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Quantifying the net impact of hybrid work on greenhouse gas emissions associated with workplace and residential energy consumption

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Executive summary

To understand the energy- and GHG emission-related impacts of telework, a survey was distributed to employees at the Public Services and Procurement Canada (PSPC), Treasury Board of Canada Secretariat (TBS), and Canada Revenue Agency (CRA). With more than 1500 participants who completed all portions of the survey, this report quantifies the impacts of telework on four domains homes, offices, transportation, and the internet. The results demonstrate:

- More telework days can reduce the overall emissions associated with telework
- When including all the above domains, emissions associated with remote work are 25% and 64% lower than in-person work in the National Capital Region (NCR) and Quebec, respectively. In absolute terms, full-time telework is estimated to decrease emissions by 1.6 and 1.3 tonnes CO_{2e} per employee versus in-person work for the NCR and Quebec, respectively.
- Telework, when compared to in-office work, results in significantly less transportation emissions
- Homes in the National Capital Region are a major source of emissions for teleworkers while home emissions in Quebec are minimal due to the low carbon intensity of dominant heating systems and electricity
- Office space reduction and divestment plans can further decrease the absolute emissions associated with telework by almost 57% in offices based on the current divestment projections
- The impact of telework on the internet use emissions is negligible compared to the other domains
- Findings suggest teleworking can be a more sustainable alternative

1 Introduction

The term "telework" was first introduced in 1973 [1] and it can be defined as working from anywhere except a dedicated traditional office through the internet with the use of telecommunication and computers [2]. With technological advances in the infrastructure required for telework, the percentage of Canadians working full-time remotely was 7% in May 2016. The COVID-19 pandemic accelerated the widespread adoption of telework in Canada, increasing from 7% in January to over 40% fulltime in April 2020 [3]. While the pandemic accelerated the widespread adoption, the percentage of Canadians working remotely was at 21% in July 2023 when most stay-at-home orders were lifted [4]. Recent polls indicate a significant preference for hybrid work models, with a tendency towards more teleworking days compared to in-person days [5].

With increasing interest in telework and hybrid work models, it is essential to understand the impacts of telework on our environment in terms of energy use and emissions. Telework primarily impacts the four domains of homes, offices, transportation, and the internet (Information and Communications Technology (ICT); hereafter referred to as the internet to simplify the text). In 2020, research on telework revealed that most prior research focused on only one or two domains. The same study also showed that savings from one domain can be offset by another domain [6]. By 2023, further investigation into various aspects of teleworkers' daily life and their relationship counted more than 50 items that can impact energy use and emissions associated with teleworkers in the four domains [7]. The latter analysis demonstrated that telework's impacts on energy use and emissions are far more complex than previously assumed. Consequently, it is essential to comprehensively examine the four domains simultaneously to accurately quantify telework's impacts on emissions and energy consumption. A comprehensive quantification of the impacts of telework on the four domains is crucial for:

- More accurate tracing of emissions and energy use associated with telework
- Improved planning and strategies for employers and organization managers
- Enhanced decision-making for urban planners
- Optimized transportation and infrastructure development
- Informed policy-making for sustainable practices
- Greater insights for environmental impact assessments
- Better resource allocation and management
- Increased energy efficiency

While most studies cover only one or two domains [8–12], to date, there has been no comprehensive study conducted on the impacts of telework on the four domains of transportation, homes, offices, and the internet. Therefore, the present study aims to conduct a comprehensive quantification of the impacts of telework on the four domains of homes, offices, transportation, and the internet by using a survey among federal employees in Canada. The survey data are used to help quantify emissions and to inform models and simulations to assess energy use and emissions associated with in-person, hybrid, and remote workers. While the scope of this study does not cover either long-term decision-making of employees and employers or a full life cycle assessment, emissions associated with each domain are assigned to Scope 1, Scope 2, or Scope 3 emissions from an organizational perspective. According to the Government of Canada's definitions, Scope 1 GHG emissions originate from sources that the government owns or directly controls, such as emissions from fuel combustion in crown-owned vehicles and crown-owned buildings. Scope 2 emissions are those resulting indirectly from the use of purchased energy, including electricity,

heating, and cooling of crown-owned buildings. Scope 3 emissions encompass indirect sources, such as those generated in the supply chain of purchased goods and services, emissions generated from travel and emissions from employee commuting [13].

By providing a comprehensive view of telework's emissions and environmental impacts, this study fills a critical gap in current research. Being the first comprehensive study in North America, the findings will provide valuable insights for policymakers, urban planners, employers, and environmental strategists, aiding in creating a robust foundation for developing informed decisions, sustainable practices, and policies that can contribute to achieving the 2050 net-zero carbon goals.

2 Methods

This section of the paper explains the methods used starting with the survey design, sample, and analysis methods.

2.1 Survey and sample

In order to capture the complex impacts of telework on the four domains, a survey was designed based on an earlier review article that uncovered more than 50 items related to telework that impact energy use and emissions along with their inter- and intrarelationships [7]. The survey was implemented in Qualtrics (an online survey tool) and distributed by the communication offices of PSPC, CRA, and TBS to employees in Quebec and the NCR from 15/12/2023 to 15/02/2024. It had four sections corresponding to the four domains along with a section on demographics. The survey was reviewed by researchers and experts in the government, including those from the TBS, which leads government-wide policy on prescribed presence in the workplace; CRA; and PSPC, which manages the federal government's portfolio of office buildings. The main questions in each domain included:

- Demographic questions and details of working arrangement, including work model, number of days working, teleworking days, etc.
- One-way commute distance
- Personal vehicle ownership
- Two travel diaries for the most recent in-person and telework days
- Seasonal changes in transportation
- Home size and type
- Home thermostat setpoints
- Average time spent on calls

The survey primarily asks about the individual employee. Understanding households with multiple employees and their mutual teleworking schedules is beyond the scope of the model and analysis.

The minimum sample size was 384 participants for a confidence level of 95% and a margin of error of 5%. After receiving ethics board approval from Carleton University (Ethics Clearance Project 119681), the survey was sent out by email to the federal employees of PSPC, CRA, and TBS in the National Capital Region and Quebec. The survey is attached as appendix A.

2.1.1 Inclusion and exclusion criteria

The initial number of responses from participants was 5650 entries. However, the survey did not force responses for travel diaries due to different limitations such as Qualtrics' limited options for making

the entries for diaries mandatory when handling three groups of remote, hybrid, and in-person employees. As a result, data filtering was carried out to remove incomplete entries. Data filtering was carried out on telework and in-person diaries based on specific criteria for the three different groups. For all three groups in both diaries, any participants with single entries above 100 km or less than or equal to zero were removed (having multiple entries that add up to more than 100 km was not an exclusion criterion). The 100 km cut-off was selected since most suburban areas or nearby cities in the National Capital Region and Quebec fall within 100 km range. The acceptance criteria for each group were as follows:

- **In-person:** Any participant that declared in-person work, zero telework days, and had no entry in telework diaries was included only if there was at least one work-related entry in the in-person diaries.
- **Hybrid:** Any participant whose total telework days did not match their total workdays and had at least one entry in both telework and in-person diaries was included only if they had at least one work-related entry in the in-person diaries.
- **Remote:** Any participant who declared remote work and their telework days matched their total days of work and had at least one entry in the telework diaries was included.

2.1.2 Participant groups and data validation

The total number of participant responses retained for this study (after applying the acceptance criteria stated in 2.1.1) was 1509, with fewer than 20 participants being in-person employees. Therefore, in-person and hybrid participants are grouped together for transportation emissions calculations since data for in-person workers was less than 20 people. Among federal employees in Canada, the hybrid work model is the preferred work model, which is the underlying reason for the low number of in-person participants. It is noteworthy to mention that values calculated for each group are for in-person and hybrid workers (group A) and remote workers (group B).

