

Short run "rebound effect" of COVID on the Transport Carbon Footprint

Carolina Rojas

Ivan Muñiz

Marc Quintana

François Simon

Bryan Castillo

Helen de la Fuente

Joaquín Rivera

Michael Widener

Abstract

COVID-19 completely transformed the mobility of cities. The restrictions on movement led to “empty cities” throughout the world, with some environmental effects in terms of clean air and the reduction of CO₂ emissions. This research considers how mobility restrictions due to COVID-19 have affected the carbon footprint of four medium-sized Chilean cities (Coronel, Temuco, Valdivia, and Osorno) that have environmental problems and are highly dependent on motorized systems. The study uses data from 2,400 household surveys at three times: pre-pandemic - T0 (winter 2019), the time of implementation of restrictive mobility policies to contain the pandemic - T1 (winter 2020), and six months later when said restrictions were gradually lifted - T2 (summer 2021). The analysis suggests that CO₂ emissions actually went up, declining in the winter, but then increasing with the greater use of cars in the summer due to the temporary effects of commuting to work, to reach levels higher than the pre-pandemic values, known as a “rebound effect.”

1. Introduction

In March 2020, mobility patterns in cities were transformed completely due to COVID-19. The restrictions on movement led to “empty cities” throughout the world. Some research has focused on COVID’s impact on the reduction of mobility in cities (Malik et al., 2020; Abu-Rayash and Dincer, 2020; Fatmi, 2020), with COVID-19 movement restrictions increasing telecommuting and online classes for students. This research considers how mobility restrictions due to COVID-19 have affected the carbon footprint of four medium-sized Chilean cities (Coronel, Temuco, Valdivia and Osorno) which have environmental problems and are highly dependent on motorized systems (Rojas et al., 2016).

Using questionnaires distributed among 2,400 families, data on mobility patterns for work and studies were obtained for each family member. This includes information on the decision to travel, telecommuting, distances traveled, and the modes of transport used. With these data, the carbon footprint is calculated for each family member by multiplying the distance traveled in each mode of transport used by a conversion factor that converts each kilometer traveled into kg of CO₂. The surveys collect information from three periods: pre-pandemic - T0 (winter 2019), the time of implementation of restrictive mobility policies to contain the pandemic - T1 (winter 2020), and six months later when these restrictions were gradually lifted - T2 (summer 2021).

With the arrival of COVID and the implementation of restrictive mobility policies, many cities in the world witnessed empty streets and clear blue skies that had not been seen for a long time. One of the most obvious advantages of forced telecommuting was improved air quality and lower CO₂ emissions. However, this expectation of a reduction in emissions associated with mobility should be taken with caution, since COVID-19 has significantly increased the percentage of trips made by car. Traveling by car minimizes the chances of COVID infection during the commute. The drop in the carbon footprint due to the reduction in the number of work commutes may actually be less than the increase in the carbon footprint due to greater car usage, such that emissions would first decrease, but then increase to levels higher than those seen in the pre-pandemic period. We call this the “rebound effect.” This research study aims to determine which of the two opposing forces (telecommuting/car use) tends to prevail. Our results indicate that the carbon footprint has exceeded pre-pandemic values, thus demonstrating a clear rebound effect.

The four cities studied are among the most polluted in Chile, due simultaneously to industrial activity, motor vehicles, heating systems, and electricity generation (Forster et al., 2020; Liu et al., 2020). It is important to note that air pollution is highly correlated with greenhouse gas emissions despite being two radically different gases. For example, motor vehicle combustion generates carbon monoxide (CO) and carbon dioxide (CO₂). The latter is a colorless and odorless

greenhouse gas that accumulates in the upper layers of the atmosphere for centuries, while the former is a gas that is harmful to health and dissipates with normal atmospheric activity. They are both forms of waste generated from the same activity, so the degree of air pollution in a city is a good indicator of its CO₂ emissions. When it comes to Latin America, many studies have focused on large metropolitan areas, such as Mexico City, Santiago (Chile), Buenos Aires, and Bogota, while medium-sized Latin American cities have received less attention. However, since the early 1980s, the percentage of the population living in medium-sized cities has grown steadily in Europe, Asia, and Latin America (United Nations, 2002). Between 1980 and 2010, the number of urban agglomerations with a population between half a million and one million inhabitants has increased from 27 to 62 (Manzano and Velázquez (2015)). Thus, it is surprising how little interest there is in studying these types of cities, despite their importance and dynamism in clear contrast to the stagnated population of large metropolises.

In general, given the global context of reduction in CO₂ emissions associated with COVID-19 mobility restrictions, the carbon footprint of residential mobility patterns is associated with greater advance in telecommuting, i.e., around 50% of the Canadian population is estimated to be working from home (Leger, 2020). However, these Chilean cities have been selected for three reasons. First, they are among the most polluted in Chile, simultaneously due to industrial activity, motor vehicles, heating systems, and electricity generation (Forster et al., 2020; Liu et al., 2020). Second, they are traditionally associated with a number of industrial sectors and regional universities, which implies a reduction of travel for study purposes. Third, they are highly dependent on private and public transport (Rojas et al, 2016).

