A preliminary scenario analysis of the impacts of teleworking on energy consumption and greenhouse gas (GHG) emissions

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Abstract. This paper uses scenario analysis to investigate the broader impact of teleworking in four scenarios including the COVID-19 pandemic, worst-, moderate-, and best-case scenarios on building-level energy use, energy consumption in transportation, and information and communication technology (ICT) usage by using the databases of the Government of Canada. The COVID-19 scenario relies on the available data for the pandemic period. The worst-case scenario is when telework has an adverse effect on energy use while the moderate- and best-case scenarios are when the minimum and maximum savings are achieved by telework. The data includes commuting distances, electricity and natural gas consumption for offices and residential buildings, and ICT usage. Then, the associated GHG emissions are calculated for transportation, residential and office buildings, and ICT and the analysis are carried out by applying a potential fraction of saving to the associated GHG emissions of each domain and scenario. This paper demonstrates the potential energy savings of teleworking significantly depends on teleworker behavior to a degree that in the worst-case scenario no potential saving is observed while the savings are significant in the best-case scenario. Therefore, the impact of telework is highly uncertain and complicated and current statistics are insufficient for accurate estimates.

1. Introduction
Teleworking is defined as working remotely out of any conventional office by using information and communications technology (ICT) [1]. In another recent definition of telework by the United States Government, it is defined as “a work flexibility arrangement under which an employee performs the duties and responsibilities of such employee's position, and other authorized activities, from an approved worksite other than the location from which the employee would otherwise work” according to the Telework Enhancement Act of 2010 [2]. In either definition, telework refers to a work arrangement in which workers or employees carry out their duties and responsibilities away from their regular office. While the concept of telework has been around for more than five decades, its potential in saving energy has been controversial [3]. For instance, Röder and Nagel showed telework has the potential to reduce energy consumption by 10% [4]. Similarly, Williams showed promising results when teleworking strategies are implemented in Japan [5]. However, Kitou and Horvath who considered both transportation and building domains concluded energy savings in transportation can be offset by increased energy consumption at homes [6]. To date, most studies on telework focused on the transportation domain while telework is a multifaceted topic meaning that the energy consumption in residential and office buildings along with ICT is vital in assessing the impact of teleworking [3]. Among all the studies on telework, only Roth et al.’s study considered all domains of telework and concluded...
that telework has the potential to save energy in different domains [7]. Nevertheless, many other studies that focused on the transportation domain of telework reported contradictory results because transportation patterns, the efficiency of vehicles, and teleworker behavior play a role in achieving savings through telework [3]. Similarly, the efficiency of devices, associated energy consumption with ICT, and teleworker behavior at home are all important aspects of telework [3]. Therefore, O’Brien and Yazdani suggested the impact of telework can be evaluated through scenario analyses, such as worst, moderate, and best for each domain of telework [3].

Despite a long history of studies on telework, the COVID-19 pandemic has created a situation where at least 21.6% of the daily activities have shifted to remote activities [8]. Although the emergence of COVID-19 in March 2020 as a global pandemic inflicted devastating damage, it created an amalgam of the scenarios for workers and their families. While they work remotely from home during the lockdowns, their commutes and errands are also minimized. However, teleworkers might use more energy in case they have children at home while the energy consumption at the schools and sports facilities is reduced. As a result, the current pandemic provides an abnormal condition for evaluating the wider impact of telework on energy consumption in societies although this is a conservative scenario where many day-to-day activities are suspended due to unprecedented circumstances. Therefore, the aim of the current study is to assess the broader impact of telework on energy consumption in terms of GHG emissions based on four scenarios, including COVID-19, worst, moderate, and best-case scenarios based on previous statistics as well as those collected during the COVID-19 pandemic in Canada.

2. Research Method

This study uses scenario analysis to investigate the impact of telework in Canada. Figure 1 shows the overall research method of this paper. Accordingly, the data is collected from the databases of the Government of Canada. Then, the fraction of potential savings for each scenario is estimated based on the COVID-19 pandemic. Next, the fraction of potential saving or adverse effect is applied to the collected data for each domain. After that, results are reported in terms of potential savings for greenhouse gases (GHG) emissions since each domain of telework has a different unit of measurement. In this study, teleworkers are those who worked in offices and had a dedicated space before telework.

2.1. Data Collection

According to Statistics Canada, 4.1% of Canadians were working from home before the COVID-19 pandemic but the number increased to 21.6% after the pandemic [8]. COVID-19 related data creates the foundation for comparison between different scenarios based on the available statistics on different domains of telework.