Data is validated by comparing travel diaries' commute distance to a question in the survey on one-way commutes. The data is validated based on group A responses as group B are remote workers with no one-way commute distance in their diaries.

2.2 Emissions calculations and data analysis methods

The emissions are estimated by using the survey data, models, and simulations. Emissions that are directly calculated using the survey without further need for simulation or modelling are labeled as ‘direct estimates,’ emissions that are calculated based on the survey but also need some form of simulation or modelling are labeled as ‘mixed estimates,’ and emissions that are calculated by simulation or modelling without using the survey are labeled as ‘indirect estimates.’

2.2.1 Transportation (direct estimates)

The transportation section includes two travel diaries: an in-person day diary and a telework day diary (hereafter, telework diary and in-person diary will be used). Participants were asked to recall their last day of telework and in-person work to complete the survey. Single- and multiple-day travel diaries are a common method of tracking participants' travel diaries. In the travel diaries of this study, in-person employees only have data in the in-person diary, hybrid employees have data in both diaries, and remote employees have data only in the telework diary.

The emissions associated with travel diaries are calculated based on transportation mode and emissions data. For personal vehicles, emissions are calculated using the federal government of Canada's Fuel Consumption Ratings (FCR) Search Tool database where emissions associated with vehicles are available based on the car's year, make, and model [14]. The emissions associated with walking and cycling are considered to be zero. The average emissions associated with carpooling are assumed to be 139 g CO_{2e} per person-kilometer [15]. For all personal vehicles, the combined fuel consumption (L/100 km) is used when needed (L_e/100 km for electric vehicles) [14,16].

Emissions associated with inter-city buses are calculated by dividing the total emissions by the total passenger kilometers travelled in 2019 which is the year preceding the COVID-19 pandemic [17]. Emissions per passenger-kilometer travelled for buses were the same for both Quebec and Ontario according to the government data [17]. In the United States, emissions for buses were approximately 42 g CO_{2e} per passenger-kilometer in 2019 [18]. STM (Société de transport de Montréal/Society of Transportation of Montreal) set the 2025 emissions target for buses to 44.7 g CO_{2e} per passenger-kilometer in 2015 [19]. The emissions for buses, subway, and commuter trains were estimated to be 161, 20, and 28 g CO_{2e} per passenger-kilometer in the Greater Toronto Area in 2002 [20,21]. The UK reported 79, 28, and 35 g CO_{2e} per passenger-kilometer for buses (local London), subway (London underground), and national rail in 2022 [22]. Emissions from trains and buses were reported to be 28.6 and 17.7 g CO_{2e} per passenger-kilometer in Australia [23]. This report assumed an average value of 24 g CO_{2e} per passenger-kilometer for train and subway and 20 g CO_{2e} per passenger-kilometer for light rail transit (LRT). As the set targets for Quebec are higher for public transportation (i.e., buses) in the 2015 documents, the same values are used for Quebec and Ontario [19]. The average emissions for electric bikes are calculated by considering electric bikes' energy use per passenger-kilometers. A recent study showed electric bikes consume from 0.007 to 0.012 kWh/km with an average consumption of 0.0095 kWh/km which is then multiplied by the emissions associated with electricity in Ontario and Quebec [24]. The emissions for electric scooters are calculated with the same method with an average consumption of 0.015 kWh/km.

The emissions associated with other non-fuel-using modes are considered zero while it is assumed to be the average of public transportation modes for other fuel-using modes. Table 1 summarizes the assumptions for the emission factors used in this report. The values used in Table 1 are identical for Ontario and Quebec, except for electric bikes, electric scooters, and electric personal vehicles, whose emissions are calculated based on provincial emission factors for electricity. The overall emissions are calculated by summing up the emissions per participant calculated by multiplying each participant's emissions per passenger-kilometer associated with each transportation mode by their corresponding distances in the diaries, based on the cold and warm seasons. This total is then divided by the number of participants in that group (Eq. 1 where E_T represents the emissions in kg CO_{2e} per employee per day, D_W is the distance travelled using transportation mode in the cold (C) or warm season (W) (in kilometers), $E_{W\text{-}C}$ is the emissions of transportation mode W (warm season) or C (cold season) per passenger-kilometer (in kg CO_{2e}), N_W is the number of participants corresponding to the groups (in-person and hybrid (group A) and remote (group B)), $ND_{W\text{-}C}$ is the total number of days for the warm seasons (W) or cold season (C) based on the participants' responses). The outcome of this calculation method is an emissions value per employee for in-person, hybrid, and remote employees based on all participants' responses.

$$E_T = \frac{\sum(D_{W-C} \times E_{W-C})}{N_A} \times ND_{W-C} \quad (1)$$

Electricity emissions for Ontario and Quebec are assumed to be 30 g CO_{2e}/kWh and 1.7 g CO_{2e}/kWh, respectively. Emissions for natural gas for Ontario and Quebec are 182 g CO_{2e}/kWh (1921 g CO_{2e}/m^3) and 182.5 g CO_{2e}/kWh (1926 g CO_{2e}/m^3), respectively [25,26].

Table 1: Emissions associated with transportation

Transportation mode	Ontario	Quebec
	kg CO_{2e}/passenger-kilometer	
Walking	0	0
Bicycling	0	0
Electric bike[1]	0.000285	0.00001651
Electric scooter	0.00045	0.0000255
Bus	0.032	0.032
Train or subway	0.024	0.024
LRT	0.02	0.02
Personal vehicle (average emissions)	0.1995[2]	0.1993[2]
Carpooling/ridesharing	0.139	0.139

[1] Electric bikes' energy use in terms of Wh/km ranges widely. For instance, Bosch eBikes use about 7 Wh/km while Aventon uses about 12.5 Wh/km. These bikes are intended for different terrains, tire pressure, etc. In this report, we assume an average of 9.5 Wh/km based on the common models available in Canada.

[2] The total number of electric vehicles in the survey dataset was 61 meaning the impact is much less compared to internal combustion engine counterparts (1383 instances) on the average emissions associated with personal vehicles.

2.2.2 Homes (mixed estimates)

Regarding homes, a mixed method was used based on data from the survey along with the results of simulation models in an earlier study. Due to privacy and confidentiality concerns, emissions from homes were based on the results of code-compliant simulation models instead of asking participants for utility bills. A recent research study modelled four different standard home types in Canada based on the Canadian building codes. The results demonstrated that code-compliant homes are more sensitive to telework, while poorer-performing homes are less sensitive to telework [27–29]. Each home in the studies was simulated with and without the presence of teleworkers [28,29]. The survey asked participants about their preferred setpoints for summer and winter seasons to compare the responses to the simulated models in terms of occupants' preferences. The four home models include:

- Home type 1 (HT1) single-zone detached home with a floor area of 137 m^2
- Home type 2 (HT2) single-zone detached home with a floor area of 230 m^2
- Home type 3 (HT3) single-zone row house with a floor area of 200 m^2
- Home type 4 (HT4) single-zone mid-rise apartment with a floor area of 97.75 m^2 [single unit]

The survey asked participants about their home type and size and were assigned to one of the home types based on their responses. Accordingly, the following are options in the survey and were assigned to the corresponding home types:

- Single detached house-one storey (HT1) (Floor areas: 56-93 m^2 and 94-139 m^2)
- Single detached house-two storey (HT2) (Floor areas: anything beyond 139 m^2)

- Townhouse/rowhouse/attached (HT3) (Any floor area)
- Multi-unit low-rise building (1-6 stories) (HT4) (Any floor area)
- Multi-unit high-rise building (more than 6 stories) (HT4) (Any floor area)

It is noteworthy that the floor areas are within a reasonable range of the Canadian averages, ensuring that the survey results are consistent with typical national data [30].