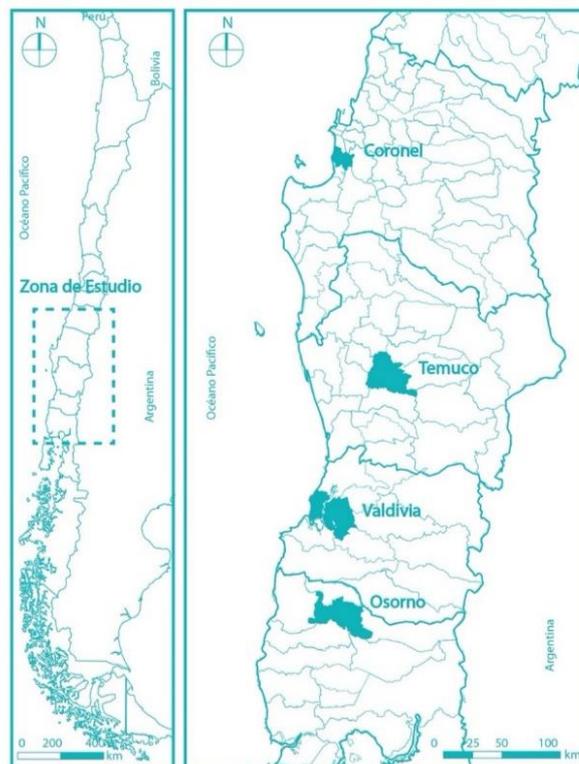
For this reason, it is important to observe Chilean cities, since the increase in motorized transport and poor quality of public transport in mid-sized cities could generate a worse situation in terms of urban development and exacerbate social inequality in access to transport. The pandemic is also an opportunity to reorganize transport systems to make them more sustainable. Muñoz (2021) proposes that Chilean cities rethink the spatial distribution of activities, improving the proximity of services, and promoting active transport (walking and bicycles). Changes in daily mobility habits could imply changes in gasoline consumption with greater expected positive effects on the environment and declines in GHGs.

2. Materials and methods

2.1. Case study

The study aims to assess the carbon footprint of mobility patterns in four cities in south-central Chile (Figure 1): Coronel, Temuco, Valdivia, and Osorno. These cities are all experiencing episodes of severe air pollution. Indeed, the four cities present annual average concentrations of coarse and fine particulate matter (respectively PM_{10} and $PM_{2.5}$) regularly exceeding the World Health Organization guidelines (Jorquera et al., 2018; Huneus et al., 2020). In 2020, according to data from Blommers Green and the NGO OpenAQ, Temuco was declared the most polluted city in the world. The cities studied are located in the south-central zone of Chile. Coronel, in the Biobio Region, is the least populated city in the study, with 116,262 inhabitants. It is functionally integrated within the metropolitan area of Concepción, along with the neighboring cities of San Pedro de la Paz and Lota (Rojas et al., 2009). The city of Temuco, which is the most populated of the four with 342,488 inhabitants, is a conurbation between the municipalities of Temuco and Padre las Casas and acts as a hub for work and studies in the Araucanía Region (Salazar et al., 2017). The cities of Osorno and Valdivia present similar demographics, bringing together other smaller urban settlements in the Los Lagos and Los Rios Regions, respectively.

Figure 1: Location of case studies.



Source: Own elaboration

The effects of the COVID pandemic have implied periods of restriction in mobility according to contagion rates. The four cities have seen an increase in confirmed cases, with differentiated peak and stabilization periods. The peak cases were seen from mid-June to October. This increase was accompanied by the application of health measures, including restricted circulation for the four cities under review, starting in September. All four cities were in lockdown during October and half of November. It should be noted that the first round of surveys was applied during this period. During the summer, there was a sharp increase in the number of cases per 100,000 inhabitants, particularly between January and February, at which time the four cities were once again subject to total lockdown. In parallel, the second round of surveys was applied during this time. It must also be noted that during January and February, residents had the possibility of requesting a vacation permit to travel to and from any municipality that was not in lockdown, and this measure led to a more dynamic interregional mobility in the country.

2.2. Survey data

The assessment of the carbon footprint of household mobility was performed by processing surveys on mobility patterns, multiplying monetary units of consumption and distance by emissions factors. The Carbon Footprint Survey conducted during the winter of 2020 (*T1*) and the summer of 2021 (*T2*) is a longitudinal survey that seeks to monitor the same cohort and compare consumption patterns in the context of the pandemic between the winter of 2020 and the summer of 2021, as well as to inquire about prior situations in the winter of 2019 (*T0*). The survey was inspired by a previous study in the city of Concepción reported in Muñiz and Rojas (2019). The survey was conducted randomly among heads of households and applied using a computer-assisted telephone interviewing (CATI) system. A total of 2,400 surveys were distributed equally among the four cities under review, with samples of 300 households per city, and information on commuter and student mobility before the pandemic (*T0* -winter 2019) and during the pandemic (*T1*-winter 2020, and *T2* -summer 2021).

2.3 Calculation of the carbon footprint

The *Carbon Footprint* is an indicator of the global environmental impact of humans on the climate, which counts the greenhouse gases associated with the consumption of goods or services. It is an indicator oriented towards consumption (IPCC, 2014). This type of consumption-oriented indicator aims to correct the low *Direct CO₂ Emissions* of rich countries due to their ability to displace polluting activities outside their borders. The method adopted consists of assigning to the final consumer the total direct and indirect emissions originated to satisfy their consumption

patterns. Another popular indicator of environmental impact oriented towards consumption is the *Ecological Footprint* of Wackernagel and Rees (1998). An interesting aspect of the *Carbon Footprint* indicator, especially for the case at hand, is that, unlike the *Direct CO₂ Emissions* indicator, the emissions associated with the electrical energy used by electric vehicles are not assigned to the power plant that generates said electricity, but to the place of consumption: use of electric-powered public transport. Regarding combustion vehicles, there is no difference between *Direct CO₂ Emissions* and *Carbon Footprint* since the place of production of emissions and mobility consumption is the same.

Households were asked about the types of transportation they used for work and study purposes, as well as the origin and destination points. Distance travelled was calculated using the Network Distance function of ArcMap software, which uses a network of graphs to calculate the distance between a given origin and destination. The IPCC database was used to indicate emissions factors for greenhouse gases (GHGs) produced from the combustion of each type of fuel. The estimated emissions factor considers the amount of CO₂, as well as the CO₂ equivalents of CH₄ and N₂O emitted during the combustion of 1kg of each type of fuel.

