Diploma Thesis

Literature review on the Impact of telework on CO2 emission and its relevancy in consideration of greenhouse effect

Submitted in satisfaction of the requirements for the degree of
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Diplomarbeit

Literaturrecherche zum Einfluss von Telearbeit auf den CO2-Ausstoß und seine Relevanz im Hinblick auf den Treibhauseffekt

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Abstract

Introduction

In recent decades, especially following the global pandemic outbreak in 2020, telework has gained popularity as a working method, and numerous studies have examined its benefits. However, the importance of environmental effects of teleworking has only recently come to light due to the pandemic. Although there has been a proof of significant decrease in carbon emissions linked to commuting, travel, and office-related activities as a result of more people working remotely, the rebound effects should not be overlooked.

Purpose

The main purpose of this thesis is to gain a general overlook through reviewing the literature and give a background to the current state of so called teleworkability in different economic sectors in countries of the first, second and third world. This thesis aims to cover a wide range of literature documents from chosen databases and determine if the impact of telework on air pollution is relevant in consideration of greenhouse effect. Additionally, a sensitivity analysis was done on the case study of Austria.

Results

Teleworkability is often discussed in relation to technological advancements and their compatibility with various job types. Globally, there are significant disparities in internet access and teleworking capabilities, with Africa having only 11% of internet users despite its large population. However, the rapid technological growth in developing countries suggests an increasing potential for telework. Approximately 20% of global jobs could be performed from home, with higher percentages in wealthier nations. The ability to work from home aligns with GDP per capita, reflecting economic differences and digital preparedness. Results of the sensitivity analysis in Austria clearly show carbon reduction for all cases except for an one-person household in the case of non-reduced office space.

Conclusion

There is compelling evidence that remote work may have significant positive effects on the environment. However, there is still a great deal of uncertainty regarding the precise impacts of teleworking on air pollution rates and its relevance. To quantify the effects of certain policies, particularly across nations or for various situations and demographic groups, further study and analysis are required.

Kurzfassung

Einleitung

In den letzten Jahrzehnten, insbesondere nach dem Ausbruch der Pandemie im Jahr 2020, hat Telearbeit als Arbeitsmethode an Popularität gewonnen und zahlreiche Studien haben ihre Vorteile untersucht. Allerdings ist die Bedeutung der Umweltauswirkungen der Telearbeit aufgrund der Pandemie erst kürzlich ans Licht gekommen. Obwohl die CO2-Emissionen im Zusammenhang mit Pendeln und Reisen aufgrund der zunehmenden Telearbeit deutlich zurückgegangen sind, sollten die Auswirkungen der Rebound-Effekte nicht übersehen werden.

Zweck

Das Hauptziel dieser Arbeit besteht darin, durch die Durchsicht der Literatur einen allgemeinen Überblick zu gewinnen und einen Hintergrund zum aktuellen Stand der sogenannten Telearbeitsfähigkeit in verschiedenen Wirtschaftssektoren in Ländern der ersten, zweiten und dritten Welt zu geben. Ziel dieser Arbeit ist es, ein breites Spektrum an Literaturdokumenten aus ausgewählten Datenbanken abzudecken und festzustellen, ob die Auswirkungen von Telearbeit auf die Luftverschmutzung im Hinblick auf den Treibhauseffekt relevant sind. Zusätzlich wurde eine Sensitivitätsanalyse für die Fallstudie Österreich gemacht.

Ergebnisse

Telearbeitsfähigkeit wird oft im Zusammenhang mit technologischen Fortschritten und ihrer Kompatibilität mit verschiedenen Jobtypen diskutiert. Weltweit gibt es erhebliche Unterschiede beim Internetzugang und den Möglichkeiten zur Telearbeit, wobei Afrika trotz seiner großen Bevölkerung nur 11 % der Internetnutzer hat. Das schnelle technologische Wachstum in Entwicklungsländern deutet jedoch auf ein zunehmendes Potenzial für Telearbeit hin. Ungefähr 20 % der weltweiten Arbeitsplätze könnten von zu Hause aus erledigt werden, wobei der Prozentsatz in wohlhabenderen Ländern höher ist. Die Möglichkeit, von zu Hause aus zu arbeiten, steht im Einklang mit dem Pro-Kopf-BIP und spiegelt wirtschaftliche Unterschiede und die digitale Bereitschaft wider. Die Ergebnisse der Sensitivitätsanalyse in Österreich zeigen eine deutliche CO2-Reduktion für alle Fälle mit Ausnahme eines Einpersonenhaushalts bei nicht reduzierten Büroflächen.

Fazit

Es gibt überzeugende Beweise dafür, dass Fernarbeit erhebliche positive Auswirkungen auf die Umwelt haben kann. Es besteht jedoch immer noch große Unsicherheit über die genauen Auswirkungen der Telearbeit auf die Luftverschmutzungsraten und ihre Relevanz. Um die Auswirkungen bestimmter Maßnahmen zu quantifizieren, insbesondere zwischen Ländern oder für verschiedene Situationen und demografische Gruppen, sind weitere Untersuchungen erforderlich.

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1 Introduction

Over the past few decades, the labor market has been impacted by a number of significant changes. These include the rise in female labor force participation, the evolution of the employer-employee relationship, and the expanding significance of information and communication technology. The time schedules and workplace locations of everyday work patterns have tended to change as a result of these advances (Cerqueira Eugênia Dória Viana, 2020). Moreover, great development of technology in recent decades and the resulting movement toward knowledge-based occupations have made it possible for teleworking to significantly increase its popularity, following the pandemic in 2020 that has only sped up this expansion (Matteo Sostero, 2020), (O'Brien, et al., 2020). Many studies describe teleworkability in terms of technological development, which, according to their argument, mostly depends on the technologies available for remote communication and how they interact with the various types of job content (Sostero Matteo, 2020) (Steffen Langea, 2020).

M. Sostero, S. Milasi , J. Hurley, E. Fernandez-Macías and M. Bisello in their joint European Commission–Eurofound report define teleworkability "*as the technical possibility of providing labour input remotely into a given economic process. We say "technical possibility" to emphasize that teleworkability depends on what types of task content can be remotely provided with the available technology. Whether teleworkability – as a potential – is actually put in practice or not in a given work process will also depend on the methods of work (namely work organisation), and the specific tools (technologies) used at work."* (Matteo Sostero, 2020).

The percentage of individuals who work in fixed workplaces has steadily decreased over the past 20 years and currently affects certain sectors significantly more than others (such as manufacturing employment). Even though this category continues to be the majority among all groups of employees, alternative work arrangements, such as multi-location employment and home-based work, currently make up an increasing portion of the labor market (Cerqueira Eugênia Dória Viana, 2020). The vast variability across nations often reflects how common teleworking was before the epidemic, with certain nations—notably, in Europe, the Benelux and Nordic countries—registering far higher rates than Southern or Eastern European nations for instance. Differences in industrial structure between states only partially explained these differences. Additional factors, such as the occupational composition within sectors and, more generally, the distribution of employment by firm size, as well as workers' and firms' digital capabilities and organizational and management cultures, also play a part. Most of the compiled research indicates that, nevertheless, the most obvious distinction between white-collar job, which is substantially teleworkable, and blue-collar employment, which has a more restricted potential for teleworking, is between the two. This is supported by survey data from the crisis and the pre-crisis, and it was further supported by teleworkability assessments based on job task characteristics. These occupational divisions in teleworking, which there is reason to believe will endure, are reflected in stark variations in teleworkability by salary and educational background. Occupational teleworkability measure of one research shows that over three-quarters of people in the top salary quintile might possibly telework, compared to around one in twenty in the worst wage quintile. Third-level educated employees have a roughly threefold higher likelihood of working remotely than their less educated colleagues (Matteo Sostero, 2020).

In 2021, about half of all CO2 emissions connected to energy were produced globally by the top 10% of emitters, compared to just 0.2% by the bottom 10%. In 2021, the wealthiest 10% produced 22 tonnes of CO2 on average per person, more than 200 times the amount produced by the poorest 10%. The top 10% emitters, who total 782 million individuals, come from all the continents. About 85% of them are found in developed nations including China, Australia, Canada, the United States, the European Union, Japan, Korea, and New Zealand. The remaining individuals are from the Middle East, Russia, and South Africa, regions with relatively high levels of income and wealth disparity and fuel mixtures that produce a lot of emissions. The bottom 10% of the world's emitters are concentrated in developing nations in Asia and Africa, where people consume very little in the way of products and services and frequently have limited or even no access to electricity (Laura Cozzi, 2023).

There are additional factors that affect teleworkability in addition to the type of work and job duties in a particular occupation. Good ICT (Information and Communications Technology) connections are necessary for a large portion of the work that may be done remotely. Important enablers include the nation's level of ICT ability, which includes a high rate of computer and internet use, education, and broadband accessibility, as well as employers that provide the required access and computer gear in specific organizations. It is clear that there is a significant disparity in ICT readiness among countries and nations, which leaders have a responsibility in resolving. In nations with advanced IT and internet infrastructure—of which the European Nordic nations or Switzerland, for instance, rank highly—telework is more likely to occur. In Bulgaria and Romania, where such services are less common, it is far less widespread (Matteo Sostero, 2020). Another research from GALLUP found out that in out of 148 surveyed countries, in 41 (all of them in Africa and Asia) less than 10% of adult respondents reported no internet access at home in 2011 (Morales, 2013). Due to ICT evolution, video-based communication and exchanging any kind of information by electronic means has become possible for anyone who has laptop or even a smartphone and adequate/sufficient internet connection. This means that theoretically, any (full-time) teleworker might be responsible for a major reduction of the environmental and economic burden through reduction or even elimination of work-transport and office needs. The literature, however, implies that there are a variety of obstacles including so-called rebound effects that undermine or completely erase the potential energy savings from telework (O'Brien, et al., 2020). Some studies advocate, that because additional miles are traveled and more energy is used, rebound effects may reverse the benefits of teleworking or further increase GHG (Cerqueira Eugênia Dória Viana, 2020).

Linked to the increased uptake of teleworking, there have been a lot of hopes, beliefs and misconceptions. This especially applies to the part of society where discussions focus on the question if telework can reduce CO2 emission and traffic congestion, or rather how great is its range on the air pollution in general. Although the effects of telework on air pollution and linked rebound effects have been studied by earlier researchers, few studies have focused on to what extent may expansion and wider adoption of telework impact CO2 emissions. Due to the fact that it requires less use of transportation and centralized office space than the traditional status quo of commuting, teleworking has generally been seen as a more environmentally friendly way for knowledge workers to operate. However, when the scope is broadened to include home office energy consumption, the Internet, long-term consumer decisions, and other so-called rebound effects, the issue is significantly more complicated than it would initially appear. Few researches have evaluated how telecommuting concurrently affects energy use at home, at the workplace, during transportation, and in communications. The findings finally demonstrate the complexity of this issue and the overall inadequacy of the datasets and methodologies currently in use to adequately address the study subject. While the majority of newer studies show some benefits, others claim teleworking really uses more energy – even in the industry that is supposed to gain the most: transportation (O'Brien, et al., 2020).

The present thesis provides both theoretical and some existing practical results and statistics. From a practical standpoint, a database and research from various articles, journals and database platforms were obtained and represented explicitly. From a theoretical perspective, history and background of telework, in terms of its impact and rebound effects have been introduced. A sensitivity analysis on a case study of Austria has been done and represented in Table 1.

1.1 Problem statement

By lowering the number of commuters using the roadways, it seems that the growth of telework or remote work has the potential to drastically reduce air pollution in urban areas. The advantages of telework for social and economic results have been the subject of numerous studies, but its effects on the environment, notably on air pollution, have received less attention. Understanding how telework could help promote environmental sustainability is becoming more and more crucial as the globe struggles to cope with the effects of climate change. Furthermore, it is uncertain in what extent does telework impact CO2 emission considering the level of its possible implementation in different countries, nations and economies.

The central question is: Does the evolution and adoption of teleworking help modifying travel patterns, sustain rebound effects and lower CO2 emissions? Moreover, to what degree is this adoption even possible?

1.2 Aims and objectives

The objective of this study is to quantify the level of teleworkability in different countries and economies and to bring attention to environmental aspects of teleworking by introducing and categorizing the existing literature on this subject (on the problem that is the impact of telework practices on air pollution), as well as to investigate to what extent it leads to rebound effects. Through analyzing the effect of telework on air pollution and focusing on identifying the variables that affect the magnitude of this impact based on the existing literature, this thesis intends to sum up the knowledge span and brings up some statistics, as well as to identify possible areas that require further research.

1.3 Limitations

In the context of climate and pollution, it is necessary to have a clear understanding of what telecommuting could bring in the future and a comprehensive evaluation of its carbon footprint. However, despite a great number of existing studies, reports and analysis, it is difficult or sometimes even impossible to evaluate the impact of telework on CO2 emissions due to effects that are not always immediately evident, such as the comparison before/after or pros/cons of teleworking. Besides, commuting and work patterns and even level of ability to implement telework may be different in different countries. There also may be differences in commute mode and distance, rebound effects, efficiency of heating and cooling of company and home offices, emission factors from energy use and electricity generation, and other factors which all should be taken into account. Further limitations concerning data collection and literature review have been introduced in paragraph 2 Data collection and methodology on page 10.

1.4 Summary of Thesis´ Structure

This thesis is basically organized in four parts. The first part displays general data collection and methodology. The second part concentrates on the term teleworkability and its scope in different nations and economies, while the third part focus on possible impact of telework on CO2 emission and introduces its benefits and so-called rebound effects. The last part offers a basic general tool for estimation of possible reduction of carbon dioxide emissions per day for each teleworker in Austria, as well as a sensitivity analysis. The thesis is structured as follows. Chapter 3 displays the problem of telewokability including the factors that affect it. Additionally, a brief explanation of the key terms is given in the same chapter. A review of earlier studies on job transformation, telework potential and linked rebound effects are presented in Chapter 4. Chapter 5 is the core of the thesis and includes calculation and a proposed basic tool for CO2 reduction-estimation in Austria and a sensitivity analysis represented in Table 1. Chapter 7 includes some of the future CO2 emission prospect. Conclusion, as well as key findings and possible takeaway that may be used to future research are represented in Chapter 7. Chapter 8 includes all references used in the thesis.

2 Data collection and methodology

Many previous studies examined the extra benefits of multiple databases on various subjects. Some came to the conclusion that conducting a single database search could be sufficient since doing so would not change the outcome. Others, however, have come to the conclusion that retrieving all references for systematic reviews cannot be done using a single database. The majority of studies on this subject base their conclusions on database coverage. However, no real conclusions could be derived on establishing an appropriate amount of needed reads for adding an extra database. It's possible that a search in a database would not show an article even though it is present there. Due to this significant limitation, it is still unclear which or how many databases are required to find all relevant references for a systematic review. Therefore, searching as many databases as possible, represents an advantage and is shown to be a best policy. By examining actual retrieval in various databases, a few studies investigate the likelihood that a single database or various combinations of databases will return the most pertinent references in a systematic review (Bramer, 2017).

A systematic literature review method was used in this thesis, as well as meta-analysis literature review. When searching for relevant references within a systematic literature review, it is advisable to use several databases in order to sufficiently select relevant literature on a specific topic. However, since the syntax of search algorithms varies depending on the database, searching databases can be demanding and time-consuming (Bramer, 2017). In this thesis seven different databases platforms were included in the statistics research, including Google Scholar (Goo), Scopus (Sco), Science Direct (Sci), Semantic Scholar (Sem), WorldCat (Wor), JSTOR (JST) and NDLTD (Dissertations and Thesis) (NDL). All of the seven chosen Platforms have similar search algorithms and searching tips.

In the first part of the research which is based on systematic literature review, every database Platform on a specific term - telework, including its synonyms was searched. So the chosen keywords included *telework*, *telecommuting*, *home office* and *remote work,* as well as *teleworkability*. After collecting the number of documents on every keyword separately, all the keywords were combined using Boolean operator OR to get a total number of documents from every platform (see Figure 1). As shown in Figure 1, the initial research hit almost 9.000 matches on Scopus, around 25.000 on Science Direct an JSTOR, over 40.000 on WorldCat and Semantic Scholar, almost 1.500 on NDLTD and over 700.000 on Google Scholar. It is important to mention, that only around one quarter maximum of the documents have had open access. In addition, Figure 2 provides a number of documents published and uploaded on each platform, each year from 1990 to 2023. On every of this platforms quotation marks can be used to search for exact phrases or expressions and by using parentheses it is possible to group your search terms and control their order.

When analyzing Figure 2 we can conclude that the research peek on almost all of the database platforms was hit in the period between 2020 and 2022. Possible explanation could be that the rapid increase in telework during and after the COVID-19 period led to an increased interest in research regarding telework and other flexible work practices. The most conclusive peek is visible by WorldCat in the same period as well as in the years 2006 and 2007. The explanation may simply lie in the fact that WorldCat displays different sources including audio books, all kind of visual media, pictures, musk sources, magazines and other.

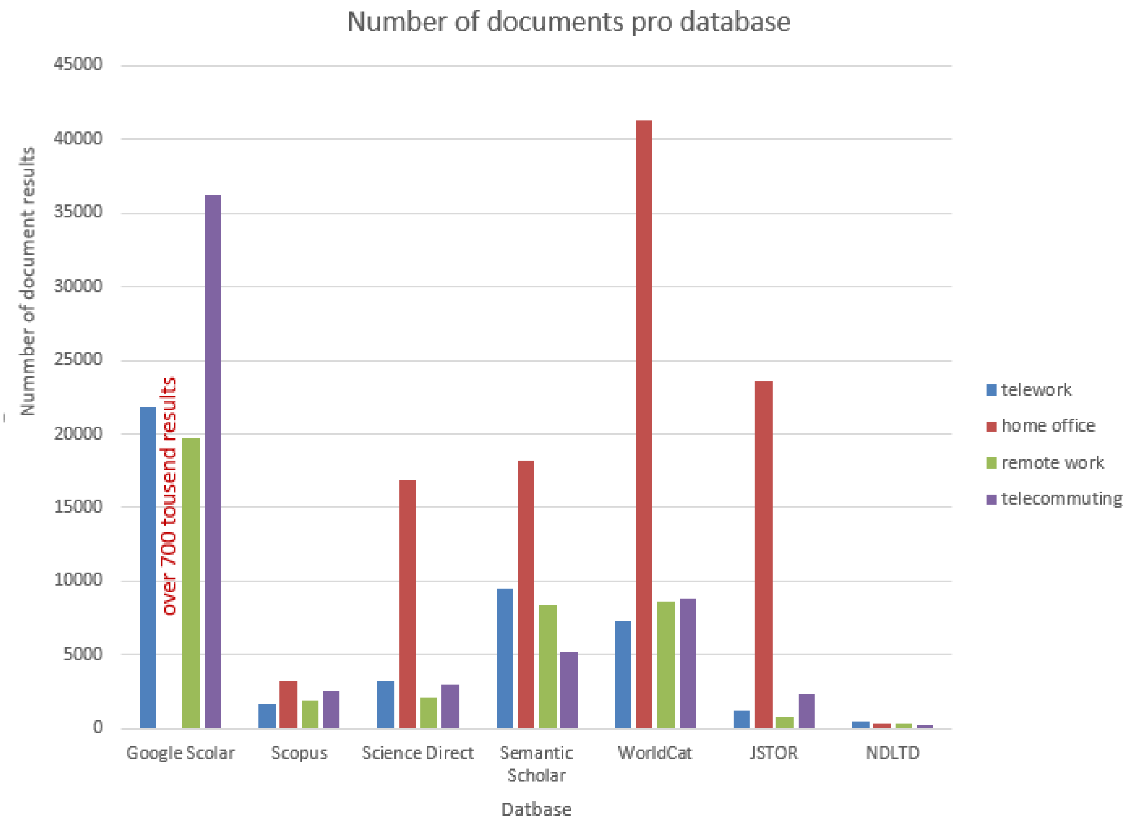

Figure 1: number of documents on every keyword searched, pro database platform

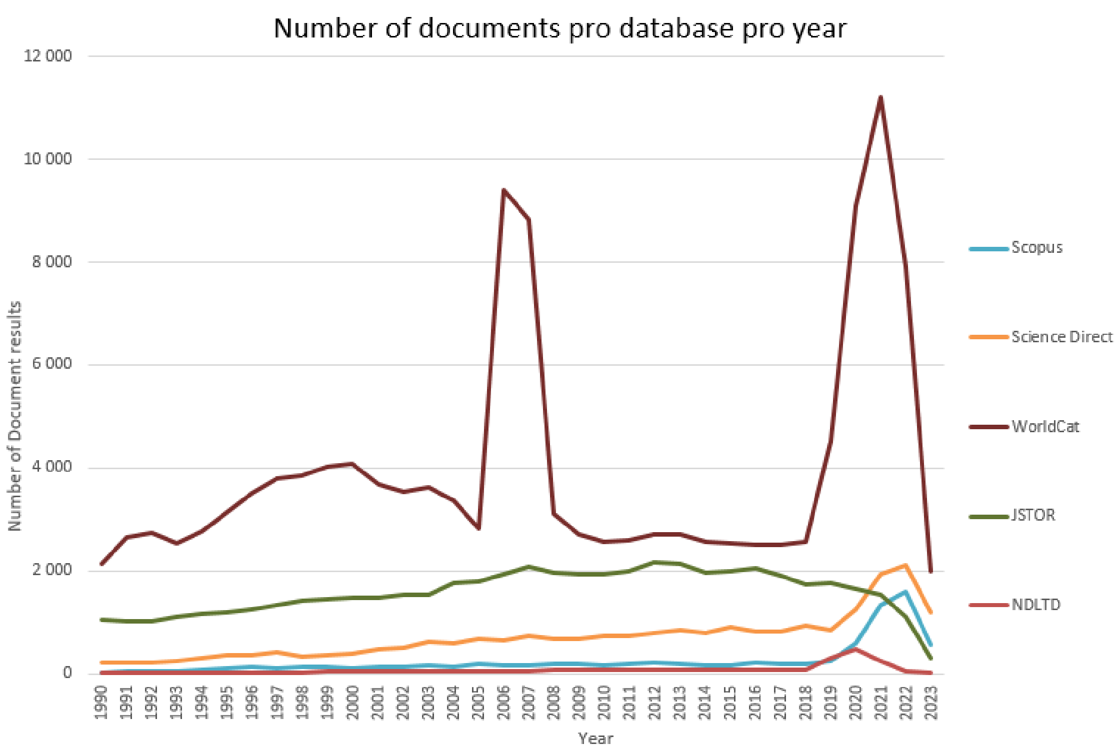

Figure 2: Number of documents added from 1990 to 2023 on different database platform

However, there are several limitations that have been discovered and acknowledged during the literature review. First, there is no easy and effective way to compare different database platforms and sort out the unique from identical documents, except going through all of them and comparing them one by one, which would be very time-consuming. Second, evaluation of the quality and relevancy of the search results is crucial after obtaining them, as well as checking if the source is current and relevant. Google Scholar for example, adds relevant articles not found in the other databases, possibly because it indexes the full text of all articles. As a result, it identifies articles in which the topic of research is not mentioned in title, abstract, or keywords, but also where the concepts are only presented in the complete text. That is why searching in Google Scholar gives the most results. It is therefore important to employ selection criteria including authority, accuracy, relevance, and scope because not all sources are reliable or relevant to your research subject. To narrow a search scope and adapt it to your criteria, most of the platforms offer using filters, or at least it is possible to use Boolean operator AND in combination with the chosen keywords to achieve the goal.

The second part of the research includes meta-analyses of the collected data from the first part and its more detailed examination. The goal was to find out which are the most frequent topics linked to telework, in order to define fields of interest of previous authors regarding to telework and their coverage. The research focused on *telework* or *telecommuting* or *'home office'* or *'remote work'* appearing in documents published between 1990 and 2023. The result of the initial research on Scopus was almost 9.000 of which 3.000 with the open access, but after implementing certain additional filters like subject area, the results varied and is shown in Figure 3. On the other side, NDLTD and Google Scholar provide no such filter and specific subjects can be searched only in combination with a keyword, using Boolean operators.