2.2.3 The internet (mixed estimates)

Participants were asked to report their use of video and audio calls on different platforms (such as Zoom or Microsoft Teams) on their telework and in-person days. This data, along with an assumption of eight hours of work, are used to estimate the internet data usage in this study. Federal employees use Microsoft Teams as a collaborative environment within their department and across federal departments. It is also used as a collaborative environment for different teams in different federal departments. Due to confidentiality concerns, participants were not asked to enter or track their data usage on their work laptops. Therefore, the hours spent on the platforms, along with estimates of data usage, are used to estimate emissions for internet use. The data use associated with online meetings can vary significantly depending on the number of participants, quality of the call, platform used, etc. While there is no systematic quantification of data usage by these platforms within academia, multiple tech sources reviewed and reported data usage based on different factors. An experimental review of Microsoft Teams (MS Teams) on iPhone showed video calls, optimized video calls, audio calls, and audio calls with shared screen consume 1.67 GB, 1.09 GB, 20.17 MB, and 28.87 MB [31]. A review by Business Tech Planet showed MS Teams' best performance and recommended bandwidth use of 1.8 GB and 0.675 GB per hour for video calls, respectively. MS Teams' recommended bandwidth for audio calls is 26.1 MB per hour. MS Teams for a one-on-one call with a shared screen uses 1.125 GB per hour using the recommended bandwidth [32]. Other reviews also show similar numbers for different platforms, although it should be noted that these platforms aim to optimize their data usage by releasing new updates [33,34]. In this study, we assumed a conservative value of 1 GB of data usage per hour for video calls, 25 MB per hour for audio calls, and 2 MB per hour for background app data (tracking system).

The internet, information and communications technology in general, comprise data centers, data transmission, and devices. A recent report and research paper estimated 0.08 kWh of data used for online video streaming per hour [35,36]. A recent Canadian study showed the fixed transmission network uses an average of 0.06 kWh per GB. The study further highlighted a range in performance, with the lowest performing networks consuming 0.29 kWh per GB, while the most efficient networks use as little as 0.0065 kWh per GB [37]. In this study, the data consumption rates are as follows: 1 GB per hour for video calls, 0.025 GB per hour for audio calls, and 2 MB per hour during standby. The electricity consumption associated with data usage is calculated using 0.06 kWh per GB. This study focused solely on the data transmission associated with employees' hours spent on video and audio calls along with the standby background data used by Microsoft Teams. Other factors, such as document uploads and data storage within federal departments, were excluded as they can be influenced by variables independent of telework. Eq. 2 shows the equation used to calculate emissions associated with the internet use, where:

- E_{video} is the emissions per hour of video calls
- $T_{video,DT}$ is the average time spent on video calls for day-type
- E_{audio} is the emissions per hour of audio call
- $T_{audio,DT}$ is the average time spent on audio calls for day-type

- $E_{standby}$ is the emissions per hour during standby assuming an 8-hour work shift

$$E_{internet,DT} = \sum(E_{video} \times t_{video,DT} + E_{audio} \times t_{audio,DT} + E_{standby} \times (8 - \sum t_{video,DT} + t_{audio,DT})) \quad (2)$$

2.2.4 Offices (indirect estimates)

Emissions associated with offices were provided for the National Capital Region (NCR) and Quebec by the Public Services and Procurement Canada (PSPC). The report from PSPC includes annual emissions (Scope 1 and 2) associated with each office building and the total number of full-time employees assigned to the offices. The emissions are normalized per employee for all the buildings in the NCR and Quebec. In the NCR and Quebec, the average office space per full-time employee is 29.85 and 33.21 m^2 with average emissions of 416 and 140 kg CO_{2e} per employee per year, respectively. These values were calculated by dividing the total emissions of offices in the NCR and Quebec by the total number of full-time employees assigned to the offices. It is assumed that PSPC would retain 30% of its office portfolio if Government of Canada employees are hypothetically allowed to work remotely. The two values used for the 0% telework scenario are based on a 30% reduction in the portfolio based on the feedback received from PSPC (Table 2 shows the full assumptions regarding telework scenarios). Portfolio/emission reductions are estimated to be proportional to a reduction of the portfolio size.

Table 2: Assumptions regarding telework scenarios and reduction in office emissions

Days of telework	0 (100% in person)	1	2	3	4	5 (100% telework)
Portfolio/emissions reduction	30%	40%	50%	50%	70%	70%

2.2.5 Integrated analysis

The integrated analysis is calculated based on the daily emissions associated with a total of 231 annual workdays per employee, considering emissions associated with each domain per employee and workday type (telework and in-person). Four weeks of vacation and public holidays were deducted from the calendar. Figure 1 demonstrates the integrated analysis of emissions for domains as a whole. Eq. 3 represents the integrated analysis where emissions for telework days and in-person days are summed up where:

- $E_{T,DT}$ is the transportation emissions per day for day type (DT; in-person or telework)
- $E_{office,scenario}$ is the office emissions per day per scenario (100% telework scenario means the total emissions multiplied by 70% emissions reduction)
- $E_{home,DT}$ is the home emissions per person for day-type
- $E_{home,DT}$ *is the internet emissions for day-type*

$$E_{total} = \sum_{DT=In-person}^{Telework}(E_{T,DT} + E_{office,scenario} + E_{home,DT} + E_{internet,DT}) \quad (3)$$

For instance, if an individual is teleworking for three days per week (90 days of in-person, 141 days of telework), emissions for the overall 90 days and 141 days are summed up based on the daily emissions for in-person and telework days. In-person daily emissions are calculated based on the transportation daily emissions for hybrid in-person diaries, average home emissions with no teleworker, average emissions of using the internet for video and audio calls, and standby. Telework daily emissions are calculated based on the transportation daily emissions for hybrid telework diaries, average home emissions with a teleworker, and average emissions of using the internet. For office emissions, normalized

emissions are multiplied by the corresponding portfolio (emissions) reduction in Table 2 (50% in this scenario).

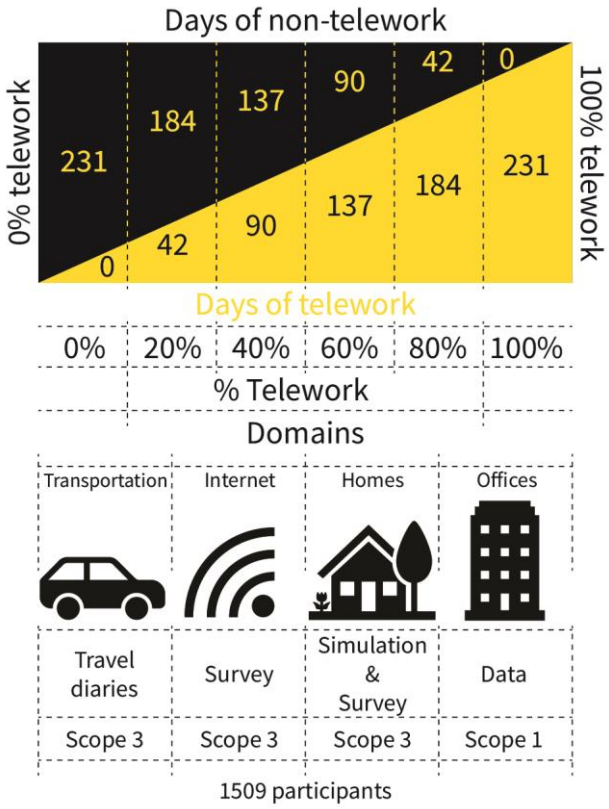

Figure 1: Summary of integrated analysis. Remote workers (282) and hybrid and in-person workers (1227) are used to calculate emissions in four domains of transportation, homes, offices, and the internet. Emissions are calculated for telework days and in-person days multiplied by the corresponding days in a year for each scenario.

Note that the analysis assumes one teleworker per household. The results do not directly apply to households with multiple teleworkers because that would require a stronger understanding of their respective teleworking schedules, carpooling, etc.

