
720p HD	0.0297
1080p HD	0.0459

3.3 Limitations

It is important to note that network operators and data centers are continuously engaged in improving their energy efficiency. When it comes to cellular networks, for instance, the full energy efficiency potential of the new generation standard is only reached a few years post the initial integration. Due to the number of factors affecting the scope of energy consumption in topics surrounding digitalization and internet, using multiple estimates and assumed values as showed in this section – while might be the only possible method at the moment – biases the results and might not represent the true energy consumption of the presented services.

On a similar note, there is no information publicly available on the energy consumption of Zoom's data centers. Generally, cloud-based services have more energy consumed in their data centers than other service providers (Mills et al, 2019), making it difficult to truly estimate the overall scope of Zoom's energy consumption and remote work efficiency.

Using Netflix as the sole indicator of digital entertainment services and malls as the sole source of on-site entertainment largely diminishes the scope of analysis. The individuals following suggestions presented in the upcoming methodological proposal section are encouraged to expand the scope of services analyzed in their research, following the methods outlined in this section and exemplified on the case of Netflix. One might say that comparing Netflix to cinema attendance would be more accurate. However, this segment of the study is supposed to be scalable, and multiple factors described above should be considered for a comprehensive study.

Finally, the internet phenomenon, at least in the analyzed countries, makes digital services accessible everywhere by definition, which is different for the availability of malls that, as previously pointed out, tend to be located in more populated areas. This could thus confuse the "preference" for "availability" and should be considered in the analyses potentially following the methodological proposal.

4 Methodological Proposal

Following the major findings of the theoretical analysis in terms of research gaps and the hypothesized impacts areas, the methodological proposal attempts to provide ideas for future research. Both of the potential research areas represented in this section can be conducted by using the estimates provided in the previous chapter but require additional data collection.

One of the main ideas behind the methodological proposal is the scalability of both case studies. For instance, more factors and relationships not previously identified in this thesis could be potentially analyzed.

4.1 Entertainment

As has been found during the theoretical analysis, younger people are more likely to get addicted or at least form a habit when it comes to the use of digital entertainment (Mahendher & Hans, 2021). Moreover, as Cheshmehzangi (2020) hypothesized in his work on household energy consumption, although the currently available data does not allow for such analysis, it is likely that the increased demand for such online platforms is not going to fully bounce back to the rates compatible with their popularity pre-pandemic, in contrast to other temporarily increased household activities. With streaming services and online gaming considered to be the driving force of Internet expansion today (Hinton et al, 2011), it is important to find answers on whether the rising demand is here to stay.

That is why I propose a study of mall attendance versus digital platform for entertainment purposes, assessing the pre-pandemic, pandemic, and presumed post-pandemic preferences for different age groups. The study would require one to perform a survey with considerable number of respondents to smooth out the differences associated with individual variation and habits. The survey must be conducted in a country with both high levels of digitalization to account for equal platform access opportunities and stringent quarantine in place during the global pandemic. In addition to estimating the longevity of the digital entertainment trend for different age groups, the study could update the estimates presented in section 3 with case-specific data and analyze the energy consumption required for both activities.

As previously mentioned in the data & methods limitations, accounting for the behaviors in gaming, social media, and other movie streaming platforms could help expand the scope of digital entertainment options and make it truly comparable with the scope of options available at a mall. Thus, this proposal should only be viewed as a suggestion but in no way a restriction to the study.

Table 7.Data required for collection to proceed with the study of entertainment preferences.

The respondent must provide answers to the same questions for three different timespans: before the COVID-19 pandemic, during the COVID-19 pandemic, after the COVID-19 pandemic	
Variable	Explanation
Age	The variable is used to see whether the younger generation is more likely to prefer digital entertainment post-pandemic
Income	The variable helps understand the link between entertainment preferences and their cost for adult respondents
Preferred device for streaming Netflix	TV/laptop/tablet/smartphone
Preferred resolution for streaming Netflix	Basic video quality/ Standard video quality/ SD/HD/Ultra HD
Type of network connection while streaming	WiFi/cellular
Time spent on watching Netflix weekly	The weekly estimates might be easier to recollect. The result is divided by 7. Used to understand the scale of consumption
Time spent in malls for entertainment purposes weekly	The weekly estimates might be easier to recollect. The result is divided by 7. Used to understand the scale of consumption
Distance to the favorite mall	Used to estimate the mobility-related energy consumption
Mode of transportation	Used to estimate the mobility-related energy consumption
Fuel consumption, if car	Used to estimate the mobility-related energy consumption (liters/km or kWh/km)

To understand the longevity of digital consumption trends and the reasons behind it, I suggest performing an econometric analysis to see whether the two types of analyzed entertainment options depend on one's age or income.