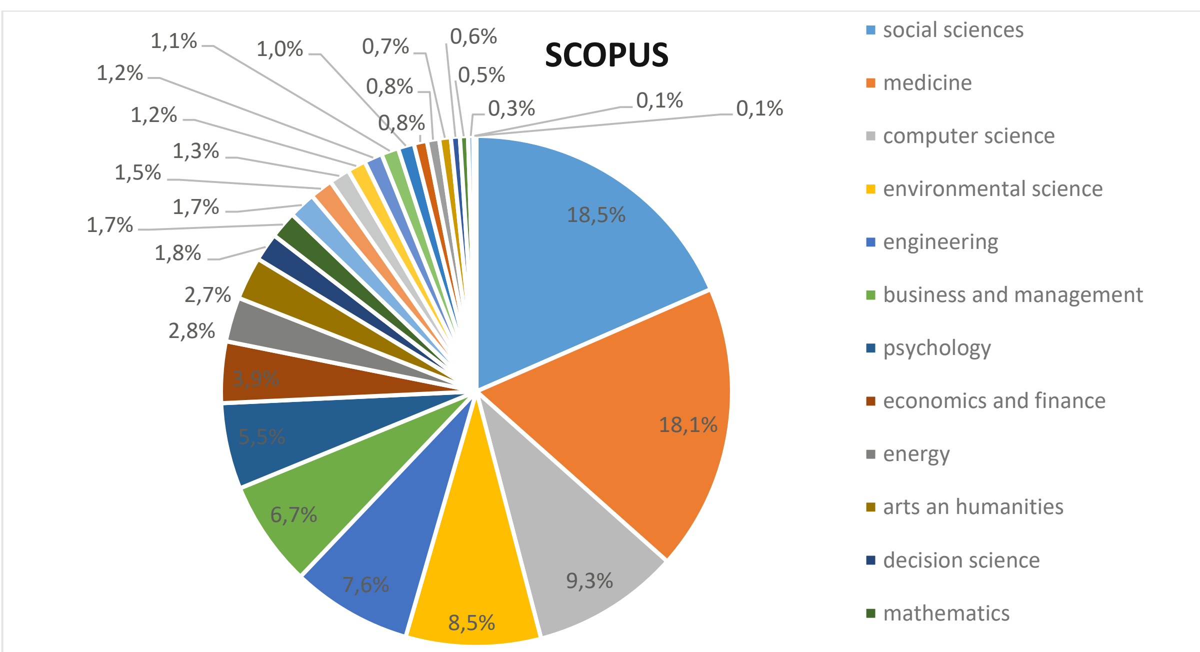

Figure 3: Subject area filter on Scopus search platform given in percentage

Similar was analyzed in ScienceDirect and JSTOR where instead of over 25.000 documents only 6.000 or 3.000 had open access, respectively. Further results with subject area filter on ScienceDirect can be observed in Figure 4. Results given by searching the same key words on SienceDirect in combination with *transportation* or *mobility* included over 6.000 documents, almost 1500 of them with an open access, while combination with *air pollution* or *CO2 emission* left us with 1800 results, less than 300 with an open access. The results by subject area are illustrated in Figure 6 and Figure 5.

When searching keywords *telework* or *telecommuting* or *'home office'* or *'remote work'* in combination with "CO2 emission" or "air pollution" or "rebound effects" on Scopus, the result showed that only 5% of 3000 documents are linked to this subject area, most of them in engineering, energy and environmental science. This sums up to 167 document results, with over 90 of them released in the period from 2020 to 2021. Most of the researches came from the United States. The same searching method delivered over 5000 documents on ScienceDirect and only 16 on JSTOR. On the other hand, the same keywords in combination with *"teleworkability"* or *"ability to work from home"* gave only 7 results in total on Scopus and over 90 on SemanticScholar.

After reading the abstracts of all the suggested relevant documents, not more than half of them remained as actually relevant and useful in purpose to this research. For the last part of the research, as the main data source was used Google and Google Scholar. All used citations are listed in paragraph 8 References.

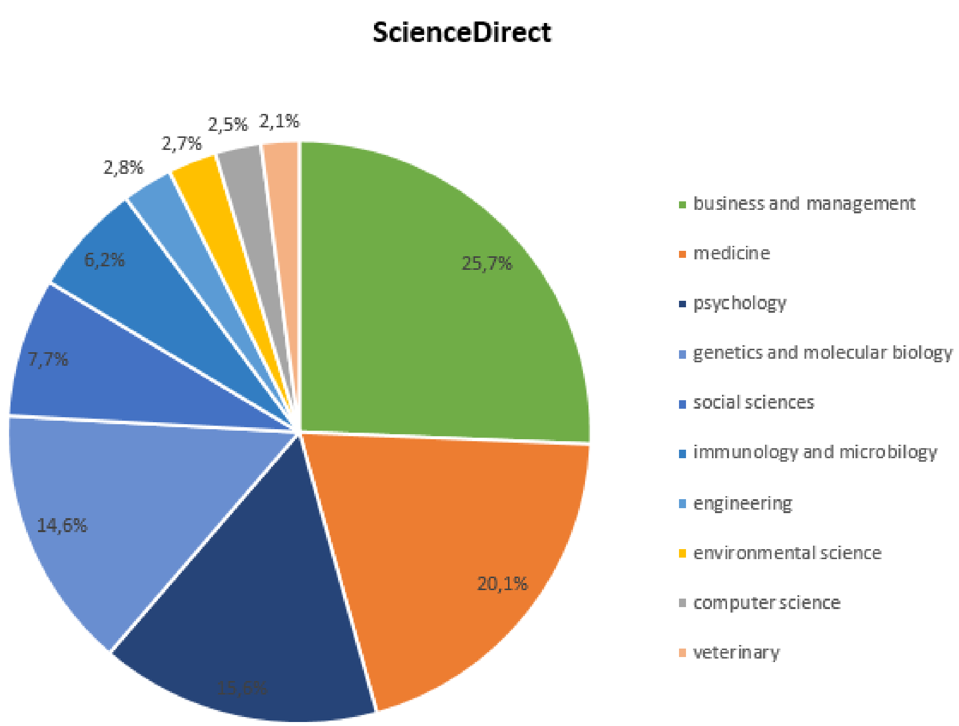

Figure 4: Subject area filter on ScienceDirect search platform given in percentage

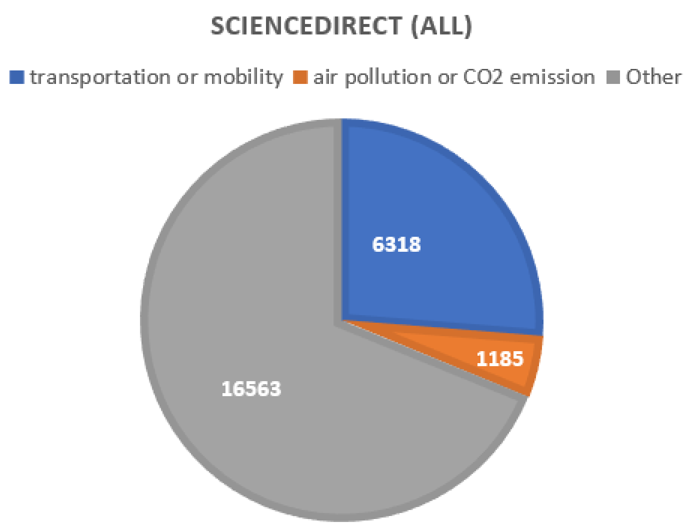

Figure 6: Total number of documents on ScienceDirect after combining key words *telework*, *telecommuting*, *home office* and *remote work* with the key words *transportation* or *mobility* and *air pollution* and *CO2 emission*.

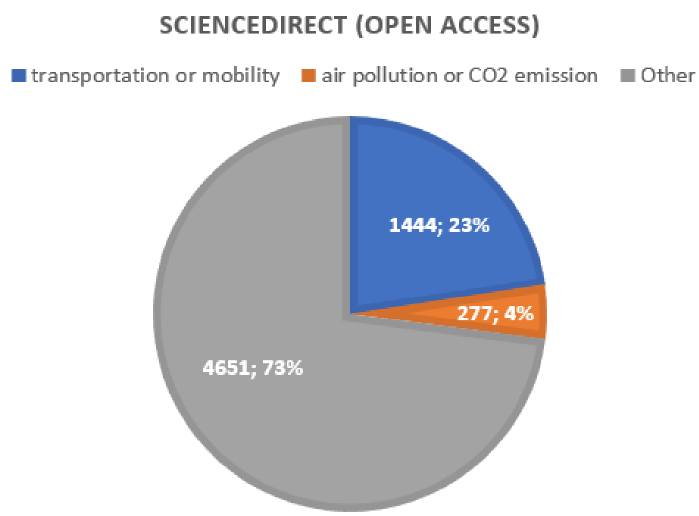

Figure 5: Number of documents with an open acces on ScienceDirect after combining key words *telework*, *telecommuting*, *home office* and *remote work* with the key words *transportation* or *mobility* and *air pollution* and *CO2 emission,* also given in % (percent).

3 Telework-ability

3.1 Literature review

3.1.1 Definition of the terms

The term *First World* initially referred to the capitalist, industrialized nations that were under the influence of Western Europe and the United States, such as NATO member states. The phrase also refers to some of the former British colonies, including Australia, New Zealand, and South Africa, as well as other industrialized nations like Japan. The former industrialized communist-socialist states, as well as the territory and sphere of influence of the Soviet Union including ex Yugoslavian and (formerly) communist Asian countries, are referred to as the *Second World*. The term *Third World* is today often used to describe the countries of Africa, Asia, Latin America, and Australia/Oceania with inferior, underdeveloped, or underachieving background, which are eager to develop further (nat)(see Figure 7).

Another term often mentioned in literature is *blue and white collar workers*. It represents a classification, frequently used to group workers into distinct groups. Both phrases refer to various things, including the kinds of labor that are done and how individuals are compensated. For instance, blue-collar workers are typically paid by the hour or on a piecework basis and typically undertake physical labor. On the other side, white-collar employees are those who work in administrative, management, or clerical capacities in an office environment. Typically, these individuals get an annual wage. But the main difference of the two is that they have different educational backgrounds.

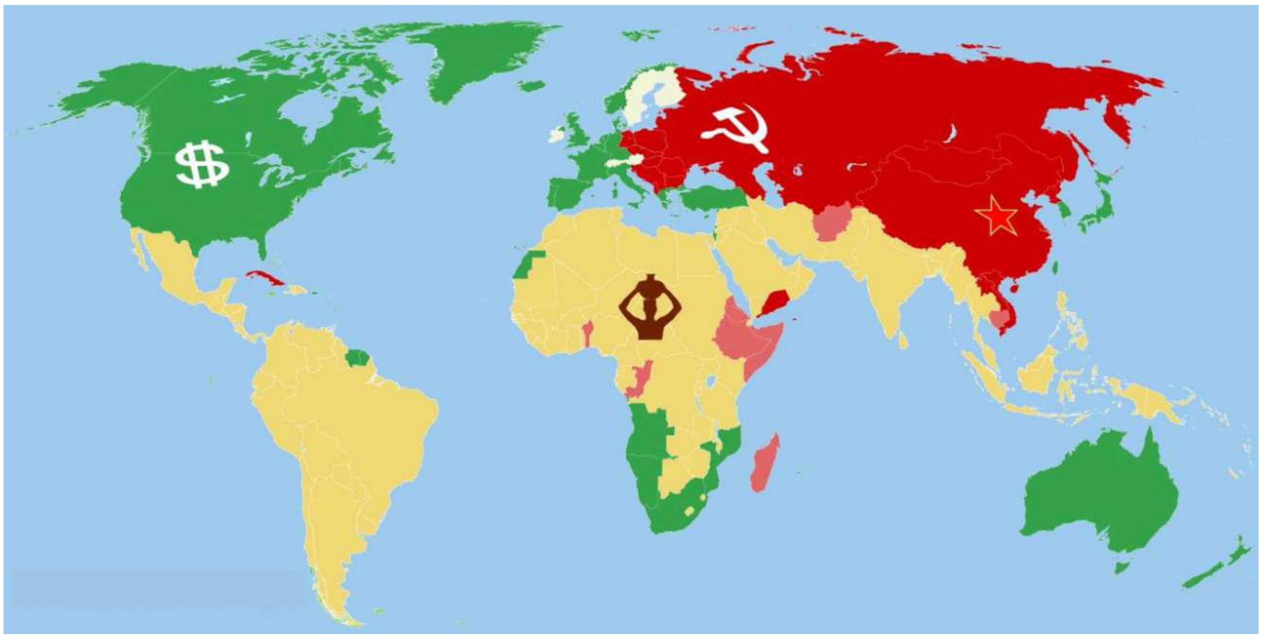

Figure 7: "Worldmap of the First, Second, and Third World. The map shows the countries of the US aligned countries of the First World (in green), the Second World (in red), the Third World (in yellow). European neutral states (in white), and countries which have been communist nations for a short period in light red." (source: (nat))

3.1.2 Economic sectors

The original definition of the economic sectors come from the economy and only consists of three sectors. They serve to classify the labor market into different areas. The primary sector includes the extraction of raw materials, the secondary sector deals with the processing of these and the tertiary sector includes all services (Sostero Matteo, 2020). In addition to the 3 economic sectors, two other sectors are sometimes mentioned: the quaternary sector - knowledge and the quinary sector - an extension of the tertiary/quaternary sector.

The primary sector is the oldest economic sector, which is about production in its most original form: the extraction of raw materials and agricultural goods. This sector includes jobs in farming, forestry (wood harvests and hunting), as well as fishing and mining. Inverse correlation exists between the primary sector and the level of development of a state. This means that the lower the number of employees of a country in the primary sector, the further the country is developed.

In developing countries, however, the primary sector is very large, but small in industrialized nations (O´Neil, 2023). The secondary sector jobs include manufacturing and construction or simply processing the raw materials of the primary sector into more valuable, manufactured goods. The further processing takes place by industry, the craft, the energy industry and the water supply. The construction industry is also included since buildings and other objects are fundamentally being manufactured in this situation (O´Neil, 2023).The tertiary sector includes all services that are provided in a country. In contrast to the primary and secondary sector, it does not deal with raw materials or property goods. This sector includes jobs and people that we interact every day with, like bus drivers, restaurant workers, sales people, and pharmacists, but also banks, trade, insurance, tourism. The tertiary sector is obviously very personnel –intensive (O´Neil, 2023). The proportions of economic sectors in selected countries and countries of the first, second and third world in general ,given in % (percent) can be observed in Figure 8 and Figure 9.

To explain the relationship between digitalization and energy usage, one paper uses the sectoral shift that results from digitalization (Steffen Langea, 2020). The issue at hand is whether, as some claim, tertiarisation goes hand in hand with digitalization. If this were the case, energy consumption may drop since services have a lower energy intensity than industrial output. The value contributed from ICT services, such as software publishing, IT, and other information services, has been increasing in OECD nations while the value added from ICT commodities, such as ICT manufacturing and telecommunications, has been declining (2019). The value contributed in ICT manufacturing has essentially remained unchanged, whereas the value added in ICT services rose by 18% for 16 EU nations between 2010 and 2016. This is according to Eurostat (Eurostat, 2019). The movement of production to nation of the Global South, like China or India, where the manufacturing in the ICT industry has been increasing quickly, is one potential explanation for the disparity in sectors represented in Figure 8 and Figure 9.

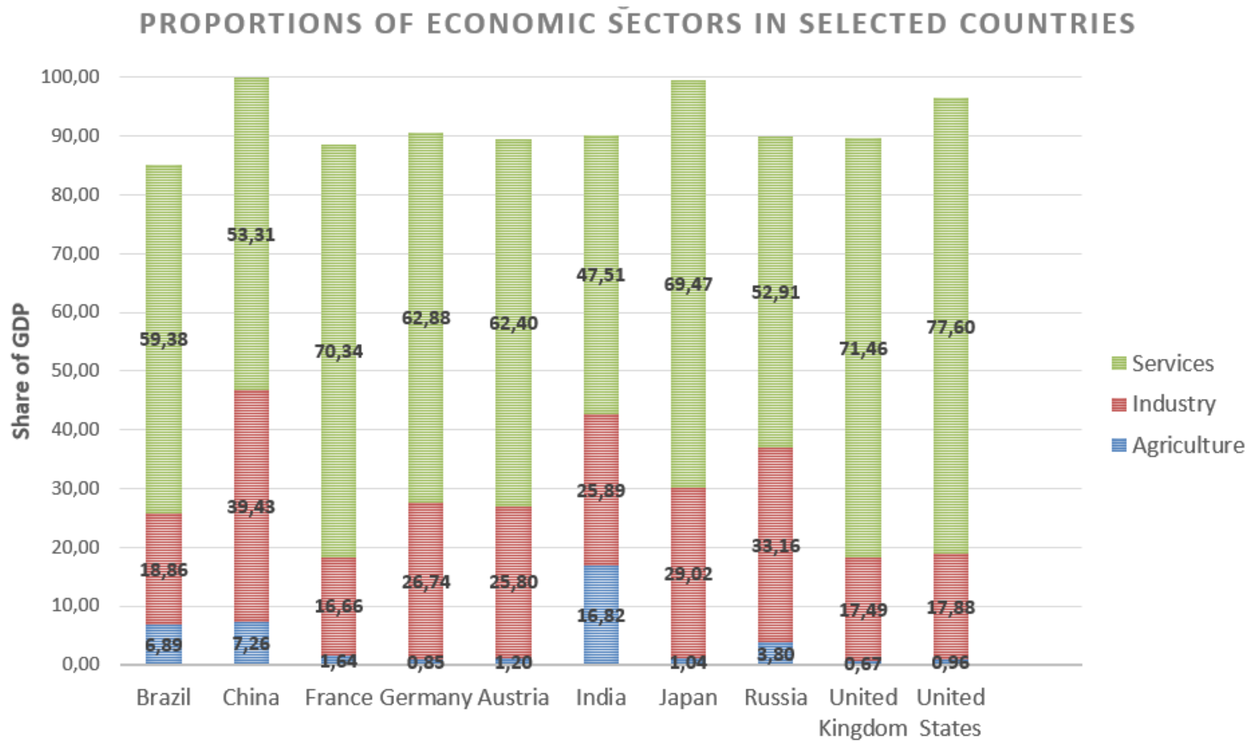

Figure 8: Share of economic sectors in gross domestic product (GDP) in selected countries in 2021 given in % (percent) (Data source: (The World Bank))
Note: The source does not provide any information regarding percentage points not adding up to or exceeding 100 percent.)

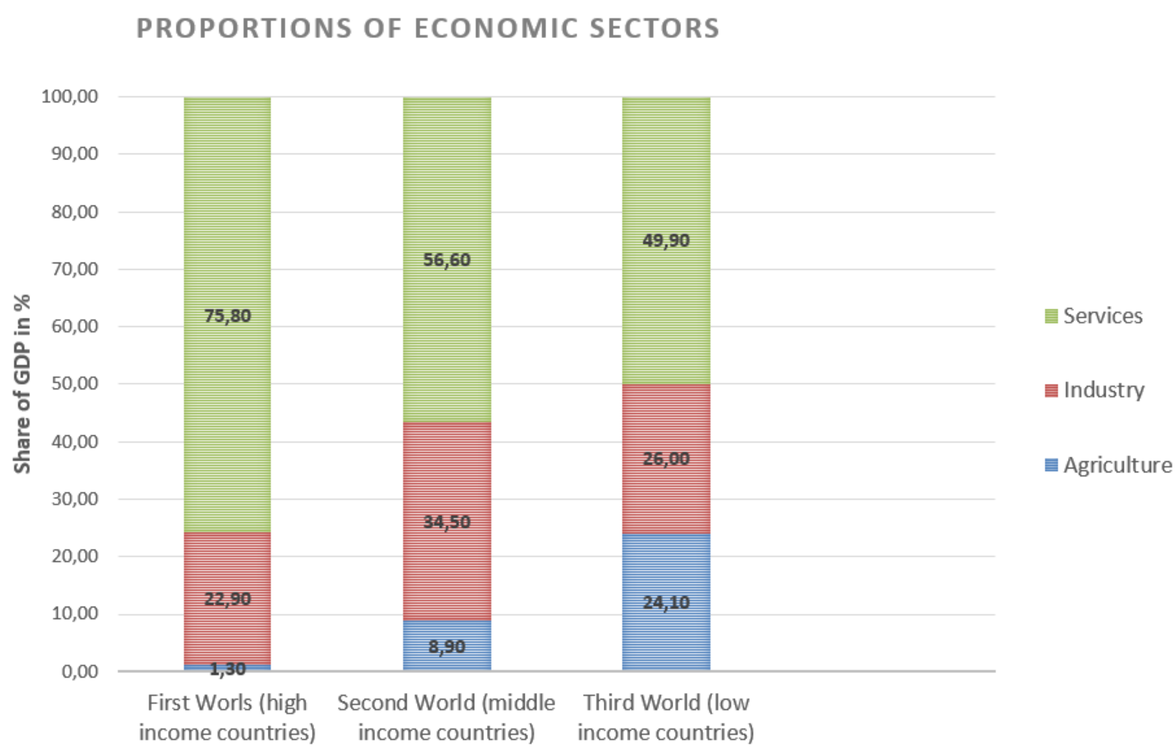

Figure 9: Share of economic sectors in gross domestic product (GDP) in countries of the first, second and third world given in % (Data source: (The World Bank))

3.1.3 Who can work from home

This section lays forth a clear theoretical framework for classifying jobs according to whether they can be technically completed remotely, as well as introducing and explaining other factors that may impact level of implementation of telework in a system. The effect of working from home on energy consumption at each household varies greatly depending on a number of factors connected to the season and the area, points out one study. The authors of the study wonder what would occur if working from home became frequent in all societies and highlight the importance of the factor how many individuals *can* actually work from home, as an answer to this question (Crow, et al., 2020).

"*The Third World is not only largely excluded from wealth, but also from technological progress*" says Fuchs (Fuchs, 2006). Despite making up over 20% of the global population, just 11% of Internet users worldwide are from Africa (data from May 2023, source: (Statistics, 2023)) However, in comparison with the data from 2005 it seems that technology development is rising rapidly even in the developing countries in the last two decades, which could therefore mean an increase of teleworkability in those countries. Another study estimated that 20% of all jobs could presumably be performed from home. In the richest nations of Europe, this number rises up to more than 45% versus about 10% in sub-Saharan Africa for example. The ability to work from home generally has a favorable relationship with GDP per capita. This is a reflection of the fundamental disparities across nations' economies and occupational systems, as well as their levels of digital preparedness (Crow, et al., 2020). However, even jobs that are compatible with remote work may face challenges, such as the lack of a dedicated workspace or the nature and complexity of tasks (Georgina Santos, 2022).

3.1.4 Factors that affect telework-ability

1) Education and income

Many researches advocate that level of education and level of income have a significant impact on the level of teleworkability in a country (Daniel Garrote Sanchez, 2021). According to the World Bank, over 70% of labor force in high income countries has advanced education, while around one quarter of labor force in low income countries can claim the same, ILO estimates (ILO, 2020). The International Labor Organization (ILO) predicted that during the pandemic, half of the workforce in high-income parts of the world, such as North America and Western Europe, was able to work from home. A research from European commission and Eurofond on telewokability from 2020 claims that, close to 40% of workers in Europe with tertiary degrees worked from home occasionally, compared to an average of 10% for those with secondary degrees and about 3% for those with little to no education. Similar to this, almost 25% of employees in the top quartile of the EU income distribution have access to telework; however, this percentage drops to less than 10% for those in the lowest half of the income distribution (Matteo Sostero, 2020). Based merely on the makeup of respective workforces, the same research claims that EU member states' shares of teleworkable jobs differ. This indicates that teleworkable employment is more widespread among nations with higher percentages of white-collar jobs and the industries in which they are more common. However, the estimates are unable to account for variations in ICT technology, legislation, and company size among member states. As it can be notable from the following chart (see Figure 10), the spectrum of teleworkable jobs lies at 27% in Romania and somewhat more than double that (54%) in Luxembourg. The Nordic and Benelux countries often have the largest percentage of teleworkable jobs, which is strongly correlated with the ranking of nations by preoutbreak teleworking prevalence. Eastern Europe and several of the bigger member nations in Southern Europe, like Spain for example, have the lowest proportions, while EU´s average lies by 38% (Matteo Sostero, 2020).

