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Did COVID-19 really change our lifestyles? Evidence from transport energy consumption in Europe

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ABSTRACT

The COVID-19 pandemic triggered substantial societal shifts and reductions in energy consumption, influenced both by the virus itself and the governmental policies implemented to curb its spread. With the end of the pandemic, it is crucial to assess whether enduring behavioural changes have occurred as they may play a vital role in achieving Paris Agreement targets. This paper examines energy consumption patterns in the European transport sector during and after the pandemic and evaluates the role of containment policies. Using quantile regression analysis, we quantify the effect of these policies on transport fuel consumption, with the Gradient Boosting Machines algorithm ranking their importance. Our results reveal significant reductions in motorised land transport and aviation use during the pandemic followed by distinct recovery patterns, with the former recovering faster than the latter. The COVID-19 policies that exerted the most influence on transport use were "school closures," "cancelling of public events," and "international travel controls." Diverse recovery patterns were observed among countries. While many countries swiftly rebounded to normality, lasting behavioural changes were seen in Sweden, Czechia, and Denmark. These countries offer valuable policy lessons for transitioning to a sustainable transport sector.

1. Introduction

Constituting more than two-thirds of global greenhouse gas (GHG) emissions, reducing energy consumption is one of the most important aspects of climate change mitigation (Gütschow et al., 2021). In particular, there is a need for urgent action in the transport sector. In 2021, the transport sector had the greatest dependence on fossil fuels compared to any other industry and was responsible for 37% of the CO_2 emissions produced by end-use sectors (IEA, 2023a). Transforming the transport sector is therefore key to meeting countries' Paris Agreement targets, including the EU and UK's commitments to reach net-zero emissions by 2050.

Transitioning to a low-carbon transport sector will likely involve widespread adoption of electric vehicles and biofuels. The extensive effort necessary to electrify the vehicle fleet and transform the infrastructure presents greater challenges for the transport sector compared to others, with aviation presenting a particularly demanding challenge. Additionally, there are wider sustainability concerns associated with biofuels, including land use competition, potential adverse effects on food security, and the need to address GHG emissions and resource intensity in their production processes (Nazari et al., 2021). Consequently, behavioural change may be essential in the transport sector.

The COVID-19 pandemic and the government actions taken to contain its spread caused significant disruption across the economy, especially in travel, tourism, entertainment, and education. This involuntary economic shutdown resulted in a significant fall in energy consumption and a 17% reduction in daily CO_2 emissions by early April 2020 compared to 2019 (Le Quéré et al., 2020). However, a sharp rebound in emissions occurred in 2021 as widely predicted (Forster et al., 2020; Le Quéré et al., 2020; Liu et al., 2020).

Pandemic containment strategies, often involving stay-at-home orders, travel restrictions, and the shutdown of public transport, led to reduced emissions from commuting and leisure travel. The COVID-19 disruption of established travel behaviours presents a unique opportunity to explore and encourage lasting, sustainable travel changes. Evidence suggests that individuals are open to reducing their travel use in

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the long term – UK survey data suggested a desire for voluntary reductions of 20–26% in air travel and 24–30% in car use after the pandemic (O'Garra and Fouquet, 2022).

In 2022, the EU eased most COVID-19-related restrictions by 2023 they had been lifted altogether. The end of the pandemic can arguably be marked as May 2023 when the World Health Organization declared that COVID-19 no longer represented a public health emergency of international concern (World Health Organization, 2023). Nevertheless, it remains uncertain whether the reductions in transport use observed during the pandemic have influenced behaviour or will have a lasting effect as people resume their regular routines.

To clarify this issue, we structure our research into three main stages. First, we analyse variations in transport energy consumption across European countries and between different transport modalities, namely, motorised land transport[1] and aviation. By employing descriptive statistics and data visualisation techniques, we explore the evolution of transport fuel consumption in Europe during and after the COVID-19 pandemic.

Second, we investigate whether a relationship exists between the stringency of COVID-19 confinement policies and transport use in Europe. Here, we quantify the effect individual COVID-19 policies had on transport fuel consumption through quantile regression analysis, with the Gradient Boosting Machines algorithm ranking their importance.

