Key Points:
- Lockdown measures in response to the new Covid-19 virus have caused the largest ever fall of annual greenhouse gas emissions
- Avoiding work travel, purchasing, and restaurants are associated with larger reductions in emissions and smaller impacts on quality of life
- These measures are promising targets for sustaining greenhouse gas emissions post-lockdown

Correspondence to:
M. Niemi,
maria.niemi@ki.se

Lockdown Measures Which Reduced Greenhouse Gas Emissions With Little Negative Impact on Quality of Life

Maria Niemi[1], **Alasdair Skelton[2]**, **Kevin Noone[3]**, and **Mats J. Olsson[4]**

[1]Department of Global Public Health, Karolinska Institutet, Stockholm, Sweden, [2]Bolin Centre for Climate Research and Department of Geological Sciences, Stockholm University, Stockholm, Sweden, [3]Bolin Centre for Climate Research and Department of Environmental Science, Stockholm University, Stockholm, Sweden, [4]Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden

Abstract Lockdown measures in response to the new Covid-19 virus have caused the largest ever fall of annual greenhouse gas emissions. A key question that we attempt to answer in this study is which, if any, of these measures can be productively encouraged post-lockdown in efforts to sustain at least part of this reduction in emissions. Sweden is uniquely suited for our study because the voluntary nature of lockdown in Sweden allowed us to assess the level of compliance to recommendations and its effects on greenhouse gas emissions. First, we assessed the change of perceived quality of life (QOL) among 746 individuals from Stockholm region due to adhering to lockdown measures. Second, we calculated the associated change of annual per capita greenhouse emissions. We found that avoiding travel for work, avoiding purchasing, and avoiding restaurants had the least negative effect on QOL, and at the same time the largest positive effect on carbon dioxide equivalent (CO_2e) emission reductions. We conclude that these are potential leverage points for stimulating behavioral change that has a positive climatic impact.

1. Introduction

Preliminary estimates (Friedlingstein et al., 2020; Le Quéré et al., 2020) indicate that the Covid-19 virus caused a 7% (3%–13% for $\pm 1\sigma$) reduction of greenhouse gas emissions in 2020. This is the largest ever annual fall in greenhouse gas emissions, surpassing the Spanish flu (1918–1920), the Great Depression (1937–1938), World War II (1939–1945), the Energy Crisis (1973), and the Financial Crisis (2008; Carbon Brief, 2020). Furthermore, it is close to the annual emissions reduction of 7.6% required to limit global warming to 1.5°C (IPCC, 2018; UNEP gap report, 2019).

Clearly, reducing greenhouse gas emissions by forced or voluntary lockdowns, such as have been seen worldwide in 2020, is not a viable long-term strategy for a societal transformation aimed at limiting global warming. However, from the 2020 lockdowns we can learn more about which (if any) emission-reducing lifestyle changes could become part of a societal transformation with minimal negative impact on other important aspects of well-being, such as quality of life (QOL). This is a concept that relates to positive and holistic aspects of well-being and health (WHO, 1998) and is a central topic for research in various disciplines including medicine, health, psychology, and environmental science (Estoque et al., 2019). Indeed, a number of the global initiatives for sustainable development (UN, 2015) and climate change mitigation (IPCC, 2014) have a central focus on the well-being and QOL impacts of these strategies. In their "QOL-Climate" assessment framework, Estoque et al. (2019) recommended that QOL can be used as a driving force for policy intervention and adaptive planning. However, in their review of previous work on the topic, they concluded that QOL assessments remain poorly connected with climate-related issues and considered this an important research gap which needs to be expanded.

In our study, we present and analyze results from a survey of perceived change to QOL associated with lifestyle changes due to lockdown measures in Stockholm, Sweden. We calculate carbon dioxide equivalent (CO_2e) emission reductions associated with each lockdown measure so as to identify lifestyle changes with minimum negative impact on QOL and maximum emission reductions. Sweden was chosen for our study for two reasons: (1) we were able to incorporate a variable degree of compliance to recommendations in our analysis because lockdown measures were voluntary; and (2) the effects of lockdown measures in Sweden can be quantified because various policies regarding reporting of environmental statistics are in place. Finally, despite the voluntary nature of lockdown measures in Sweden, reductions of CO_2e emissions in 2020

are substantial. These include an 82% reduction of air traffic, measured by the number of flights landing at Swedish airports (Swedavia, 2020), and an 8%–12% reduction of road traffic, based on congestion charges in Stockholm (Transportstyrelsen, 2020) in April and May 2020 (compared with April and May 2019). These reductions, sustained for an entire year, would equate to a 9.5–10.1-million-ton reduction in CO_2e emissions. This is more than 10% of Sweden's annual consumption-based emissions (Naturvårdsverket, 2020a).

2. Methods

In our study, we assessed both compliance to, and change of QOL resulting from lifestyle changes associated with lockdown measures in Stockholm and associated CO_2e emissions reductions. This was in order to find out whether any of the lockdown measures could be good candidates for climate change mitigation activities with low cost in terms of decreased QOL. This was an explorative study with cross-sectional design, in which our aim was to quantify associations between Covid-19 restrictions, their climate impact and QOL in a broad sample of people living in the Stockholm Region. The data collection was conducted between May 30, 2020, when the recommendations from the Public Health Agency had been in place for 2.5 months (since mid-March 2020), and June 13, 2020 after which some restrictions were gradually eased. The data collection period was carefully chosen as this was the point in time when public perception in Sweden was that restrictions would be successively lifted, that is, at the perceived end of the first wave of the pandemic.