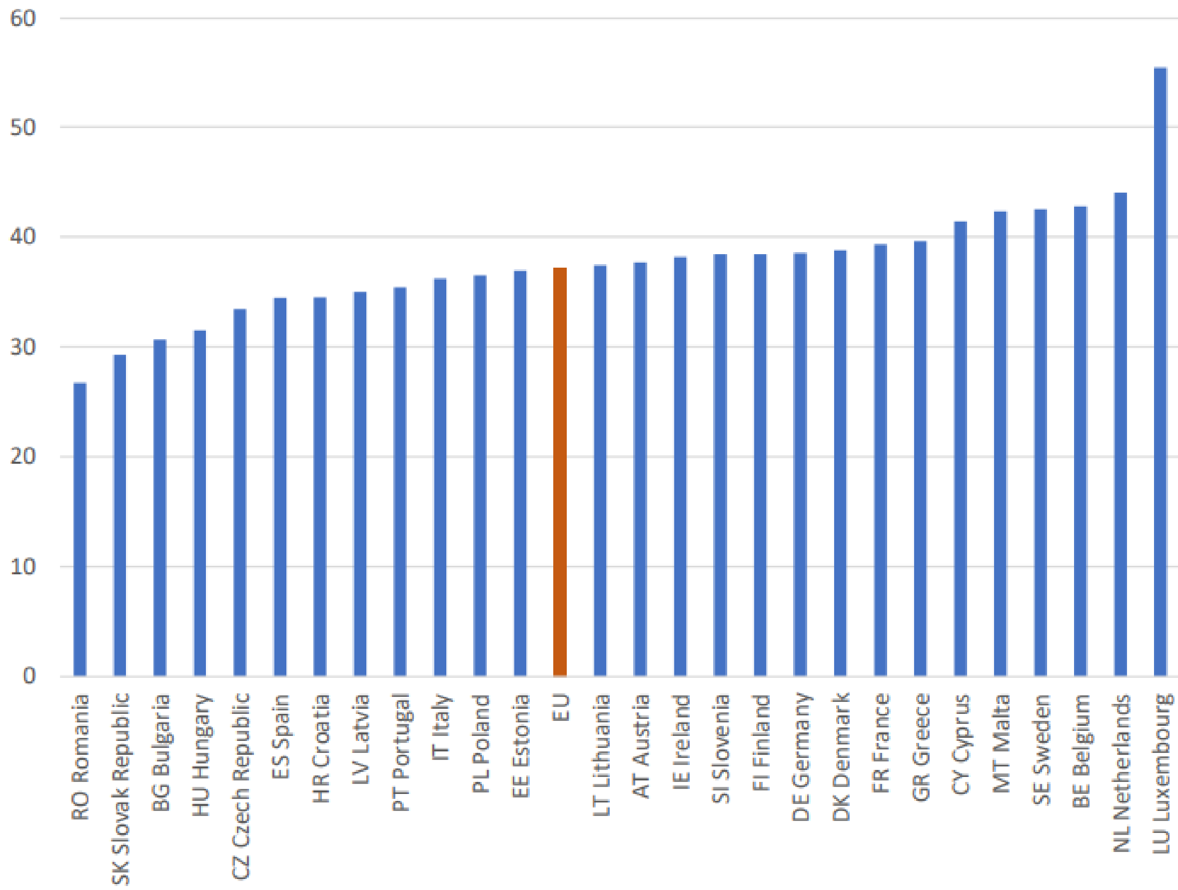

Figure 10: Share of teleworkable employment in EU countries given in percentage (Source: (Matteo Sostero, 2020))

As one study claims, least likely to be able to work from home are poorly educated workers (Daniel Garrote Sanchez, 2021). This has to do with the previously mentioned obstacles like limited access to reliable internet connection and inadequate availability of essential technological devices. According to one survey, one out of every five occupations worldwide can be done from home. This proportion falls to one job out of every 26 in low-income nations. One could assume that this new trend anticipates a rise in inequality, especially in wealthy nations where higher paid and educated individuals are enjoying better working conditions and managing advantages since they are more likely to be able to work from home (Daniel Garrote Sanchez, 2021).

Global disparities existing in economic sectors, energy use, and the consumption patterns, are also present when talking about emissions of carbon dioxide (CO2). Emissions vary significantly among nations, generations, and income categories (Laura Cozzi, 2023). The average North American in 2021 produced 11 times more energy related CO2 than the average African, shows the research. However, differences across income groups are the most consequential. According to this study, in 2021, the top 1% of emitters had carbon footprints that were more than 50 tonnes of CO2 per person, more than 1000 times larger than the carbon footprints of the bottom 1% of emitters, while the average carbon footprint associated with energy use worldwide was around 4.7 tonnes of CO2 per person. These drastic divides are an obvious indicator for the existing differences socio-economic factors like wealth, energy consumption and lifestyle in general (Laura Cozzi, 2023).

2) Internet access and ICT

Internet access is an important precondition for being able to work from home. While 90% of high income countries´ population has the privilege of utilizing internet, 80% of individuals in low income countries face the challenge of unreliable or no internet access (The World Bank).

With the development of communication and information technology (ICT) over the past several decades, employment have changed notably in type and task content, which has contributed to the increase in the availability of home-based labor, primarily observed in affluent nations. Particularly, high-skilled occupations that require substantial cognitive abilities and can be effectively performed remotely have built up due to the ICT revolution (Daniel Garrote Sanchez, 2021).

The absence of the internet is one of the main barriers for working from home for a lot of positions. The digital divide represents a cycle of limited economic mobility which further disrupts a worker´s ability to connect with their employers, access online job platforms, take part in virtual meetings and perform tasks that are dependent on online collaboration. Even when a certain job is in theory suited for being done remotely, that option may in fact not be accessible if the employee's place of residence does not carry proper equipment and needed digital devices. D. G. Sanchez, N. Gomez Parra, C. Ozden, B. Rijkers, M. Viollaz, and H. Winkler did a research on teleworkability based on detailed information on occupation characteristics from the O* NET surveys. In order to display the significance of ICT and precisely quantify the meaning of its restriction they first divided the telework jobs into four different types of occupations: (a) those that can be performed from home and require internet; (b) those that can be performed from home without the use of internet; (c) those that cannot be performed from home and do not require internet; and (d) those that cannot be performed from home but do require internet. In the second part of the research, the same authors tried to rate the actual availability of internet services by occupation and country. The research included 107 countries out of 180 for which 2-digit occupations were available. Based on the standard DN2020 metric, 23.9 percent of all jobs possess the potential to be successfully carried out from the comfort of one's home. Yet when the critical factor of internet access is taken into consideration, this promising percentage experiences a slight decline, falling down to 18.7%. (A definition and further explanation to The International Classification of Occupations (ISCO) can be found on the following website https://ilostat.ilo.org/resources/concepts-and-definitions/classification-occupation/)

The authors came to the conclusion that in the United States, 33.3 percent of all jobs can be performed from home and require internet access—e.g., fall into group (a), similar like in Europe – 37%, another research claims (Matteo Sostero, 2020), while an additional 3.3 percent can be accomplished from home without internet usage—e.g., fall into group (b). After applying their occupation-level measures to other countries, the authors determined that around 30% of all examined job in affluent countries could easily be done from home if proper internet access existed, whilst slightly over 2% of the jobs could be performed from home in low income countries with the same conditions. Further information from this research can be observed in following charts (Daniel Garrote Sanchez, 2021) (see Figure 11 and Figure 12).

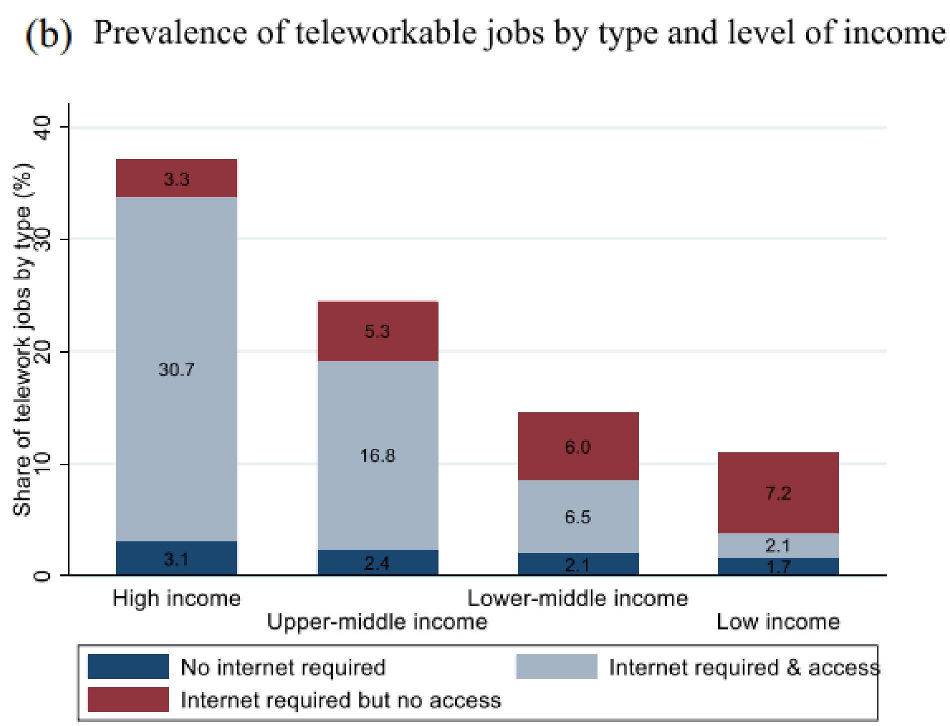

Figure 11: "Source: Authors' elaboration based on income and employment data from International Labour Organization (ILO), internet requirement from O* NET surveys, internet access from the 2019 Gallup World Poll (GWP) and GDP per capita from the World Development"

The presented chart demonstrates that a relatively small percentage of telecommutable jobs can be done without regular demand of internet connection. The average proportion is little over 3%, and no country has a share higher than 5%. Therefore, very few tasks can be successfully completed from home without internet connectivity. Developing nations suffer from two disadvantages: first, they have fewer employment that allow for remote work, and second, internet access is far more restrictive there than in wealthier economies. 11% of all occupations in low-income nations are telecommutable. Only 3.8% of such tasks, however, can be successfully carried out from home.

(a) Home-based work vs GDP per capita

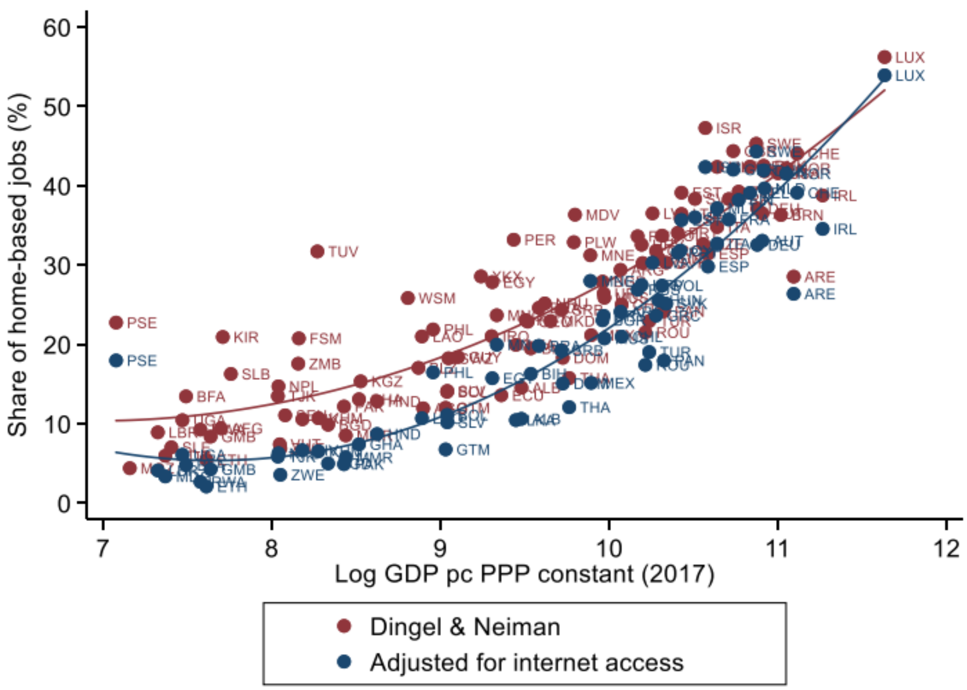

Figure 12: "Source: Authors' elaboration based on income and employment data from International Labour Organization (ILO), internet requirement from O* NET surveys, internet access from the 2019 Gallup World Poll (GWP) and GDP per capita from the World Developmen

At the same time, the lack of internet connection in high-income nations only prevents one out of every twelve telecommutable occupations from being effectively conducted from home (3.3 percent of 37.1 percent). As a demonstrative example, around 9 percent of all jobs in Rwanda display the potential for remote work according to the DN2020 measure, while taking onto account internet access lowers the frequency to less than 3%. On the other hand, in countries like Switzerland or Sweden, this bias stays trivial which only proves that barriers on internet access are of little significance (see Figure 12) (Daniel Garrote Sanchez, 2021). Another research from GALLOP discovered that in out of 148 surveyed countries in 41 less than 10% of population (with only adults taken into account) reported no internet access at home in 2011, all of them with residence in Africa and Asia. An estimated 2.9 billion individuals, or 37% of the world's population (including children), have never used the Internet in 2021, according to data from the International Telecommunication Union (ITU), the United Nations' specialized agency for information and communication technologies (ICTs) ((ITU), 2021). ITU data also reveal that there is still a significant disparity in connectivity. 96% of the 2.9 billion people who are still offline, according to estimates, are in developing nations mostly of Asian and African continent.

As it can be deducted from the following chart (see Figure 13), more than half of the world's complete labor force is situated in Asia, Africa and the Pacific. Taking into account previous information that in 41 countries on these continents less than 10% of population have internet access, it is easy to come to the realization of why the majority of the labor force in mentioned countries is not able to work from home and take part in this so evolving trend.

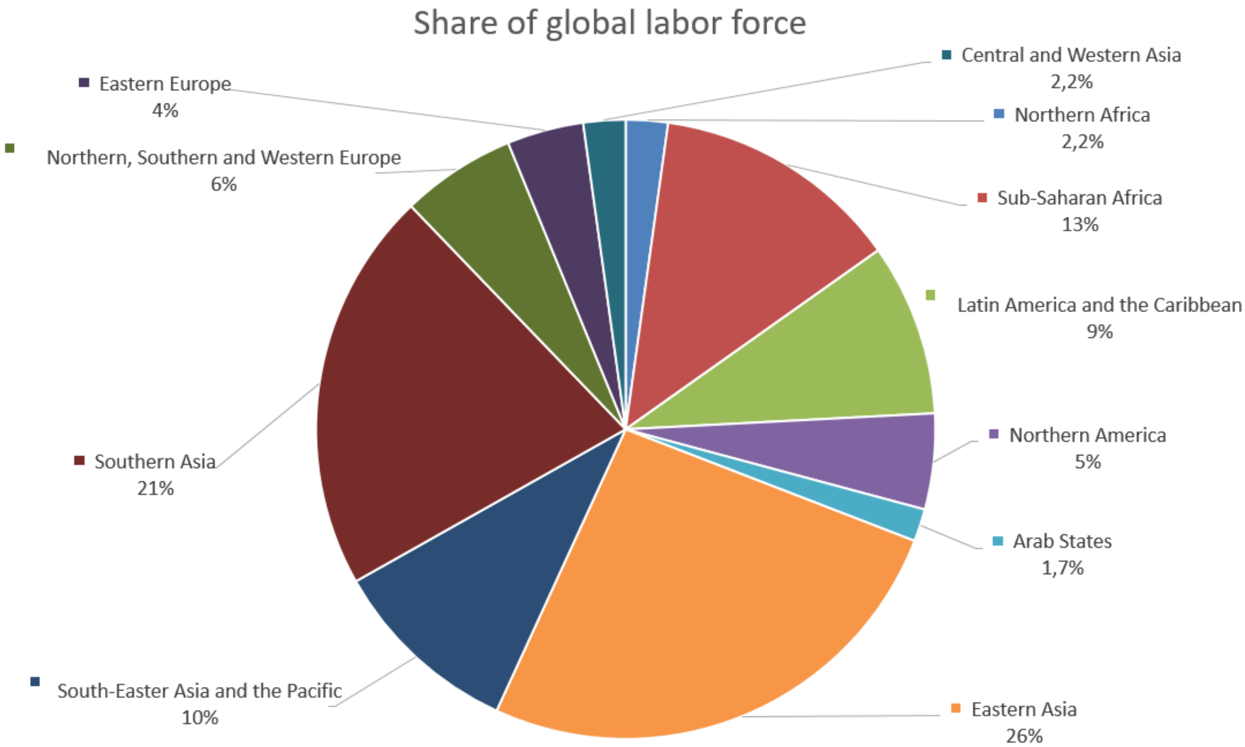

Figure 13: Regional shares of the global labor force (in percent), 2022. Source: ILO Modelled Estimates and Projections (ILOEST) Database, Nov. 2022 edition, ILOSTAT

3) Demographic factor

In comparison to rather poorer Southern European nations and EU member states in Eastern Europe, the percentage of home-based work tends to be larger in more developed parts of Northern European countries. However, it is important to recognize that there is a lot of variation within countries. According to the general principle, the work that is done in major cities like Madrid, Paris, Berlin, or Warsaw is more likely to be suitable for remote work than work done in more rural parts of the countries (Daniel Garrote Sanchez, 2021). As shown by M. Sostero, S. Milasi, J. Hurley, E. Fernandez-Macías and M. Bisello in their joint European Commission–Eurofound report, the employment share of telework-friendly professions is disproportionately high in major metropolitan regions. These areas with higher densities of population have historically had more congestion, which has led to longer commute times. This set of circumstances is where the first idea of telework was originally derived from (Matteo Sostero, 2020).

4) Job Type

The same research estimates that the proportion of jobs that might be teleworked in Europe (approximately 37%) is significantly higher than the actual pre-COVID-19-outbreak prevalence of teleworking (15%) across all countries in the world. This gap is equal to 43 million employees, or 22% of all workers, who might have worked from home but chose not to before the COVID-19 crisis. The second key finding is that dependent employees make up almost all of this gap space (see Figure 14 below) (Matteo Sostero, 2020).

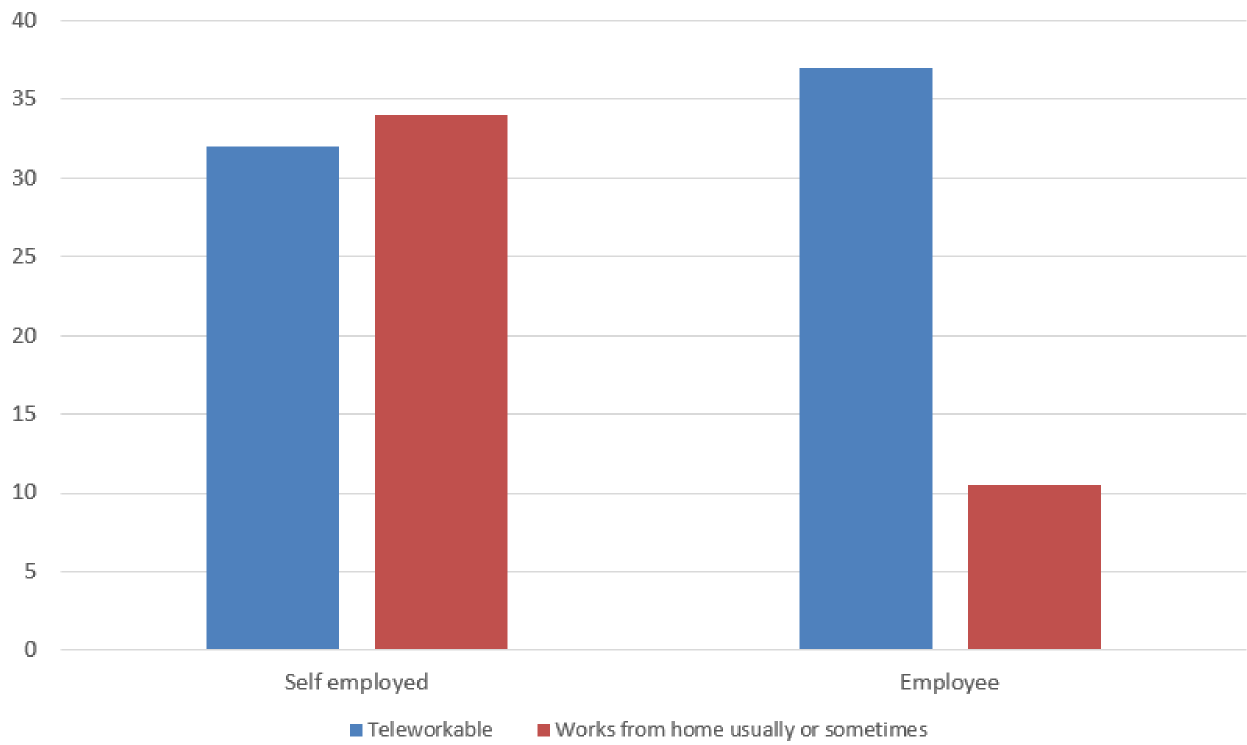

Figure 14: Share of teleworkable employment compared to incidence of teleworking (2018), Source: LFS. Note: 'teleworkable' refers to share of employment in teleworkable occupations according to our operationalisation; 'works from home usually or sometimes' refers to share of employment from LFS 2018 microdata

On the next chart, focus remained on the category of dependent employees, which comprises more than 5 in 6 workers throughout the EU countries and represents the area with the largest disparity between potential and actual teleworking. The distinction between white-collar and blue-collar occupations is the first notable variation in teleworkability (see Figure 15 below). In contrast to blue-collar labor (craft and related trades workers, plant and machine operators and elementary occupations barely 2%), where most occupational categories are not teleworkable due to the physical demands of the occupations and accompanying place-dependence, white-collar work (from 54% of associate professional employment to 85% of clerical support workers) is far more teleworkable (Sostero Matteo, 2020).

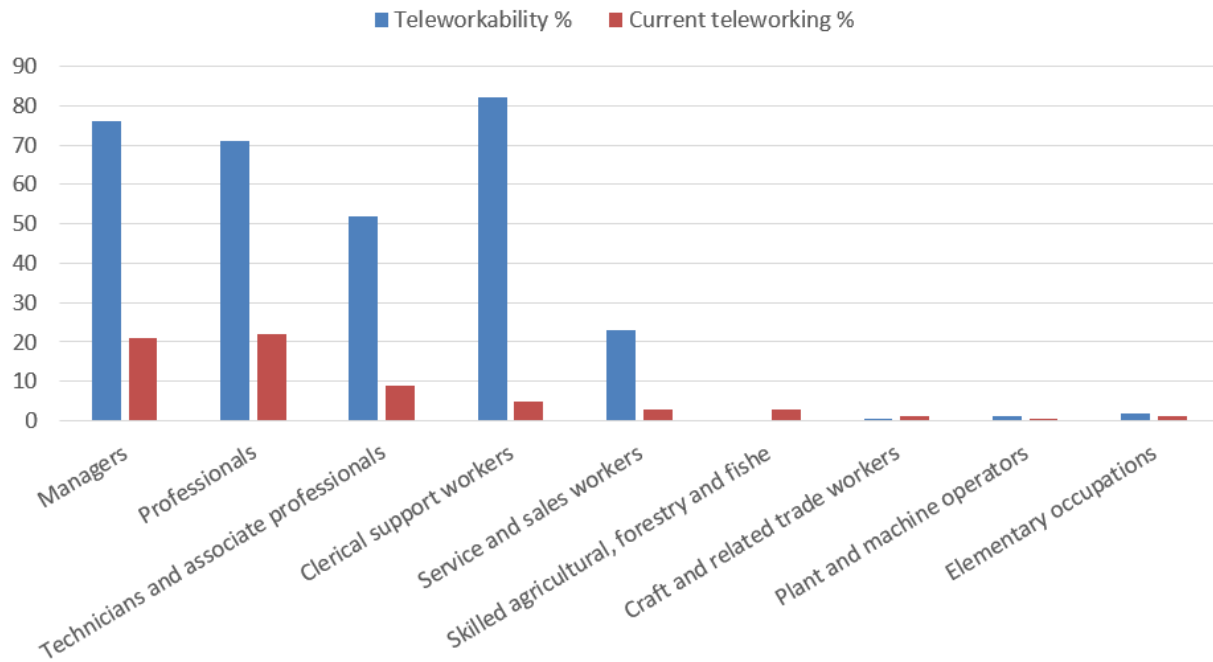

Figure 15: Teleworkability and actual teleworking among employees by broad occupation group. Source: LFS, COVID group. Note: employees only. "Teleworkability" refers to share of employment in teleworkable occupations according to our operationalisation; 'Current telework' refers to share of employment working from home usually or sometime according to LFS 2018 microdata

3.2 Results and Discussion

According to the newest data from ILOSTAT, global estimated labor force participation rate is 59.7% (ILO, 2020). This means that almost 60% of world´s population is employed, which does not necessarily mean that everyone is able to work from home. The different areas´ adaptability skills to remote working is significantly influenced by the geographical distribution of industries and occupations. In areas with higher degrees of rurality, there are naturally fewer occupations accessible from distance working. Nearly one-third of jobs in the majority of nations of the first world are thought to be completely suitable for remote work. Therefore, regions with higher percentages of jobs that can be performed remotely tend to be more urban in nature (OECD, 2021). This makes countries of the first world more suitable and easily adaptable to teleworking in general.

According to the sources of The World Bank (The World Bank), over 60% of the global labor force works in the tertiary sector, around 30% in the secondary sector and less than 10% works in the primary sector. After explicit observation of Figure 8 and Figure 9 one can notice that over 75% of the first world and just around 50% of the third world countries´ labor force works in the tertiary sector (services). On the other hand, almost 25% of the third world´s population is in the primary sector employed, whereby barely 1% of the first world´s population has jobs in the same sector.

A study done on University of Chicago demonstrates a definite positive correlation between income levels and the percentage of occupations that can be performed from home (Dingel, et al., 2020). As New York Times reported (Goldberg, 2023), a survey from March 2023. found that 40% of workers in USA are fully remote or hybrid and according to Eurostat in Netherlands over 60% of employed people work remote, whereby around 20% of workers in EU work remotely (Eurostat, 2019).

Even though poorer nations have lagged behind in terms of education for a while, and richer nations have traditionally benefited from better standards, the poor countries are catching up. In other words, education spreads more quickly in developing nations than in wealthy ones. In 1870, the U.S., Switzerland, and Norway had the greatest average number of school years, which was around five. On the other hand, most of the low-income nations in 1870, the average number of years in education was close to zero. However, schooling years surged in the middle of the 20th century. For instance, Bangladesh's average number of years in school (around eight) has almost caught up to that of Denmark and Norway (10 years) by 2010. By 2010, Malawi, Benin, and Uganda had around six years of education (Guillaume Vandenbroucke, 2020). Since education and technology go hand in hand with one other, this would also mean economic and technological upturn for those countries.