Finally, we analyse whether a lasting behavioural shift persisted in Europe after restrictions were lifted. To achieve this, we compare expected fuel consumption with actual consumption during the period when restrictions were eased. Additionally, we assess the influence of fuel prices by considering their respective price elasticities.

Our analysis contributes to a deeper understanding of transport patterns during and after the pandemic. Specifically, our findings provide nuanced insights into which COVID-19 policies significantly influenced transport use in Europe and to what degree, while also demonstrating that certain countries have sustained changes in transport patterns post-pandemic.

The article is structured as follows. Section 2 reviews the background literature and Section 3 outlines the empirical data and methods employed. Section 4 presents the results of the analysis, followed by an interpretation of the findings and a discussion of the outcomes in Section 5. Finally, the concluding section summarises the main findings and outlines policy implications.

2. Background literature

2.1. COVID-19 policy measures

The COVID-19 pandemic prompted countries worldwide to implement various measures to curb the spread of the virus. Italy was the first European country to respond with intervention measures in March 2020 (Bosa et al., 2022). In the following weeks, other EU nations adopted similar policies, which included restricting economic activities, encouraging social distancing, and prohibiting large gatherings (Flaxman et al., 2020). They often entailed closing businesses deemed non-essential as well as schools and universities (Colfer, 2020). While these measures were similar in nature and design, they varied considerably in their specifics, stringency, and duration (Pinheiro, 2021).

The most stringent lockdowns were typically implemented in regions with the highest COVID-19 fatality rates such as Italy, Spain, and France (IMF, 2020). These measures imposed severe restrictions on people's movements (Santamaria et al., 2020). In contrast, some governments chose less stringent confinement measures or no lockdowns at all, as seen in the Netherlands and Sweden (Sabat et al., 2020).

Studies examining the pandemic containment policies tend to focus on their effectiveness in curbing the spread of the virus and reducing mortality rates (Plümper and Neumayer, 2022; Vinceti et al., 2020). However, there has also been growing interest in understanding the broader impact of these measures, including effects on the economy (Spelta and Pagnottoni, 2021; Feng et al., 2022) and mental health (Iob et al., 2020). Additionally, some studies have explored the public perception of these policies, examining factors like trust in government, compliance, and attitudes towards risk and safety (Bargain & Aminjonov, 2020; Sabat et al., 2020).

Further literature has also been devoted to the lessons learnt from COVID-19 for climate change action (Mestre Garcia et al., 2023), which we now summarise with a focus on energy consumption and GHG emissions, the transport sector, and perceptions of sustainability.

2.2. COVID-19 impact on energy consumption and GHG emissions

According to the IEA (2022a), global energy demand decreased by 4% in 2020, with the transport sector experiencing the largest fall at 16%. The lower energy consumption during the pandemic resulted in a significant fall in global CO_2 emissions, with the IEA (2023b) estimating a 5.1% reduction in 2020. While many expected emissions to quickly rebound as the pandemic subsided and the economy recovered (Le Quéré et al., 2020), others proposed that there could be lasting impacts on energy consumption patterns, encouraging a shift to more sustainable and low-carbon pathways (IEA, 2022a).

However, emissions sharply rebounded in 2021, rising 6% from 2020. Emissions continued to climb in 2022, although more slowly than in 2021, reaching a new record of over 36.8 $GtCO_2$. The surge in emissions from oil, primarily due to increased activity in the aviation sector, was a major driver of this growth (IEA, 2023b).

The decline in energy consumption during the pandemic was even more pronounced in the EU, where Eurostat (2021) reported that gasoline and diesel consumption decreased by 25% and 18%, respectively, in 2020. The pandemic had varying effects on energy consumption across sectors in the EU, with the transport sector being particularly impacted as illustrated in Fig. 1.