3 Results

In this section, the results of emissions associated with each domain and the integrated analysis are presented. Domain-specific emissions are reported on a daily basis for 1) in-person and hybrid (group A) and 2) remote employees (group B) for telework and in-person workdays. The integrated analysis is reported on an annual basis to compare the annual emissions associated with days of telework. Sections 3.1 to 3.4 explain the summary of daily emissions associated with employees in different seasons for the four domains in Table 3 and Table 4.

Table 3: Summary of daily emissions associated with employees in different seasons in the NCR

Daily and annual emissions for the four domains				
Transportation emissions per employee per day (kg CO_{2e}/day.employee)				
	Hybrid and in-person			Remote
NCR	In-person		Telework	Telework
Cold season	7.91		2.17	2.65
Warm season	7.28		2.04	2.45
Office emissions per employee (corresponding to portfolio size with 0 days of telework)				
NCR	Scope 1		Scope 2	Total emissions
Per year (kg CO_{2e}/year.employee)	186		230	416
Home emissions per home per day with and without teleworker (kg CO_{2e}/day.home)				
NCR			Without teleworker	With teleworker
Remote			NA	16.61
In-person and hybrid			17.22	17.78
Average internet use				
	In-person		Telework	
	Video	Audio	Video	Audio
In-person and hybrid (hours per day)	2.47	0.45	2.22	0.41
Remote (hours per day)	NA	NA	0.49	0.16

Table 4: summary of daily emissions associated with employees in different seasons in Quebec

Daily and annual emissions for the four domains				
Transportation emissions per employee per day (kg CO_{2e}/day.employee)				
	Hybrid and in-person			Remote
Quebec	In-person		Telework	Telework
Cold season	7.90		2.17	2.65
Warm season	7.27		2.03	2.45
Office emissions per employee (corresponding to portfolio size with 0 days of telework)				
Quebec	Scope 1		Scope 2	Total emissions
Per year (kg CO_{2e}/year.employee)	135		5	140
Home emissions per home per day with and without teleworker (kg CO_{2e}/day.home)				
Quebec			Without teleworker	With teleworker
Remote			NA	0.17
In-person and hybrid			0.18	0.19
Average internet use				
	In-person		Telework	
	Video	Audio	Video	Audio
In-person and hybrid (hours per day)	2.47	0.45	2.22	0.41
Remote (hours per day)	NA	NA	0.49	0.16

3.1 Transportation (Scope 3)

Table 3 and 4 demonstrate the daily emissions associated with employees in kg CO_{2e} for cold and warm seasons. Remote employees produce, on average, 20% to 22% more emissions compared to hybrid and in-person employees' emissions during telework days, although their overall emissions are lower than the telework and in-person days combined for hybrid and in-person participants.

3.2 Homes (Scope 3)

Table 3 and 4 show the emissions associated with homes in the NCR and Quebec for remote and in-person and hybrid employees (group A) per day in kg. The difference between emissions for homes is based on whether a teleworker is present at home. The underlying reason behind the low emissions of telework (group B) days compared to in-person and hybrid (group A) days is that almost 32% of remote employees live in apartments (HT4) which has the lowest emissions among four home types. In contrast, only 20% of in-person and hybrid workers (group A) live in apartments (HT4). In terms of emissions, the main difference between the NCR and Quebec is the prevalent heating system. In the NCR, homes rely on natural gas while in Quebec homes use electric baseboards [38]. An earlier study, along with the national statistics, demonstrates that Quebec has the lowest emissions per household due to the use of electric baseboards and the lowest emissions associated with electricity [39].

3.3 Internet (Scope 3)

Table 3 and 4 show the average internet use of participants for different platforms used for video and audio calls such as Zoom and Microsoft Teams. In addition, Microsoft Teams allows employees to show their availability, which is a standby background app refresh. The results demonstrate that video and audio calls are higher for in-person and hybrid (group A) employees compared to remote workers. This is due to exemptions to work remotely (exclusively) that are provided by the government for jobs such as translators, IT staff, and HR staff, who carry out focused-based activities that do not need collaboration. Audio calls are also prevalent as employees access digital branch services through the government's call center. Additionally, 1.1% of in-person and hybrid workers (group A) indicated that they do not use any online meeting tools during their in-person days.

3.4 Offices (Scope 1)

Table 3 and 4 demonstrate the emissions associated with employees per year in kg CO_{2e}. Scope 1 and Scope 2 emissions for the NCR and Quebec are shown in the table. Emissions for Quebec are significantly lower due to lower emissions factors associated with electricity and the prevalent use of electricity for heating compared to the NCR where the dominant heating systems rely on natural gas.

3.5 Integrated analysis

The integrated analysis is reported annually in Table 5 and Table 6. Accordingly, the highest fluctuation in emissions belongs to transportation in both the NCR and Quebec. However, in the NCR, the dominant source of emissions is associated with homes, whereas in Quebec, the highest emissions are from transportation due to significantly lower emissions from homes. The overall emissions associated with telework can vary significantly depending on the location of teleworkers. Comparing telework and in-person days shows approximately a 25% and 64% reduction in the NCR and Quebec, respectively (Figure 2,Figure 3, Figure 4, and Figure 5). Emissions for remote days should be interpreted separately from the first five scenarios in these figures as the sample size for remote workers was separated from other groups. The reduced emissions for homes in Figure 2, Figure 3, Table 5, and Table 6 for remote workers is due to different home types since remote employees owned more apartments which have lower emissions compared to houses that have higher emissions.

Table 5: Overall emissions for each domain in the NCR; the emissions reduction for remote workers in the home domain is due to a different sample size used to calculate emissions (Refer to the preceding text for more on the reasons behind this change).

Annual emissions per employee (kg CO_{2e}/year.employee) in the NCR						
Days of telework	0 (in-person)	1	2	3	4	5 (remote)
Transportation	1,806	1,544	1,282	1,020	758	605
Internet	1.036	1.015	0.994	0.972	0.951	0.212
Homes	3,979	4,005	4,031	4,058	4,084	3,838
Office	416	357	297	297	178	178
Total	6,202	5,907	5,611	5,376	5,021	4,621

Table 6: Overall emissions for each domain in Quebec; the emissions reduction for remote workers in the home domain is due to a different sample size used to calculate emissions (Refer to the preceding text for more on the reasons behind this change).

Annual emissions per employee (kg CO_{2e}/year.employee) in Quebec						
Days of telework	0 (in-person)	1	2	3	4	5 (remote)
Transportation	1,804	1,542	1,281	1,019	758	605
Internet	0.059	0.058	0.056	0.055	0.054	0.012
Homes	42	42	43	43	44	41
Office	140	120	100	100	60	60
Total	1,986	1,704	1,424	1,162	862	706

3.5.1 NCR

In the NCR, homes in all scenarios are the main contributors to emissions although teleworking has hardly any impact (increase or decrease) on emissions in homes. The share of homes is most dominant in full telework scenarios (5 days telework; almost 83% of emissions come from homes in the NCR). For fully in-person days, homes are still dominant but comprise almost 64% of emissions. The second most emission-intensive domain is transportation in all scenarios. The emissions share of transportation decreases from almost 29% to 13% for fully in-person to fully remote. Regarding offices, the emissions and the number of full-time employees associated with the government buildings play an important role in emissions for the NCR and Quebec. The office emissions for the fully in-person scenario represents 7%, while the office emissions for the fully remote scenario represent 4% in the NCR.

3.5.2 Quebec

The emissions share of transportation decreases from almost 91% (fully in-person) to 86% (fully remote) of the total in Quebec since transportation is the main source of emissions. Office emissions in the fully in-person scenario represent almost 7% and 8% for the fully remote scenario in Quebec. Homes have the lowest emissions in Quebec and comprise slightly less than 6% of emissions in all scenarios due to clean electricity and the prevalent use of electric heating.