4 Impact of telework on pollution

4.1 Literature review

Several studies refer to telecommuting as an effective approach for reducing travel demand, particularly during the busiest times of the day, peak hours (Cerqueira Eugênia Dória Viana, 2020) (Röder, et al., 2019) (O'Brien, et al., 2020). This might sound encouraging, given the fact that, in Europe for example, almost 75 percent of the ultimate energy used is used by transportation, workplaces, residences and retail establishments, as one study claims (Röder, et al., 2019). The equation is yet not that simple.

The primary and oldest advocate of teleworking in the literature study on its environmental effects is the opportunity to reduce transportation demand and costs. In theoretical terms, teleworkers are able to eliminate all travel on teleworking days. The research is pretty clear in pointing out that teleworkers often only use teleworking rarely (once or twice a week), which drastically limits the potential. Also, eliminating the work-related travel, does not mean elimination of the car-use by other members of the family, which can even totally erase this potential (O'Brien, et al., 2020). Using a car for pleasure or shopping during worktime at home represents rebound effects that have to be considered. Although telework is anticipated to be an asset for energy conservation, its impact on energy consumption relies on how the technology and equipment is used in the office buildings and at home (Nakanishi, 2015). When telework is implemented, the energy consumption at the workplace, which is mostly utilized for air conditioning, lighting, and office equipment, is anticipated to go down. If the majority of employees visit the office, the office may remain open and the available space won't be reduced even though some people telework and don't come in (Nakanishi, 2015).

O´Brian and Alibadi gave a perfect illustrated example with underlined rebound effects in order to explain the complexity of the situation: “*Bob gets a new job in engineering consulting and brings his family to a new city as a result. Bob’s new boss allows him to work up to three days a week at home; this was used as a perk to recruit him from a different company. Because Bob’s wife plans to get a job a local school, wherever they end up living, Bob and his wife opt to live in the suburbs, about 30 km from the central business district where his office is located. He figures that this is a bit far to commute, but if he only must do it twice per week, then his average commute (normalized by five days per week) is merely 12 km each way. That’s better than the 15 km he used to drive each way to work every day. And now they can afford a much bigger house to accommodate their three teenaged children. Moreover, Bob’s company gave him funding to furnish the home office of his dreams. He’s got a powerful desktop computer with four LED monitors, a laser printer, and a heavily used high-speed Internet connection so he can videoconference with his colleagues and clients and use cloud computing. The office is on the second floor of the house and has big windows. As a result, the furnace (in the heating season) and central air-conditioning (in the cooling season) are often running on full to keep Bob’s office comfortable, even though the family is away and the rest of the house is unoccupied. At work, Bob has a dedicated cubicle. Because he is free to choose which days he works from home and the company is relatively small, it is not worth risking letting someone else use Bob’s cubicle in case he needs to come into the office. After all, Bob’s salary is still an order of magnitude higher than the employer’s cost to lease his cubicle. The open-plan office where Bob’s cubicle is located has overhead lighting that is controlled by a schedule for the entire space even when he’s working from home. Bob leaves his computer on most of the time because he may need to access his files from home. Back at home, now that Bob’s car is in the driveway three days a week, his teenaged children drive to school (even though it’s within walking distance) and they each drive to an after-school sporting activity that would not have been possible if Bob drove the car to work. The kids recommend that the family buy a bigger car next time; Bob figures they can justify a less fuel-efficient car since he’s commuting so much less now so the gas bill won’t be too expensive. While Bob used to pick up some groceries for dinner on the way home from work, he or his wife now drive 7 km to the nearest suburban big-box grocery store.”* (O’Brien, et al., 2020)

This only proves the fact that working from home should not be considered a completely eco-friendly way of living. Its assessment requires consideration of various factors beyond the simple notion of reduced carbon footprint resulting from individuals staying at home. Therefore, there is a certain complexity that should be considered, when evaluating its environmental impact. Conceptual relationship between zero impact, potential of telework and rebound effects can be observed in the following illustration (see Figure 16).

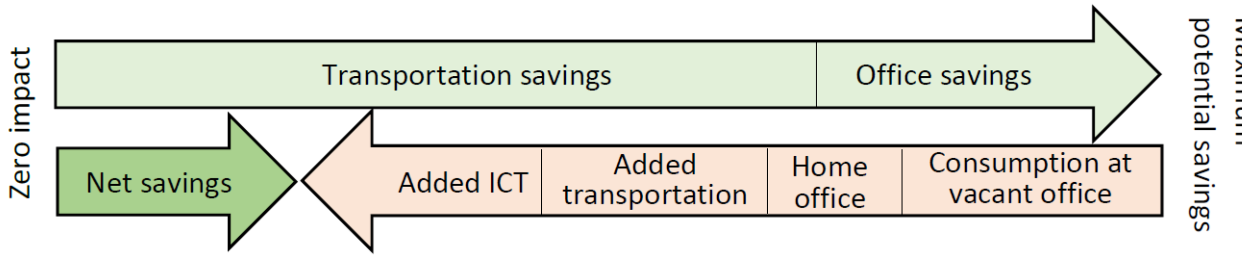

Figure 16: Illustration of potential for net energy savings from telecommuting and rebound effects (Source: (O’Brien, et al., 2020))

4.1.1 Transportation and mobility

Potential

There is definitely potential to cut down on travel with telework and teleconferences, but this potential hasn't been fully utilized up until now. Policymakers and some academics have actively promoted the benefits of telework, which include a decrease in the number of trips and kilometers traveled (Cerqueira Eugênia Dória Viana, 2020). Individuals and companies need to make an intentional decision to cut back on the usage of the vehicle and the airplane, as ICTs by themselves cannot fix the issue. The fact of modern work and living is that people must be adaptable and frequently travel large distances in order to maintain both professional and personal social contacts. The problem is, people are used to certain lifestyle, including travel and technology demand, as well as many “leisure” activities, which are all linked to relatively high energy requirements.

The capacity of telework to cut down on energy consumption and greenhouse gas emissions is also influenced by the mode of transportation it replaces, claim O´Brian and Alibadi (O’Brien, et al., 2020). The value of teleworking is substantially smaller in areas with a large share of walking, cycling, and public transport than in expansive cities with heavy traffic where commuters predominantly rely on personal autos and there is heavy traffic. Furthermore, the impact of remote work on energy consumption can be negative if the primary commuting mode before remote work was public transport or active transport – walking or cycling (Georgina Santos, 2022). According to a study, those who have favorable opinions of cycling and public transportation rather that of driving are more likely to engage in telework. If teleworkers only need to make a few roundtrips each week, on the other hand, they could be more willing to use public transport, further lowering the environmental effect of commuting (O’Brien, et al., 2020).

Similarly, if the primary commuting mode was the car, the overall energy consumption may increase if the additional emissions from working from home exceed the emissions saved from reduced commuting and workplace occupancy (Georgina Santos, 2022). Another study demonstrates that if a commuter drives more than roughly 6 kilometers to work, working from home is likely to lower their carbon dioxide (CO_2) footprint. However, like already mentioned, working from home might result in higher CO_2 emissions due to increased domestic energy use for short car journeys or those made by public transportation. The authors discovered that if everyone who can work from home did so for even one day a week, it would save around 1% of the world's annual oil consumption for road passenger transport. This conclusion was reached by analyzing commuting trends and labor market statistics. Given the rise in home energy consumption that would result from this, the total effect on world CO2 emissions would be a reduction of 24 million tonnes (Mt) annually, which is almost equal to Greater London's yearly CO2 emissions, claim the authors (Crow, et al., 2020). The typical automobile in the United States uses around 45% more gasoline than the average car in Europe for a journey of equal duration, therefore fuel efficiency differences are also important to mention (Crow, et al., 2020).

French bioinformatics conference (JOBIM 2020) investigated what kind of effect on GHG a switch to a remote conference would have (Valentin Guignon, 2021). They came to a conclusion that if the conference happened face to face it would produce about 12603kg CO2, and only 110 kg if it was held online. Divided it equals 0.16 kg eCO2 per attendee, which then represents 0.01% of the yearly carbon budget compatible with the Paris Climate Agreement. These emissions are mainly consisting of manufacturing, transport, and electricity consumption of users' computers. When it comes to the offline conference, only the travel of the individuals was considered in calculating the carbon footprint. As a result, the decision was made to host the conference in a virtual format.

Rebound effects

Recent research has shown that teleworking has a limited effect on cutting down on kilometers traveled and GHG emissions and it has also been linked to a number of rebound effects. According to study data, while telework may save travel expenses and time, the time saved on commuting may be utilized for other activities or transformed into longer or more frequent personal travels. As a result, compared to non-telecommuters, telecommuters may drive more for both daily commutes and personal travel. Longer commute times are reported by employees who are allowed to work from home, sometimes because they have higher-paying management and professional roles or reside further from the workplace. Additionally, recent research has shown that families with at least one teleworker tend to travel more and have bigger travel expenses (Cerqueira Eugênia Dória Viana, 2020).

Few studies have examined the travel habits of home-based employees (non-teleworkers), despite the fact that telework has been a popular topic in academic literature. The rise in home-based employment is correlated with improvements in ICT as well as a rise in the percentage of contract and independent employees. According to the research, home-based company owners travel more frequently than non-home-based workers on average each day for both work-related and non-work-related reasons. Some of these include shopping, socializing, and recreation. Although home-based professionals often don't commute, their work-related travel may nonetheless be substantial (Cerqueira Eugênia Dória Viana, 2020).

Travel has the greatest energy intensity of all activities, according to all research that treats it as a separate activity, as it also includes underlying energy required to construct transportation infrastructure and vehicles. However, there are differences in energy intensities across different modes of transportation: direct energy intensities are highest for car drivers, lowest for those who take public transportation, and zero for those who walk or ride a bicycle (supposed no e-bikes are used) (Jan C.T. Bieser, 2022).

A strategy for regulating travel demand may be aided by changes to the working day, particularly the variety of workplaces, which will help to lessen traffic and the negative impacts of transportation on the environment, such as greenhouse gas emissions. However, studies on teleworking frequently point out a number of rebound effects, including the trade-off between commuting and leisure travel or dwelling relocation. Although effects of telework on travel patterns have been studied by earlier researchers, only a few studies have focused on how other workplace changes, such as working from several locations or from home, may impact travel behavior (Cerqueira Eugênia Dória Viana, 2020). Additionally, there is research that suggests teleworkers and home-based workers reside in more suburban locations and are more likely to go locally by car (Cerqueira Eugênia Dória Viana, 2020). E.D.V. Cerqueira, B. Motte-Baumvol, L.B. Chevallier, O. Bonin (Cerqueira Eugênia Dória Viana, 2020) point out that most studies focus solely on commuter travels, typically excluding business trips like delivery of goods and client visits.

In order to calculate GHG emissions, the authors of one study on relationship between travel patterns and CO2 emissions (Cerqueira Eugênia Dória Viana, 2020), developed a model and implemented different kinds of factors. The number of weekly trips and the distance traveled are factors that their model considers when attempting to comprehend the various effects and travel patterns. The model is constructed in two phases. While the second step assesses the impact of travel patterns on CO2 emissions, the first stage tries to better understand the relationship between workplaces and travel patterns. Some of the factors also included vehicle type and size, number of passengers in car, type of mode of transport used, as well as type of fuel. Cycling and walking journeys received no carbon emissions credit. The final step was to multiply the trip distance by the CO2 emission factor for each mode of transportation to get to the total CO2 trip emissions (Cerqueira Eugênia Dória Viana, 2020).
According to this study's findings, employees who have a fixed place of employment report using public transportation and walking/biking more frequently than the national average. Given that employees who have a stable place of employment typically reside in high-density regions, these travel patterns are closely related to indices of land use. Although home-based employees use cars more frequently than the typical person, they also commute more frequently on foot or by bicycle. Additionally, the average distance travelled demonstrates that the majority of their visits are local or are concentrated at the local level. As a result, these two categories have lower overall CO2 emissions, with home-based employees having somewhat greater emissions since they use cars more frequently. Contrarily, it is revealed that those who work from home, have various locations of employment, or telework are highly dependent on their cars. The greatest average CO2 emission levels are reported by teleworkers, who also travel the most weekly miles and on average take more trips both for business and for pleasure. The large percentage of teleworkers who drive is directly tied to the fact that they typically live in low-density regions. Additionally, they report traveling more miles than usual on both business and leisure excursions, resulting in increased CO2 emissions. Workers who work at various locations also account for significant

distances traveled, particularly for travels linked to their jobs, although to a lesser extent (Cerqueira Eugênia Dória Viana, 2020).

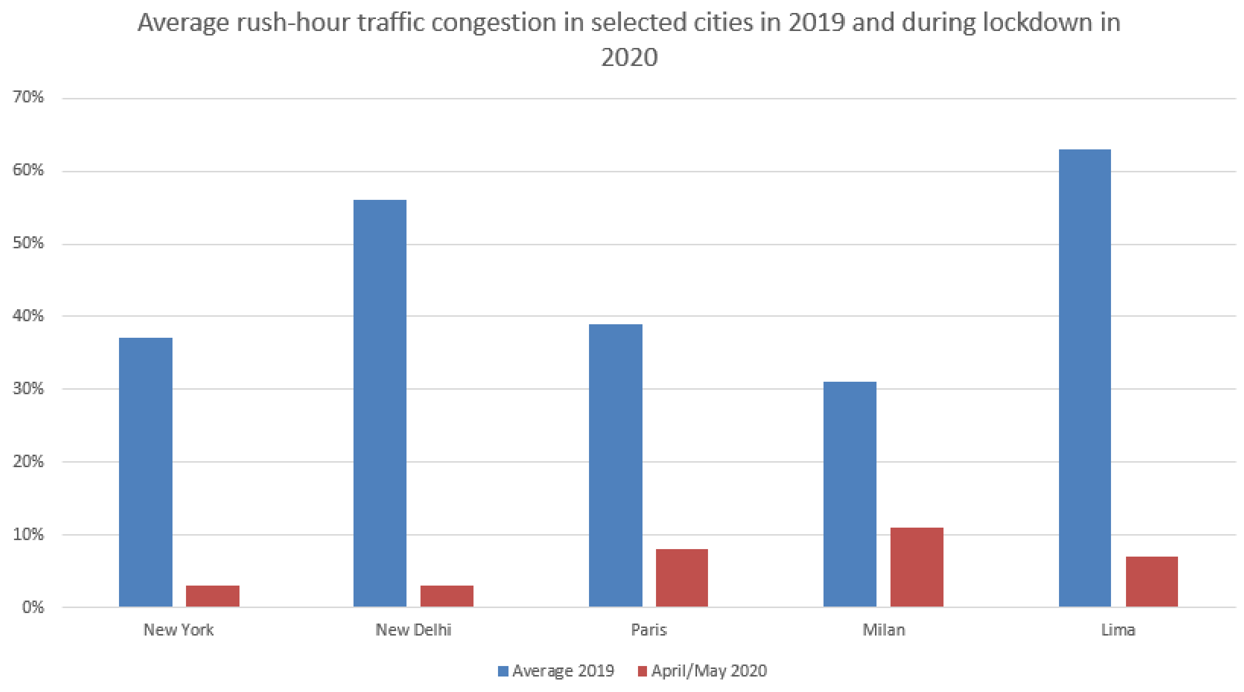

Figure 17: Average rush-hour traffic congestion in 2019 and during lockdown in 2020. (Source: (Crow, et al., 2020))

The provided diagram presents a comparative analysis of average rush hour traffic congestion in major cities during two distinct periods: average 2019 and April and May of 2020, during which the world was met with the global lockdown inflicted by the COVID-19 pandemic (see Figure 17). The striking differences depicted in the diagram, particularly observed in New York and New Delhi, highlight the significant impact of the lockdown measures on reducing traffic congestion and consequently benefiting the environment. This visual representation underlines the crucial role that traffic patterns play in eco-friendliness. The data shown in the diagram vividly demonstrates the dramatic decline in traffic levels, highlighting the positive environmental implications associated with reduced vehicular movement.

Moreover, the diagram invites a deeper analysis of the role played by teleworking, particularly the adoption of home office practices, in contributing to these significant changes. The correlation between the lockdown-induced rise in remote work and the subsequent decrease in rush hour traffic congestion becomes evident. Home office arrangements allowed individuals to work from the comfort of their residences, thus minimizing the need for daily commuting and thereby reducing traffic volume during peak hours. The diagram thus underlines the potential of teleworking as an attainable solution to mitigate the environmental impact of daily commuting and highlights the need to consider such flexible work arrangements in future sustainability strategies (Crow, et al., 2020). Of course, the lockdown measures that were to be followed during the pandemic, disabled the option of frequent personal travels, which furthermore accentuated the differences between the periods.

4.1.2 Energy Home vs. Office

Potential

The benefits and rebound effects are best acknowledged and investigated during extreme situations like the global COVID-19 pandemic. Lockdowns during the pandemics have impacted home energy usage as well. Energy utilities reported higher household demand despite a 20% or more decline in total electricity usage as a result of consumers spending more time at home. Weekday hourly demand trends matched a typical Sunday. The average home power usage on weekdays increased by 20% to 30% in several regions of the United States, while home power use in the United Kingdom increased by 15%, claims the same study (Crow, et al., 2020).

Theoretically, it could be possible to reduce office space in order to reduce energy consumption, by arranging workplace just for present employees. In practice however, this is very complicated, knowing that most teleworkers work remotely only 20-60% of the time, as newest surveys show (O'Brien, et al., 2020).

On the other hand, currently there is no proof that teleworking has potential to reduce energy use at home. The only probable exception is that teleworkers may be motivated to conserve energy since in the contrary to the central office, they do have to pay for it themselves at home (O'Brien, et al., 2020). The influence of Heating, Ventilation, and Air Conditioning technology and energy sources on GHG emissions is very dependent. Homes in some countries, like North America, frequently use centralized Heating, Ventilation, and Air Conditioning systems with limited room-by-room temperature control. A teleworker may therefore unavoidably condition the entire house to pleasant conditions, even if they only require a tiny fraction of it to be comfortable. However, a study found that only one-third of workers are alone at home when they work remotely, potentially offsetting waste from Heating, Ventilation, and Air Conditioning (O'Brien, et al., 2020).

Some studies give various examples of how to reduce energy consummation in office buildings. Technologies still exist to reduce energy usage in unoccupied areas even if an area is not fully filled - for example, due to non-full time remote working. These consist of demand-controlled ventilation, occupancy-based heating, and lighting controls. Because they primarily affect nearby people, radiant heating and cooling have the ability to give comfort with more precision than air-based systems, which often encourage air mixing over vast rooms. Also, to lower plug loads while equipment is not in use, so-called smart plugs and occupant feedback can be employed. Additionally, since the same laptop is used at both the workplace and at home, teleworking inevitably decreases plug loads in the office. Moreover, by eliminating the biggest energy-hogs from inhabited rooms (computers), lowering cooling loads in large dimensions is possible (O'Brien, et al., 2020).

Rebound effect

Despite some evidence that working from home can save emissions connected to transportation, several research show that doing so increases household energy demand during the day. Homeworkers require proper heating, lighting, and typically some electrical equipment, which increases energy use and CO2 emissions (Cerqueira Eugênia Dória Viana, 2020). Depending on geographical variations in the typical size of homes, heating and cooling requirements, and appliance efficiency, working from home might result in an increase in household energy usage of between 7% and 23% compared to working in an office, Crow and Millot estimate (Crow, et al., 2020). It is important to mention the fact that a lot of companies still keep the office space even when an employee does work from home most of the time, which means double cooling, heating and lighting costs.

Office building rules and a general lack of incentives contribute to the fact that most structures are not built to efficiently adapt to varied occupancy. For instance, the bulk of lighting energy is used for overhead lighting in open-plan workplaces, which is unaffected by the presence of a single person. Furthermore, office buildings usually have relatively coarsely controlled lighting and Heating, Ventilation, and Air Conditioning systems, controlling the whole floor or wing at the same time, which means that the building's systems must maintain comfortable temperatures and ventilation regardless of whether a specific occupant is present or not (O'Brien, et al., 2020).

Research on telecommuting usually concentrate on the effects of travel and do not take into account changes in the amount of time spent on non-commuting activities and the energy impact of these changes. Many studies have tried to prove that saving time on commuting is related to saving energy by not driving to work (as using cars have been proved as biggest energy consumer and air pollutant), ignoring other relative variables like time spent on substitute activities and their energy impact. A study from Switzerland provides a time-use strategy to evaluate changes in commuting time, time spent on travel and non-travel activities, and time spent on leisure activities and related energy impact. Analysis of time-use data reveals that spending more time on non-commuting activities like "sleep," "leisure" "personal, household, and family care," or "eating and drinking" is correlated with less energy expense, in contrast to activities like "private travel", "meal preparation at home", and energy-demanding or away-from-home "leisure" activities, which are linked to relatively high energy requirements. For instance, one research calculated that in Finland in 2009, "watching TV" was connected to 3.4 MJ per hour (MJ/h), "general housework" to 20.2 MJ/h, and "leisure travel" to 128.5 MJ/h (Jan C.T. Bieser, 2022). Authors of the same study have underlined the importance of future investigation of relationship between telecommuting and amount of time spent on non-travel activities, such as their energy requirement. This further proves that home office is not to be considered an environmentally friendly way of working, nor a batter alternative, without completing a thorough research on the subject first.

Some studies evaluate the direct and indirect energy consumption as well as the greenhouse gas emissions of various activities. Direct effects result from the use of power or fuels directly during an activity, such as the usage of a TV set's electricity or a car's fuel. As an example, the energy necessary to make an electronic equipment or a car is integrated in the commodities and services that are utilized to carry out an activity (Jan C.T. Bieser, 2022).

4.1.3 Information and communication technology

Potential

The ongoing argument in environmental and ecological economics over whether economic growth can be separated from environmental factors like energy consumption is relevant to the question of whether digitalization may help reduce energy usage (Steffen Langea, 2020). In the best case scenario, teleworking has no influence on ICT-related energy usage or GHG emissions since direct technology-free communication that takes place in usual office settings, such face-to-face meetings, has no effect on the environment (O'Brien, et al., 2020). A study done in Germany investigated the effect of digitalization on energy consumption (Steffen Langea, 2020). The ICT industry is expanding globally, although regional growth in ICT manufacturing and services varies, shows the study. Generally speaking, the expansion of the ICT industry results in increased direct energy use. In the ICT industry, energy efficiency has been rising concurrently for decades. Jonathan Koomey made the finding based on a pattern that has existed since the 1950s (Koomey, et al., 2010). In contrast to Moore's law, which asserts that processing power doubles every 18 to 24 months, Koomey's law states that energy efficiency of computers doubles about every 18 months, which is consistent with the idea that processors have grown more efficient. The energy used for each data transfer has also lowered and is expected to do so further. The energy efficiency of data centers has also increased quickly. However, there is considerable debate over the level of efficiency gains, anticipated growth in data quantities, and their effects on power use. Which of the two aforementioned effects—sector expansion or improvements in energy efficiency—predominates determines whether the overall energy consumption of the ICT industry rises or falls. Despite some positive impacts, this study indicates that the growing impacts are dominant, leading to an overall rise in energy consumption as a result of digitalization (Steffen Langea, 2020).

The research also reveals a link between computer use and the prevalence of telework, yet a weaker one than may be predicted. Working with computers "all of the time" or "nearly all of the time" is quite likely to be reported by those who worked from home, especially on an infrequent basis. Employees who have never worked from home, however, also report engaging in heavy computer use. This implies that, among all the elements influencing telework, the use of computers is an enabling technology, but that in the end, the job's duties or a person's position within the company ultimately matter more (Sostero Matteo, 2020).

Rebound effects

Because ICT production generates waste and hazardous pollutants, reduce ICTs does not inevitably lead to reduced environmental effect. ICT devices like laptops and smartphones are made of hazardous materials like lithium or cadmium batteries. Environmental performance evaluations of computer technologies reveal that they do not significantly reduce material outputs. There are three key lifetime phases for desktop computing: manufacturing, usage, and disposal (Fuchs, 2006). Researches on Oxford University estimated the power usage of various different staff desktop and laptop combinations using a lifecycle assessment approach specifically designed for the IT industry and discovered that the annual GHG effect (also known as carbon footprint) for their typical desktop computer and screen over a six-year period will be around 778 kg CO2e (Carbon dioxide equivalent). Only 15% of this is due to power use while in use, with about 85% coming from manufacturing and delivery (University of Oxford, 2022). For example, the production of a single laptop generates around a third of a tone of CO2, and the extraction and processing of those materials requires about 190,000 liters of water, which is an essential natural resource (Computing, 2019). According to The Global E-waste Monitor 2020, e-waste production in 2019 was estimated at 53.6 million metric tons (Mt9, or 7.3 kg per capita, with screens and monitors accounting for 13% of the waste (Forti, et al., 2020). The same study claims that, the most of the world's electronic garbage (24.9 Mt) was generated in Asia in 2019, whereas Europe produced the most electronic waste per person (16.2 kg).