2.1. Survey

We assessed QOL and compliance to restrictions by conducting a survey of residents in Stockholm. The first part of the survey consisted of background demographic questions with multiple choice answer alternatives, as follows: Gender (male/female/other); age (ranges 18–35; 35–45; 45–55; 55–65 and 65+ years); main occupation (working; studying; on sick leave; unemployed; on parental leave; retired and other); annual income before tax (under 100; 100–200,000; 200–300,000; 300–400,000; 400–500,000; 500–600,000; over 600,000 Swedish Krona); education level (not completed primary school; completed primary school; completed high school; completed university/college); living conditions (living alone; living with one other person; living with several other persons; other); civil status (single; partner; partner but living apart; married; other); number of children living at home (0; 1; 2; 3 or more). Also, the respondents were asked to indicate if they had, during the past half year, undergone a dramatic life event such as the death or illness of a closely related person, separation from a partner, loss of employment, or economic hardship.

This survey section was followed by the World Health Organization Quality of Life abbreviated version (WHOQOL-BREF; WHO, 1998), which has been designed by the WHO to assess health-related QOL in a cross-cultural context. The WHOQOL-BREF is a 26-item questionnaire derived from the WHOQOL-100 survey with 100 questions, that is used to assess overall QOL and considers QOL in four domains, namely, physical well-being, psychological well-being, social relationships, and environment. Each question is scored on a five-point Likert scale, and the domain scores range from 4 to 20, with higher scores indicating better QOL. In addition to collecting WHOQOL-BREF responses as baseline data, the questionnaire was used as an informative "primer," so that participants would have some knowledge about what the researchers meant, when using the term "Quality of Life" in the follow-up questions described below.

In our research survey, the WHOQOL-BREF was followed by questions assessing level of compliance with restrictions recommended by the Swedish Public Health Agency during lockdown, on a four-point Likert scale – "not compliant" "partly compliant," "mostly compliant," and "fully compliant." These restrictions concerned hand hygiene, social distancing, avoiding social gatherings and places where crowds gather, avoiding travel, and isolating oneself in one's home. Each of the compliance questions was followed by a follow-up question about how much the respondent regarded that the specific restriction had impacted their QOL – assessed on a five-point Likert scale with the following verbal anchors: "very positive," "a little positive," "no effect," "a little negative," and "very negative."

2.2. Data Collection

The survey was distributed via (1) an announcement in a newspaper which is delivered free of charge to all homes in Stockholm, (2) social media, and (3) e-mail lists of evening class students at Stockholm University, totaling 2,672 students. The survey answers were collected anonymously through an online survey constructed on the *Karolinska Institutet* secure servers, in order to safeguard participant anonymity, and participants provided written informed consent before filling in the survey. All participants provided informed consent. No ethical approval was sought, as the Swedish Act concerning the Ethical Review of Research Involving Humans (2003:460) states that studies with adults using informed consent need approval only if they use a method with the potential to physically or mentally influence a person or if they involve sensitive information that can be traced back to individual people. Due to the data having been gathered from human participants, it is exempted from being made publicly available along the lines of the FAIR data project.

2.3. Statistical Analysis

The software used for analysis was IBM SPSS version 26. Descriptive statistics were used to describe the frequency of the baseline variable categories among the participants as well as QOL measures. In order to assess the covariation between adoption of recommendations and change in QOL (ΔQOL), analysis of variance (ANOVA) analyses were conducted with ΔQOL as dependent variable. Also, we tested adding demographic background variables to a two-way-ANOVA model, including gender, age, economic status, and number of children living at home as factors, in order to assess if they carried a main effect on ΔQOL and if there was an interaction between demographic variables and recommendation adoption (termed "compliance" hereafter) on ΔQOL. Nominal alpha levels were set at 0.05%.

2.4. CO_2e Emissions

2.4.1. Data

For each of the restrictions recommended by the Swedish Health Authority during lockdown (apart from isolating oneself in one's home, as we are not able to estimate the change in emissions from this recommendation based on any available data), we estimated change of emissions in kg-CO_2e/year, mostly using data provided by Statistics Sweden for environmental pressure from household consumption expenditure categorized according to the United Nations Classification of Individual Consumption According to Purpose (COICOP; Statistics Sweden: Environmental pressure from household consumption expenditure by purpose COICOP and substance. Year 2008–2017).

2.4.2. CO_2 Emission Estimates

Instead of calculating only a single value for each emissions category, we used a Monte Carlo simulation approach to try to assess the degree of variability we could expect in the results for CO_2e emissions. With this approach, each variable parameter in a calculation is randomly perturbed around its central value, and then used to calculate the quantity of interest. Since, in general, we do not know the probability density functions of all of the variables included in the calculations, we assume a uniform distribution for the parameters and perturb each one by ±20% around its central value. We used 1,000 iterations for all calculations.

3. Results

Altogether 746 individuals filled in the online survey. Due to the forms of distribution, we were not able to collect information about how many people saw the newspaper adverts or social media announcements and are thus not able to provide data on response and rejection rates. However, the number of students that the survey was e-mailed to was 2,672, and with 44 responses from students, this amounts to a response rate of 2% among that specific group of participants. The socio-demographic background variables of the participants are presented in Table 1. The age of the participants ranged from 18 years to 65 and above, the majority of the participants were female (83%) and had completed university or college education (77.2%). Also, the majority did not have children who were living at home with them (70.4%), and most of the participants were currently working (52%). Our sample, therefore, represents a broad range of ages, but is