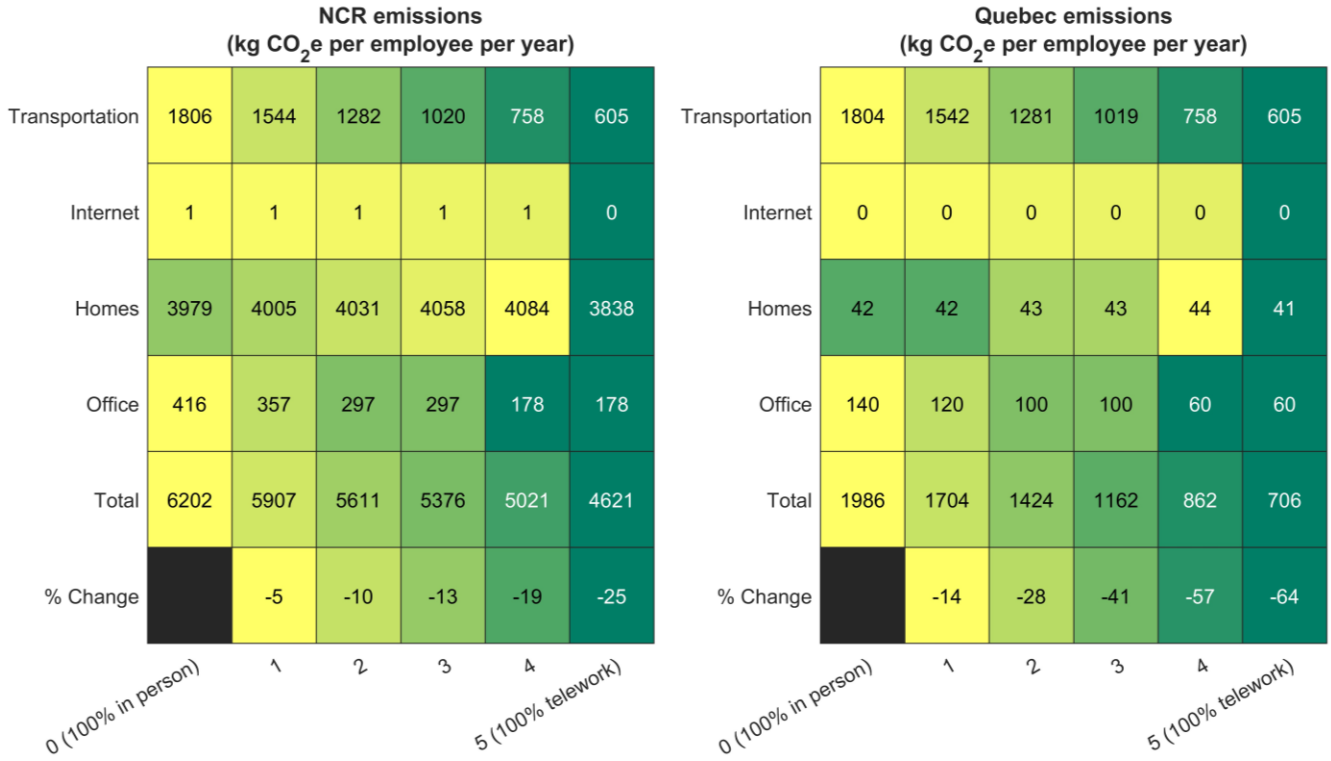

Figure 2: Estimated emissions associated with telework in kg CO_{2e} per employee per year. Green shows smaller values and the numbers on the horizontal axis represent the total number of telework days per week. The values in each cell are estimated emissions in kg CO_{2e} per year, rounded to the nearest kg, for different scenarios. Results for remote employees (100% telework), particularly in the homes domain, should be interpreted separately from the five preceding scenarios.

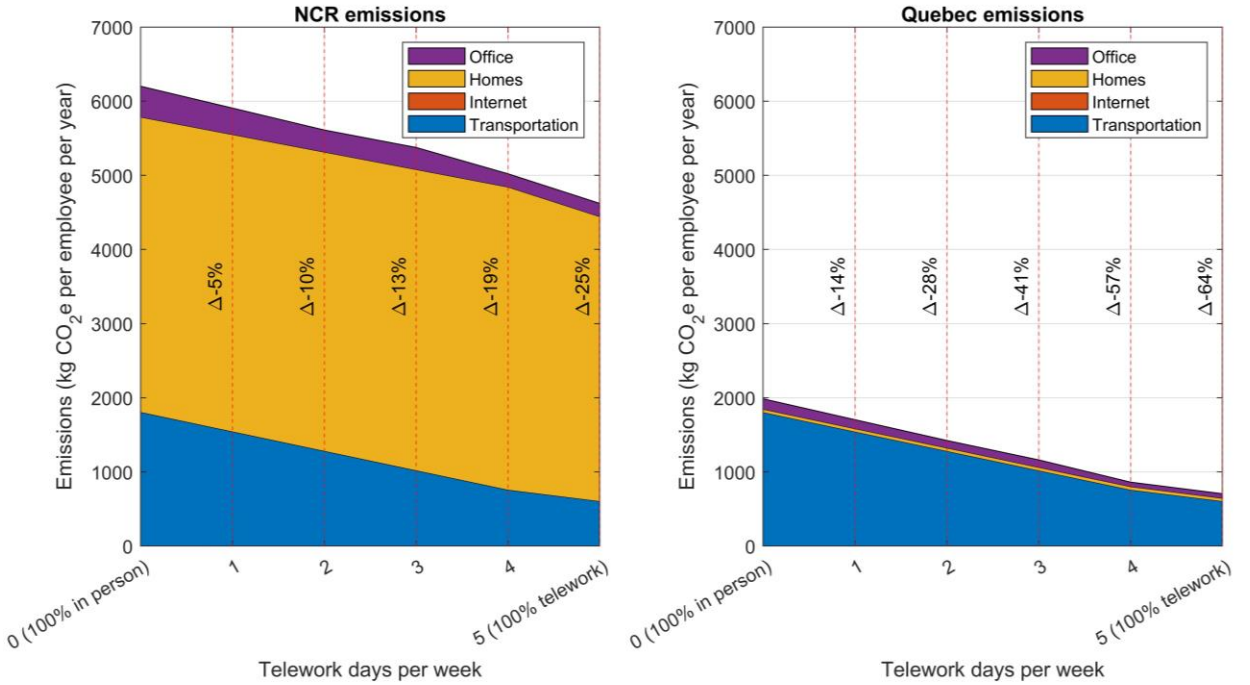

Figure 3: Estimated emissions associated with telework in kg CO_{2e} per employee per year. The Δ values in the graph indicate the change in total emissions from the baseline of 0 telework days (fully in person).

In both Quebec and the NCR, the internet in all scenarios comprises less than 1% of emissions, making it almost negligible in all scenarios. The results show that the fully in-person work model has the highest emissions due to the increased emissions associated with transportation. Regarding offices, portfolio divestment plans can significantly contribute to reducing emissions for hybrid work models and full telework scenarios.