Consumer electronics remanufacturing is seen as a critical step towards lowering e-waste and enhancing overall sustainability. One study assessed the CO2 emissions associated with remanufacturing laptops and the emissions saved by doing so as opposed to producing new laptops, which involves the extraction of fresh materials, energy-intensive manufacturing, and the necessary shipping. The authors came to the conclusion that the average amount of CO2 emissions during the phases of extraction, production, transportation, and end-of-life are determined to be 331kg for a freshly produced laptop according to the databases of manufacturing businesses. The CO2 emission for a refurbished laptop is estimated at 21 kg based on the operations of the remanufacturing firm. The effect avoided by remanufacturing is determined to be 310 kg. This obvious CO2 emission difference between newly made and previously used laptops demonstrates the advantages of remanufacturing in terms of environmental impact (Yuksek, et al., 2023).

5 Calculation, Results and Discussion

5.1 Literature review

Based on the information provided by The World Bank (The World Bank), 4,6 metric tons of CO2 emissions per capita was produced in the world in 2019. Multiplied with over 8 billion people, makes over 36 billion metric tons of CO2 emissions released in the atmosphere just in 2019. Countries of the first world make around 5,6% of world´s population (around 0,45 billion people), reproduced alone 9,6 metric tons of CO2 emission per capita in 2019, which gives 4,3 billion metric tons of C02 altogether.

The evaluation of carbon reduction also includes uncertainty and rebound effects. While some research simply included qualitative descriptions of the pertinent uncertain parameters, other studies failed to take uncertainties into account. Commonly used techniques for quantifying uncertainty in carbon reduction include Monte Carlo simulation, robust optimization, and modeling to produce alternative scenarios. Monte Carlo simulation has been extensively utilized in uncertainty modeling for carbon reduction through teleworking. It tends to be used when both the unknown parameters and their distributions are known. Earlier studies primarily focused on the carbon reduction advantages of a specific percentage of telework implementation without taking into account the diverse potentials of teleworking implementation in different industries, which might cause mistakes in the conclusions. Furthermore, many countries, especially ones with low-income and poor economy background, currently lack research on the effects of teleworking on carbon reduction, which slows down and even prevents making a fair judgment and right conclusion on global situation (Wenzhu Li, 2023). D. Crow and A. Millot did a research in 2020 on how much energy can working from home save and how much emissions. The results of the research can be observed in the following chart (see Figure 18) (Crow, et al., 2020).

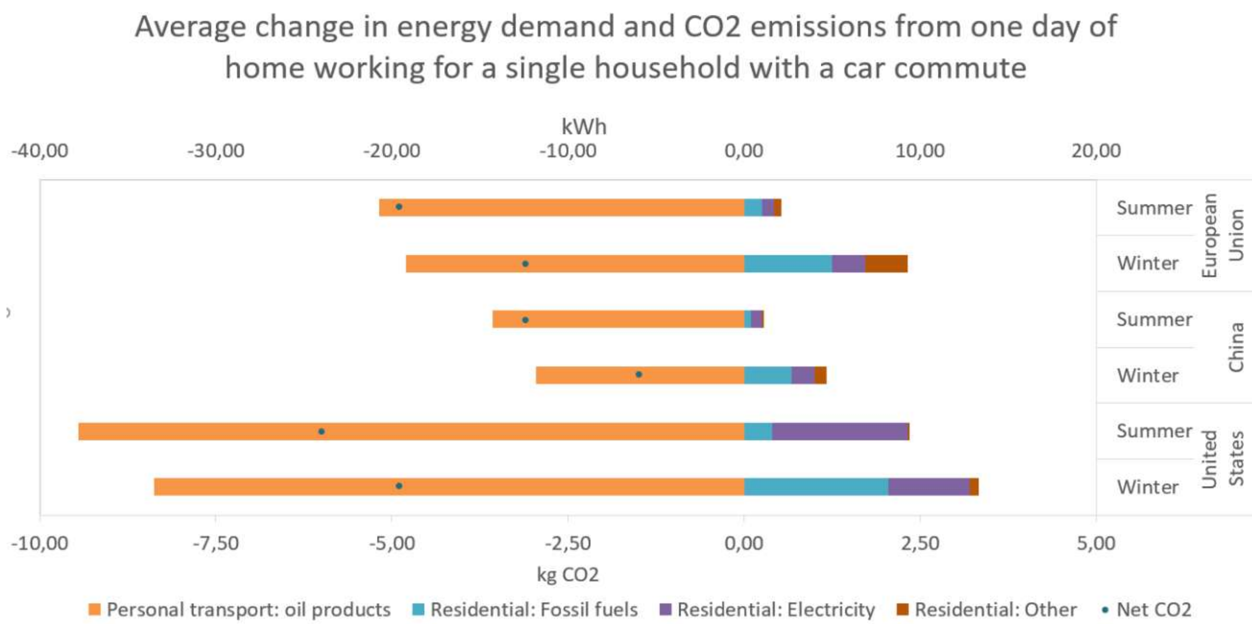

Figure 18: Average change in energy demand and CO2 emissions from one day of home working for a single household with a car commute (source: (Crow, et al., 2020))

The chart depicts the analysis of the average change in energy demand and CO2 emissions resulting from a single household's transition to home working, specifically focusing on the impact of a car commute. The analysis includes three regions: Europe, the United States, and China, with data provided for both winter and summer periods. The factors taken into consideration include personal transport (oil products), residential energy consumption (fossil fuels, electricity, and other), and net CO2 emissions (bottom axis).

The impact of working from home on transportation exhibits significant variation depending on the region and time of year. Notably, differences in fuel efficiency play a crucial role, with the average car in the United States consuming approximately 45% more fuel than its European counterpart for a trip of equivalent distance. Consequently, the United States demonstrates the highest energy consumption and CO2 emissions among the analyzed regions, while China exhibits the lowest levels in these categories. In each category, the net CO2 value is negative, indicating that households committed to home office practices contribute to a reduction in CO2 emissions. This suggests that home office has a positive environmental effect in these regions. It is important to note that the results also differ between winter and summer periods, with energy consumption and fossil fuel usage generally being lower during the summer months compared to winter. Furthermore, the utilization of mobile air conditioning in cars significantly impacts fuel consumption. Estimates indicate that approximately 4% of total fuel consumption for commuting by car in the United States, China, and Europe in 2019 can be attributed to mobile air conditioning. Overall, the chart provides insights into the energy demand and CO2 emission changes associated with home working for a single household with a car commute. The analysis highlights the regional differences and the significance of fuel efficiency, as well as the positive environmental impact of home office practices. It is worth noting that the data presented in the chart pertains to the 2019/20 timeframe.

In absence of enough studies that researched and calculated a total impact of telework on air pollution and especially CO2 emissions in Austria, this thesis attempts to set a calculation tool for estimating the overall CO2 footprint of remote work using the findings form collected relevant research papers on the topic and bringing them together. As previously acknowledged, there are a few main factors that affect this impact and they include transportation, home-related energy use and office- related energy use.

5.1.1 Transportation

Teleworking has the potential to be a crucial tool in the fight against air pollution and increased traffic. However, research on the subject suggests that depending on the context—including social norms, transportation system features, and the location of activities related to places of residence—the consequences of teleworking may notably differ. According to a research from 2020, an increase of teleworking for a bit over 5% decreases average air pollution and GHG emissions from cars for approximately 2,5% in a typical medium-sized European city, which means that it would have an even greater impact in bigger cities with larger teleworking potential. This research result supports the theory that encouraging policies to increase teleworking in such metropolitan regions may generate a positive cumulative effect that would ultimately reduce air pollution and GHG in Europe. The same research applies that in Europe, 44% of the population resides in medium-sized cities. The results presented in this study show that the changes in transportation and mobility patterns due to an increase in teleworking rate, lead to a reduction of road traffic pollutant emissions of 0,08% (from − 0.38% to − 0.46%) in emissions per 1% rise in the teleworking rate. Two teleworking scenarios, the "balanced" scenario (teleworking rate fixed at 7.35%, which matches the estimated rate of global working population in a medium-sized European metropolitan area) and the "increased" scenario (teleworking rate fixed at 13.00% corresponding an estimated national average rate), have been simulated for this study. According to their findings, a 5.65% increase in the number of teleworkers might lead to an average decrease of 2.14% to 2.60% in the amount of pollutants emitted by cars (Quentin M. Tenailleau, 2021).

W. Li, N. Liu and Y. Long show in their case study of Beijing, China the quantitative technique that was provided to evaluate the advantages of teleworking in terms of carbon reduction in various industries. First estimates were made of the penetration rates of teleworking in several industries. After that, utilizing the data from the large-scale trip survey, the carbon reduction of teleworking was evaluated through the shorter commute distance. Finally, a citywide sample of the research participants was included. With the use of Monte Carlo simulation, the magnitude and the uncertainty of the advantages of carbon reduction were assessed. The findings revealed that, firstly, teleworking may reduce carbon emissions by an average of 1.32 million tons, or 7.05% of all road transport carbon emissions in Beijing. And secondly, there was a significant potential for carbon reduction in the professional, academic, and technical service, information and communication industries. The carbon reduction advantage of teleworking was also partially diminished by the rebound effect, which also requires consideration in the total evaluation. The authors suggest that this approach can also be used in other parts of the world, assisting with the realization of global carbon neutrality objectives (Wenzhu Li, 2023).

The study concentrated on the CO2 released into the atmosphere by vehicles, both light (such as cars, motorcycles and taxis) and heavy (such as trucks and buses). Walking and biking are examples of green transportation that produce no or very little carbon emissions. Public transportation has set routes and working hours, indicating that it won't be significantly affected by changes in people mobility patterns. As a result, while estimating carbon emissions, the low-carbon transportation options listed above were not taken into account in this research. Since the idea of carbon neutrality is expanding rapidly, it would result in a continued increase in the percentage of new energy vehicles, which are also considered in this study´s computation (Wenzhu Li, 2023).

The research describes the procedure as follows:

"*The commuting VKT* (meaning: vehicle kilometers traveled) *in the ith industry with the jth modes of transport, denoted as Lij (m), can be calculated using the average travel speed of different transportation modes and commuting time, as is shown in Eq. (1). Then, the total decreased commuting VKT by teleworking in a day, denoted as △L, can be further obtained by the teleworking penetration and commuting VKT, as is shown in Eq. (2).*

$$L_{ji} = \sum_{k=1}^{n_k} (\mathrm{T}ak - \mathrm{T}\,dk) \cdot v_j \qquad (1)$$

$$\Delta L = \sum_{i=1}^{n_i} \left(p_i \cdot \sum_{j=1}^{n_j} L_{ij} \right) \qquad (2)$$

where Ta (s) and Td (s) are, respectively, the arrival time at the office and the departure time from home, Vj (m/s) is the average speed of the jth modes of transport (i.e., car, truck, taxi, motorcycle, etc.), Pi is the teleworking penetration in the ith industry, nk represents the number of trips in Lij, ni is the number of industry types, and nj is the number of transport modes.

(…) Let EFj (kg CO2/km) denote the CO2 emission factors of the jth modes of transport, which can be calculated by:

$$EF_j = y_j \cdot N_j \cdot H_j \cdot O_j \qquad (3)$$

where Yj(L/km) is the fossil fuel consumption of the jth modes of transport; Nj (Kcal/L) is the net calorific value, which represents the amount of heat emitted by the combustion of a unit of fossil fuel; Hj(kgCO2/Kcal) is the carbon content that reflects the CO2 emitted per unit of heat released; and Oj is the oxygenation rate of the combustion of fossil fuels. After distinguishing the fuel types of different travel modes, we brought in the data of calorific value, carbon content, and fossil fuel consumption per 100 km, as the oxygenation rate was equal to unity. Additionally, the EFj (kg CO2/km) for the new energy vehicles was obtained by multiplying the electricity carbon emission factor (kg CO2/(kW·h)) by the electricity consumption per kilometer ((kW·h)/km) and was then divided by the grid transmission efficiency. Let Cij (kgCO2) denote the carbon emission in the ith industry with the jth modes of transport, and △C (kgCO2) represents the total annual carbon reduction by teleworking, which is calculated as follows:

$$C_{ij} = EF_j \cdot L_{ij} \qquad (4)$$

$$\Delta C = D \cdot \sum_{i=1}^{n_i} \left[EC_i \cdot \left(P_i \cdot \sum_{j=1}^{n_j} C_{ij} \right) \right] \qquad (5)$$

where D is the number of workdays per year, and ECi is the expansion coefficient of the ith industry, which is calculated by the ratio of the total industrial population in the city to the industrial population in the survey data. Then, the citywide quantitative assessments can be obtained, solving the problem that household travel survey data include only a portion of the municipal population. When calculating the ECi using the population data in different industries, some employees cannot be divided into a specific industry, including individual business households, rural contracting households, and individual partnerships. They can be considered as the total industrial population data according to the proportion of employees by industry." ((Wenzhu Li, 2023), Page 3 und 4).

A study in Italy examined the potential benefits of remote working on the environmental impacts of urban transport in the country and presents the results of a research study conducted in four Italian cities (Roberta Roberto, 2023). The study explores different forms of remote work, such as telework and smart working, and their effects on work-life balance, well-being, and urban development. Transportation is a major contributor to greenhouse gas emissions and energy consumption, making it crucial to evaluate the environmental impacts of urban transport. The study reveals that the transport sector accounts for a significant portion of total energy consumption and greenhouse gas emissions in both Europe and Italy. In Italy, the transport sector is responsible for a quarter of total greenhouse gas emissions, with road transport being the main contributor. Passenger cars alone contribute to a substantial portion of national emissions, with road transport also generating nitrogen oxides, non-methane volatile organic compounds, particulate matter, and carbon monoxide emissions. The study highlights that remote working has the potential to reduce CO2 emissions by decreasing the need for private vehicle commuting. The research survey collected data from public employees who had adopted remote working, and the results show that, on average, these workers saved approximately 6 kg of CO2 per day by avoiding commuting (with an average round-trip distance of 35 km). Extrapolating these savings to the entire sample indicates that a remote worker can achieve CO2 emission reductions of at least 3.8 kg per day.

For estimation of the reduction, the authors used the following equation:

$$\mathrm{Q_{pi}} = \sum_{1}^{n} \mathrm{F_{FsT}} \cdot \mathrm{km} \cdot \mathrm{d}$$

Where:

Q_{pi} represents the emitted quantity of pollutant

i, n are the number of respondents in the sample

F_{FST} represents pollutant emission factor by fuel, size, abatement technology and type of route (urban, rural, mixed)

km are the kilometers driven per day and

d are the days worked remotely

Both of the previously represented studies rely on large-scale travel survey data, which provide a helpful tool for assisting in the development of new remote working regulations. The surveys date from period before epidemic, and were used to estimate the lowering of fuel consumption and travel demand and thus caused emissions of greenhouse gases, due to employees' various mobility preferences. The study from Beijing was based on 24-h travel diary, which limits the potential of the results and study´s range of application, since most of the rebound effects need time to show so that they can be taken into account.

To analyze the consequences locally, worldwide, and on the urban environment, it is necessary to conduct specialized evaluations of the rebound effects caused by a potential rise in car/two-wheel kilometers driven as a result of the adoption of teleworking. Leisure travel as well as weekday commute should be taken into account in analyses. The rebound effect that also partially offset the carbon reduction benefit of teleworking, which must be taken into account in the overall assessment, are not directly included in neither of the previously described studies, even though both studies highlight the importance of the same. A further limitation that is to be noted is that just a small percentage of workers choose remote work and also just a small amount of them participated in the surveys, which may not accurately represent the workforce's demographics as a whole.

Although both studies have taken into account many important factors, such as a type of transportation, a type of gasoline used, a length of journey etc., this omission significantly limits the value of the results.

5.1.2 Home-related energy use

One research initiative focuses on simulating the energy use and emissions of teleworkers' homes in United Kingdom. The researchers examined a few different geographical regions, from small village in rural area to a large city in metropolitan area. They first develop a deterministic model and infer probability distributions from the data's observations. However, they perform a historical simulation that takes into account all the variables of each observation at once rather than a Monte Carlo simulation, which ignores correlations between variables. When running 400,000 iterations with 400,000 residential properties, for example, they might input all of the building archetype variables of one property as one iteration, then input additional variables like the external temperature into the same iteration. They would then repeat with combinations of variables from another property and yet another temperature so that they can determine how much household construction contributes to the total effects of teleworking on energy usage and emissions. After that, they perform a worldwide sensitivity analysis to see how various factors affect the change in household carbon emissions caused by teleworking. They use Sobol indices, which break down the overall variance of the output of the model and show the relative contributions of each input. This provides a rating of factors according to their impact on the extra household carbon emissions that teleworkers generate. Sobol indices offer a global sensitivity analysis as opposed to a local one since they take into account how the correlations between the input variables affect the variance of the outputs. Global sensitivity analysis is chosen since there is a link between the input variables (for instance, between wall insulation and floor insulation).

The research describes the procedure as follows:

"The deterministic model has three steps. Step 1 (Equation 1) calculates a non-teleworker's annual carbon emissions ($CO2_N$) as the sum of annual transport emissions (CO2Ntravel), and home ($CO2_{Nhome}$) emissions. Step 2 (Eq. 2) does the same for a teleworker ($CO2_{TW}$), while Step 3 (Eq. 3) calculates the difference in carbon emissions between the two (ΔCO2). (….)

$$CO2_N = CO2_{Ntravel} + CO2_{Nhome} \quad (1)$$

$$CO2_{TW} = CO2_{TWtravel} + CO2_{TWhome} \quad (2)$$

$$\Delta CO2 = CO2_{TW} - CO2_N = \Delta CO2travel + \Delta CO2home \quad (3)$$

(….) Our literature review demonstrates that teleworking's main influence on domestic energy use is the additional energy required for heating, lighting and ICT during working hours. Hence, the difference between teleworker's and non-teleworker's domestic carbon emissions (ΔE_{home}) is estimated as the sum of changes in heating, lighting and ICT emissions.

$$\Delta CO2_{home} = \Delta CO2_{heat} - \Delta CO2_{light} + \Delta CO2_{ICT} \quad (4)$$

(….) The difference of home heating carbon emissions (kg) between teleworker and non-teleworker:

$\Delta CO2_{heat} = CF_a * E_{H,a}$

where CF_a is carbon emission conversion factor for the fuel for heating system a, since different dwellings have different heating systems and therefore different heating fuels. EH;a is the annual consumption of heating fuel by heating system a (kWh). (…) $E_{H,a}$ is space heating requirement for heating system a (kWh)

$$E_{H,a} = \sum_m t \cdot n_m \cdot [H \cdot (Ti,m - Te,m) - U_m \cdot G_m] \cdot f_{TW} / \eta_a \qquad (5)$$

where t is the number of extra heating hours on a teleworking day, nm is the number of teleworking days in the month m (assumed to be 21.75), [m is utilization factor for gains in the month m, Gm is total heat gain (Watts) for the month m, H is the heat transfer coefficient (W/K), Ti,m is the working-day mean internal temperature (C) for the month m, Te,m is working-time external temperature (C) for the month m, f_{TW} is teleworking frequency (days/week), η_a is the Coefficient of Performance (COP) for heating system a. See Appendix for more details. $\Delta CO2_{heat}$ and $E_{H,a}$ depend upon the area the teleworker uses for heating, and the time for heating. We assume two scenarios for the area of heating." ((Yao Shi, 2023), Page 5 and 6)

To estimate the teleworker's additional carbon emissions from lighting over the course of a year, the authors used the following equation:

$$\Delta CO_{2Light} = \alpha_1 \cdot (\Delta sz_{r_{oo}m})^{0.4714} \cdot L_{LE} / L \cdot t \cdot f_{TW} \cdot CF_E \qquad (6)$$

With α_1 as a conversion factor,
ΔSZ_{room} is the area of one room (m2),
L_{LE}/L the proportion of low-energy lighting outlets,
CF_E is the carbon emission conversion factor for electricity (kg CO2/kWh)

And to estimate the additional carbon emissions from ICT at home:

$$\Delta CO_{2ICT} = CF_E \cdot Eff_C \cdot t \cdot f_{Tw} \qquad (7)$$

with CF_E the carbon emission conversion factor for electricity (kg CO2/kWh)
Eff_C the rate of energy used by a laptop (W) (assumption of the authors 50 W on average. Other assumptions 2 h per day for videoconferencing and 6 h for other usage)

The authors show that the largest portion of the increased residential energy use and carbon emissions caused by teleworking are related to heating. They calculated that the additional heating energy demand is seven times more than the increased ICT energy demand and 40 times greater than the additional lighting energy demand, even if the teleworker simply warms a single room to 19 C for one hour each day. Therefore, heating schedules, desired interior temperatures, the structural soundness of the home, and the heating system's efficiency performance will all have a significant impact on the amount of energy and emissions saved by teleworking. The research predicted that increasing the amount of time spent heating from 1 to 3 hours per day and indoor temperatures from 19 to 21 degrees Celsius will about double the additional energy consumption and carbon emissions. Also, if a full-time teleworker just warms one room at home, depending on the options selected for heating duration and needed temperature, he or she will have 16–85% greater energy consumption and carbon emissions than a non-teleworker. However, this number rises to 58-117% if they heat the entire building, claims the study. This disparity highlights the significance of trying to minimize heating area (Yao Shi, 2023).

The final findings of this study imply that behavioral factors like the area heated, rather than the thermal performance of the building, are more important in determining the difference in emissions. With the exception of helping to shorten the time it takes to turn the heat off when just one room is heated, factors like building shape, property type, and window U-value are significantly less significant. In contrast, when individuals work from home, lowering heating area, cutting heating time, converting to lower-carbon energy, or enhancing heating efficiency performance are crucial for cutting domestic carbon emissions.

5.1.3 Office-related energy use

A study was done on Technology Transfer Center, Teikyo University in Tokyo, Japan (Nakanishi, 2015), in order to calculate the difference in energy consumption caused by telework, considering office equipment and home appliances utilization. The study´s core conclusion regarding the energy consumption in the workplace was that the company's teleworking policy determines how much energy telework saves there. The amount of energy used by the office will decrease dramatically if telework is deployed on a wide scale under the company's direction and a significant part of the workspace is closed. But the energy savings impact won't be perceived if telework is only partially adopted. The author proposed an energy consumption model, that helped and was used for this thesis´ approximation tool development. Framework of the energy consumption model of telework in the office and at home is illustrated on the following Figure (See Figure 19).

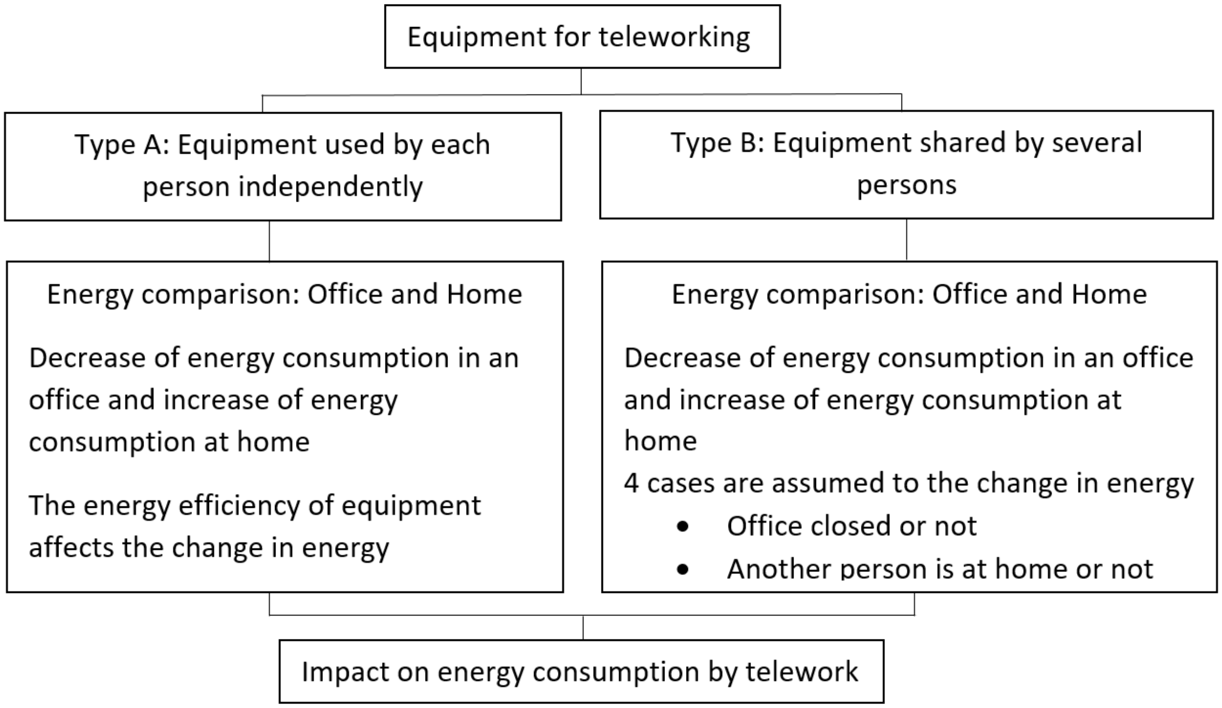

Figure 19: Structure of the energy consumption model of telework (source (Nakanishi, 2015))

The type of equipment used during telework divides the model into two segments. The equipment used by teleworkers on their own (Type A) is covered in the first section of the model. These include a personal desktop computer, a laptop or a desk lamp. The equipment that is shared with other teleworkers or their families (Type B) is covered in the second section of the model and include air conditioner (heating device), ceiling lights or computer servers for example. Regarding Type B, four scenarios are contrasted and analyzed, including the equipment, energy rise at home, and energy loss at the workplace. The reduction in workplace space and the number of individuals at home define these scenarios.
These include:
"*Case 1: Office space is reduced and the teleworker is alone at home. Energy consumption in the office is reduced while energy consumption at home increases. The effect of telework is determined by the comparison of the efficiency of the equipment in the office use and that of at home.*

Case 2: Office space is reduced and the teleworker is with his/her family. Energy consumption in the office is reduced and the increase of energy consumption at home is small. The energy saving effect of telework is large.