The following emissions factors were applied for each of the transportation methods and/or combinations taken by users (Table 1). While the survey asked about the type of fuel used in private transport, in the case of other types of transportation, the most used fuel was considered according to information from the Chilean Ministry of Transport and Telecommunications.

Table 1.
Emissions factors by transportation method.

Main transportation methods	Emissions factors (kg of CO ₂ -eq/L)	
	<i>Gasoline</i>	<i>Diesel</i>
Walking/Bicycle/Work from home	0.000	NA
Car	0.192	0.159
Share Taxi	0.058	NA
Microbus	0.058	NA
Taxi	0.192	NA
Train	0.020	NA
Other	0.058	NA

Source IPCC (2014)

A high percentage of commutes used more than one type of transport, therefore mixed emissions factors were calculated, considering the average occupation of each type of transport. In concrete terms, 84 mixed emissions factors were calculated (Appendix Table 1). It was surprising to find such a high number of combinations used by commuters, reflecting an extremely flexible use of

the modes of transport available to students and workers, depending on their location with respect to the school/university or workplace, as well as other factors such as income or car ownership.

The mixed emissions factors were multiplied by fuel consumption corresponding to the commuting distance declared by household member i , for work or study purposes. This multiplication yields the number of kilograms of CO₂ (kg CO₂ eq).

$$\text{Eq 1. Carbon footprint (kg CO}_2)_i = \text{Commuting distance}_i * \text{Combined Conversion factor } z_i$$

where $z = (1 \dots 84)$ is the combined conversion factor. Then, the carbon footprints for each of the i household members are added up.

$$\text{Eq 2. Carbon Footprint of household } j = \sum_{i=1}^n \text{Carbon footprint (kg CO}_2)_i$$

where n is the number of household members.

This calculation is carried out for: a) mobility for work and study purposes; and b) before the pandemic (T0) and during the pandemic (T1 and T2). The results are presented on a monthly time scale.

3. Results.

The most remarkable result of this research is the detection of a rebound effect in the carbon footprint of work-related mobility as a result of COVID and mobility restriction measures to curb the pandemic. Anti-COVID policies reduced worker mobility, which resulted in a significant drop in the per capita carbon footprint. However, six months later, mobility restrictions were relaxed and the carbon footprint of work-related mobility per capita was above pre-pandemic levels (Table 2).

In terms of commuting to work, these cities are not highly associated with service jobs or telecommuting, but rather activities tied to the primary sector that require in-person work (industries). The lockdown never affected more than 50% of workers. In this context, the highest reduction in emissions was seen in Coronel (-45%), followed by Valdivia with -34%, Temuco with 31%, and significantly lower in Osorno at -16%. In the summer (T2), emissions begin to recover and even increase over pre-pandemic figures. The greatest rebound effect occurs in Osorno, where the per capita carbon footprint in T2 more than doubles the pre-pandemic value. This trend does not occur in travel for study purposes (Table 2, Figure 2).

Table 2.

Monthly carbon footprint (kgCO₂) corresponding to mobility (T0: Average month before the pandemic, winter 2019; T1: average winter month 2020; T2: average summer month 2021).

City	Work			Study		
	T0	T1 (change over T0)	T2 (change over T0)	T0	T1 (change over T0)	T2 (change over T0)
Coronel	173	95 (-45%)	176 (+2%)	37	0 (-100%)	6 (-84%)
Temuco	86	59 (-31%)	108 (+26%)	40	4 (-90%)	2 (-94%)
Valdivia	105	69 (-34%)	170 (+62%)	50	4 (-91%)	30 (-40%)
Osorno	82	69 (-16%)	183 (+122%)	67	0 (-100%)	16 (-76%)
Total	446	293 (-34%)	637 (+43%)	194	8 (-96%)	55 (-72%)

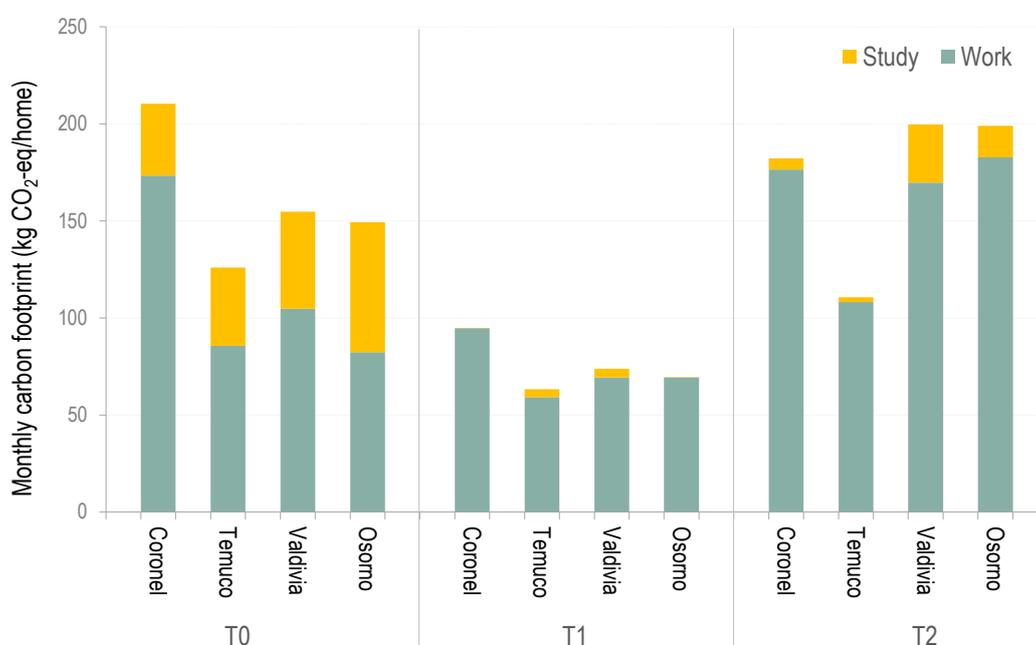


Fig. 2. Carbon footprint from work & study transportation (monthly average per home). Monthly carbon footprint corresponding to mobility (T0: Average month before the pandemic, winter 2019; T1: average winter month 2020; T2: average summer month 2021).