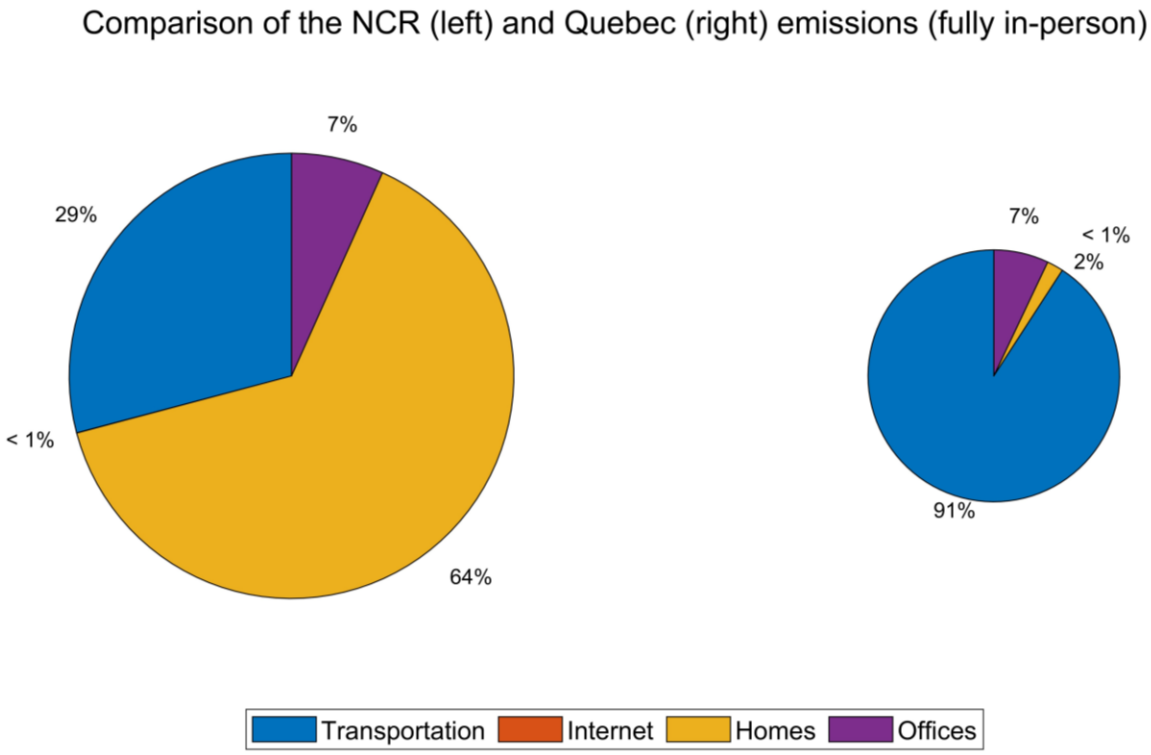

Figure 4: Differences in emissions associated with the NCR and Quebec for the fully in-person scenario. The circle area corresponds to the magnitude of emissions. Emissions associated with internet use are less than 1% and do not appear on the charts.

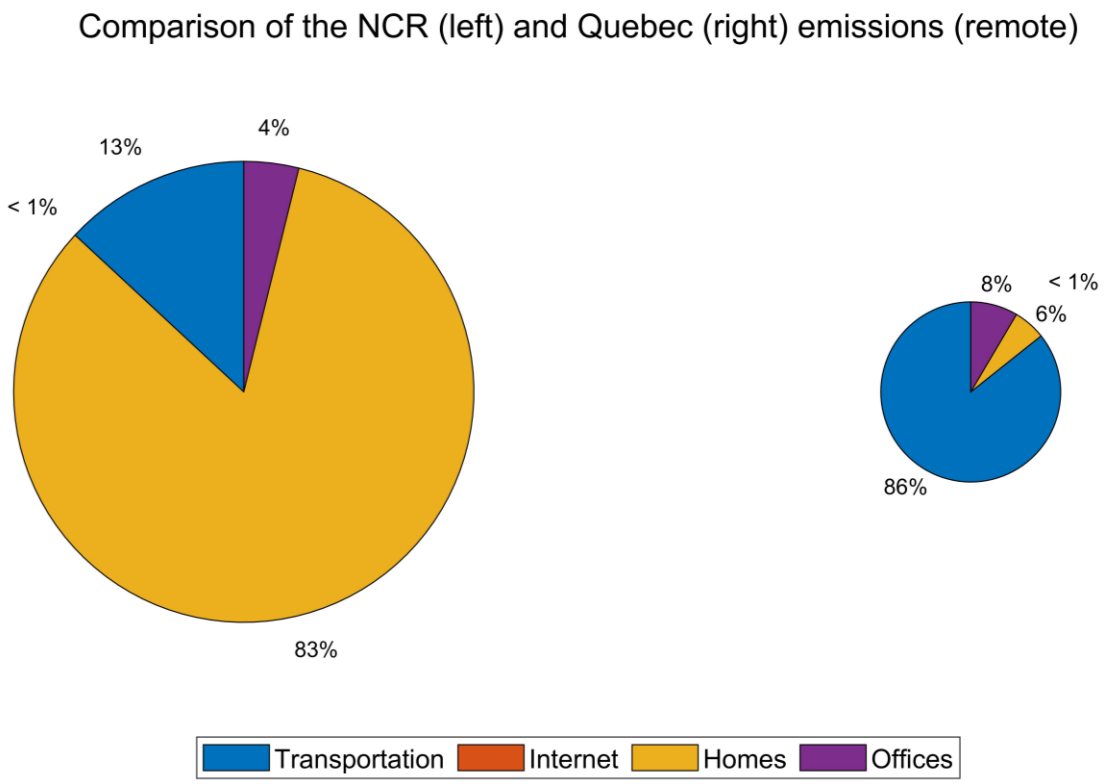

Figure 5: Differences in emissions associated with the NCR and Quebec for remote scenario (100% telework) The circle area corresponds to the magnitude of emissions. Emissions associated with internet use are less than 1% and do not appear on the charts.

4 Discussion

In this section, the results are compared to recent findings regarding telework and emissions and discuss potential behavioral changes and preferences that can impact the sustainability of telework. In the end, policy recommendations are presented based on the findings.

Our study demonstrates the savings from transportation are significantly higher than the increase in home emissions (a reduction of 66.5% or 1.2 tonnes CO_{2e} in transportation emissions per person and only an increase of less than 5% in homes (0.069 tonnes CO_{2e} in the NCR and 0.002 tonnes in Quebec)).

The majority of previous research relies on statistical data, national averages, modelling, and other methods without detailed participant surveys. By surveying more than 1500 participants in this study, our results found that transportation emissions can decrease by more than 60% for government employees while the increase in their home energy use is less than 10%. The results of the present study also show that the impact of telework on emissions associated with the internet is negligible.

Maximizing emissions reduction induced by telework requires interventions in various domains. The transportation sector has the highest potential for reducing emissions as policies targeted at promoting electric vehicles (EVs), improving use of public transportation (and better service), and promoting active transportation can replace non-EV vehicle use for employees resulting in significant emissions reduction. Homes, as the domain with the highest emissions in the NCR regardless of telework status, require a more comprehensive approach to mitigate emissions. Energy-efficient upgrades, such as

envelope optimization, smart thermostats, and behavioral changes can significantly decrease home energy use and emissions. Shifting the timing of energy-intensive activities can also help reduce emissions (e.g., laundry on evenings and weekends). Reducing emissions associated with homes is crucial, as this domain holds the largest proportion of overall emissions in the NCR. Quebec homes produce significantly lower emissions due to grid cleanness and cost-competitive electricity.

Regarding office spaces, encouraging portfolio divestment and optimizing space utilization through hot-desking or hoteling strategies can further reduce the overall emissions associated with offices. Emissions associated with the internet are mostly negligible in terms of differences between telework and in-person work although more efforts are required to decarbonize the emissions associated with different components of internet use such as reducing emissions in data centers. Combining all these efforts can ensure that telework becomes a more sustainable alternative to traditional work models. Adopting a sustainable telework or hybrid work model can contribute to the 2050 net-zero carbon goals.

4.1 Policy recommendations

Based on the findings of this study, different policies can be employed to ensure that hybrid or telework work models remain sustainable and contribute to a greening plan. The following policies in Table 7 can be implemented at different levels of organizational, provincial, regional, and national.