In order to compare the two activities, one must use the case-specific data to estimate the energy consumption in the discussed cases:

(1) $Netflix\ Individual\ energy\ consumption = \left(data\ usage\ of\ the\ chosen\ resolution \frac{GB}{hr} * \left(data\ transmission \frac{kWh}{GB} + data\ centers \frac{kWh}{GB}\right) + device\ energy\ consumption \frac{kWh}{hr}\right) * time$

(2) $Individual\ share\ of\ energy\ consumption = \frac{mall\ size * energy\ use\ intensity/8760}{number\ of\ daily\ visitors} * time$

Furthermore, the following calculation is required for the final estimation:

(3) $Mobility - related\ energy\ consumption = distance\ to\ the\ mall * fuel\ consumption$

Finally, the simple calculation can be performed to find out the energy-consumption difference associated with mall attendance and Netflix viewership:

(1) $Energy\ consumption\ difference = Netflix\ individual\ energy\ consumption - (Individual\ share\ of\ mall\ energy\ consumption + Mobility\ related\ energy\ consumption)$

4.2 Work

As hypothesized based on the available data and literature, a similar number of people was using computers for work before and during corona in the technologically advanced countries of the Global North (such as Sweden and Germany). Although it is widely believed that remote work is more efficient, the real situation is too context-dependent for such generalizations. Based on the available evidence, the energy-efficiency of built environment and space utilization might have more weight in the arguments for and against working from home (Cicala, 2020).

For instance, lightning, cooling and heating constitute the lion share of the building electricity consumption (IEA, 2020). In this case, the rate of office space utilization has to be compared to the employees' household and home size and the consequent energy-efficiency. Since the home size is correlated with one's income, companies with higher numbers of employees receiving above middle-income salaries are more likely to change the pro- homebased work narrative. To put it simply, working from a compact office environment might be more energy-wise than heating and lighting a big house for 8 more hours per day, depending on the associated mobility considerations. However, since those owning a house are likely to be located in the suburbs (Cicala, 2020), the energy-consumption required for their mobility might indeed outweigh the inefficiency of working alone from a large house which, again, depends on the type of vehicle. Overall, it will be difficult to generalize the benefits of both remote and office work due to the number of variables involved.

Given the productivity increases associated with the global pandemic (University of Essex, 2020), companies dedicated to sustainable business practices might want to consider the associated implications. In this situation, the firm in question could perform a case study. The variables required for data collection and their purpose in the analysis are indicated in Table 8 (represented on the next page due to the large size).

Table 8. Key variables for the telework case study

Variable	Explanation
Office electricity consumption before the pandemic	Used to analyze energy consumption per employee
Number of employees working in the office	Used to analyze energy consumption per employee
Survey required, respondent: employee	
Employee household size	Number of people living in the same household The variable is used to analyze energy consumption per tenant
Home electricity consumption during the pandemic	The variable is used to analyze energy consumption per tenant
Preferred Zoom resolution settings	Used to adjust the supplied Zoom data consumption figures to personal preferences of the employees
Average hours of Zoom calls per day	Used to adjust the supplied Zoom data consumption figures to the work situation
Distance to work	Used to calculate the mobility-related energy consumption
Mode of transportation	Used to understand the mobility-related energy consumption
Fuel consumption, if car	Used to calculate the mobility-related energy consumption (litres/km or kWh/km)

Following the survey, one can start preparing the results by performing a series of simple calculations before the final comparison. The formulas suggested to analyze the collected data are presented below:

(1) $Energy\ consumption\ per\ employee\ = \frac{Office\ electricity\ consumption}{number\ of\ employees}$

(2) $Energy\ consumption\ per\ tenant = \frac{Home\ electricity\ consumption\ during\ the\ pandemic}{household\ size}$

(3) $Mobility - related\ energy\ consumption = distance\ to\ work\ *\ fuel\ consumption$

(4) $Zoom - related\ energy\ consumption = average\ hours\ of\ Zoom\ calls\ per\ day * hourly\ energy\ consumption,$

where the hourly energy consumption is defined by the preferred Zoom resolution settings, following the proposed energy intensity chart.

Finally, the main comparison can be performed using the following formula:

(5) $$Energy\ saved = energy\ consumption\ per\ employee + mobility\ related\ energy\ consumption - (energy\ consumption\ per\ tenant + Zoom\ related\ energy\ consumption)$$

5 Conclusion

The relationship between digitalization and energy consumption is so complex and interlinked today, that it is nearly impossible to present a comprehensive study without considering the energy consumed by the Internet. Additionally, the complexity of the related infrastructure is even more difficult to navigate and quantify, which might explain the limited amount of literature on the topics discussed in this thesis. Although this study did not measure the relationship per se – this would be a cumbersome process that would take much more time than was allocated for the thesis work – it attempted to illustrate the existing research gaps identified through the theoretical analysis and currently available data. Most importantly, the main aim of the thesis was to propose a way to fill these research gaps. Moreover, the thesis accounted for the behavioral and consequent energy consumption differences associated with the outside pressures, in terms of governmentally imposed restrictions and personal preferences.