Case 3: Office space is not change and the teleworker is alone at home. Energy consumption in the office is not reduced and energy consumption at home increases. Total energy consumption will increase by the introduction of telework. This case of telework should be avoided for the energy saving.

Case 4: Office space is not change and the teleworker is with his/her family. Energy consumption in the office is not reduced and the increase of energy consumption at home is small. Telework does not affect the energy use in this case." (Nakanishi, 2015)

According to how many workers utilize the equipment, the overall energy consumption of Type A equipment will either rise or fall (Figure 20). When a worker uses telework, Type A equipment is not used at the office, which reduces Type A equipment's energy usage there. However, the identical type of Type A equipment is utilized at home and uses energy there instead. The difference in energy consumption relies on the energy efficiency of the equipment at the office and at home, assuming that the working hours (length of using the equipment) are the same. Given that Type B equipment includes an air conditioner, which has the highest energy consumption of all the telework-related equipment, it is crucial to take into account the usage context when estimating the equipment's potential for energy savings. Due to the fact that the equipment is shared by the users, the energy consumption of Type B equipment is high for the first person who flips the switch, but it is not as high for the second or third person (Figure 21).

The quantity of energy usage will go up when someone works remotely from home, but how much will depend on how many people are using the workspace. According to the same survey, 64% of teleworkers work alone in their workspaces and only use the lighting and air conditioning for themselves. As a result, the energy consumption at home may increase by around 80% of that in the office, or up to 27% if telework replaces all office activities. However, the adoption of telework will result in an increase in energy usage if the office is open. In this case, telework can not be seen as viable means of energy conservation, shows the study (Nakanishi, 2015).

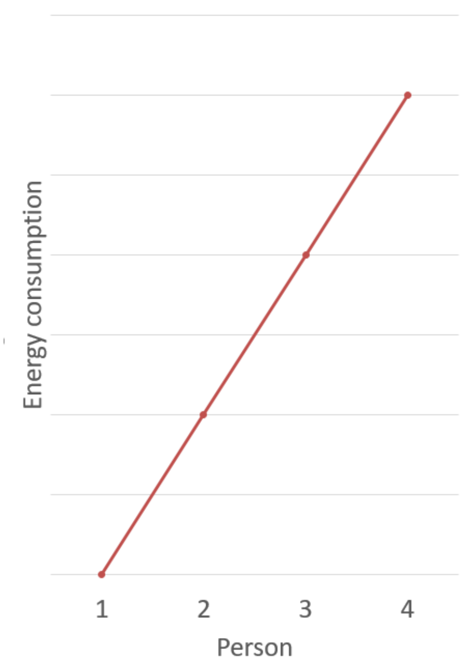

Figure 20: Energy consumption Type A equipment

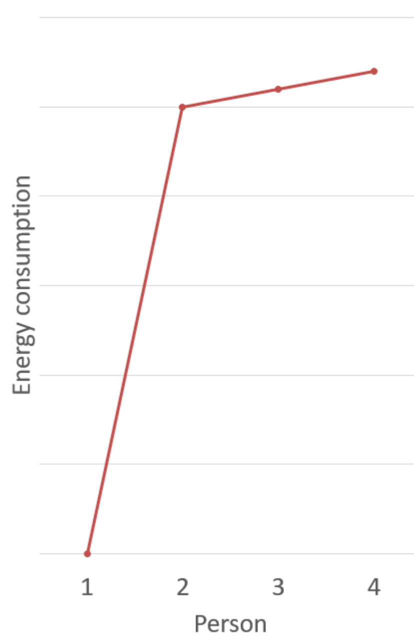

Figure 21: Energy consumption Type B equipment

5.2 Estimation of CO2 reduction for Austria

It should be pointed out, that this estimation is made on the basis of the research on various different studies and their assessments. It does not give an exact value of CO2 emissions, but rather a rough approximation, since it does not take all important factors into consideration because of the missing information and limited resources. Also, some of the previously introduced estimations are adjusted and used to help developing the estimation in this thesis. Please note that this tool provides a basic estimation and does not base on a survey or questionnaire from real-life teleworkers, but a theoretical combination of circumstances. Moreover, the study does not include an estimation with great number of iterations, examining every possible set of circumstances and wide range of possible scenarios addressing the environmental impact that may appear, but a few randomly chosen ones. The model's energy consumption was based on public data from different sources. There are a few problems and limitations linked to this kind of study, including basically the impossibility to do a research and predict all kind of scenarios and assembly of circumstances. It is not possible to access and predict behavioral patterns of all feasible teleworkers without a survey in order to estimate possible CO2 impact. For instance, if a teleworker maintains his corporate office while concurrently maintaining a fully functional home office, it is not sufficient to completely remove the daily commute trip if the teleworker would drive as much or more for other, non-work reasons. The long-term effects of teleworking must also be considered because some of these effects take decades to develop, like considering increased commute time and distance because reportedly, teleworkers tend to live further from their workplace. There is a lot that has to be recorded and examined. Additionally, actual CO2 reduction may vary based on individual commuting patterns, modes of transport, and other local factors like climate patterns, as well as the cost of gasoline or electricity. This means that reduction of CO2 estimated for two cities of the same country are not necessarily the same, giving the previously mentioned factors can vary greatly. Another problem are former commuters who used to walk or ride a bicycle or the bus, but now take more leisure trips by driving a personal car or flying more because they telework. Furthermore, there are teleworkers, whose home office consumes more energy than their previous daily travel and workplace put together.

The estimation showed on the next few pages can be observed in Table 1 on the page 58, Table 2 on the page 62 and Table 3 on the page 64.

As previously noted, there are a few main factors that influence the impact of teleworking on CO2 emissions and they include transportation, home-related energy use and office- related energy use. Based on that, here is a proposed basic general outline for a tool to estimate CO2 emissions from teleworking in Austria:

5.2.1 Transportation

To estimate the impact of transportation on CO2 emission, following model is proposed:

1. Commuting Distance Estimation:

- Gathering data on the average commuting distance in Austria.

- Calculating the average commuting distance saved per day for teleworkers.

2. Mode of Transportation:

- Determining the common modes of transportation used for commuting in Austria, such as cars, public transportation, or bicycles for example.
- Collecting data on the average CO2 emissions associated with each mode of transportation per kilometer.

3. Teleworking Frequency:

- Determining the frequency of teleworking (e.g., number of teleworking days per week).

4. CO2 Emission Calculation:

- Calculating the total distance saved per week by multiplying the average commuting distance saved per day by the teleworking frequency.
- Calculating the CO2 emissions avoided per week for each mode of transportation by multiplying the total distance saved by the average CO2 emissions per kilometer.

5. Results and Visualization:

- Providing a visual representation of the estimated CO2 emissions saved for each mode of transportation.
- Presenting the estimated CO2 emissions saved from teleworking in Austria.

1. Commuting Distance Estimation

- **Number of teleworkers and commuting distance**

Based on data from Statistics Austria, there were 2.29 million commuters in Austria in 2021, 27 average road kilometers travelled for work (both directions) per day and average commuting time was 27 minutes (both directions) per day (Statistics Austria, 2021).

From previous data and research, we know that economic sectors as well as income and education are the main representatives of teleworkability. As it can be observed in Figure 22, approximately 70% of Austria´s labor force is employed in third sector (Statistics Austria, 2021). The same source claims that only 6% work in the first sector. Logically, this would mean that in a first world country like Austria, a significant number of commuters should be able to work from home. According to ILO, 38% of employers switched to remote work in 2020, with the outbreak of Covid-19 virus (ILO, 2020). The results of study done in April by the Institut für empirische Sozialforschung and Arbeiterkammer Wien, done on a sample of 2200 respondents, revealed that 42% of those questioned who were employed, worked from home (with more than half doing so on a daily basis), 48% were unable to work from home, and 10% were able to but chose not to for a variety of reasons (IFES, 2020). This number dropped to 21% until 2021. Another research from OECD found out that in almost all regions in Austria, the proportion of occupations that can be performed remotely is comparable to or greater than the OECD median region (32%), however some regions are more suited for widespread teleworking than others. From 31% in Burgenland to 44% in Vienna, the proportion of occupations that allow for remote work differs among areas (OECD, 2020).

From the previous information, we can conclude that general teleworkability in Austria lies around 40%, which makes 0.92 million people who could telework on daily basis. This lies around Europe´s general estimated teleworkability value of 37%, but giving that Austria is one of the richest economies in Europe, this number is still very low. In comparison, the research shows that in the same period (in 2020, beginning of Corona outbreak), number of employees who worked remotely hit 60% (Statista, 2022).

For the purpose of this thesis´ research, different percentage is going to be used in calculation, in order to reveal what happens when 5% or 20% more or less people are working remotely. With the intention to present best and worst case scenario, as well as a few iterations in between, an Excel sheet was made. Detailed approximation and calculation results are shown in Table 1 on the page 58, Table 2 on the page 62 and Table 3 on the page 64.

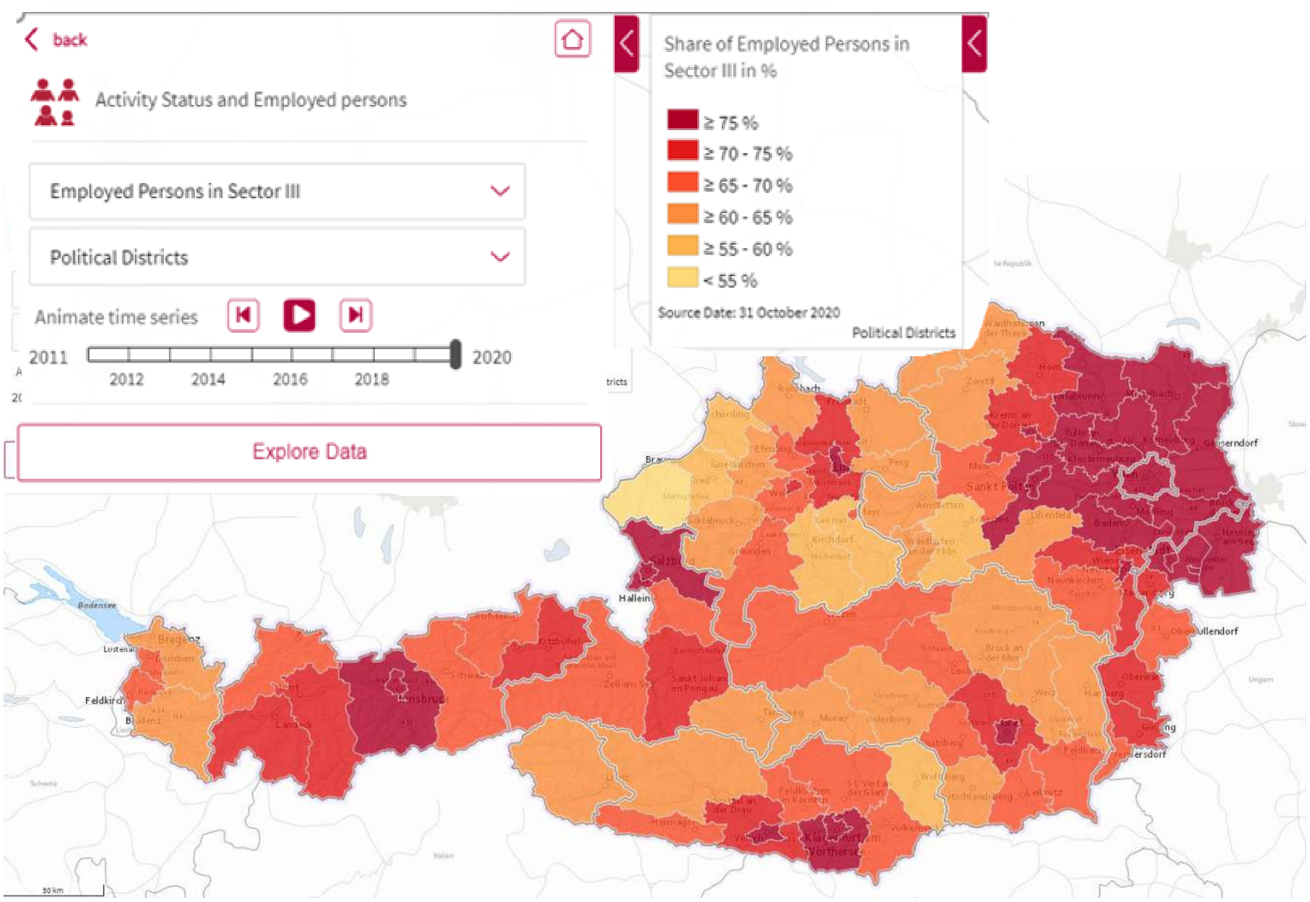

Figure 22: Illustrated share of employed people in sector 3 in Austria in 2020, given in % (source (Statistics Austria, 2021))

- **Average commuting distance saved per day**

Coming from the fact that extreme situations like Covid-19 pandemic in 2020, should not be considered as normal, average precedent, 5-days a week home office would be too ambitious and unrealistic. Globally, the average weekly usage of home offices was around 1.5 days in 2022. Germany was just under the global average with about 1,4 days every week, claims Statista (Statista, 2022). For the purpose of this calculation, it will be considered, that this 40% possible teleworkers work 1 to 5 days a week in home office, so 1, 3 or 5 days/week will be examined.

For example, 1,5 days/week multiplies 27 km (average distance traveled for work), make 40.5 km/week/employer saved.

By multiplying 40.5 km/week with 0.92 million commuters who are able to work remotely, we get 37.26 million road kilometers travelled saved per week, or 0.72 million kilometers a year, just in Austria.

In order to show best, as well as worst case scenario, both, 1-day and 5-days a week scenarios, as well as 3-days a week of teleworking are observed in Table 1, Table 2 and Table 3.

2. Mode of transportation

- **Common modes of transportation used**

Almost one third of people in Austria commute to work using their private cars or motorcycles (Numbeo, 2023). The road infrastructure is well-developed, and there is an extensive network of highways and roads throughout the country. Developed countries have comprehensive public transportation systems, including buses, trams, and trains and these systems provide convenient and efficient options for commuting to work. Even though, public transportation is widely available in Austria, particularly in urban areas like Vienna, Graz, Linz, or Salzburg, only one third of employers are using them for commuting. Austria is known for its cycling culture and has a well-developed network of bicycle lanes and paths. Some people choose to cycle to work, especially in urban areas where the infrastructure is more bike-friendly. Major cities also offer bike-sharing systems, providing easy access to bicycles for commuting purposes. Walking is also a common mode of transport especially for shorter distances, particularly in city centers or compact neighborhoods. 18% Austrians prefer to cycle or walk to work if their workplace is within a reasonable distance from their home, confirms Numbeo (Numbeo, 2023). The main means of transportation used in Austria for transport to work are shown in Figure 23.

It's important to note that the availability and usage of these modes of transport can vary based on factors such as the size of the city or town, the distance to be covered, and personal preferences. Moreover, as research also confirms, commuters who previously used to cycle or walk to work, are more likely to see an increase in net energy consumption, even if there are considerable regional and seasonal variations. But even after considering this, some studies are assuring that over a typical year, the total energy saved through reduced commuting would still be almost four times more than the rise in domestic energy usage (Crow, et al., 2020).

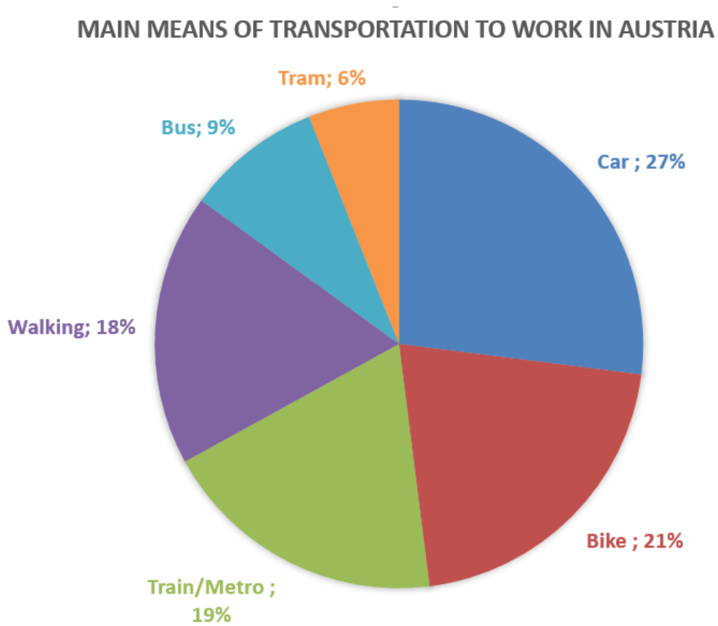

Figure 23: Main means of transportation to work and school in Austria. (Data source: (Numbeo, 2023))

- **CO_2 emissions associated with mode of transportation**

The average values of CO2 emissions per minute for each mode of transportation are taken from Numbeo (Numbeo, 2023). It is assumed that walking produces 0 g of CO2 per minute.

- bus produces 20g of CO2 per minute (for each passenger)
- car produces 133g of CO2 per minute (assumes only driver)
- train produces 10g of CO2 per minute (for each passenger)
- tram produces 15g of CO2 per minute (for each passenger)
- motorbike produces 80g of CO2 per minute

Using the previous data, total CO2 Emission Index can be calculated as follows:

Index = gCO2/min (depending on the transportation type) x % (percentage of teleworkers using the certain transportation type)

$Index_{CAR}$ = 133 gCO2/min x 0,27 = 35,91 gCO2/min

$Index_{BIKE}$ = 80 gCO2/min x 0,21 = 16,8 gCO2/min

$Index_{TRAIN/METRO}$ = 10 gCO2/min x 0,19 = 1,9 gCO2/min

$Index_{BUS}$ = 20 gCO2/min x 0,09 = 1,8 gCO2/min

$Index_{TRAM}$ = 15 gCO2/min x 0,06 = 0,9 gCO2/min

$Index_{MAIN}$ = $Index_{CAR}$ + $Index_{BIKE}$ + $Index_{TRAIN/METRO}$ + $Index_{BUS}$ + $Index_{TRAM}$ = 57,31 gCO2/min

An illustrated representation of CO2 footprint per minute (given in %) of different transportation types used by commuters in Austria is shown in the following pie chart (Figure 24).

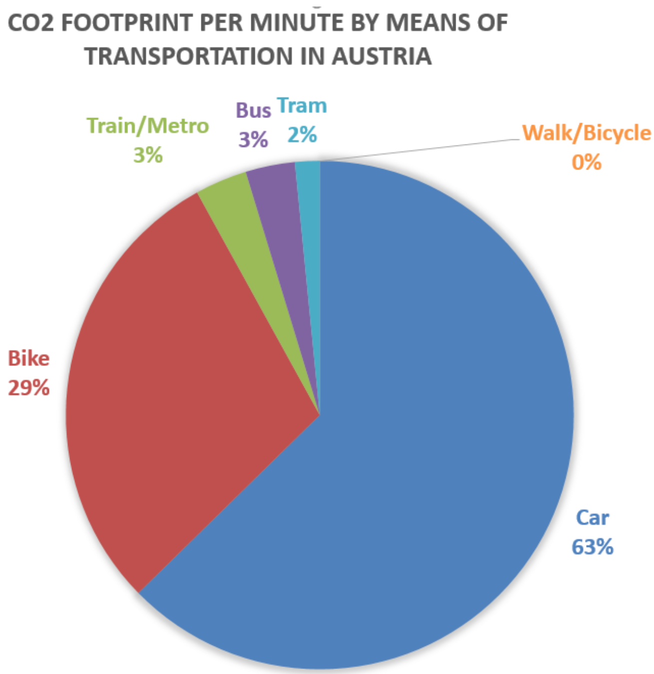

Figure 24: CO2 footprint by means of transportation in Austria, given in %.

3. Teleworking Frequency

Average teleworking frequency has been previously determined and used in calculations as 1,5 days/week. As already mentioned before, a 1-day, 3-days and 5-days teleworking scenarios are all represented in Table 1, Table 2 and Table 3.

4. CO2 Emission Calculation

- **Total distance saved per week**

1,5 days/week x 27 km (average distance traveled for work) = 40,5 km/week/employer (for the assumption that a person works 1,5 days a week remotely)

- **CO2 emissions avoided per week**

For total amount of CO2 emissions avoided per week is Index $_{MAIN}$ multiplied with the average daily amount of time spent on commuting:

57,31 gCO2/min x 27 min/day = 1547,37 gCO2/day or 1,55 kgCO2/day for each commuter

CO2 emissions avoided per week for each mode of transportation can be calculated by multiplying the total distance saved by the average CO2 emissions per kilometer. So the numbers are presented as follows:

for car: Index_{CAR} x 27 min/day = 35,91 gCO2/min x 27 min/day = 969,57 gCO2/day per person

for bike: Index_{BIKE} x 27 min/day = 16,8 gCO2/min x 27 min/day = 453,60 gCO2/day per person for train and metro: $Index_{TRAIN/METRO}$ x 27 min/day = 1,9 gCO2/min x 27 min/day

= 51,30 gCO2/day per person

for bus: $Index_{BUS}$ x 27 min/day = 1,8 gCO2/min x 27 min/day = 48,60 gCO2/day per person

for tram: $Index_{TRAM}$ x 27 min/day = 0,9 gCO2/min x 27 min/day = 24,30 gCO2/day per person

The presented calculation is represented in the chart on the previous page (see Figure 24).

Since the data shows that 18% of Austrians mostly cycles or walks to work, this should also be taken into account. The previously calculated number of possible teleworkers is 0.92million, but since 18% of them would most likely experience increase of energy consumption rather than decrease, the number reduces by 18%. The total number of employees that would contribute the CO2 reduction in transportation area is then 0.92 million x 0,82 which gives the total number of 0.75 million commuters.

More comprehensive calculation is given in Table 1 on the page 58.

5.2.2 Energy consumption at home

To estimate the energy consumption-related CO2 emissions for Austria through teleworking, we need to consider the energy usage at home during teleworking days. A simple tool to help with the estimation would consider:

1. Determining the number of teleworkers

- Estimating the number of people who currently telework or are expected to telework in Austria (see paragraph 5.2.1 Transportation on the page 47).

2. Calculating the average teleworking days per week

- Determining the average number of teleworking days per week for teleworkers. Here see also see paragraph 5.2.1 Transportation on the page 47.

3. Estimating the energy consumption at home

- Finding out the average energy consumption at home during teleworking days. This includes electricity usage for lighting, computers, heating, cooling, and other appliances.

4. Calculating the CO2 emissions per unit of energy

- Determining the CO2 emissions associated with each unit of energy consumed. The CO2 intensity varies depending on the energy sources used in Austria, such as fossil fuels, renewable energy, or a mix of both.

5. Calculating energy-related CO2 emissions per teleworker

- Multiplying the average energy consumption at home (from step 3) by the CO2 emissions per unit of energy (from step 4). This will give the estimated energy-related CO2 emissions per teleworker.

6. Calculating total CO2 emissions

- Multiplying the energy-related CO2 emissions per teleworker (from step 5) by the total number of teleworkers (from step 1). This gives an estimation of the total energy consumption-related CO2 emissions through teleworking in Austria.

As it has already been determined in paragraph 5.2.1 Transportation on the page 47, based on data from Statistics Austria (Statistics Austria, 2021), there were 2.29 million commuters in Austria in 2021 while minimum teleworkability-rate lies at 40%. This gives 0.92 million teleworkers in Austria. For the average number of teleworking days, 1.5 day/week is taken as appropriate rate, since it was estimated as a worldwide average by previous studies, although 1, 3 and 5 days are also considered in the calculation in Table 1 and Table 2.

3. Estimating the energy consumption at home

- The average energy consumption at home during teleworking days

Teleworking may induce a drop of rush-hour congestion and gasoline use, but on the other hand it affects residential demand for energy in a negative way. To estimate the overall energy consumption, it's necessary to determine the duration of teleworking, the energy ratings of specific equipment, and personal habits regarding heating, cooling, cooking, and entertainment. Gathering precise information and conducting energy audits at individual homes can provide more accurate estimations tailored to specific situations. Estimating the energy consumption of a teleworker in Austria, including work equipment, heating or cooling, and personal energy usage like cooking or TV, requires considering multiple factors and individual habits. It is important to note that actual energy consumption may vary significantly depending on various factors such as equipment efficiency, insulation of the home, personal preferences, and energy-saving practices. Due to the lack of any kind of survey or research on impact of telework on domestic energy consumption in Austria, here is an estimation based on available references:

1. Work Equipment:

- Laptop/Computer: A typical desktop computer or laptop can consume around 50-150 watts per hour (100 watts per hour on average), depending on usage and specifications (U.S. Department of Energy, 2023).