2.3. COVID-19 impact on the transport sector

COVID-19-related restrictions have provided an opportunity to rethink mobility options to help overcome the significant challenges inherent in decarbonising the transport sector. Fuel efficiency improvements have been limited, and the transport sector, including international aviation, is the only sector in the EU that has seen an increase in GHG emissions over recent decades, with total emissions rising by 33% between 1990 and 2019 (EEA, 2022).

Research on the post-pandemic future of the transport sector generally falls into two categories: optimistic papers that foresaw a more sustainable, low-carbon transport industry and those that predicted emissions would rebound to pre-COVID-19 levels. Nonetheless, there is a consensus that the COVID-19 pandemic has provided a unique opportunity for change and that stronger policy action from governments and institutions is needed to seize this opportunity (Christidis et al., 2021; Drews et al., 2022a; Pianta et al., 2021; Rothengatter et al., 2021; Schulte-Fischedick et al., 2021).

According to Schulte-Fischedick et al. (2021), the COVID-19 crisis caused an 11.2% reduction in emissions from surface passenger transport in the EU between 21 January and September 21, 2020 compared to 2019 baseline levels. However, the authors expressed concern about future transport emissions because lockdown-like restrictions like those implemented during the pandemic are neither desirable nor sustainable in the long term. They believe current trends are unlikely to lead to a transition towards a more environmentally sustainable path. Conversely, a 2020 global survey revealed optimism among

[1] Motorised land transport covers rail and road transport, as they share the same primary fuels for transport purposes, namely motor gasoline, gasoil, and diesel.

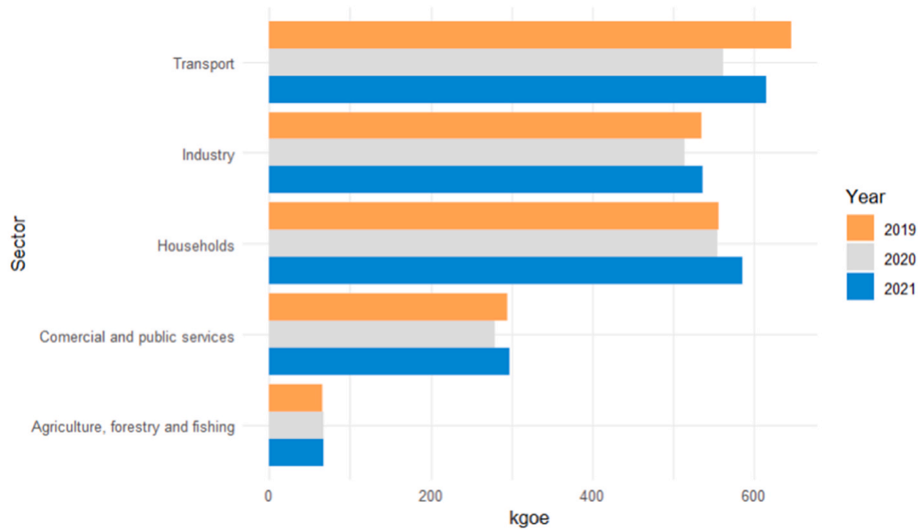

Fig. 1. Total energy consumption per capita in EU27. Bars indicate final energy consumption per capita in the main energy sectors in the EU27 and compare the differences in consumption for the years 2019, 2020, and 2021 in kilograms of oil equivalent (kgoe). Data source: Eurostat (2023a).

policymakers regarding decarbonisation strategies for a swift transition of the transport industry in a post-pandemic future, partly driven by the momentum gained from the COVID-19 restrictions (Pianta et al., 2021).

Articles examining the impact of the COVID-19 pandemic on mobility behaviour have explored several themes, including the perceived contagion risk associated with public transport (Schulte-Fischedick et al., 2021) and the increasing popularity of cycling and walking initiatives promoted in many cities after the first lockdown (Nikitas et al., 2021). Abdullah et al. (2020) investigated how COVID-19 affected travel behaviour and mode preferences, finding that respondents tended to prioritise infection-related factors and favour safer transport modes, such as private cars, walking, and cycling, while decreasing their use of public transport. However, the shift towards non-motorised modes like walking and cycling was limited due to inadequate infrastructure in many cities.