Table 1
Socio-Demographic Background Variables of Participants

Variable	N	%	Variable	N	%
Gender			Education level		
Female	619	83.0%	Not completed primary school	1	0.1%
Male	125	16.8%	Completed primary school	11	1.5%
Unspecified	2	0.3%	High school	158	21.2%
Age			University/college	576	77.2%
18–30	130	17.4%	Living conditions		
30–45	171	22.9%	Living alone	242	32.4%
45–55	134	18.0%	Living with one other person	271	36.3%
55–65	127	17.0%	Living with several other persons	220	29.5%
65 +	184	24.7%	Other	13	1.7%
Main occupation			Civil status		
Work	388	52%	Single	251	33.6%
Study	119	16%	Partner	136	18.2%
Sick leave	12	1.6%	Partner but living apart	51	6.8%
Unemployed	15	2.0%	Married	271	36.3%
Parental leave	8	1.1%	Other	37	5%
Retired	189	25.3%	Number of children living at home		
Other	15	2.0%	0	525	70.4%
Annual income before tax			1	83	11.1%
Under 100,000 Sek	106	14.2%	2	107	14.3%
100–200,000 Sek	99	13.3%	3 or more	31	4.3%
200–300,000 Sek	117	15.7%	Dramatic event past half year		
300–400,00 Sek	122	16.4%	Yes	191	25.6%
400–500,000 Sek	97	13.0%	No	555	74.4%
500–600,000 Sek	99	13.3%	QOL-BREF score	(mean)	(SD)
Over 600,000 Sek	106	14.2%	Physical domain	15.1	3.0
			Psychological domain	14.2	2.7
			Social domain	14.0	3.0
			Environment domain	15.4	2.4

Abbreviation: QOL-BREF, Quality of Life abbreviated version.

over-represented by females and highly educated persons. The WHOQOL-BREF scores of the participants (see Table 1), are quite similar to those found in international general population samples (Skevington et al., 2004).

3.1. Quality of Life (QOL)

The impact on QOL of the restrictions recommended by the Swedish Health Authority during lockdown is shown in Figure 1. Each point on the five-point Likert scale used for this assessment was assigned a value for change in QOL (ΔQOL) as follows: "very negative" = 1; "a little negative" = 2; "neutral" = 3; "a little positive" = 4, and "very positive" = 5. These values were used to calculate mean values and 95% confidence intervals (CI). Results are listed in Table 2. For the category, "avoiding places where crowds gather," we also assessed what alternatives were chosen. These are shown in Figure 2. Mean values indicate that recommendations concerning hand hygiene, avoiding shops, and restaurants as well as avoiding travel for work had,
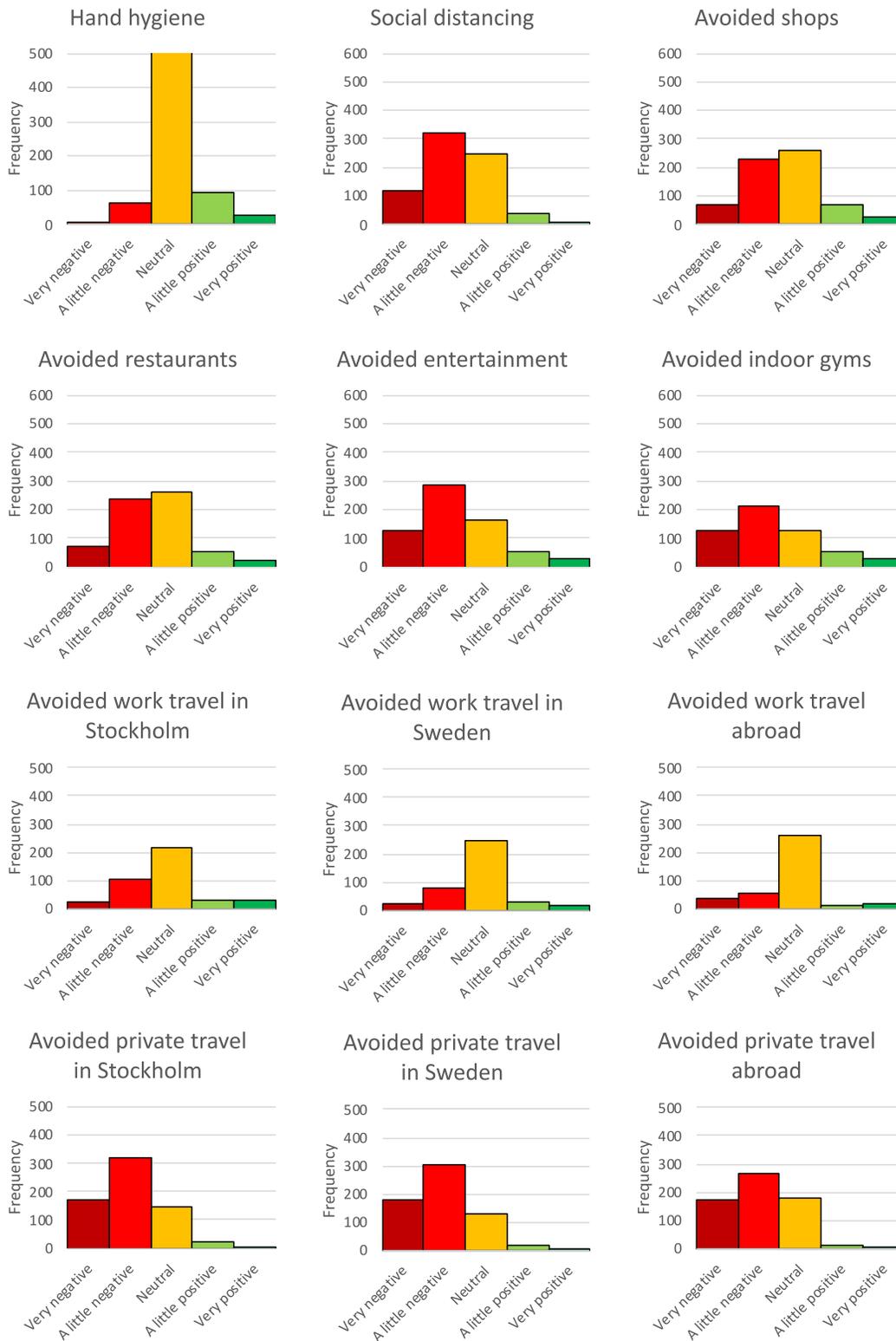
Figure 1. QOL change in response to recommendation from Swedish Health Authority. QOL, Quality of Life.