2.1.1. Transportation. To make the results of this study comparable to future studies, the average commute distance is reported according to data received from Statistics Canada [9]. Accordingly, Table 1 shows the average one-way commute distance is 8 km for Canadians with less than 60 minutes commute time while it is 40 km for those with more than 60 minutes commute time [9]. The corresponding GHG emissions per km in terms of CO₂e are estimated to be 153 g of CO₂e per km for passenger automobiles and light trucks [10] (Table 2).
2.1.2. Residential and Office Buildings. The average electricity and gas usage per household in Canada was obtained from Statistics Canada [11]. Accordingly, the average electricity consumption is 40 GJ per household and the average gas consumption is 92 GJ per household. It should be noted that other fuel types, almost 20% of the total fuel consumed by residential buildings, were not investigated. The total number of households was 12.4 million in Canada [12]. This number was obtained to analyze the impact of total consumption on GHG emissions. A comprehensive Canadian survey on office and commercial buildings showed the total energy use for institutional and commercial buildings was 842.2 PJ but only 176.6 PJ was used by non-medical offices non-medical [13]. The total floor area for such offices was 147.5 million m² [13]. We obtain an energy use intensity of 1.19 GJ/m² by dividing the total energy use of offices by their floor area.

2.1.3. ICT. The data for ICT usage (focused here on data transmission-related energy/emissions) was obtained from the communications monitoring dataset and it separates the average upload and download usage [14] and mobile data [15]. Accordingly, the average data usage for upload and download was 13 GB and 153 GB per month, respectively (Table 1). Only 86% of Canadian households have active subscriptions [14]. Furthermore, the average data usage over mobile data was 1.8 GB per month (Table 1) with an 88% active subscriber out of the total Canadian population [15]. The corresponding GHG emissions for the transfer of data are estimated to be 3 kg of CO₂e per GB [16] (Table 2).

| Item | Available data |
|------|---------------|
| Teleworkers and transportation | Teleworkers before Covid-19 4.1% |
| | Teleworkers during covid-19 21.6% |
| | Average commute distance for Canadians (<60 minutes) 8 km |
| | Average commute distance for Canadians (>60 minutes) 40 km |
| | Total number of commuters by car (alone and with passenger <60) 11,763,405 |
| | Total number of commuters by car (alone and with passenger >60) 853,610 |
| ICT | Average upload data usage 13 GB per month |
| | Average download data usage 153 GB per month |
| | Mobile data (average) 1.8 GB per month |
| Residential buildings | Canadian household electricity usage (average – heating and other electricity usages combined) 40 GJ per household |
| | Canadian household natural gas usage (average – 43% of total fuel used in households) 92 GJ per household |
| | Total number of households 12.4 million |
| | Average number of people per household 2.9 people |
| Offices | Total floor area of offices (non-medical) 147.5 million of m² |
| | Total energy use for offices (non-medical) 176.6 PJ |
| | Energy intensity for institutional and commercial buildings 1.1 GJ/m² |
| | Energy intensity for offices 1.19 GJ/m² |

2.1.4. Associated GHG emissions. In this section, CO₂e from combustion and the use of natural gas and electricity in Canada are described. Each province in Canada has a different CO₂e associated with generating electricity. British Columbia, Manitoba, and Quebec are exceptions because their electricity generation does not yield notable GHG emissions due to its use of renewable energy [17]. To make the results of this study more generalizable, we calculate the average of CO₂e for electricity among all provinces (Table 3). The value for electricity is converted to tonnes/GJ to make the comparison clearer.
Table 2. Corresponding GHG emissions for transportation, ICT, electricity, and natural gas usage.

| Item                                      | GHG emissions                        |
|-------------------------------------------|--------------------------------------|
| Transportation (per km - new cars and light trucks) | 153 g CO$_2$e/km                     |
| Internet data                             | 3 kg of CO$_2$e per GB                |
| Electricity (average of all Canadian provinces) | 0.39 tonnes/MWh (equivalent to 0.1 tonnes/GJ) |
| Natural gas (average for Canada)          | 63.29 kg CO$_2$e/GJ                   |