Table 7: Policy recommendations based on the findings of this study

Transportation	
Incentivize low-emission transport	• Provide subsidies or tax incentives for employees to purchase electric vehicles (EVs) and use public transportation. • Develop and expand infrastructure for EV charging stations, especially in residential areas and near workplaces. • Encourage carpooling and the use of ride-sharing services through incentives or subsidies.
Promote active transportation	• Invest in and improve infrastructure for walking and cycling, including safe pathways, bike lanes, secure bike parking, and showers in office buildings. • Offer incentives for employees who choose to walk or bike to work, such as stipends or health benefits.
Public transportation enhancement	• Improve the efficiency and coverage of public transportation networks to make them more reliable and accessible. • Offer discounted or free public transportation passes for employees who commit to using public transportation regularly.
Internet	
Optimize data usage	• Encourage the development and adoption of data-efficient communication platforms to reduce the energy consumption associated with video conferencing.
Green data centers	• Support the development of green data centers that use renewable energy sources and have optimized energy usage. • Encourage companies to utilize cloud services provided by green data centers.
Homes	

Energy efficiency upgrades	• Provide grants or low-interest loans for homeowners to upgrade their homes with energy-efficient appliances, insulation, and windows. • Offer tax incentives for clean energy systems, such as solar panels and geothermal heating (where possible).
Smart home technologies	• Promote the adoption of smart home technologies that can optimize energy usage, such as smart thermostats and lighting systems. • Provide educational resources and incentives for teleworkers to implement energy-saving practices at home.
Offices	
Divestment and space optimization	• Encourage organizations to downsize their physical office spaces in order to reduce the overall energy consumption and greenhouse gas emissions associated with maintaining large office buildings. • Make sure divestment of surplus office buildings is coordinated with like-minded organizations that aim to achieve net-zero emissions by 2050. • Promote the use of shared office spaces or coworking spaces to maximize the use of existing infrastructure.
Sustainable office practices	• Implement energy-saving measures in office buildings, such as dimmable LED lighting, efficient HVAC systems, and clean energy sources. • Encourage flexible work arrangements that allow employees to work from home or in shared spaces to reduce the need for permanent individual workspaces.
Comprehensive policies	
Integrated telework policies	• Develop comprehensive telework policies that include guidelines for sustainable teleworking practices, such as minimizing travel, using energy-efficient technologies, and optimizing home office setups. • Provide training and resources for employees and managers on best practices for sustainable teleworking.
Monitoring and reporting	• Implement systems for monitoring and reporting the environmental impact of telework, including energy use and emissions across all four domains. • Use monitoring data to continuously improve telework policies and practices to make sure they contribute to emission reduction goals.
Community and urban planning policies	
Urban design and zoning	• Incorporate telework considerations into urban planning and zoning regulations, promoting mixed-use developments that reduce the need for long commutes. • Encourage the development of telework hubs in residential areas and provide shared workspaces that reduce the need for commuting.
Public awareness and education	• Launch public awareness campaigns to educate citizens about the environmental benefits of telework and how they can contribute to sustainability goals. • Provide resources and support for communities to adopt sustainable telework practices such as local initiatives and community programs.

4.2 Recap and key takeaways

By surveying more than 1500 participants and quantifying the emissions associated with them, the results of this study demonstrated the difference between emissions associated with telework and in-person days is significant. In this study, emissions from homes, office, transportation, and Internet use were summed. In the NCR, the reduction from 6202 kg CO_{2e} per year per employee for fully in-person to 4621 kg CO_{2e} for fully remote per year per employee (total emissions) shows the potential of telework as a sustainable alternative. Similarly, the same conclusion can be drawn for Quebec based on a reduction from 1986 kg CO_{2e} per year per employee (fully in-person) to 706 kg CO_{2e} per year (fully remote) per employee (total emissions). Home and transportation emissions are dominant emission contributors in the NCR and Quebec, respectively. However, the overall fluctuation in terms of the impact caused by telework on housing emissions is much less than transportation. Transportation is a domain that can benefit the most from telework. Furthermore, the results demonstrate portfolio divestment plans and strategies for organizations and employers can significantly contribute to greening plans and reducing emissions. Overall, the difference (reduction) between emissions associated with remote work and in-person work is about 1581 and 1280 kg CO_{2e} per year per employee in the NCR and Quebec, respectively. The changes between the remote and in-person employees' emissions are 25% and 64% lower in the NCR and Quebec. As a result, telework is a sustainable alternative to traditional work models with conventional office space.

While this study demonstrates that telework is a sustainable alternative to the traditional work model, the upcoming discussions within the federal government that have been communicated with employees could impact the decisions of some employees in different domains. For instance, some employees might decide not to relocate farther away in anticipation of return-to-office policies. With such policies, some employees might reevaluate their financial status and its impact in different domains. For example, high costs of parking and fuel might prevent some employees from driving a car in anticipation of returning to their offices downtown. Others might reconsider relocating farther from their original residences due to potentially longer commute times.

Given these considerations and the lack of longitudinal studies on the impacts of telework, this paper concludes that telework can be a sustainable alternative to traditional work models as long as all stakeholders consciously and voluntarily contribute to adopting sustainable behaviors and to making conscious sustainable decisions associated with different domains and aspects of their lives that can impact the emissions and the 2050 net zero goals.

4.3 Limitations and Considerations

While this study employed some of the most rigid inclusion criteria for its participants and quantification methods, it has some potential limitations associated with it. Additionally, there are considerations that should be taken into account when applying the findings of this study to other regions globally. These limitations and considerations include:

- This study relied on simulation models for estimating the emissions associated with homes.
- The sample of this study for in-person employees was limited to Government of Canada employees working for the Treasury Board of Canada Secretariat (TBS), Public Services and Procurement Canada (PSPC), and the Canada Revenue Agency (CRA) in the National Capital

Region and Québec. At the time of the survey, the Government of Canada prescribed its employees to adopt a hybrid work model at the time of this study, working in the office 2 to 3 days per week.

- Although this study employed some of the most rigid techniques to assure the high quality of transportation data, it still used a self-reported travel diary for telework and in-person days.
- Internet usage was self-reported and this study only considered video and audio conferencing data transfers without considering data storage, cloud storage, and other types of data transfer.
- Emissions associated with offices are based on portfolio divestment forecasts in this study and energy use reduction strategies are not considered.
- Emissions associated with the office domain are based on crown-owned office buildings in the NCR and Quebec.
- This report calculated the NCR employee home emissions for employees based on Ontario grid emission factors.
- Due to confidentiality assurance, some major demographic information, such as income levels, was not collected in this study that can potentially impact home size and type, car ownership, and commute distance.
- This study did not investigate strategies for reducing energy use and emissions associated with homes
- Emissions calculations are region-specific and provinces, territories and countries with different emission factors for electricity and natural gas can have different results. In general, teleworking in regions with low-emission energy supplies to buildings is most affected by transportation. Milder climates with low heating and cooling loads are also most affected by transportation emissions.
- The analysis assumes one teleworker per household. The results do not directly apply to households with multiple teleworkers because that would require a stronger understanding of their respective teleworking schedules, carpooling, etc.

4.4 Future study recommendations

To address the limitations and considerations associated with this study, this study recommends future research to:

- Conduct studies with larger sample sizes for each return-to-office scenario (e.g., 2, 3, and 4 days in the office) to compare emissions
- Track teleworkers and non-teleworkers over one year to track changes in their home energy use and emissions
- Focus on quantifying transportation emissions by tracking participants' single-day, three-day, and weekly transportation data.
- Investigate divestment plans for different sectors and other strategies for reducing energy use and emissions in offices.
- Examine the demographics of teleworkers and non-teleworkers in order to identify other underlying causes of decisions made by teleworkers and non-teleworkers

- Develop strategies for minimizing energy use and emissions in the home domain as the most dominant domain in terms of emissions.
- Focus on different sectors to quantify the impact of telework on other employment types that might not necessarily allow a full adoption of telework strategies
- Study different regions, classify them, and quantify the overall impacts of telework on energy use and emissions.
- Consider all domains when studying telework as savings from one domain can be offset by another domain.
- Investigate habits and behaviors developed by in-person, hybrid, and remote employees over a period of time.