Table 2
Change of Quality of Life, Compliance to, and Change of per Capita Emissions Associated With Lockdown Measures in Sweden

Recommendation by Swedish Health Authority				N	ΔQOL	$\Sigma k/N$	Dependency of ΔQOL on k	ΔCO_2e for $k = 1$ kg-CO_2e/ (person × year)	Φ
Hand hygiene				731	3.11 (95% CI: 3.06, 3.15)	0.88		+4.0 (95% CI: 2.55, 5.96)	0.00
Social distancing				733	2.31 (95% CI: 2.25, 2.37)	0.75		0	0.00
Avoiding places were people crowd together	Shops			654	2.64 (95% CI: 2.57, 2.71)	0.62	$F_{(2.643)} = 11.8$, $p = 0.000$	−235 (95% CI: 175, 303)	0.15
	Restaurants			642	2.55 (95% CI: 2.48, 2.62)	0.77	$F_{(2.626)} = 0.68$, $p = 0.506$	−147 (95% CI: 94, 209)	0.10
	Entertainment			655	2.35 (95% CI: 2.27, 2.43)	0.95	$F_{(2.636)} = 4.86$, $p = 0.008$	−10 (95% CI: 7.2, 12.7)	0.01
	Gyms			552	2.34 (95% CI: 2.25, 2.43)	0.80	$F_{(2.490)} = 2.89$, $p = 0.056$	−29 (95% CI: 21.3, 36.9)	0.02
Avoided travel	Stockholm	Work		408	2.82 (95% CI: 2.73, 2.91)	0.71	$F_{(2.311)} = 1.60$, $p = 0.203$	−221 (95% CI: 163.5, 281.2)	0.21
		Private		673	2.06 (95% CI: 1.99, 2.12)	0.77	$F_{(2.656)} = 7.20$, $p = 0.001$	−318 (95% CI: 226.4, 444.7)	0.02
	Sweden	Work		393	2.83 (95% CI: 2.75, 2.91)	0.80	$F_{(2.210)} = 2.35$, $p = 0.098$	−121 (95% CI: 87.4, 158.1)	0.13
		Private		637	2.01 (95% CI: 1.95, 2.08)	0.85	$F_{(2.609)} = 6.06$, $p = 0.002$	−120 (95% CI: 86.3, 158.3)	0.00
	Abroad	Work		370	2.78 (95% CI: 2.7, 2.87)	0.81	$F_{(2.166)} = 1.28$, $p = 0.280$	−119 (95% CI: 86.2, 159.0)	0.12
		Private		634	2.08 (95% CI: 2.01, 2.14)	0.95	$F_{(2.606)} = 0.25$, $p = 0.780$	−579 (95% CI: 438.6, 730.4)	0.06

The abbreviations used in this table are as follows: N = number of respondents; ΔQOL = perceived change of quality of life; k = compliance; $\Sigma k/N$ is an overall compliance factor given by the sum of compliance values, k, divided by the number of respondents, N; ΔCO_2e = per capita change of annual CO_2e emissions; Φ = semi-quantitative factor given by the product of normalized change of quality of life, normalized change of emissions and compliance factor, $\Sigma k/N$; and CI = confidence interval.

on average, negligible effect on QOL ($2.5 < \Delta QOL < 3.5$), whereas recommendations concerning social distancing, avoiding entertainment and gyms as well as avoiding travel for private reasons had, on average, a negative effect on QOL ($\Delta QOL < 2.5$).
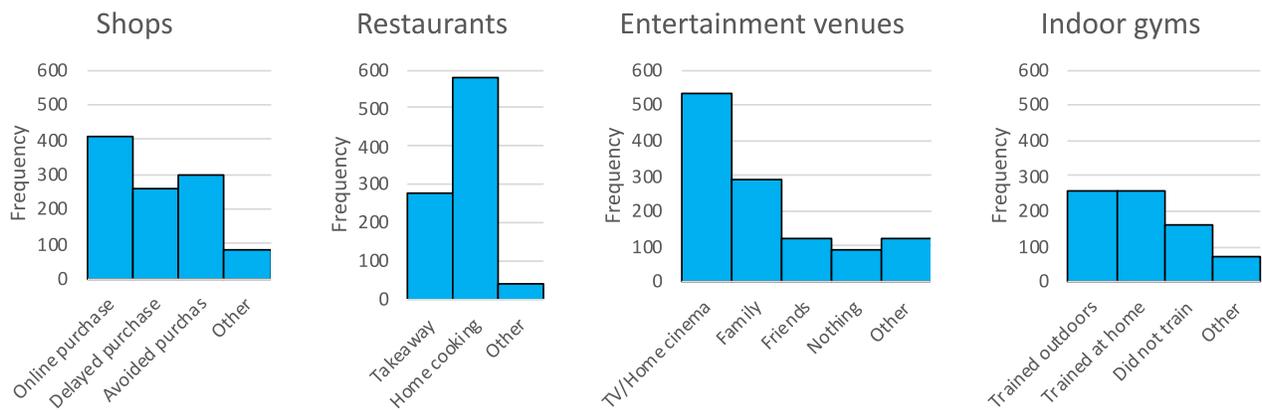