How did rebound effect occur?

In the cities surveyed, before the pandemic (T0), 44% of households had 2 people working outside the home, and 38% had 1 person working outside the home. In the winter (T1), 46% of the 1,200 households had one person working outside the home, and 19% had two. In the summer (T2), 23% of households had two people commuting to work, while 49% had just one member (Appendix Table 2). Before the pandemic (T0), 1,880 people from the 1,200 households commuted to work, versus 1,129 people who commuted during the winter (T1), representing a

36% decrease. Winter (T1) data show a drastic reduction compared to T0, since the country was undergoing its first wave of the pandemic, which brought about stricter and longer measures such as lockdown, and many workers began to work from home. In the summer (T2), when there was greater flexibility, there were 1,244 people commuting to work, for a reduction of 33% in comparison to pre-pandemic figures (T0) and a slight increase over the winter data (T1) (Table 3).

Table 3.

Number of people working outside the home (T0: Average month before the pandemic, winter 2019; T1: average winter month 2020; T2: average summer month 2021).

City	T0	T1	T2
Coronel	463	280	328
Osorno	466	287	317
Temuco	476	281	296
Valdivia	475	281	303
TOTAL	1880	1129	1244

These data indicate that the rebound effect in the mobility footprint is not due to the fact that in T2 there are fewer workers telecommuting than before the pandemic. A certain degree of telecommuting seems to have consolidated for some professions and it is unlikely to disappear after the pandemic.

Data clearly indicate that the rebound effect is due to increased car use. Before the pandemic (T0), 55% of trips to work were made by car. With the first mobility restrictions (T1), this percentage grew to 62% and six months later (T2) it grew to 64% (see % and flows Figure 3). Public transportation by bus has been the most affected by the pandemic, considerably reducing its share in cities. This trend is fairly consistent with what has been reported in large cities across the world by press [reports](#) and research. Faced with the perception of a high probability of contagion in public transport, the population has responded by preferring private transport, turning it into a prophylactic element that reduces the probability of contracting the coronavirus.

The commuting distances used to calculate the carbon footprints averaged 23km for both purposes (Table 4). In the winter, work commutes dropped by an average of 13km and recovered in the summer up to 24km. Study commutes dropped considerably to 2km, with a peak of 2.8km.

Table 4.

Average distance travelled (km).

School	T0	T1	T2	Work	T0	T1	T2
All	23.46	2.16	2.81		23.73	13.68	23.99
Only commuters	23.46	55.17	48.17		23.73	22.62	34.39

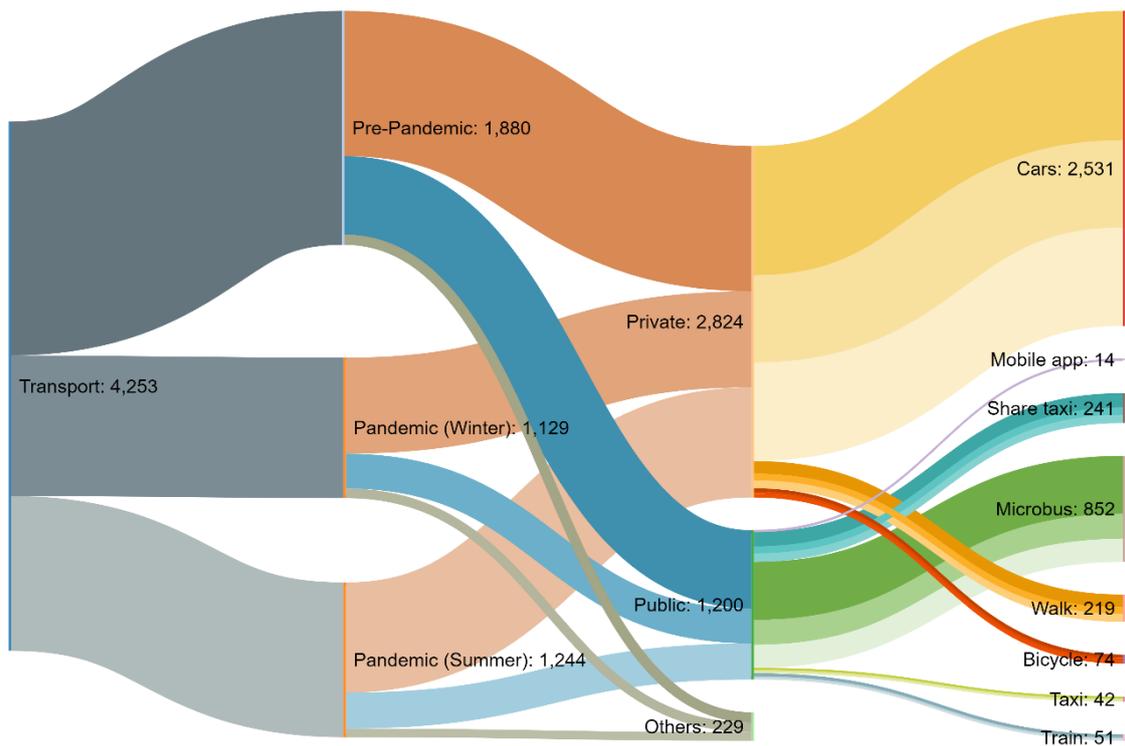
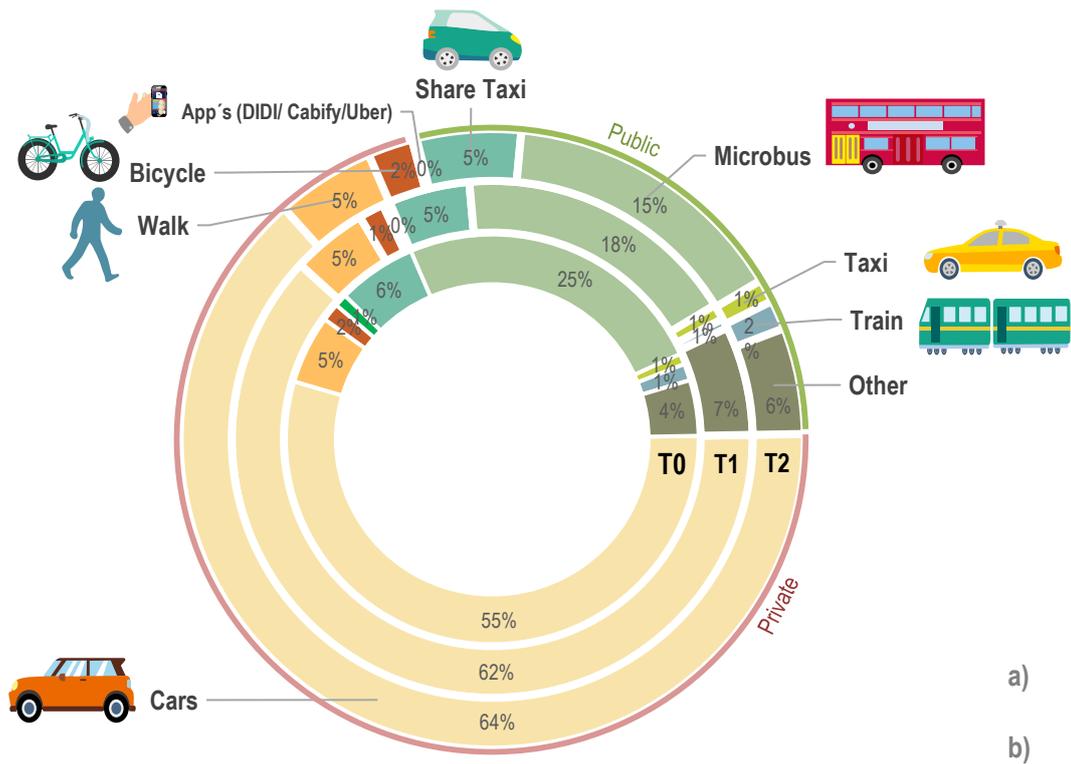