2.2. Scenarios

2.2.1. COVID-19 scenario. A recent study that analyzed the electricity demand in Alberta, Ontario, British Columbia, and New Brunswick provinces showed a weighted average of 6.25% reduction in electricity demand across industrial and commercial, and residential sectors in Canada [18]. This is in accordance with reports from Ontario, Canada that announced a decrease in electricity usage was observed [19]. Although these values are due to the widespread shutdown of many facilities, we will use a 6.25% reduction for our calculations in this scenario. For natural gas consumption, we calculated the consumption and corresponding savings for both commercial and institutional, and residential sectors from available data on Statistics Canada [20] by multiplying the average consumption in these two sectors by the number of households and offices. According to our calculations, both sectors experienced decreases in natural gas consumption. The decreases were 6.44% and 5.49% for commercial/institutional and residential sectors, respectively. Furthermore, the total sales of diesel and motor gasoline were compared from the available data during COVID-19 (2020) to the same period in 2019 to calculate the impact of COVID-19. Accordingly, the sales of gasoline dropped by 14.25% [21] and this percentage was applied to transportation during COVID-19 in calculations. One limitation of this calculation is that the traveled distance in kilometers is not directly associated with the liters of motor gasoline or diesel burned. However, there is an analogy between this drop in motor gasoline and diesel sales and the 18% increase in the number of teleworkers (Table 1). Therefore, a 14.25% drop seems a reasonable value for calculations. During the COVID-19 pandemic, the ICT usage has increased by 38%, though 80% of the ICT usage is dedicated to social media, gaming, etc. [22] (Table 3).

2.2.2. Worst-case scenario. In this scenario, transportation distance and associated GHG emissions increase [3]. Accordingly, the amount of increases is extracted from a previous study that reported a 33% increase in the daily traveled distance [23]. For heating, calculations rely on a previous study that showed telework might increase the heating by 8.2% in residential buildings [24]. In this scenario, the offices are assumed to consume as much energy as they were consuming before the start of telework since buildings normally operate based on fixed schedules. In the worst-case scenario, the maximum increase in ICT usage is assumed to be the same as the ICT usage during the COVID-19 pandemic as at this time everything is online, and online leisure activities have increased to their maximum (Table 3).

2.2.3. Best-case scenario. In this scenario, transportation is replaced with other options such as cycling or other means of green transportation that do not produce any GHG emissions [3]. For the best-case scenario, this paper assumes there are some occupancy-based measures in place. In this regard, a previous study on occupancy-based thermostats showed a potential of 34% saving on the total energy use of the residential building [25]. In another study implementing a variable air volume (VAV) system resulted in 19% to 42% of savings in residential buildings [26]. This study assumes a 24% potential saving as a preliminary estimate in the best-case scenario to avoid exaggeration based on the reviewed studies. In offices, savings of 25% and 27% were observed in the total energy use in previous studies [27,28]. This study assumes potential savings of 26% for the best-case scenario in offices. Moreover, the ICT does not change in the best-case scenario (Table 3).
2.2.4. **Moderate-case scenario.** In this scenario, transportation remains the same and neither increases nor decreases. This paper assumes half of the potential savings in the best-case scenario for residential buildings as the moderate-case scenario (12%). Similarly, an average savings of 13% was applied in this scenario for offices. In the moderate-case scenario, the ICT usage is assumed to be the average of no change and worst-case scenario (19%) [22] (Table 3).

Table 3. Scenarios of the current study [derived from [3]] and calculation method.

| Scenario   | Best                          | Moderate | Worst                          | COVID-19               |
|------------|-------------------------------|----------|--------------------------------|------------------------|
| Transportation | Clear Transportation (0 GHG emissions) | No change | 33% increase | 15% decrease |
| Offices    | 26% saving (Highly efficient technologies) | 13% saving (Efficient systems) | No change (fixed schedules) | 17% decrease for electricity and gas |
| Residential | 24% saving (Highly efficient technologies) | 12% saving (Efficient systems) | 8.2% increase (larger house, increased number of occupants, lighting, and HVAC) | 17% decrease for electricity |
| ICT        | No change                     | 19% increase | 38% increase | 38% increase |

Calculation method

Transportation: Daily commute distance × owners × 365 days × GHG emissions × scenario fraction
Buildings: Annual electricity and natural gas × GHG emissions × scenario fraction
ICT: Monthly used GB × active subscribers × 12 months × GHG emissions × scenario fraction

3. Results

Table 4 shows the calculated values for three main domains of telework, including transportation, ICT, and buildings in the base case. Each domain has its own specific units in the dataset but GHG emissions are all calculated based on Mt CO2e to make results comparable.

Table 4. Calculated GHG emissions for all domains of telework (base case).

| Item                        | Total value | Unit    | Associated GHG emissions |
|-----------------------------|-------------|---------|--------------------------|
| Total Transportation        | 128,251,640 | km/day  | 7.16 Mt CO2e             |
| Base Total ICT Usage        | 1,827,184,640 | GB/month | 65.80 Mt CO2e            |
| Residential - Electricity   | 496,000,000  | GJ      | 49.60 Mt CO2e            |
| Residential - Natural Gas   | 1,140,800,000 | GJ      | 7.20 Mt CO2e             |
| Office - Electricity        | 72,406,000   | GJ      | 7.24 Mt CO2e             |
| Office - Natural Gas        | 90,066,000   | GJ      | 5.70 Mt CO2e             |
| Total                       | -            | -       | 208 Mt CO2e              |