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5 Appendix A: Questionnaire on energy/carbon impact of hybrid work

1. Demographics and general questions

1. What gender do you identify as?

- Male
- Female
- Non-binary/non-conforming
- Transgender
- Prefer not to say

2. What is your age?

- 18 – 24 years old
- 25 - 34 years old
- 35 - 44 years old
- 45 – 54 years old
- 55 – 64 years old
- 65 years old and above

3. Which one best describes your work circumstances?

- I work in an occupation that requires me to work fully in-person
- I work in an occupation that allows me to work either in-person or remote
- I work in an occupation that allows me to work fully remotely

4. What is the highest degree or level of education you have completed?

- Some high school
- High school
- Trade school/college
- Bachelor's degree
- Master's degree
- Ph.D. or higher

5. How many members permanently live in your home, including yourself?

- Enter the number

6. Please describe your household members' current type of job.

Occupant	Work type	Work status	Total number of working days per week	Number of working days at home per week	Number of working days on the weekends	Number of days at home per week
Yourself	Full-time/ part-time/ not working/ retired/ student/ child	Full-time/ remote/ hybrid				
1	…					
2						
3						
…						

2. Homes

1. Where do you spend most of your time during office hours to telework?
   - At home in a dedicated home office
   - At home in the living/dining room
   - At home a bedroom
   - At home elsewhere
   - Outside of the home - please specify: _____

2. In what type of home do you live?
   - Single detached house-one storey
   - Single detached house-two storey
   - Townhouse/rowhouse/attached
   - Multi-unit low-rise building (1-6 stories)
   - Multi-unit high-rise building (more than 6 stories)
   - Other: _____

3. What is the approximate size of your home?
   - Less than 600 ft^2 (less than 56 m^2)
   - 601 to 1000 ft^2 (56 to 93 m^2)
   - 1001 to 1500 ft^2 (94 to 139 m^2)
   - 1501 to 2000 ft^2 (140 to 186 m^2)
   - 2001 to 2500 ft^2 (187 to 232 m^2)
   - Greater than 2500 ft^2 (greater than 232 m^2)
   - Not sure

4. Which of the following best describes your home:

- Rented
- Owned

5. Which of the following home utilities do you or members of your household pay for (select all that apply)?
   - Electricity (also known as hydro)
   - Natural gas
   - Fuel oil

6. Which best describes your heating system?
   - Natural gas furnace
   - Electrical furnace
   - Heat pump (consumes electricity)
   - Electric baseboard
   - Not sure
   - Other - please specify: _____

7. Which best describes your cooling system?
   - Central air conditioner
   - Central heat pump
   - Window air conditioner(s)
   - None

8. Which option best describes your thermostat(s) at home?
   - A single smart thermostat (Nest, ecobee, or similar with phone app and/or Wi-fi connectivity)
   - Multiple smart thermostats (Nest, ecobee, or similar with phone app and/or Wi-fi connectivity)
   - A single manual or programmable thermostat (I can change the setpoint and/or setpoint schedule with this thermostat)
   - Multiple manual or programmable thermostats (I can change the setpoint and/or setpoint schedule with these thermostats)
   - No thermostat (I don't have control over the indoor temperature)
   - Not sure

9. Please estimate the temperature setpoint you use in your home

	Cold season/winter	Warm season/summer
Day (at least one person home)		
Day (empty/unoccupied)		
Night (home)		

10. For each of the following types of equipment during the time you stay at home to telework, how do you expect them to affect your energy consumption compared to days when you leave your home to work?
    a) Computer-office equipment at home

b) Lighting
c) Cooking (stove, oven, and microwave)
d) Laundry

1. No impact; 2. Slightly higher (less than 25%); 3. Higher (between 25 and 50%); 4. Much higher (more than 50%)

11. If you could have the option to heat and cool your home as two independent zones (e.g., you can heat an individual room such as your office, to improve comfort and save energy), how much would you be willing to pay to upgrade your home as a one-time cost?

- $0 (I don't want to spend money to do it)
- Under $3000
- Between $3000 and 5000
- More than $5000
- I don't have the option to upgrade my home

3. Offices

1. Which best describes your workspace if you work in-person at your employer's office? (Check all that match)

- I have a dedicated workspace that only I work at
- I have a dedicated workspace but there is also a shared workspace I can use during my teleworking days
- I have a shared workspace I can use during my teleworking days but I don't have a dedicated office/desk
- I work fully remotely and I have neither a dedicated nor a shared office

4. Transportation

1. How many kilometres is your one-way commute to your workplace from your home?

- Enter a number (km)

2. On average, how many kilometres per day do you travel for non-work destinations?

- Enter a number (km)

3. Does your mode of transportation vary based on warm and cold seasons?

- Yes/no

4. Regarding transportation, some change their predominant mode of transportation based on the season. What are your preferred months for warm and cold seasons?

Warm season: Select starting month – Select ending month

5. If you have the same job as before COVID-19, has your primary mode of transportation for commuting to work changed since then?

- Different job

- Yes
- No

6. Did you relocate your home since COVID-19 began? If yes, approximately how much farther from your workplace did you move (in kilometres)?

7. What's the average distance you commute to work in kilometres (one-way)? Fill in all cells that apply.

	Warm season	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Public transportation	Bus							
	Streetcar/tram							
	Train							
	Light rail transit (LRT)							
Personal vehicles	Personal vehicle							
	Carpooling, ridesharing, etc.							
	Uber, taxi, etc.							
Activ	Bicycling							
	Walking							
	Cold season	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Public transportation	Bus							
	Streetcar/tram							
	Train							
	Light rail transit (LRT)							
Personal vehicles	Personal vehicles							
	Carpooling, ridesharing, etc. (excluding household members)							
	Uber, taxi, etc.							
Acti	Biking							

	Walking							

8. What's the average distance you travel per day for non-work trips in kilometres? Fill in all cells that apply.

	Warm season	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Public transportation	Bus							
	Streetcar/tram							
	Train							
	Light rail transit (LRT)							
Personal vehicles	Personal vehicle							
	Carpooling, ridesharing, etc. (excluding household members)							
	Uber, taxi, etc.							
ctive	Biking							
	Walking							
	Cold season	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Public transportation	Bus							
	Streetcar/tram							
	Train							
	Light rail transit (LRT)							
Personal vehicles	Personal vehicles							
	Carpooling, ridesharing, etc. (excluding household members)							
	Uber, taxi, etc.							
ctive	Biking							
	Walking							

9. On days when you commute to work, do you add errands and other trips (e.g., grocery shopping, picking up kids, etc.)?

- Never
- Sometimes
- Frequently
- Nearly every committee

10. (If yes to above), now that you are teleworking, how many kilometres (one-way) are household members traveling more or less since you can no longer combine your trips?

Household members	Kilometres traveled	Indicate
A	X	Less/more
B	X	Less/more
…	X	Less/more

5. ICT

1. On average, how many daily hours do you spend on videoconferencing (e.g., Zoom, Teams) when teleworking?

Weekday	Video	Audio
Zoom		
Teams		
Weekend		
Zoom		
Teams		

2. On average, how many daily hours do you spend on videoconferencing (e.g., Zoom, Teams) when working in person?

Weekday	Video	Audio
Zoom		
Teams		
Weekend		
Zoom		
Teams		

3. How many *more* daily hours do you spend on non-work activities on days that you telework?

- Enter hours

4. Please describe the percentage of WiFi and mobile data used for work-related and non-work-related usage.

	WiFi (out of 100%)	Mobile data (out of 100%)
Work		
non-work		