Fig. 3. Transportation modes used in the three periods evaluated
a) Transportation Modes in %. shows how, the percentage of car use in T2 exceeds the pre-pandemic values (T0) at the cost of a decrease in more sustainable transportation methods, such as bicycles, walking, or public transport.
b) **Flows of Transportation Modes.** shows the flows of workers' people mobility uses transported mode, where cars increase in T2 (Summer)

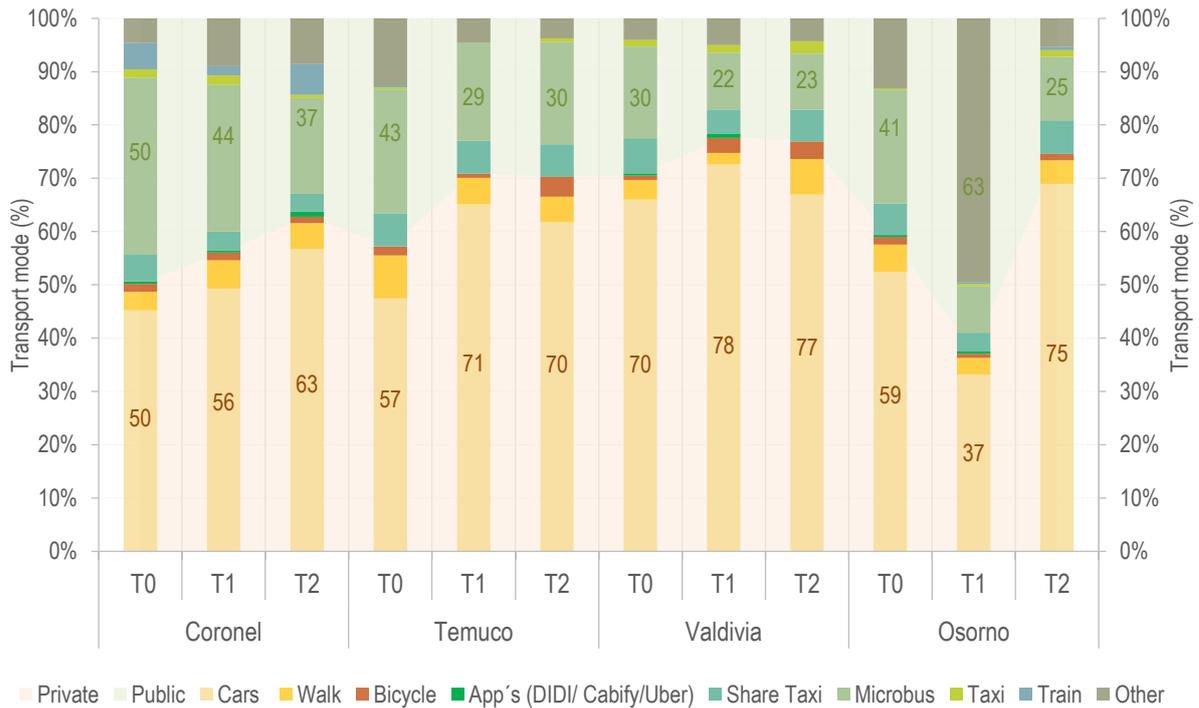


Fig. 4.
Transportation modes used by city

Figure 4 shows how, in the four cities, the percentage of car use in T2 exceeds the pre-pandemic values (T0) at the cost of a decrease in more sustainable transportation methods, such as bicycles, walking, or public transport.