Figure 2. Alternatives chosen when "avoiding places where crowds gather.".
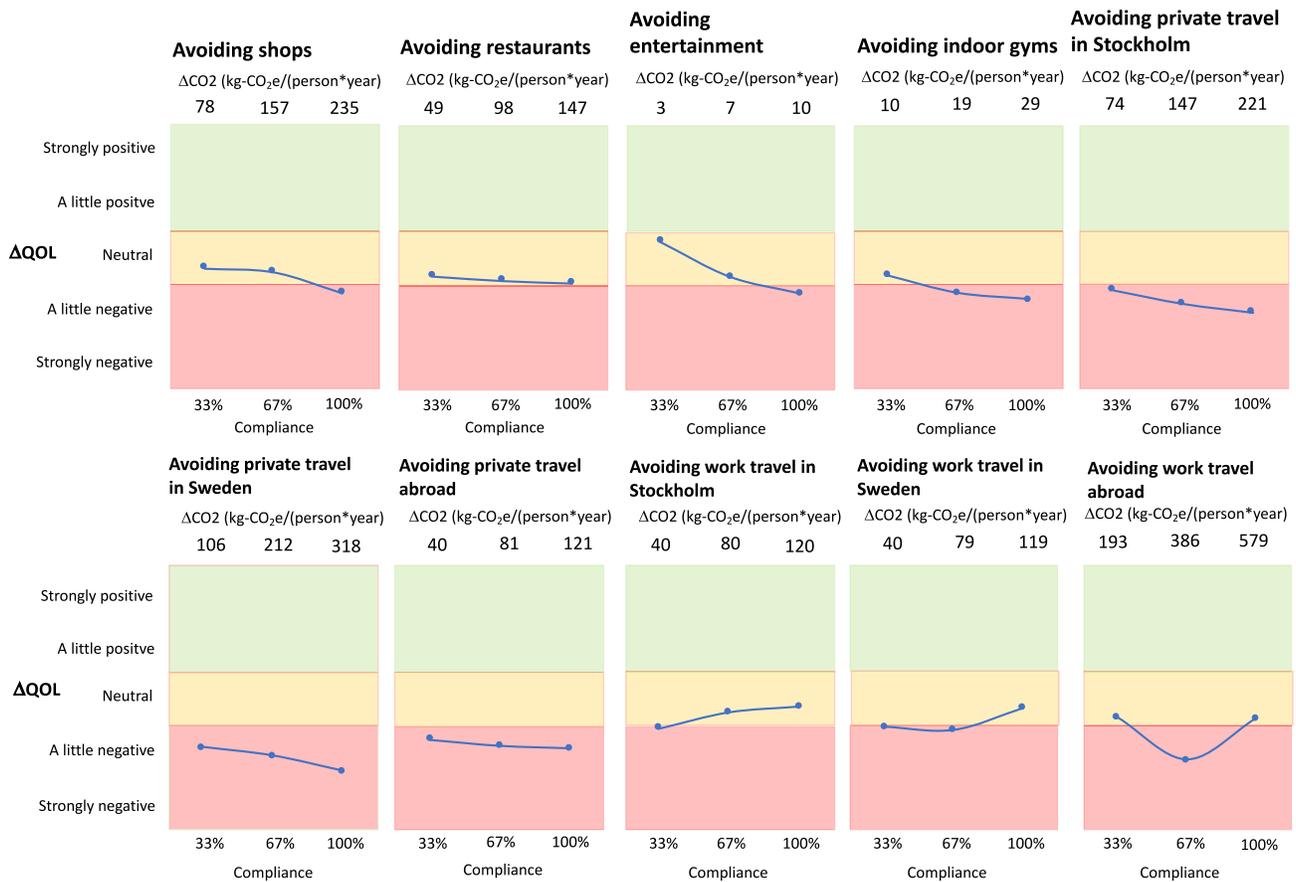
Figure 3. Relationship between QOL and compliance. QOL, Quality of Life.
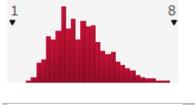
3.1.1. Compliance

Each point on the four-point Likert scale used to assess compliance was assigned a value (k) for compliancy as follows: "not compliant" = 0, "partly compliant" = ⅓, "mostly compliant" = ⅔, and "fully compliant" = 1. These values were summed and divided by the number of respondents, N, to calculate a semi-quantitative factor for overall compliance, $\Sigma k/N$, for each of the recommendations made by the Swedish Health Authority (Table 2).

Plots of ΔQOL as a function of compliance for each recommendation (Figure 3) reveal an overall tendency for higher levels of compliance to be associated with more negative effects on QOL. This is valid for all categories except for recommendations concerning avoiding travel for work, for which higher levels of compliance are associated with less negative effects on QOL.

A one-way ANOVA for each category, performed assuming equidistance between verbal anchors on ΔQOL (Table 2), revealed statistically significant differences in mean ΔQOL between different levels of compliance for recommendations concerning avoiding shopping (F (2.643) = 11.82, p = 0.000); avoiding entertainment (F (2.636) = 4.86, p = 0.008); avoiding private travel within Stockholm (F (2.656) = 7.20, p = 0.001); avoiding private travel within Sweden (F (2.609) = 6.06, p = 0.002); and isolating oneself in one's home (F (2.329) = 14.26, p = 0.000). There were no statistically significant differences in mean ΔQOL between different compliance levels for any other categories.

When adding the demographic background variables: Age, gender, income, and number of children to form two-way ANOVA analyses, including the three levels of compliance the following results emerged: Age had a significant main effect on ΔQOL when combined with the compliance levels for social distancing (F (4) = 3.504; p = 0.008), avoiding shopping (F (4) = 11.816; p = 0.000), avoiding work travel in Stockholm (F

Table 3
Probability Density Function for Annual CO₂e emissions

Category	Graph	Mean (kg CO$_2$e/year)	5%	95%
Hand hygiene		4	3	6
Avoided shops		235	175	303
Avoided restaurants		147	94	209
Avoided entertainment		10	7	13
Avoided indoor gyms		29	21	37
Work trips Stockholm		221	169	288
Private trips Stockholm		318	226	445
Work trips abroad		119	86.2	159.0
Private trips Sweden		120	86.3	158.3
Private trips abroad		579	438.6	730.4
Work trips Sweden		121	87.4	158.1

(4) = 2.583, $p = 0.037$), and avoiding work travel abroad (F (4) = 2.964; $p = 0.02$). Income, on the other hand, had a significant main effect when combined with avoiding work travel abroad (F (6) = 2.246; $p = 0.039$). Finally, the number of children in the household had a significant interaction effect on ΔQOL, when combined with compliance levels of avoiding work travel abroad (F (7) = 2.099; $p = 0.043$). There was, however, no significant main effect of the number of children on ΔQOL in itself. None of the other demographic background variables, including gender, had any significant main or interaction effect on ΔQOL.