Table 5 shows the total calculated emissions for each domain in Mt CO2e. Although the available data from Statistics Canada shows a nominal decrease in total GHG emissions for buildings, ICT usage has increased significantly. GHG emissions are almost 11% more than the baseline due to the pandemic. Similarly, the total GHG emissions were significantly higher in the worst-case scenario compared to the baseline (slightly more than 20%) due to a significant increase in transportation and ICT usage. The savings are less than 1% in the moderate-case scenario. In contrast, the best-case scenario yields substantial savings in terms of GHG emissions (18%). It should be noted that the lower share of the transportation from GHG emissions is due to our calculations for commuters’ vehicles only (almost 12.5 million vehicles for commutes only).
Table 5. Calculated GHG emissions for each scenario.

| Domain                          | Baseline | COVID-19 | Worst  | Moderate | Best   |
|---------------------------------|----------|----------|--------|----------|--------|
| Total Transportation            | 7.16     | 6.14     | 9.53   | 7.16     | 0.00   |
| Total ICT Usage                 | 65.78    | 90.77    | 90.77  | 78.28    | 65.78  |
| Total GHG emissions for buildings| 134.74   | 126.85   | 144.73 | 118.44   | 102.15 |
| Total                            | 207.68   | 223.77   | 245.03 | 203.88   | 167.92 |

4. Discussion

In the previous section, the results of our preliminary analysis for different scenarios were presented. Figure 2 shows the overall view of each scenario. A primary source of GHG emissions is transportation. Although its corresponding GHG emissions decreased during the pandemic due to stay-at-home orders and travel bans, there is evidence suggesting that teleworking increases GHG emissions for the transportation sector because individuals are more willing to live in suburban areas or locations away from downtown core [23]. “Insights from Markets” report also shows that sales of motor gasoline and diesel fuel decreased from $1.12\times10^11$ to $9.56\times10^10$ liters which yields a decrease of 14.25% [21] which is in accordance with the percentage of teleworkers. This value could be slightly higher if all road transportation was not considered.

The ICT usage as the second source of GHG emissions fluctuates significantly in different scenarios. During the COVID-19 pandemic, many leisure activities are not available. As a result, many shifted toward social media, cloud gaming platforms, and online streaming services and 80% of the increase belongs to these platforms [22]. It is unclear how this trend will change once the pandemic ends but there is a potential that some of these technologies, such as extensive video conferencing on different applications, will continue to be used more with the emergence of new platforms.

The buildings can be considered a source of uncertainty since many different factors are involved in buildings. Teleworker behavior [29], the efficiency of systems, and different technologies, such as demand-controlled ventilation [30,31], can significantly impact GHG emissions. Although consumption of natural gas and electricity in buildings decreased during the pandemic, the available data for such conclusions are reported for the different sections in the entire country. In normal situations, other sectors such as commercial buildings might offset any potential saving. This issue was investigated in our worst-case scenario. However, there are multiple measures, such as occupancy-based lighting or occupancy-based thermostat setpoints, that can help buildings to adapt to partial occupancy that can significantly save energy [30,32,33].

5. Conclusion

The current study aimed to assess the broader impact of telework on energy consumption based on different scenarios during the COVID-19 pandemic in Canada. Accordingly, baseline GHG emissions
were calculated for three main domains of transportation, office and residential buildings, and ICT. Then, GHG emissions were calculated based on previous studies or available data from the COVID-19 situation in four different scenarios. These scenarios included best, moderate, worst-case scenarios plus a scenario analysis for the COVID-19 pandemic based on the available data in Canada.

The results showed ICT usage has increased significantly although the electricity and gas usage decreased during the COVID-19 pandemic. The results suggest ICT offsets much of the potential savings in this regard. However, it should be noted that leisure activities were suspended due to local lockdowns and stay-at-home orders during the pandemic. Moreover, the results illustrate the worst-case scenario has a significant negative impact on total GHG emissions due to a substantial increase in transportation and ICT usage while the moderate scenario reduces the GHG emissions slightly. In contrast, the best-case scenario reduces the GHG emissions substantially since transportation is removed and buildings operate with energy-efficient systems and occupancy-based technologies.

A limitation of this study was the unavailability of datasets for specific years. In future studies, it would be better to use data and possible reports from the same year. The second limitation was the unavailability of data for non-work-related travels and errands for households. The third limitation was the inadequacy of data on some aspects such as the efficiency of each office buildings, technologies being used in offices or houses, etc. Therefore, future research should aim at closely following a single population (e.g., Canadians) to understand the intricacies of the relationships between people’s behavior and the corresponding environmental impact. Furthermore, the long-term impacts of telework should be studied thoroughly.

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