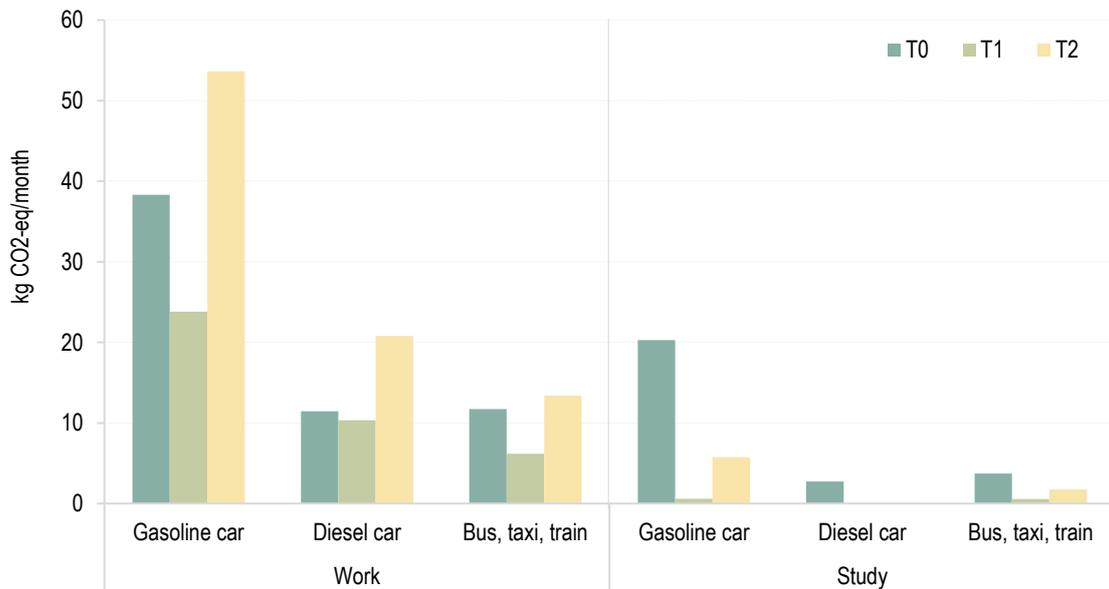


Fig. 5.
Per Capita carbon footprint from transportation. Carbon footprint for mobility (T1: average winter month 2020, T2: average summer month 2021) according to the type of transport used

Figure 5 shows, for the average worker and student, the evolution of the carbon footprint between T0 and T2 for each mode of transport. If we look at work-related mobility, we see a rebound effect in the carbon footprint of private car travel, regardless of whether the car is gasoline or diesel-powered. These results demonstrate beyond any doubt that the rebound effect is due to the increase in the percentage of trips made by car.

Results clearly show the existence of a rebound effect in the carbon footprint of work-related mobility. The existence of a possible rebound effect on the volume of emissions has also been suggested very recently by Li and Li (2021). In their study, they show how extreme events only reduce emissions in the short term. In the long term, emissions continue to grow once the extreme event stops acting, returning to a previous situation characterized by lower energy efficiency and lower energy prices.

The results obtained are consistent with the hypothesis proposed in Li and Li (2021), but with significant differences. First, we capture a rebound effect, not in the long term, but in the short term. The lower emissions due to the reduction in the number of trips are quickly neutralized due to greater use of the car. You do not have to go long term to see the rebound effect. The rebound effect is already taking place. The long-term expectations are even worse in terms of an increase in the carbon footprint, since the fear of COVID contagion and confined living conditions have led to many families to plan on leaving the city and moving to nearby rural areas, a decision that takes more time than buying a car, for instance. This increasing suburbanization would further increase the volume of emissions, given the dependence on the car that living in this type of location implies.

4. Discussion

The main result obtained in this study is to detect a “rebound effect” in the carbon footprint associated with commuting mobility due to COVID and the restrictive mobility measures adopted. With the first mobility restrictions, the carbon footprint was reduced, but in a few months, it began to grow to exceed pre-pandemic levels. This result largely coincides with that obtained in Li and Li (2021). Commuting mobility has been affected by the pandemic. In the first place, in an obvious way, the number of trips has been reduced (telecommuting increases); and second, less obviously, car use has increased. Traveling by car avoids the possibility of contagion that occurs when using public transport. In terms of carbon footprint, both elements act in opposite directions. Telecommuting reduces the carbon footprint and increased use of the car increases it. Our results indicate that the “telecommuting effect” is less than the “car use effect”, hence the rebound effect.

First, commuting mobility drops, which reduces the carbon footprint. But as these measures are relaxed and telecommuting decreases, the footprint increases due to the greater use of the car, which goes from 55% in pre-pandemic, to 64%. The increased use of the car is worrying because: a) it is the mode of transport with the largest associated footprint per km traveled; b) it is the only possible means of transport in many peri-urban areas, medium-sized cities being especially dependent on this mode of transport; and c) it entails a relevant cost (about \$ 100 per month) that is difficult to assume by the families most affected at work as a result of COVID and by the groups with less income in general. Regarding mobility for study purposes, it has followed a different pattern. Mobility restrictions have been more demanding, and the footprint falls steadily during the pandemic period studied. 97% of students stayed at home, demonstrating the effectiveness of the closure of educational centers nationwide.