3.2. CO$_2$e Emissions

Per capita impact on annual CO$_2$e emissions for each lifestyle change brought about by the restrictions recommended by the Swedish Health Authority and assuming full compliance ($k = 1$) are listed in Table 2 and presented in this section.

3.2.1. Hand Hygiene

The Swedish Health Authority recommended "regular" hand washing using warm water for 30 s. Given usage of 2 L of warm tap water per hand wash, usage of 0.037 kWh per L to heat tap water from 6° to 38°C, an estimate of 6–10 hand washes per day and that biofuel used to heat water in Stockholm releases 18 g-CO_2e/kWh (IPCC, 2015), we calculate an annual emissions increase of 4.0 (95% CI: 2.55, 5.96) kg CO_2e/(person × year) coupled with hand hygiene (Table 3).

3.2.2. Social Distancing

The Swedish Health Authority recommended social distancing by at least 2 m whenever possible. We assumed that no emissions increase or decrease is caused directly by social distancing.

3.2.3. Avoiding Places Where Crowds Gather

The Swedish Health Authority recommended avoiding places where crowds gather. They specifically named shops, restaurants, indoor gyms, and entertainment venues (e.g., theaters and cinemas).

3.2.3.1. Avoiding Shops

Given consumption based emissions of 838 kg-CO_2e/(person × year) for COICOP categories 03 – "Clothing and shoes," 05 – "Furnishings, household equipment, and routine maintenance" and 09 – "Recreation and culture" (omitting categories 0941 – "Sport and recreation services" and 0942 – "Cultural services"; Statistics Sweden, 2020) and that 28% of 654 persons who avoided shops during lockdown did not make the intended purchase (Figure 2), we calculate an annual emissions decrease of 235 (95% CI: 175, 303) kg CO_2e/(person × year) for avoided purchases (Table 3).

3.2.3.2. Avoided Restaurants

Given consumption based emissions of 1,151 kg-CO_2e/(person × year) for COICOP category 01 – "Food and drink" and 254 kg-CO_2e/(person × year) for COICOP category 1111 – "Restaurants and cafés" (Statistics Sweden, 2020), an average frequency for eating out of 5–10 times per month (Raneblad, 2015), and that 64% of 642 persons who avoided restaurants during lockdown cooked food at home rather than ordering takeaway (Figure 2), we calculated an annual emissions decrease of 147 (95% CI: 94, 209) kg CO_2e/(person × year) for avoided restaurant visits (Table 3).

3.2.3.3. Avoided Entertainment Venues

Given consumption-based emissions of 27 kg-CO_2e/(person × year) for COICOP category 0942 – "Cultural services" which includes television (Statistics Sweden, 2020) and that 36% of 655 persons who avoided entertainment venues during lockdown spent time with families instead (Figure 2), we calculate an emissions decrease of 10 (95% CI: 7.2, 12.7) kg CO_2e/(person × year) for avoided entertainment (Table 3).

3.2.3.4. Avoided Indoor Gyms

Given consumption-based emissions of 42 kg-CO_2e/(person × year) for COICOP category 0941 – "Sport and recreation services" and that 68% of 552 persons who avoided indoor gyms during lockdown trained at home or outdoors instead (Figure 2), we calculate an emissions decrease of 29 (95% CI: 21.3, 36.9) kg CO_2e/(person × year) for avoided use of indoor gyms (Table 3).

3.2.4. Avoided Travel

The Swedish Health Authority recommended avoiding unnecessary travel for work or pleasure within Stockholm, Sweden and abroad at different times during lockdown. Alternatives, such as working from home and online meetings were recommended. In our study, we consider travel for work and pleasure separately.

3.2.4.1. Avoided Travel in Stockholm

Given consumption-based emissions for COICOP category 0735 – "public transport" of 79 kg-CO_2e/(person × year) and consumption-based emissions of 950 kg-CO2e/(person × year) for commuting by car in Stockholm (based on emissions of 3.8 kg-CO_2e for a representative commuting distance of 18.5 km and

250 working days per year: Ecopassenger 2020; Trafikförvalningen, 2015) and that, of persons who avoided traveling in Stockholm, 51% would have traveled by public transport, and 19% would have traveled by car, we calculate an emissions decrease of 221 (95% CI: 163.5, 281.2) kg-CO_2e/(person × year) for avoided work trips in Stockholm (Table 3). Given that 41% of trips in Stockholm are for work and 59% are for pleasure (Trafikförvalningen, 2015), we calculate an emissions decrease of 318 (95% CI: 226.4, 444.7) kg-CO_2e/(person × year) for avoided private trips in Stockholm (Table 3).

3.2.4.2. Avoided Travel in Sweden

Given consumption-based emissions of 274.6, 111.6, and 2.4 kg-CO_2e for a representative trip length in Sweden of 470 km (Stockholm to Gothenburg) by plane, car, and train (or bus), respectively (Ecopassenger, 2020), an average of 0.37 domestic flights per person in Sweden (Naturvårdsverket, 2020b), and that for work trips in Sweden, 50% are by car, 15% are by plane, and 35% are by train or bus (Trafikanalys, 2019), we calculate an emissions decrease of 121 (95% CI: 87.4, 158.1) kg-CO_2e/(person × year) for avoided work trips in Sweden (Table 3). Given that 50% of trips in Sweden are for work and 50% are for pleasure (Trafikförvalningen, 2015) and that, for private trips in Sweden, 67% are by car, 20% are by plane, and 13% are by train or bus (Trafikanalys, 2019), we calculate an emissions decrease of 120 (95% CI: 86.3, 158.3) kg-CO_2e/(person × year) for avoided private trips in Sweden (Table 3).