- Monitor: The energy consumption of a computer monitor can range from 15 to 60 watts per hour (38 watts per hour on average), depending on the size and technology (LCD, LED, etc.) (Energy Star, 2023).

- Lighting: Energy-efficient LED bulbs usually consume around 5-15 watts per hour per bulb (10 watts per hour on average), depending on the brightness (Energy Star, 2023).

- Other Equipment: Additional equipment like printers, routers, and chargers may consume additional energy, but their impact is generally lower compared to the computer and lighting, so they would not be considered in this estimation.

2. Heating or Cooling:

- Heating: The energy consumption for heating depends on various factors such as the type of heating system (e.g., gas, electric, district heating) and insulation of the home. The average energy consumption for heating in Austria is approximately 150-200 kWh (average consumption 175 kWh) per square meter per year, according to data from the Austrian Energy Agency (Energieagentur), 2023). However, this consumption may vary significantly based on climate, insulation quality, and personal preferences for indoor temperature. According to Statista (Statista, 2022), the average living space per person with main residence in Austria is approximately 50 square meters. This would mean that around 24 kWh (175kWh x 50 m² / 365 days) would be consumed per person per day, or 1000 watts per hour per person for heating.

- Cooling: Energy consumption for cooling is typically lower in Austria due to its moderate climate. Air conditioning units can range from 400 to 600 watts or average 500 watts per hour (assuming it has to cool down a 30 m² room) depending on the size and efficiency of the system, but their usage may be limited to hot summer months (Energy Star, 2023).

Also, depending on the season, either heating or cooling can come into equation. Heating period in Austria lasts from October to April (Fuchs, 2022) and even though cooling is restricted to not so many hot summer days, it consumes more energy than heating according to the sources, so to calculate as many scenarios, both heating and cooling will be considered in this estimation.

3. Personal Energy Usage:

- Cooking: Energy consumption for cooking varies based on the type of appliances used. Electric stoves typically consume around 400 watts the most modern ones and up to 1.600 watts per hour ones that are over 10 years old, while electric ovens may consume around 1.000 to 3.500 watts per hour. It's important to consider the frequency and duration of cooking activities (U.S. Department of Energy, 2023). Let´s say that cooking for an hour takes approximately around 1.500 watts.

- TV and Entertainment: The energy consumption of televisions depends on the size and technology. LCD or LED TVs consume around 50-150 watts per hour (100 watts per hour on average), while larger screens or older models may consume more. Other entertainment devices like gaming consoles or media streaming devices may also contribute to energy consumption (Energy Star, 2023) but are not considered in the estimation.

The number of hours a teleworker spends working from home can vary. For the purpose of the estimation, let's assume an average teleworking day of 8 hours. Based on the above assumptions, a rough estimation of the daily energy consumption for a teleworker in Austria can be calculated by adding up the energy consumption of the equipment:

Total Energy Consumption = (Computer Consumption + Monitor Consumption + Lighting Consumption + Other Equipment + Cooling/Heating) * Duration of Teleworking + (Cooking+ Entertaining Equipment) * Duration of using the appliance

= (100 watt/h + 40 watts/h + 2x10 watt/h + 1000 watt/h (heating)) * 8 h + (1500 watt/h + 100 watt/h) * 1 h

= 10880 watt hours = 10,88 KWh per day per teleworker (if a person is living alone)

If, for example, there are 2 teleworkers at home on the same day, energy consumption is lower per person and the total energy consumption could look like this:

Total Energy Consumption = (Computer Consumption *2 + Monitor Consumption * 2 + Lighting Consumption + Other Equipment + Cooling/Heating) * Duration of Teleworking + (Cooking+ Entertaining Equipment) * Duration of using the appliance = 12.000 watts

So one teleworker consumes 10,88 kWh a day on average, while two teleworkers consume 12,0 kWh a day on average, or 6,0 kWh per person. It can be noted that one teleworker consumes almost twice as much as two teleworkers in the same household. Further approximation and scenarios can be observed in Table 1.

4. and 5. Energy-related CO_2 emissions per teleworker

- Determining the CO_2 emissions associated with each unit of energy consumed

To calculate the CO_2 emissions associated with energy consumption, we need to consider the CO_2 intensity of the energy sources in Austria. The CO_2 emissions per kilowatt-hour (kg CO_2/kWh) can vary depending on the electricity mix, including renewable and fossil fuel sources. According to Eurostat (Eurostat, 2019), the average CO_2 emissions per kilowatt-hour in Austria were approximately 0.27 kg CO_2/kWh in 2019. By multiplying the average energy consumption at home (from step 3) by the CO_2 emissions per unit of energy, the estimated energy-related CO_2 emissions per teleworker is given.

So a rough approximation pro teleworker looks like this:

CO_2 Emissions = Total Energy Consumption (in kWh) * CO_2 Emissions per kWh CO_2 Emissions = 10,88 kWh * 0,27 kg CO_2/kWh CO_2 Emissions = 2,94 kg CO_2 per day per teleworker

6. Calculating total CO_2 emissions

- Multiplying the energy-related CO_2 emissions per teleworker (from step 5) by the total number of teleworkers (from step 1). This gives an estimation of the total energy consumption-related CO_2 emissions through teleworking in Austria.

2,94 kg CO_2 per day/teleworker * 0,92 million teleworkers = 2705 tons CO_2 per day in Austria

5.2.3 Energy consumption in office building

To estimate the energy consumption-related CO_2 emissions for an office building, we need to consider the energy usage at the office during non-teleworking days. The tool for the estimation would be very similar to the one for energy consumption at home. However, since the assessment of the energy of the electronic equipment, lightning, heating/cooling and ventilation for an office building is much more complicated than for the residential building, an estimation of a previous study is used for the final CO_2 emission estimation.

A few studies evaluated energy consumption of an office building and came to the conclusion that average energy requirement lies around 22,5 kWh per square meter per year (Ornetzeder, 2016). Average office space per employee is 5 square meters (just personal office space) according to Arbeitsinspektion Österreich (Arbeitsinspektion, 2022). Besides that, common office space like the foyer/reception, meeting and conference rooms, the tee kitchen or cafeteria and toilets make additional few square meters per employee that also have to be taken into account. According to a research from Energieinstitut of Vienna (Jandrokovic, et al., 2012) the average energy consumption per employee in an office building is 1700 kWh a year, which makes 7,08 kWh a day per employee (1700kWh/240 work days a year). The estimated energy-related CO_2 emissions per teleworker would be:

7,08 kWh * 0,27 kg CO_2/kWh = 1,91 kg CO_2 per day per teleworker

According to WKO (WKO, 2023), Laptop instead of desktop saves about 70 percent of energy per year. The problem is, many teleworkers use both laptop and a desktop or even two when working from home. The same study claims that the used energy in an average office building is distributed as follows (see Figure 25):

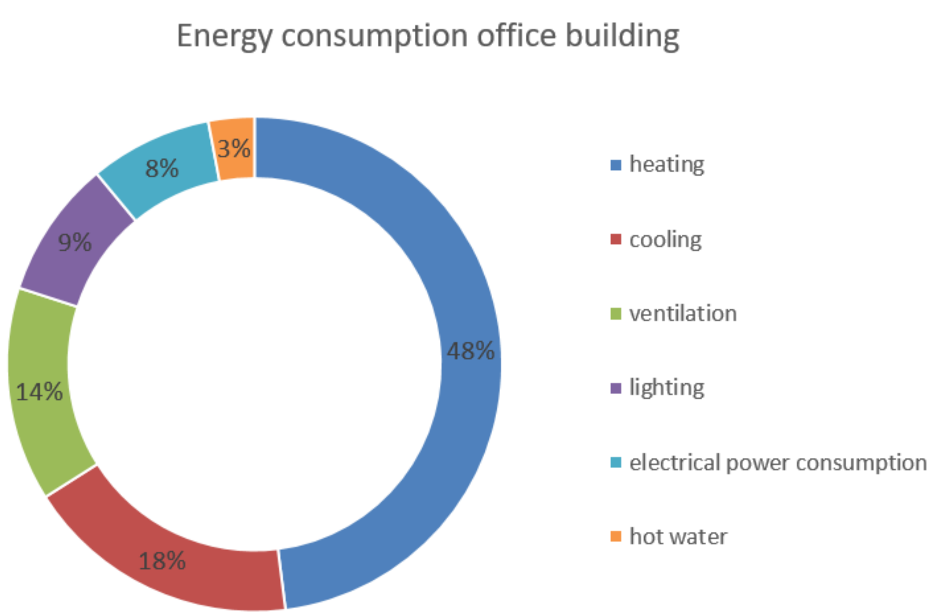

Figure 25: Energy consumption of an average office building in Austria, given in percentage (%)

5.2.4 Results and total reduction

If we assume that the office space does not consume extra energy while teleworker is working remotely, as well as that neither teleworker nor anybody from the household is using the private car for leisure and other no-work trips in the working hours (assuming also that a teleworking is living alone) the reduction per teleworker per day is estimated like this:

-1,55 kg CO2 (reduction from transportation) + 2,94 kg CO2 (home related energy) – 1,91 kg CO2 (reduction from saved office space) = - 0,52 kg CO2 per teleworker per day

Further approximations with other scenarios and other set of circumstances are shown in the following table (see Table 1, Table 2 and Table 3).

Table 1: Results of a sensitivity analysis of CO2 emission given in kgCO2 per person per week

[kgCO2]		1 person household	2 person household	office space: unreduced	office space: reduced	Rebound effect: car usage active	Rebound effect: 2p.h. 1TW; 1NTW
Transportation	telework: never	7,75	15,50			0,00	15,50
	telework: 1/week	6,20	12,40			1,55	13,95
	telework: 3/week	3,10	6,20			4,65	10,85
	telework: 5/week	0,00	0,00			7,75	7,75
	no rebound 5 dayTW	0,00	0,00			-	-
Office-related energy use for electronics	telework: never	0,76	1,53			-	1,52
	telework: 1/week	0,61	1,22			-	1,37
	telework: 3/week	0,31	0,61			-	1,07
	telework: 5/week	0,00	0,00			-	0,00
	no rebound 5 dayTW	0,00	0,00			-	-
Home-related energy use for elecrtonics 8h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	0,30	0,60			-	0,30
	telework: 3/week	0,91	1,81			-	0,91
	telework: 5/week	1,51	3,02			-	1,51
	no rebound 5 dayTW	1,51	3,02			-	-
Office lightning	telework: never	0,86	1,72	Lightning the	means lower	-	1,72
	telework: 1/week	0,69	1,38	whole building	energy costs	-	1,55
	telework: 3/week	0,34	0,69	even though	reciprocally	-	1,20
	telework: 5/week	0,00	0,00	some employees	to reduction of	-	0,86
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-
Home lightning 8h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	0,04	0,04			-	0,04
	telework: 3/week	0,13	0,13			-	0,13
	telework: 5/week	0,22	0,22			-	0,22
	no rebound 5 dayTW	0,22	0,22			-	-
Office heating	telework: never	4,87	9,75	Heating the	means lower	-	9,74
	telework: 1/week	3,90	7,80	whole building	energy costs	-	8,77
	telework: 3/week	1,95	3,90	even though	reciprocally	-	6,82
	telework: 5/week	0,00	0,00	some employees	to reduction of	-	4,87
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-

Home heating	telework: never	0,00	0,00			-	0,00
8h per day	telework: 1/week	2,16	2,16			-	2,16
	telework: 3/week	6,48	6,48			-	6,48
	telework: 5/week	10,80	10,80			-	10,80
	no rebound 5 dayTW	10,80	10,80			-	-
Office cooling	telework: never	1,72	3,44	Cooling the	means lower	-	3,44
	telework: 1/week	1,38	2,75	whole building	energy costs	-	3,10
	telework: 3/week	0,69	1,38	even though	reciprocally	-	2,41
	telework: 5/week	0,00	0,00	some employees	to reduction of	-	1,72
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-
Home cooling	telework: never	0,00	0,00			-	0,00
8h per day	telework: 1/week	1,08	1,08			-	1,08
	telework: 3/week	3,24	3,24			-	3,24
	telework: 5/week	5,40	5,40			-	5,40
	no rebound 5 dayTW	5,40	5,40			-	-
Home personal	telework: never	0,00	0,00			-	0,00
energy usage	telework: 1/week	0,43	0,43			-	0,43
Cooking +	telework: 3/week	1,30	1,30			-	1,30
Entertaainment	telework: 5/week	2,16	2,16			-	2,16
1h per day	no rebound 5 dayTW	2,16	2,16			-	-
Office	telework: never	1,34	2,68	Ventilationg the	means lower	-	2,68
ventilation	telework: 1/week	1,07	2,68	whole building	energy costs	-	2,68
	telework: 3/week	0,54	2,68	even though	reciprocally	-	2,68
	telework: 5/week	0,00	2,68	some employees	to reduction of	-	2,68
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-

Total CO2 emission [kgCO2]		**Heating season**	**Cooling season**
Case 1	telework: never	15,59	12,43
/person/week	telework: 1/week	15,41	11,80
1 pers. househ.	telework: 3/week	15,05	10,55
office space	telework: 5/week	14,69	9,29
reduced	no rebound 5 dayTW	14,69	9,29
Case 2	telework: never	15,59	12,43
/person/week	telework: 1/week	16,71	12,47
1 pers. househ.	telework: 3/week	17,45	12,55
office space not	telework: 5/week	21,19	12,63
reduced	no rebound 5 dayTW	14,69	9,29
Case 3	telework: never	15,59	12,43
/person/week	telework: 1/week	14,36	11,29
2 p. h. (2 TW)	telework: 3/week	11,90	9,02
office space	telework: 5/week	9,44	6,74
reduced	no rebound 5 dayTW	8,10	5,40
Case 4	telework: never	15,58	12,43
/person/week	telework: 1/week	15,63	12,25
1 TW, 1NTW	telework: 3/week	15,72	11,89
office space	telework: 5/week	15,42	11,15
reduced	no rebound 5 dayTW	-	-

Net CO2 value	per person per week in [kgCO2]	Heating season		Cooling season	
Case 1	= telework 5/week - telework never =	-0,90	-6%	-3,15	-25%
Case 2		5,60	36%	0,20	2%
Case 3		-6,15	-39%	-5,70	-46%
Case 4		-0,16	-1%	-1,28	-10%
Net CO2 value	per person per week in [kgCO2]	Heating season		Cooling season	
Case 1	= telework 3/week - telework never =	-0,54	-3%	-1,89	-15%
Case 2		1,87	12%	0,12	1%
Case 3		-3,69	-24%	-3,42	-27%
Case 4		0,13	1%	-0,54	-4%
Net CO2 value	per person per week in [kgCO2]	Heating season		Cooling season	
Case 1	= telework 1/week - telework never =	-0,18	-1%	-0,63	-5%
Case 2		1,12	7%	0,04	0,3%
Case 3		-1,23	-8%	-1,14	-9%
Case 4		0,04	0,3%	-0,18	-1%

* Important notice: The energy values for heating and cooling refer to average values considering 365 days in a year and do not refer to different seasons. Therefore the difference between heating and cooling season quantify the average value as well and would in reality display a larger value differences for winer and summer season. However, for the purpose of this table´s calculation, the average yearly value is taken as the average seasonly value.

Table 1 outline the sensitivity analysis of the average change in energy demand and CO2 emissions resulting from a single household's transition to home working. The table shows the transition with data provided for both heating (winter) and cooling (summer) periods. The factors taken into consideration include personal transport, residential and office energy consumption including lighting, heating, cooling, ventilation, as well as energy consumed for electronics. Five telework scenarios are presented in the table: non-telework (telework: never), telework once a week, three times or five times a week, along with five days a week with no rebound effects (no rebound 5 day TW). This no rebound means that office ventilation which normally works constantly, is not taken into account when a person is working remotely. Data for these scenarios is represented and taken from chapters *5.2.1 Transportation*; *5.2.2 Energy consumption at home* and *5.2.3 Energy consumption in office building*. The analysis includes four cases which are inspired by the cases from (Nakanishi, 2015) mentioned in chapter *5.1.3 Office-related energy use* on the page 44.

The cases are defined like this:

Case 1: The teleworker is alone at home and office space is reduced. On days when a person works remotely, less energy is consumed in the office, but more energy is consumed at home.

Case 2: The teleworker is alone at home but office space is not changed. Energy consumption stays put even though the person is working remotely. The implementation of telework will result in an increase in overall energy usage.

Case 3: There are two teleworkers in the household and office space is reduced. Office energy use is lower, and there is barely any rise in energy use at home.

Case 4: There are two teleworkers in the household and office space is reduced. This case represents a rebound effect since one worker is not working remotely and the other one is. It also represents a case where there is one teleworker in the household who lives with their family. Energy consumption at home is not reduced and telework does not affect the energy use in this case.

The energy and CO2 emissions are calculated based on the assumed consumption patterns for the different scenarios which can be found throughout this chapter. The final CO2 footprint is calculated by adding the resulting emissions from these scenarios.

It is important to note that the results also differ between winter and summer periods, with energy consumption and fossil fuel usage generally being lower during the summer months compared to winter. Depending on the season, differences in heating and cooling play a crucial role, with the average heating costs in Austria consuming approximately 50% more energy and therefore have greater carbon footprint than cooling for the same conditions. Consequently, case 2 (5 days a week telework) demonstrates the highest energy consumption and CO2 emissions in heating season among the analyzed cases, while case 3 (5 days a week telework) exhibits the lowest levels in these categories. Net CO2 value is not negative in each category, indicating that households committed to home office practices do not always contribute to a reduction in CO2 emissions and that the consideration of rebound effects and other aspects are very important. Case 3 shows the biggest CO2 reduction – up to 39% reduction, for both heating and cooling season, which was expected considering that two people in household consume almost half as much energy per person than one-person household. On the other hand, case 1 reveal a notable decrease, while case 2 shows the biggest increase in carbon footprint for both cooling and heating season, up to 36% in heating and 2% in cooling season. This suggests that home office only has positive environmental effect in case when the office space is reduced or the energy consumption is limited to minimum when a person is working remotely. In general, teleworking 5 times a week brings bigger carbon reduction than teleworking for one day a week for both heating and cooling scenarios, except for case 2, which confirms the previous statement.

Overall, the table provides insights into the energy demand and CO2 emission changes associated with remote working for a single household with per week for different scenarios and set of circumstances. The analysis highlights the differences in results considering the number of commuting days, the significance of electronics efficiency at home and in the office, as well as the differences that arise by considering heating and cooling season.

In order to observe how different modes of transportation affect net CO2 emission value, Table 2 represents the similar as Table 1, however it reflects all modes of transportation and their CO2 value separately. C02 values of home and office parts of the equation remain the same, all taken from Table 1. Data for Transport scenarios was taken from chapter *5.2.1 Transportation.* The analyse includes the same four cases represented in Table 1.

The first thing in Table 2 that catches the eye is that in all four scenarios (TW never, TW 1/week, TW 3/week, TW 5/week) a car as a mode of transportation has by far the highest CO2 emission value, almost twice the value of motorbike and several times greater value as other modes of transportation. This proves the impact personal vehicles, especially cars, have on pollution. The carbon footprint value for walking or biking is assumed to be zero.

Table 2: Results of the sensitivity analysis considering all modes of transportation separately

Transport-ation art [kgCO2]	= Index * km * days	1 person household	Rebound effect: car usage stays active	Total CO2 emission [kgCO2] Case 1 Heating	Case 1 Cooling	Case 2 Heating	Case 2 Cooling	Case 3 Heating	Case 3 Cooling	Case 4 Heating	Case 4 Cooling
Car	telework: never	17,96	4,85	25,79	22,64	25,79	22,64	16,82	13,66	16,81	13,66
	telework: 1/week	14,36	4,85	23,57	19,97	24,87	20,64	15,34	12,28	15,83	12,46
	telework: 3/week	7,18	4,85	19,13	14,63	20,57	16,64	12,39	9,51	13,88	10,06
	telework: 5/week	0,00	4,85	14,69	9,29	21,19	12,63	9,44	6,74	11,55	7,27
Motorbike	telework: never	10,80	-	18,64	15,48	18,64	15,48	13,24	10,08	13,23	10,08
	telework: 1/week	8,64	-	17,85	14,24	19,15	14,91	12,48	9,41	12,97	9,60
	telework: 3/week	4,32	-	16,27	11,77	18,39	13,77	10,96	8,08	12,45	8,62
	telework: 5/week	0,00	-	14,69	9,29	21,19	12,63	9,44	6,74	11,55	7,27
Train/ Metro	telework: never	1,35	-	9,19	6,03	9,19	6,03	8,51	5,36	8,51	5,36
	telework: 1/week	1,08	-	10,29	6,68	11,59	7,35	8,70	5,63	9,19	5,82
	telework: 3/week	0,54	-	12,49	7,99	15,50	9,99	9,07	6,19	10,56	6,73
	telework: 5/week	0,00	-	14,69	9,29	21,19	12,63	9,44	6,74	11,55	7,27
Bus	telework: never	2,70	-	10,54	7,38	10,54	7,38	9,19	6,03	9,18	6,03
	telework: 1/week	2,16	-	11,37	7,76	12,67	8,43	9,24	6,17	9,73	6,36
	telework: 3/week	1,08	-	13,03	8,53	15,91	10,53	9,34	6,46	10,83	7,00
	telework: 5/week	0,00	-	14,69	9,29	21,19	12,63	9,44	6,74	11,55	7,27
Tram	telework: never	2,03	-	9,86	6,71	9,86	6,71	8,85	5,70	8,85	5,69
	telework: 1/week	1,62	-	10,83	7,22	12,13	7,89	8,97	5,90	9,46	6,09
	telework: 3/week	0,81	-	12,76	8,26	15,70	10,26	9,20	6,32	13,88	6,87
	telework: 5/week	0,00	-	14,69	9,29	21,19	12,63	9,44	6,74	11,55	7,27
Walking/ Bicycle	telework: never	0,00	-	7,84	4,68	7,84	4,68	7,84	4,68	7,83	4,68
	telework: 1/week	0,00	-	9,21	5,60	10,51	6,27	8,16	5,09	8,65	5,28
	telework: 3/week	0,00	-	11,95	7,45	15,08	9,45	8,80	5,92	10,29	6,46
	telework: 5/week	0,00	-	14,69	9,29	21,19	12,63	9,44	6,74	11,55	7,27
	Net CO2 /person/week in [kgCO2]	Car	= TW 5/week - TW never =	-11,10	-13,35	-4,61	-10,01	-7,38	-6,92	-5,26	-6,39
		Motorbike		-3,95	-4,96	2,55	-2,85	-3,80	-3,35	-1,69	-2,81
		Train/Metro		5,50	3,25	12,00	6,60	0,93	1,38	3,04	1,92
		Bus		4,15	1,90	10,65	5,25	0,25	0,70	2,36	1,24
		Tram		4,83	2,58	11,32	5,92	0,59	1,04	2,70	1,58
		Walk/Bike		6,85	4,60	13,35	7,95	1,60	2,05	3,71	2,59
	Net CO2 /person/week in [kgCO2]	Car	= TW 3/week - TW never =	-6,66	-8,01	-5,22	-6,00	-4,43	-4,15	-2,93	-2,81
		Motorbike		-2,37	-3,72	-0,25	-1,71	-2,28	-2,01	-0,78	-3,60
		Train/Metro		3,30	1,95	6,31	3,96	0,56	0,83	2,05	-1,46
		Bus		2,49	1,14	5,37	3,15	0,15	0,83	1,65	1,38
		Tram		2,90	1,55	5,84	3,55	0,35	0,63	5,04	1,18
		Walk/Bike		4,11	2,76	7,25	4,77	0,96	1,23	2,46	1,78
	Net CO2 /person/week in [kgCO2]	Car	= TW 1/week - TW never =	-2,22	-2,67	-0,92	-2,00	-1,48	-1,38	-0,98	-1,20
		Motorbike		-0,79	-1,24	0,51	-0,57	-0,76	-0,67	-0,26	-0,49
		Train/Metro		1,10	0,65	2,40	1,32	0,19	0,28	0,68	0,46
		Bus		0,83	0,38	2,13	1,05	0,05	0,14	0,55	0,32
		Tram		0,97	0,52	2,26	1,18	0,12	0,21	0,62	0,39
		Walk/Bike		1,37	0,92	2,67	1,59	0,32	0,41	0,82	0,59

Observing the left part of the table, representing the cases 1-4, it is notable that car and motorbike, aka. personal vehicles, have much bigger CO2 value difference in scenario *TW never* than *TW 5/week*, in cooling season even twice as big. The most exceptional impact is to be observed in scenario Walking/Bicycle where the deviation hits up to 270% (case 2, heating). These differences are best to be observed by comparing Net CO2 values.

As expected, the biggest CO2 value net difference is in scenario *TW 5/week – TW never* and the smallest in *TW 1/week – TW never*. It is important to note, that net CO2 value is negative in all scenarios with car and motorbike and positive in all scenarios for all other transportation arts (with exception of three scenarios where the situation is vice versa – e.g. Motorbike, Case 2, heating). Table 2 represents a clear proof that in context of transportation, the only scenario where telework would positively affect CO2 emission is cutting back on personal vehicle usage. Furthermore, it highlights the rebound effect caused by previous walkers/bikers switching to home office and increasing the net CO2 emission value to up to 3 times (Case 2, heating).