In this context, it is important to plan post-pandemic cities, with a series of public policies to avoid the transport and vehicular congestion situation from having a greater impact than before the pandemic. For this reason, the Chilean cities studied urgently require reactivation of their public transport system and the prioritization of routes for more sustainable modes such as walking, cycling, and electric vehicles, including taxis, e-bikes and public transport that is less dependent on fossil fuels. Otherwise, there is a risk of accelerated motorization, whose effect on increased emissions will not be temporary but long-term and affect the country's climate goals.

4. Conclusion

The positive environmental effects of COVID-19 restrictions have not shown up as expected. The drop in the carbon footprint due to the reduction in the number of commutes for work and study purposes is less than the increase in the footprint due to greater car use in summer, such that emissions first decreased, but then increased up to levels higher than pre-pandemic values, generating a “rebound effect.” When the cities experimented total restriction of movement, they failed to fully take advantage of the chance to plan more sustainable cities for non-motorized transport methods, also supported by environmentally positive synergies between urban development, air quality, and CO₂ emissions. On the contrary, the 2,400 household surveys showed that in the summer, when cities began to recover activity, the “rebound effect” was greater, and even hit higher levels than before the pandemic due to a high dependence on cars for commuting to work and poor-quality public transportation, increasing the carbon footprint per capita. This is particularly concerning, since cities have not yet seen a reactivation of student mobility. Therefore, the post-pandemic scenario is projected to have a greater environmental impact despite the country's decarbonization efforts.

References

- Abu-Rayash, A., Dincer, I., 2020. Analysis of mobility trends during the COVID-19 coronavirus pandemic: Exploring the impacts on global aviation and travel in selected cities. *Energy Research & Social Science* 68, 101693. <https://doi.org/10.1016/j.erss.2020.101693>
- Fatmi, M., 2020. Covid-19 impact on urban mobility. *Journal of Urban Management*, 270-275. <https://doi.org/10.1016/j.jum.2020.08.002>
- Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey et al., 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Table 2.14, pp. 212. Available at: <https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf>
- Huneus, N., Urquiza A., Gayó, E., Osses, M., Arriagada, R., Valdés, M., Álamos, N., Amigo, C., Arrieta, D., Basoa, K., Billi, M., Blanco, G., Boisier, J.P., Calvo, R., Casielles, I., Castro, M., Chahuán, J., Christie, D., Cordero, L., Correa, V., Cortés, J., Fleming, Z., Gajardo, N., Gallardo, L., Gómez, L., Insunza, X., Iriarte, P., Labraña, J., Lambert, F., Muñoz, A., Opazo, M., O’Ryan, R., Osses, A., Plass, M., Rivas, M., Salinas, S., Santander, S., Seguel, R., Smith, P., Tolvett, S. 2020. El aire que respiramos: pasado, presente y futuro – Contaminación atmosférica por MP2,5 en el centro y sur de Chile. Centro de Ciencia del Clima y la Resiliencia (CR)2, (ANID/FONDAP/15110009), 102 pp. Online www.cr2.cl/contaminacion/
- IPCC (2014). Cambio climático 2014. Informe de síntesis
- Jorquera, H., Barraza, F., Heyer, J., Valdivia, G., Schiappacasse, L.N., Montoya, L.D. 2018. Indoor PM2.5 in an urban zone with heavy wood smoke pollution: The case of Temuco, Chile. *Environmental Pollution* 236, 477–487. <https://doi.org/10.1016/j.envpol.2018.01.085>
- Leger. 2020. COVID – 19 tracking survey results. Online <https://leger360.com/surveys/concerns-about-covid-19-april-21-2020/>
- Li, R., Li, S. 2021. Carbon emission post-coronavirus: Continual decline or rebound? *Structural Change and Economic Dynamics*, 57, 57-67. <https://doi.org/10.1016/j.strueco.2021.01.008>
- Liu, Z., Ciais, P., Deng, Z., et al. 2020. Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. *Nature Communication*. 2020;11:5172.<https://www.nature.com/articles/s41467-020-18922-7>

Malik, A.A., Couzens, C., Omer, S.B., 2020. COVID-19 related social distancing measures and reduction in city mobility (preprint). *Epidemiology*.

<https://doi.org/10.1101/2020.03.30.20048090>

Manzano, F. A., & Velázquez, G. Á. (2015). La evolución de las ciudades intermedias en la Argentina. *Geo Uerj*, (27), 258-282.

Muñiz, I., Rojas, C., 2019. Urban form and spatial structure as determinants of per capita greenhouse gas emissions considering possible endogeneity and compensation behaviors. *Environmental Impact Assessment Review* 76, 79–87. <https://doi.org/10.1016/j.eiar.2019.02.002>

Muñoz, J.C (2020). Movilidad con covid-19 y la oportunidad de repensar las ciudades. Santiago: Comité Científico Asesor de Cambio Climático; Ministerio de Ciencia, Tecnología, Conocimiento e Innovación. Online <https://www.minciencia.gob.cl/comitecientifico/documentos/covid-19/Movilidad-con-covid-19-y-la-oportunidad-de-repensar-las-ciudades.pdf>

Rojas, C., Muñiz, I., García-López, M. 2009. Estructura urbana y policentrismo en el Área Metropolitana de Concepción. *EURE* (Santiago) 35. <https://doi.org/10.4067/S0250-71612009000200003>

Rojas, C., Paéz, A., Barbosa, O., Carrasco, J. 2016. Accessibility to Urban Green spaces in Chilean cities using adaptive thresholds. *Journal of Transport Geography*, 57, 227-240. <https://doi.org/10.1016/j.jtrangeo.2016.10.012>

Salazar, G., Irrázaval, F., Fonck, M., 2017. Ciudades intermedias y gobiernos locales: desfases escalares en la Región de La Araucanía, Chile. *EURE* (Santiago) 43, 161–184. <https://doi.org/10.4067/s0250-71612017000300161>

United Nations (2002) World Urbanization Prospects. The 2001 revision Data Tables and Highlights. Population Division Department of Economic and Social Affairs United Nations Secretariat.