3.2.4.3. Avoided Travel Abroad

Given consumption-based emissions of 647, 482.2, and 80.2 kg-CO_2e for a representative trip length abroad of 2,700 km (Stockholm to Madrid; Kamb and Larsson, 2018) by plane, car, and train (or bus), respectively (Ecopassenger 2020), an average of 1.01 international flights per person in Sweden (Naturvårdsverket, 2020b) and that for international travel from Sweden, 22% is by car, 71% is by plane, and 7% is by train or bus (Resebarometern 2019), we calculate an emissions decrease of 698 kg-CO_2e/person/year for avoided travel abroad of which 119 (95% CI: 86.2, 159.0) kg-CO_2e/(person × year; 17%; Tillväxtverket, 2017) is for avoided work trips abroad and 579 (95% CI: 438.6, 730.4) kg-CO_2e/(person × year; 83%; Tillväxtverket, 2017) for avoided private trips abroad (Table 3).

3.2.5. Additional Sources of Error

In addition to the error ranges obtained from our Monte Carlo simulations, other sources of error that cannot be ruled out include: (1) longevity of an action which reduced emissions, for example, if a person who avoided making a purchase during lockdown made that purchase immediately after lockdown restrictions were eased; and (2) coupled emissions reductions or gains, for example, differences between home and office energy consumption associated with working from home. These sources of error are probably minor, but should nevertheless be kept in mind when viewing our results.

3.3. QOL and CO_2e Emissions

In this section, we identify lifestyle changes which had the least negative effect on perceived QOL and also caused a substantial reduction of per capita annual CO_2e emissions. We do so by defining and calculating a semi-quantitative factor, Φ, which is the product of normalized observed ΔQOL relative to minimum (ΔQOL_{min}) and maximum (ΔQOL_{max}) values, normalized calculated change of emissions (ΔCO_2e) relative to minimum (ΔCO_2e_{min}) and maximum (ΔCO_2e_{max}) values, and overall compliance ($\Sigma k/N$) for the categories in our study:

$$\Phi = \left(\frac{\Delta QOL - \Delta QOL_{min}}{\Delta QOL_{max} - \Delta QOL_{min}} \right) \cdot \left[1 - \left(\frac{\Delta CO_2e - \Delta CO_2e_{min}}{\Delta CO_2e_{max} - \Delta CO_2e_{min}} \right) \right] \cdot \frac{\Sigma k}{N} \qquad (1)$$

Higher values of Φ identify lifestyle changes which had a less negative effect on perceived QOL and at the same time caused a substantial reduction of per capita annual CO_2e emissions. Lower values of Φ identify lifestyle changes which had a large negative effect on perceived QOL and/or little effect on annual CO_2e

Table 4
Activities With Φ Values 0.1 or Greater

Activity	Φ
Avoided work travel Stockholm	0.21
Avoided shops	0.15
Avoided work travel Sweden	0.13
Avoided work travel abroad	0.12
Avoided restaurants	0.1

emissions. Using Φ, we will identify behavioral changes that have the potential for substantial positive climate impact.

3.3.1. Social Distancing and Hand Hygiene

Social distancing had a negative effect on perceived QOL for 60% of 733 respondents and negligible effect on per capita annual CO_2e emissions. Hand hygiene recommendations had a negative effect on QOL for only 9% of 731 respondents. However, hand hygiene was associated with an increase of per capita annual CO_2e emissions. For these reasons, Φ values are close to zero and neither social distancing nor hand hygiene will be considered further in terms of climate impact.

3.3.2. Avoiding Places Where Crowds Gather

The Swedish Health Authority specified four actions for "avoiding places where crowds gather." These were to avoid shops, restaurants, entertainment venues, and indoor gyms. Of these actions, avoiding shops, and restaurants had a negative effect on perceived QOL for fewer respondents (45% of 654 respondents and 48% of 642 respondents, respectively) than avoiding entertainment venues and indoor gyms (63% of 655 respondents and 62% of 552 respondents, respectively). Also, avoiding shops and restaurants had larger impacts on per capita annual CO_2e emissions (235 and 147 kg-CO_2e/[person $\times$ year], respectively) than avoiding entertainment venues and indoor gyms (10 and 29 kg-CO_2e/(person $\times$ year), respectively). The substantial impacts of avoiding shops and restaurants on per capita annual CO_2e emissions arose because 28% of respondents who avoided shops opted to purchase fewer items (rather than waiting or buying items online), and 64% of respondents who avoided restaurants cooked food at home (rather than purchasing takeaway food). For these reasons, Φ values were comparatively high for avoiding shops and restaurants (0.15 and 0.10, respectively) and close to 0 for avoiding entertainment venues and indoor gyms.

3.3.3. Avoided Travel

The Swedish Health Authority recommended avoiding unnecessary travel within Stockholm, within Sweden, and to other countries. In general, avoided travel for work had a negative effect on perceived QOL for fewer respondents (24%–33%) than avoided travel for private reasons (69%–76%). Although the effects of travel restrictions within Stockholm, within Sweden, and to other countries had fairly similar effects on perceived QOL, impacts on per capita annual CO_2e emissions differed considerably. Avoided travel abroad had most impact on per capita annual CO_2e emissions because this travel option is most often (71%) by air. However, most of this impact (83%) was from avoided private travel which had a strongly negative effect on perceived QOL. Mainly because of its volume, avoided travel in Stockholm had a larger effect compared with avoided travel in Sweden on per capita annual CO_2e emissions. For these reasons, Φ values were highest for avoided travel for work within Stockholm (0.21) and considerable for avoided travel for work within Sweden and abroad (0.13 and 0.12, respectively).