Table 3 on the next page represents results of the sensitivity analysis considering differences in distance traveled including all modes of transportation. Since number of teleworking days is not relevant for this approximation and leads to the same values for case 1 and 2, as well as case 3 and four, Table 3 excludes four cases examined in previous tables. That leaves us with two cases - case 1/2 and case 3/4. For the number of teleworking days, the average value of 1,5 days/week was taken, while the number of office days equals 3,6 (5 working days – 1,5 days TW). The distance varied with values 10 km, 20 km, 27 km (average commuting distance in Austria) and 40 km for comparison with a higher distance. Net CO2 value is the same for heating and cooling in all scenarios because all office/home related costs from Table 1 were multiplied with 3,6/1,5 days which gives no space for heating and cooling values to vary.
Values in table grow with growing distance for every mode of transport, except for walking/biking where they remain the same as a consequence of CO2 index for that mode of transport ($Iindex_{walking}$ = 0 $kgCO_2$/min). As expected, only negative values are to found in net section difference between distance 27 km and distance 40 km.

Table 3: Results of the sensitivity analysis considering differences in distance traveled and all modes of transportation separately

Transportation art [kgCO2]	= Index * km * 1,5 days	1 person household	Total CO2 emission [kgCO2]			
			Case 1/2		Case 3/4	
			Heating	Cooling	Heating	Cooling
Car	distance 10km	2,00	11,75	7,97	8,91	5,88
	distance 20km	3,99	13,75	9,96	9,91	6,88
	distance 27km	5,39	15,14	11,36	10,60	7,58
	distance 40km	7,98	17,74	13,95	11,90	8,87
Motorbike	distance 10km	1,20	10,96	7,17	8,51	5,48
	distance 20km	2,40	12,16	8,37	9,11	6,08
	distance 27km	3,24	13,00	9,21	9,53	6,50
	distance 40km	4,80	14,56	10,77	10,31	7,28
Train/Metro	distance 10km	0,15	9,91	6,12	7,99	4,96
	distance 20km	0,30	10,06	6,27	8,06	5,03
	distance 27km	0,41	10,16	6,38	8,11	5,09
	distance 40km	0,60	10,36	6,57	8,21	5,18
Bus	distance 10km	0,30	10,06	6,27	8,06	5,03
	distance 20km	0,60	10,36	6,57	8,21	5,18
	distance 27km	0,81	10,57	6,78	8,32	5,29
	distance 40km	1,20	10,96	7,17	8,51	5,48
Tram	distance 10km	0,23	9,98	6,20	8,02	5,00
	distance 20km	0,45	10,21	6,42	8,14	5,11
	distance 27km	0,61	10,36	6,58	8,21	5,19
	distance 40km	0,90	10,66	6,87	8,36	5,33
Walking/ Bicycle	distance 10km	0,00	9,76	5,97	7,91	4,88
	distance 20km	0,00	9,76	5,97	7,91	4,88
	distance 27km	0,00	9,76	5,97	7,91	4,88
	distance 40km	0,00	9,76	5,97	7,91	4,88
Net CO2 /person/week in [kgCO2]	distance 27km - distance 10km	Car	3,39	3,39	1,70	1,70
		Motorbike	2,04	2,04	1,02	1,02
		Train/Metro	0,25	0,26	0,13	0,13
		Bus	0,51	0,51	0,26	0,25
		Tram	0,38	0,38	0,19	0,19
		Walk/Bike	0,00	0,00	0,00	0,00
Net CO2 /person/week in [kgCO2]	distance 27km - distance 20km	Car	1,40	1,40	0,70	0,70
		Motorbike	0,84	0,84	0,42	0,42
		Train/Metro	0,11	0,11	0,05	0,05
		Bus	0,21	0,21	0,11	0,05
		Tram	0,16	0,16	0,08	0,08
		Walk/Bike	0,00	0,00	0,00	0,00
Net CO2 /person/week in [kgCO2]	distance 27km - distance 40km	Car	-3,99	-3,99	-2,00	-2,00
		Motorbike	-2,40	-2,40	-1,20	-1,20
		Train/Metro	-0,30	-0,30	-0,15	-0,15
		Bus	-0,60	-0,60	-0,30	-0,30
		Tram	-0,45	-0,45	-0,23	-0,23
		Walk/Bike	0,00	0,00	0,00	0,00

6 Future CO2 emission and energy generation prospect

About 20% of the world's carbon dioxide emissions come from the car industry. Without tackling this significant source of emissions, it will be impossible to stabilize atmospheric quantities of greenhouse gases. A major financial risk might be posed to the sector by impending climate change laws as a result of the substantial emissions emitted per car produced. To lay the groundwork for an industry-wide response strategy to climate change and manage the related financial and environmental risk, a group of students in Netherlands has designed an innovative electric car with a carbon-capturing system, The World Economic Forum reports (The World Economic Forum, 2023). This creation features two filters capable of absorbing up to 2 kg of CO2 during its operation, which spans 30,000 km. Named ZEM (zero emission mobility), the vehicle is primarily constructed using 3D-printed recycled plastics. While electric cars emit minimal carbon during use, their production, particularly battery manufacturing, can cause notable pollution. This implies that it takes considerable mileage for an electric car to achieve "carbon parity" with its fossil fuel counterparts. The students behind this initiative, from the Eindhoven University of Technology, envision a future where service stations systematically empty the carbon filters. While the global fleet of electric cars exceeds 10 million, reaching sustainable energy targets requires 230 million by 2030. However, challenges like costs and charging infrastructure remain to be addressed.

Another important sector that impact the world's carbon dioxide emissions greatly is electricity and heat sector. Those two recorded the largest jump in CO2 emissions by industry in 2021, rising by more than 900 Mt reveals IEA (IEA, 2022). Since more fossil fuels were used to help satisfy the rising demand for power, this was responsible for 46% of the rise in emissions worldwide, claims the source.

In 2023, Finland has introduced the world's first sand-based battery to tackle a key renewable energy challenge: maintaining consistent power supply year-round. The battery converts renewable electricity into heat, which heats 100 tonnes of sand up to 500 degrees Celsius. This stored heat is then used for winter heating in local homes, businesses, and even industrial processes currently reliant on fossil fuels. Unlike lithium-based batteries, which are costly and ecologically impactful, the sand battery utilizes abundant and diverse sand materials. This innovation could reshape energy storage, offering a sustainable and scalable solution (The World Economic Forum, 2023).

A further step towards technological progress in this area was also made in Europe. Namely Switzerland is innovatively integrating solar panels onto its railway tracks by utilizing the meter-wide, unused space between the rails. This inventive approach involves a train laden with solar panels traveling along the tracks, seamlessly deploying the photovoltaic modules similar to unfurling a carpet. In a collaborative effort, the start-up Sun-Ways and the Federal Institute of Technology Lausanne initiated a pilot project near Buttes in western Switzerland. Encouraged by its success, the project has extended to encompass the country's expansive 5,000 km rail network, projecting a potential to contribute 2% of Switzerland's total electricity consumption. Sun-Ways envisions a broader global impact, stating that approximately 50% of the world's railways could be equipped with their innovative system. Remarkably, the deployed panels are fully detachable, facilitating maintenance work, and possess no visual or environmental ramifications, in contrast to conventional solar panels installed on buildings, fields, or mountain landscapes. Beyond Switzerland's initiative, solar innovation within rail contexts is underway in other nations, including the UK, Italy, and Germany, where tests are being conducted on panels embedded into railway sleepers. This promising railway-solar convergence is aligned with the broader objective of achieving net-zero emissions by 2050. Meeting this ambitious goal necessitates an annual solar power output growth of 25% by 2030. As the world strives toward sustainable energy futures, the integration of renewable sources within existing infrastructure demonstrates both practicality and potential for transformative change (The World Economic Forum, 2023).

Another problem that is significantly linked to CO2 emission impacts is electrical and in general plastic waste disposal. One part of the problem was presented in one of the previous chapters *4.1.3 Information and communication technology – rebound effects.* About 4% of all greenhouse gas (GHG) emissions are caused by the manufacture, conversion, and waste management of plastics, says a report on climate change and plastic pollution done by OECD (OECD, 2023). Through the end-of-life handling of plastics, waste management techniques also have an impact on the GHG intensity of plastics. In 2019, emissions from recycling made up 22% of the total end-of-life emissions while emissions from incineration made up 70%, claims the same source. By lessening the demand for primary plastics, which have a greater carbon footprint, recycling plastics lowers GHG emissions. When compared to the manufacturing of a similar primary plastics polymer, the average reduction in GHG emissions across all regions is more than two-thirds.

Researchers at the Swiss Federal Institute of Technology (EPFL) have developed plant-based plastic that naturally degrades into sugar. Utilizing corn husks and other plant residues, scientists employ specialized chemicals to transform sugar molecules within these materials into plastic-like components. This special plant plastic exhibits durability, heat resistance, and excellent oxygen barrier properties, making it suitable for applications like food packaging, textile fibers, and 3D printing. Importantly, when its utility ceases, another chemical process facilitates its conversion back into sugar. While conventional plastic boasts versatility and affordability, its persistence poses a significant environmental challenge, with decomposition timelines ranging from decades to centuries. A mere 9% of the 8.3 billion tonnes of plastic produced globally have been recycled, highlighting the pressing need for sustainable alternatives. The breakthrough in creating plant-derived plastic not only addresses environmental concerns but also offers a potential avenue for reducing plastic waste and its associated long-term impacts (The World Economic Forum, 2023).

The results of the analysis considering all these different future prospects and their impact on CO2 emissions in connection with teleworking are represented in the following table (see Table 4 on the page 67).

The researches of Transport&Environment created a tool that gathers all the most recent information on CO2 emissions related to driving an electric, diesel, or gasoline automobile in order to provide an answer to the issue of how much CO_2 can an electric car save in comparison with the one driving on diesel or gasoline. The quantity of CO_2 released during the generation of energy or the burning of fuel, as well as the carbon effect of mining resources for batteries or the construction of a power plant, have all been taken into consideration. They showed that the average CO_2 emissions of electric automobiles in Europe are more than three times lower than those of identical fuel vehicles (Gimbert, 2022).

This was considered in the following table like this:

For total amount of CO_2 emissions coming from transportation, $Index_{MAIN}$ is multiplied with the average daily amount of time spent on commuting and divided with 3 to consider the possible reduction when using electrical rather than fuel vehicles (except for metro and tram):

$$Index_{MAIN} = Index_{CAR}/3 + Index_{BIKE}/3 + Index_{TRAIN/METRO} + Index_{BUS}/3 + Index_{TRAM} = 20{,}97\ gCO_2/min$$

20,97 gCO_2/min x 27 min/day = 566,2 gCO_2/day or 0,57 $kgCO_2$/day for each commuter (instead of 1,55 $kgCO_2$/day)

For the home and office related heating, was 0 CO_2 emissions considered, provided that sand batteries are going to be used in the future. The average energy consumption per employee in an office building would not be 7,08 kWh a day per employee but 7,08-7,08*(0,48+0,03) = 3,47 kWh. The estimated energy-related CO_2 emissions per teleworker would be:

3,47 kWh * 0,27 kg CO_2/kWh = 0,94 kg CO_2 per day per teleworker

Table 4: Results of the sensitivity analysis with adaptation for previously mentioned future prospects

[kgCO2]		1 person household	2 person household	office space: unreduced	office space: reduced	Rebound effect: car usage active	Rebound effect: 2p.h. 1TW; 1NTW
Transportation	telework: never	2,85	5,70			0,00	10,60
	telework: 1/week	2,28	4,56			0,57	5,13
	telework: 3/week	1,14	2,28			1,71	3,99
	telework: 5/week	0,00	0,00			2,85	2,85
	no rebound 5 dayTW	0,00	0,00			-	-
Office-related energy use for electronics	telework: never	0,76	1,53			-	1,52
	telework: 1/week	0,61	1,22			-	1,37
	telework: 3/week	0,31	0,61			-	1,07
	telework: 5/week	0,00	0,00			-	0,00
	no rebound 5 dayTW	0,00	0,00			-	-
Home-related energy use for elecrtonics 8h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	0,30	0,60			-	0,30
	telework: 3/week	0,91	1,81			-	0,91
	telework: 5/week	1,51	3,02			-	1,51
	no rebound 5 dayTW	1,51	3,02			-	-
Office lightning	telework: never	0,86	1,72	Lightning the	means lower	-	1,72
	telework: 1/week	0,69	1,38	whole building	energy costs	-	1,55
	telework: 3/week	0,34	0,69	even though	reciprocally	-	1,20
	telework: 5/week	0,00	0,00	some employees	to reduction of	-	0,86
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-

Home lightning 8h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	0,04	0,04			-	0,04
	telework: 3/week	0,13	0,13			-	0,13
	telework: 5/week	0,22	0,22			-	0,22
	no rebound 5 dayTW	0,22	0,22			-	-
Office heating	telework: never	0,00	0,00	Heating the	means lower	-	0,00
	telework: 1/week	0,00	0,00	whole building	energy costs	-	0,00
	telework: 3/week	0,00	0,00	even though	reciprocally	-	0,00
	telework: 5/week	0,00	0,00	some employees	to reduction of	-	0,00
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-
Home heating 8h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	0,00	0,00			-	0,00
	telework: 3/week	0,00	0,00			-	0,00
	telework: 5/week	0,00	0,00			-	0,00
	no rebound 5 dayTW	0,11	0,00			-	-
Office cooling	telework: never	1,72	3,44	Cooling the	means lower	-	3,44
	telework: 1/week	1,38	2,75	whole building	energy costs	-	3,10
	telework: 3/week	0,69	1,38	even though	reciprocally	-	2,41
	telework: 5/week	0,00	0,00	some employees	to reduction of	-	1,72
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-
Home cooling 8h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	1,08	1,08			-	1,08
	telework: 3/week	3,24	3,24			-	3,24
	telework: 5/week	5,40	5,40			-	5,40
	no rebound 5 dayTW	5,40	5,40			-	-
Home personal energy usage Cooking + Entertaainment 1h per day	telework: never	0,00	0,00			-	0,00
	telework: 1/week	0,43	0,43			-	0,43
	telework: 3/week	1,30	1,30			-	1,30
	telework: 5/week	2,16	2,16			-	2,16
	no rebound 5 dayTW	2,16	2,16			-	-
Office ventilation	telework: never	1,34	2,68	Ventilationg the	means lower	-	2,68
	telework: 1/week	1,07	2,68	whole building	energy costs	-	2,68
	telework: 3/week	0,54	2,68	even though	reciprocally	-	2,68
	telework: 5/week	0,00	2,68	some employees	to reduction of	-	2,68
	no rebound 5 dayTW	0,00	0,00	work from home	the office space	-	-

Total CO2 emission [kgCO2]		**Heating season**	**Cooling season**
Case 1 /person/week 1 pers. househ. office space reduced	telework: never	5,81	7,53
	telework: 1/week	5,43	7,88
	telework: 3/week	4,66	8,59
	telework: 5/week	3,89	9,29
	no rebound 5 dayTW	4,00	9,29
Case 2 /person/week 1 pers. househ. office space <u>not</u> reduced	telework: never	5,81	7,53
	telework: 1/week	5,75	8,55
	telework: 3/week	4,60	10,59
	telework: 5/week	5,51	12,63
	no rebound 5 dayTW	4,00	9,29
Case 3 /person/week 2 p. h. (2 TW) office space reduced	telework: never	5,81	7,53
	telework: 1/week	5,46	7,37
	telework: 3/week	4,75	7,06
	telework: 5/week	4,04	6,74
	no rebound 5 dayTW	2,70	5,40
Case 4 /person/week 1 TW, 1NTW office space reduced	telework: never	8,26	9,98
	telework: 1/week	5,75	7,84
	telework: 3/week	5,64	8,46
	telework: 5/week	5,14	8,70
	no rebound 5 dayTW	-	-

Net CO2 value	per person per week in [kgCO2]	Heating season		Cooling season	
Case 1	= telework 5/week - telework never =	-1,82	-33%	1,75	23%
Case 2		-0,30	-5%	5,10	68%
Case 3		-1,77	-31%	-0,80	-11%
Case 4		-3,12	-38%	-1,28	-13%
Net CO2 value	per person per week in [kgCO2]	Heating season		Cooling season	
Case 1	= telework 3/week - telework never =	-1,15	-20%	1,05	14%
Case 2		-1,21	-21%	3,06	41%
Case 3		-1,06	-18%	-0,48	-6%
Case 4		-2,63	-32%	-1,52	-15%
Net CO2 value	per person per week in [kgCO2]	Heating season		Cooling season	
Case 1	= telework 1/week - telework never =	-0,38	-7%	0,35	5%
Case 2		-0,06	-1%	1,02	13,5%
Case 3		-0,35	-6%	-0,16	-2%
Case 4		-2,51	-30,4%	-2,14	-21%

* Important notice: The energy values for heating and cooling refer to average values considering 365 days in a year and do not refer to different seasons. Therefore the difference between heating and cooling season quantify the average value as well and would in reality display a larger value differences for winer and summer season. However, for the purpose of this table´s calculation, the average yearly value is taken as the average seasonly value.

The difference between Table 4 and Table 1 is easy notable. Table 4 shows that in all cases that consider heating season, as well as case 3 and 4 in cooling season, the reduction of CO2 emission is pledged. This reduction rises up to almost 40% in case 4 in heating and 20% in cooling season. On the other side, this makes the difference and raise of the emissions in cooling season in case 2 to up to 70% when a person switches from TW never to TW 5/week. All things considered, implementing telework would make more difference and improvement in the reduction of carbon footprint when all these prospects could be implemented in the future. However, the previous table does not consider all the future prospects and the possible consequences they would bring with.

7 Conclusion

With a subject like this it is easy to neglect the downsides because of the societal profit it would bring to us, especially considering the alarming situation with climate change and the influence humans had on it. Naturally, we jump at the first chance of turning something positive into our first choice when choosing how to solve the problem, but positioning teleworking as the key is not advisable without thorough evaluation. Despite the fact that the concept of teleworking seems promising in terms of reducing air pollution as well as over-use of infrastructures and transportation utilities, research has shown that it is more complicated than initially thought. Literature on the subject has discovered many rebound effects linked to telework and its impact on CO2 emissions.

The International Labor Organization (ILO) predicted that during the pandemic, half of the workforce in high-income parts of the world, such as North America and Western Europe, was able to work from home. Although, just a small portion of the workforce is made up of teleworkers in rich countries, the fact is that the wage of pollution per capita coming from wealthier countries is much more massive in comparison to one coming from poor countries. Nevertheless, it is expected that digitalization will result in rising energy consumption if it is to boost economic development, through higher worker productivity for instance.

Low income countries like Philippines or the whole African continent (excluding South Africa), produce relatively low amount CO_2 emissions per capita, while most of the high income countries are the opposite. For instance, United States produced over 14 metric ton of CO_2 emissions per capita in 2019, while Nepal or Central African Republic produced less than 0,5, according to the World Bank database. This brings us to the logical conclusion that even though the low income, poor countries may not have the same technology or educational prospects at the moment to implement telework in order to reduces pollution, the evidence show that it would make a difference just for the wealthier countries to do so. Starting from the fact that, high-income, technologically-strong, wealthy countries are responsible for 30 times more CO_2 emissions that the developing countries and that telework could potentially reduce up to 40% of CO_2 emissions per teleworker (see Table 1, case 3), it is safe to wonder if this growth would actually contribute to the global reduction of carbon footprint. Of course, the complexity of the problem and the solution prevents us to adopt it as an eventual fix of this ongoing problem.

The long-term consequences of the growing trend of remote work on energy consumption and emissions are still uncertain. While an incremental rise in remote work could potentially lead to a decreased demand for office spaces and associated energy consumption in commercial buildings, resulting in a broader reduction in energy usage and CO_2 emissions, there are potential counteracting factors to consider. One such factor is the tendency for individuals who work from home to choose to reside farther away from their workplace, which could offset any potential reduction in energy demand for commuting. Thus, it is important to comprehensively analyze and understand the multifaceted impacts of remote work on energy consumption and emissions to accurately assess its overall environmental implications. More extensive and long-term studies dealing with varied settings such as different countries, nations and economies, are undoubtedly required in order to produce better information that can address the topic and answer the question in the heading. Also, there is a number of other important factors, including the frequency of telecommuting, the characteristics of the office and home environment, form of used transportation or even the climate patterns, as well as the cost and share of gasoline or electricity in the state where the program is implemented, that influence external costs which can greatly influence the final results and should be taken into account and examined even more carefully over the upcoming years.

The possible consequences telework would have on work-related well-being should not be overlooked. The rise of telework, fueled by technology advancement and changing workplace relations, has sparked a discussion about its possible effects on wellbeing at work. A range of potential effects from this paradigm shift should be carefully considered. On the one hand, telework's independence and flexibility may improve wellbeing by allowing people to choose their own work hours and avoid the stress of regular journeys. Furthermore, the removal of physical barriers can promote a better sense of work-life balance by enabling people to effortlessly juggle their personal and professional lives. On the other side, the isolation brought on by fewer in-person encounters can cause people to feel detached and lonely, which might harm their general psychological health and morale. It's crucial to strike a balance between the benefits of telework and the ways in which its drawbacks can be minimized. To do this, deliberate actions must be taken to promote communication, address ergonomic concerns, and maintain a strong organizational culture, all of which support workers' overall well-being. In this context companies should define a general hybrid-work framework from which teams and employees could be the ones who ultimately decide its intensity. By doing this, businesses will guarantee that telework has a good influence on employees´ wellbeing since it protects the advantages of telework while minimizing its hazards.

Over time, it has been discovered that environmental performance of telework depends on how it is planned and implemented, many authors claim. There are scenarios in which telework has a large potential to reduce emissions and resource use, but there are other situations in which it merely increases the environmental burden placed on society. However, the impact and effectiveness of remote work on GHG emissions will vary among countries due to factors such as the proportion of jobs compatible with remote work, the energy generation mix, the share of gas and electricity in energy consumption, and the mode share of commuting trips. While remote work has implications for job-related well-being and can be desired by many individuals, its environmental impact must be evaluated in a broader context. Comprehensive policies and measures that prioritize sustainable transportation and energy consumption reduction are crucial for effectively mitigating greenhouse gas emissions. It is also important to consider the individual conditions and factors specific to each country, particularly in developing nations, when assessing the outcomes and effectiveness of remote work as an eco-friendly approach.

All researches agree that all of those situations would need to be researched, recorded, and their outcomes measured and published, so that some definite conclusion about the impact of telework on CO2 emission could be made. Many researches argue that the minor separation of environmental factors from human demands is insufficient in light of the current difficulties. To stay inside planetary borders (environmental limits within which humanity can safely operate), there must be a sharp absolute decoupling. These findings demonstrate the significant positive effects that remote working can have on both the quality of life for workers and the environment. The studies emphasize the importance of policymakers recognizing the multiple dimensions impacted by remote working and developing specific strategies to support this option, particularly for individuals with limited alternatives to private transport and those affected by congestion-related delays. It is crucial to consider remote working as a choice rather than an obligation, taking into account the diverse circumstances and priorities of workers and companies. Implementing such measures can contribute to reducing CO2 emissions and addressing the challenges associated with greenhouse gas emissions and urban transportation.

The outcomes of the analysis done in this paper exhibit a complex interplay between various factors, both within the household and the office environment. The cases presented show distinctive energy consumption patterns, demonstrating that the impact of remote work is a

complex matter. Notably, the results reveal that the net CO2 value is not consistently negative across all scenarios, emphasizing that the reduction in CO2 emissions cannot be solely attributed to remote work. The presence of rebound effects and the optimization of electronics efficiency in both home and office spaces emerge as primary considerations. Furthermore, the influence of seasonal variations must be taken into account, as energy consumption and fossil fuel usage exhibit fluctuations between winter and summer months. This inconsistency is particularly significant in the context of heating and cooling, where case-specific heating costs in Austria lead to differential carbon footprints. In particular, Case 3 stands out, showcasing the most fundamental CO2 reduction for both heating and cooling seasons, mirroring the benefits of reduced energy consumption in a two-person household. Contrarily, Case 2 demonstrates the highest energy consumption and CO2 emissions during heating seasons among the analyzed cases, suggesting the need for conscientious energy management. In context of transportation, convincingly the only way that teleworking would contribute the reduction of carbon footprint is that personal vehicle – drivers work from home. Every other mode of transportation has very little positive influence or most often a clear negative impact.
Overall, the findings underscore the complex nature of the relationship between remote working, energy consumption, and CO2 emissions. The table's insights emphasize the importance of multifaceted strategies to optimize energy efficiency, such as implementing reduced office space and enhancing electronics efficiency. With a future-oriented perspective, this analysis encourages organizations to consider these important aspects when designing teleworking policies, focusing on scenarios that demonstrate genuine environmental benefits, especially in the context of reduced office space and minimized energy consumption. This kind of approach is essential to making use of the potential of remote work for sustainable energy practices.

Ultimately, from the standpoint of urban planning, teleworking might potentially be used as a long-term strategy to lower carbon emissions. All facts considered, promoting awareness of the energy and pollution effects of telecommuting is crucial for integrating it with environmental protection, particularly a GHG reduction, especially after proving that using home offices is much more feasible as it is implemented in reality.

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