Wackernagel, M., & Rees, W. (1998). *Our ecological footprint: reducing human impact on the earth* (Vol. 9). New society publishers.

Appendix Table 1

Average emissions factor for 84 combinations of modes of transport declared in the survey

Type(s) of transport	Factores de emisión (kg de CO ₂ -eq/km)	
	Gas	Diesel
Walking	0.000	NA
Walking, Transport App (DIDI/ Cabify/Uber)	0.096	NA
Walking, Collective Taxi	0.029	NA
Walking, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.083	NA
Walking, Other	0.029	NA
Walking, Taxi	0.096	NA
Transport App (DIDI/ Cabify/Uber)	0.192	NA
Auto	0.192	0.159
Car, Walking	0.096	0.080
Car, Walking, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.110	0.102
Car, Walking, Other	0.083	0.072
Car, Transport App (DIDI/ Cabify/Uber)	0.192	0.176
Car, Bicycle	0.096	0.080
Car, Bicycle, Walking	0.064	0.053
Car, Bicycle, Taxi	0.128	0.117
Car, Bicycle, Taxi, Transport App (DIDI/ Cabify/Uber)	0.144	0.136
Car, Collective Taxi	0.125	0.108
Car, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.147	0.136
Car, Bus / Bus	0.125	0.109
Car, Bus / Bus, Walking	0.083	0.072
Car, Bus / Bus, Walking, Collective Taxi	0.077	0.069
Car, Bus / Bus, Transport App (DIDI/ Cabify/Uber)	0.147	0.136

Car, Bus / Bus, Bicycle	0.083	0.072
Car, Bus / Bus, Collective Taxi	0.103	0.092
Car, Bus / Bus, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.125	0.117
Car, Bus / Bus, Other	0.103	0.092
Car, Bus / Bus, Taxi	0.147	0.136
Car, Bus / Bus, Taxi, Transport App (DIDI/ Cabify/Uber)	0.159	0.150
Car, Bus / Bus, Taxi, Collective Taxi	0.125	0.117
Car, Bus / Bus, Taxi, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.138	0.132
Car, Bus / Bus, Train	0.090	0.079
Car, Other	0.125	0.108
Car, Taxi	0.192	0.176
Car, Taxi, Collective Taxi	0.147	0.136
Car, Train	0.106	0.090
Car, Train, Collective Taxi	0.090	0.079
Bicycle	0.000	NA
Bicycle, Walking	0.000	NA
Bicycle, Collective Taxi	0.029	NA
Bicycle, Other	0.029	NA
Bicycle, Taxi, Collective Taxi	0.083	NA
Collective Taxi	0.058	NA
Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.125	NA
Collective Taxi, Other	0.058	NA
Bus / Bus	0.058	NA
Bus / Bus, Walking	0.029	NA
Bus / Bus, Walking, Transport App (DIDI/ Cabify/Uber)	0.083	NA
Bus / Bus, Walking, Collective Taxi	0.039	NA

Bus / Bus, Walking, Taxi	0.083	NA
Bus / Bus, Walking, Taxi, Collective Taxi	0.077	NA
Bus / Bus, Transport App (DIDI/ Cabify/Uber)	0.125	NA
Bus / Bus, Transport App (DIDI/ Cabify/Uber),Other	0.103	NA
Bus / Bus, Bicycle	0.029	NA
Bus / Bus, Bicycle, Walking	0.831	NA
Bus / Bus, Bicycle, Transport App (DIDI/ Cabify/Uber)	0.083	NA
Bus / Bus, Bicycle, Collective Taxi	0.039	NA
Bus / Bus, Bicycle, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.083	NA
Bus / Bus, Collective Taxi	0.058	NA
Bus / Bus, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.103	NA
Bus / Bus, Collective Taxi, Other	0.058	NA
Bus / Bus, Other	0.058	NA
Bus / Bus, Taxi	0.125	NA
Bus / Bus, Taxi, Transport App (DIDI/ Cabify/Uber)	0.147	NA
Bus / Bus, Taxi, Collective Taxi	0.103	NA
Bus / Bus, Taxi, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.125	NA
Bus / Bus, Taxi, Collective Taxi, Other	0.091	NA
Bus / Bus, Train	0.039	NA
Bus / Bus, Train, Bicycle, Walking	0.020	NA
Bus / Bus, Train, Collective Taxi	0.045	NA
Bus / Bus, Train, Other	0.045	NA
Bus / Bus, Train, Taxi	0.090	NA
Bus / Bus, Train, Taxi, Collective Taxi	0.082	NA
None (Work from home)	0.000	NA
Other	0.058	NA

Taxi	0.192	NA
Taxi, Transport App (DIDI/ Cabify/Uber)	0.192	NA
Taxi, Collective Taxi	0.125	NA
Taxi, Collective Taxi, Transport App (DIDI/ Cabify/Uber)	0.147	NA
Train	0.020	NA
Train, Transport App (DIDI/ Cabify/Uber)	0.106	NA
Train, Collective Taxi	0.039	NA
Train, Other	0.039	NA
Train, Taxi	0.106	NA

Table Annex 2

	Coronel (Bío-Nº Bío)			Temuco / Padre Las Casas (La Araucanía)			Valdivia (Los Rios)			Osorno (Los Lagos)		
	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
0	8%	29%	20%	8%	34%	31%	9%	33%	25%	8%	31%	26%
1	43%	51%	55%	36%	42%	45%	36%	44%	51%	39%	46%	46%
2	39%	16%	23%	47%	20%	21%	44%	20%	22%	44%	19%	26%
3	7%	3%	3%	9%	3%	3%	9%	2%	2%	7%	3%	2%
4	3%	0%	0%	1%	1%	1%	1%	0%	0%	2%	1%	0%