3.3.4. Effective Activities at a Low Cost in QOL

The activities having Φ values 0.1 or greater are listed in Table 4. These represent the activities that had the least negative effect on QOL and at the same time the largest positive effect on CO_2e emission reductions.

4. Conclusions

In our study, we aimed to investigate possible win-win opportunities for climate change mitigation without negative impact on QOL: In the context of planning and policy, QOL assessment can help diagnose which actions need to be prioritized (Estoque et al., 2019).

We identify the activities that had the least negative effect on QOL and at the same time the largest positive effect on CO_2e emission reductions as potential leverage points for stimulating behavioral change that has a positive climatic impact. Avoiding travel for work is clearly the lowest hanging fruit from a climate and QOL perspective. Decreased consumption seems also to be a potential win-win category. These conclusions are further illustrated in the figures where the compliance levels for each restriction are plotted against the estimated change in CO_2 emissions (Figure 3).

Our results indicate that avoiding travel for work ($\Phi = 0.12$–0.21), avoiding shops ($\Phi = 0.15$) and avoiding restaurants ($\Phi = 0.10$) are actions which had a negative effect on perceived QOL for less than half (24%–33%, 45%, and 48%, respectively) of the respondents to our questionnaire. We therefore identify these actions as high impact targets for campaigns aimed at encouraging actions to reduce CO_2e emissions after lockdown. We further note that higher levels of compliance were associated with less negative effects on QOL for travel for work, pointing to this action as an especially promising target for such campaigns. Also, taking into consideration that the lockdown measure of isolating oneself in one's home had a significant negative impact on QOL (F (2.329) = 14.26, $p = 0.000$), it is not possible to clearly delineate the exact impacts of each lockdown measure on QOL separately – there is bound to be some mediating effects between them. For example, the perceived negative QOL impact of reduced private travel is probably further impacted by the overall sense of isolation. It is thus possible that some of the restrictions assessed in this study would in and of themselves not have the same level of negative impact on QOL, if they were adhered to in a different situation which does not also involve social isolation and seclusion. Finally, we note that during the lock-downs, societal transformations have happened at an unprecedented pace, motivated by the need to protect an older generation from severe illness due to Covid-19; we note that when motivated, societal transformations *can* happen; and we also note that even post-Covid-19, societal transformations remain vital, motivated by the need to protect a younger generation from severe effects of climate change.

Data Availability Statement

Due to the data having been gathered from human participants, it is exempted from being made publicly available along the lines of the FAIR data project.

References

Carbon Brief. (2020). Retrieved from https://www.carbonbrief.org/analysis-coronavirus-set-to-cause-largest-ever-annual-fall-in-co2-emissions

Ecopassenger. (2020). Retrieved from http://www.ecopassenger.org/

Estoque, R. C., Togawa, T., Ooba, M., Gomi, K., Nakamura, S., Hijioka, Y., & Kameyama, Y. (2019). A review of quality of life (QOL) assessments and indicators: Toward a "QOL-Climate" assessment framework. *Ambio*, *48*(6), 619–638. https://doi.org/10.1007/s13280-018-1090-3

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., et al. (2020). Global Carbon Budget 2020. *Earth System Science Data*, *12*, 3269–3340. https://doi.org/10.5194/essd-12-3269-2020

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC.

IPCC. (2015). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Vol. 1, pp. 335). Cambridge University Press.

IPCC. (2018). In V. Masson-Delmotte, et al. (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. IPCC.

Kamb, A., and Larsson, J. (2018). *Klimatpåverkan från svenska befolkningens flygresor 1990–2017* (pp. 33). Chalmers.

Le Quéré, C., Jackson, R. B., Jones, M. W., Smithau, A. J. P., Abernethyau, S., Andrewau, R. M., et al. (2020). Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, *10*, 647–653. https://doi.org/10.1038/s41558-020-0797-x

Naturvårdsverket. (2020a). Retrieved from http://www.naturvardsverket.se//klimatutslapp

Naturvårdsverket. (2020b). Retrieved from https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Flygresor-per-person

Raneblad, E. (2015). *Restaurangvanor hos vuxna i Sverige – En enkätstudie*. Unpublished BSc thesis (pp. 24). Umeå University.

Resebarometern (2019). Retrieved from https://www.erv.se/privat/reseinformation/resebarometern/

Skevington, S. M., Lotfy, M., O'Connell, K. A., & Group, W. (2004). The World Health Organization's WHOQOL-BREF quality of life assessment: Psychometric properties and results of the international field trial. A report from the WHOQOL group. *Quality of Life Research*, *13*(2), 299–310. https://doi.org/10.1023/B:QURE.0000018486.91360.00

Statistics Sweden. (2020) *Miljöpåverkan från hushållens konsumtion efter ändamål COICOP och ämne. År 2008–2017*. SCB [2020-04-06]. Retrieved from https://www.scb.se/mi1301/

Swedavia. (2020). Retreived from https://www.swedavia.se/om-swedavia/statistik/

Tillväxtverket. (2017) *Tillväxtverket*. Retrieved from https://tillvaxtverket.se/statistik.html

Trafikanalys. (2019) *Resvanor i Sverige. Rapport 2020-05-27. Trafikanalys*. Retrieved from https://www.trafa.se/

Trafikförvalningen. (2015). *Resvanor i Stockholms län. Rapport 2016-04-19. Version 1.1. Trafikförvalningen, Stockholms läns landsting* (pp. 81).

Transportsyrelsen. (2020). Retrieved from https://www.transportsyrelsen.se/sv/vagtrafik/statistik/trangselskatt11/stockholm/

UN. (2015). *Transforming our world: The 2030 agenda for sustainable development*. Retrieved from un.org

UNEP gap report. (2019). Retrieved from https://www.unenvironment.org/resources/emissions-gap-report-2019

WHO. (1998). *WHOQOL User Manual*. World Health Organization.