Based on the analysis, it was found that many questions surrounding digitalization and Internet expansion tend to generalize the topic, which is inappropriate in this case. One of these questions was: Is remote work more energy-efficient? Contrary to what may seem as the right answer at face value, it depends. Due to the recent global pandemic, a natural experiment was created, enabling the researchers to understand the impacts of telework better by collecting the available household energy consumption during the lockdown. With the large number of our amenities consuming energy on a daily basis and largely varying lifestyles, the true effect is very individual. Based on the available data and literature, employees of the knowledge-intense services in countries with high levels of internet penetration and digitalization were hypothesized to be the same group of people who used computers in the office before the pandemic and who could continue working remotely. In this case, I argue that the rate of space utilization and other context-dependent variables, such as mobility, would be able to portray the true energy consumption difference between telework and office work. Hence, a case study was suggested in the methodological proposal section. Importantly, the main target group of the proposal is thought to be companies engaged in sustainable strategy development. With evidence suggesting that at least some hybrid versions of remote work are to stay in place due to the unexpected productivity increases, it is important for companies to raise questions that go beyond "less mobility – less energy consumption" view and see the big picture of where and how the energy is consumed. It is thus assumed that the answer to such big question as remote work efficiency will differ on a case-by-case basis.

Similarly, more research is needed into the benefits of digital entertainment – one of the main drivers of Internet expansion. Importantly, another question arises: Is digital entertainment more energy-wise than on-site activities? Again, the answer depends on the scope of options analyzed. On one hand, the effect could be considered insignificant relative to the amounts of energy consumed by on-site premises with different entertainment options. Furthermore, the energy efficiency of data centers and transmission is being continuously improved, while the improvement potential of the existing buildings is somewhat limited to their original design. On another hand, the scope of energy consumed by the shopping centers or cinemas is rather constant, compared to the Internet-related entertainment services. The latter keep expanding due to the growing demand, driving service providers to increase the amounts of videos and games (for example) stored in its infrastructure. Although the individual contribution might be lower for digital entertainment, there are only that many malls in the world, while the Internet will keep growing and possibly reaching much higher aggregate energy consumption values than those attributed to built environments.

Another factor that has to be analyzed is the longevity of the ongoing digital trends. Following the available body of research, it is difficult to detangle the presumed growth in digital entertainment after the pandemic due to the formation of new habits from the simple continuation of the old trends. Due to the digital competence levels associated with higher use of the online leisure services and the younger people establishing digital habits faster, it is presumed that the trend will be disproportionately higher in the younger age groups. However, depending on the country in question and the availability of social safety nets, the adults whose income had been hit by the global pandemic might stick to the digital entertainment due to its cost-efficiency.

6 Discussion

Initially, this study was supposed to analyze the household electricity consumption. However, the number of variables involved in the topic – variables that, if avoided, could bias the hypotheses – convinced me to expand the scope. Probably one of the main takeaways of this study for me is the complexity of systems involved in the Internet-related processes and how their analysis is further affected by individual behaviors.

As conceptualized by the design of this study – namely, a thorough methodological proposal – more research is needed to even begin to understand the current effects and efficiency potential of digitalization and Internet expansion. Moreover, as previously argued on the example of Bitcoin, every tool can be applied in responsible and irresponsible manners. Consequently, it is up to researchers to study how to exploit the potential of those innovations that would decrease the overall energy burden. Moreover, it is up to all actors – public and private sector, and the society – to raise the awareness on scopes of energy consumption. For instance, people are unlikely to think about the energy implications of their actions that do not necessarily show up on their electricity bill – such as going to the mall or gaming on a cloud. Simply because the energy consumption of such activities is not directly indicated in the bills does not mean it was not included in the service price. Energy is expensive, and with many of our daily activities depending on its provision, people need to understand how their behaviors affect its unseen consumption.

Seeing that the energy-related CO_2 emissions largely depend on the source of energy, the extension will be disregarded in this thesis. After all, switching to alternative energy is a different (and crucial) objective, but it does not change the amount of energy required to fuel the digital systems in place today. If one were to consider the environmental footprint of the studied topics, regional specifications for energy sources would be needed, as countries with similar internet- and digitalization- related energy consumption estimates might have a completely different footprint, depending on the local energy structure.

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