Restrictions like border closures and concerns about air travel safety prompted a notable shift towards domestic tourism, reducing international travel (UNWTO, 2021). Furthermore, the United Nations World Tourism Organization (UNWTO, 2021) also reported increased interest in nature, rural tourism, and road trips due to travel restrictions and a preference for outdoor experiences.

In a 2022 Norwegian study, participants reported that reducing their air travel during the pandemic positively impacted their well-being, with many acknowledging that over 30% of work-related flights were non-essential (Guillen-Royo, 2022). The study also showed that those who preferred walking, cycling, or public transport in urban areas tended to choose trains or buses for long-distance travel rather than flights or cars.

Working from home has also emerged as a prominent topic within the mobility discourse. A recent study by Huang et al. (2023) suggests that remote work arrangements can support sustainable development by reducing the negative externalities linked to transport. The study also found that shorter leisure trips can enhance teleworkers' well-being. Furthermore, an OECD (2021) report highlighted that hybrid work arrangements are becoming increasingly accepted globally. A survey conducted in the EU confirmed this trend, with 65% of participants expressing interest in a hybrid working model (Ahrendt et al., 2022).

2.4. COVID-19 impact on perceptions of sustainability

The "finite pool of worry" hypothesis suggests that individuals can only prioritise a limited set of concerns (Hansen, 2004; Weber, 2006). Thus, during the COVID-19 pandemic, it was expected that heightened worries about health and financial well-being would overshadow climate change concerns. However, recent research by Stefkovics and Hortay (2022), Drews et al. (2022a) and Evensen et al. (2021) suggests that despite challenges posed by the pandemic, public concern for the environment and support for climate policy persisted and even increased. This finding challenges the finite pool of worry concept and underscores the need for ongoing environmental initiatives.

There is limited literature explicitly addressing the public's environmental perceptions post-pandemic. Most studies from 2020 to 2023 focus on policy perception or government trust in COVID-19 management rather than examining whether the public believes in a return to normality or a greener future supported by teleworking, reduced travelling, or smart green transport. The few studies addressing this issue tend to focus on individual countries rather than adopting a multi-country perspective. For instance, Lewandowsky et al. (2021) found that most citizens in the US and UK citizens desired a sustainable future but perceived that others wanted to return to normality. The authors believe this could be problematic because individuals tend to align their attitudes and behaviours with what they believe is the prevailing majority opinion.

Similarly, Savin et al. (2022) found that most respondents in a representative national Spanish survey after the first wave of the COVID-19 pandemic expected negative government climate action due to reduced attention and budgetary constraints. While some respondents expressed positive expectations for individual actions, such as increased environmental awareness and responsible consumption, many cited competing priorities (Savin et al., 2022).

Research concerning the impact of COVID-19 policies on passenger transport is limited, with studies focusing mainly on specific countries and the peak periods of 2020. In response, Mannattuparambil et al. (2022) comprehensively studied the impact of COVID-19 policies on passenger transport across several countries during the first and second waves of the pandemic. However, the authors characterised the second wave as the "new normal" despite high restrictions still in place in many countries. Moreover, the study did not analyse lasting effects, highlighting the need for further research.

The present study addresses these gaps by analysing the lasting impact of the pandemic on energy consumption within the transport sector across European countries. By examining long-term effects, we aim to provide insights into sustainable and low-carbon pathways in the post-pandemic era.

3. Materials and methods

3.1. Data

The transport sector was chosen for investigation because it experienced the most significant shifts in energy use during the pandemic. This study focuses on the fuels used in motorised land transport and aviation. The selection of the European Union (EU27) and the UK is based on their early exposure to the COVID-19 pandemic and the diversity of measures implemented across these countries, offering a broad range of data variation. Additionally, data from these countries are consistent due to standardised practices in data collection and reporting, enabling accurate comparisons (see Table A1 in the Appendix for descriptive statistics).

We utilised multiple databases: data on gross inland deliveries (observed) and consumer price fluctuation data were sourced from Eurostat and the UK government, the COVID-19 Stringency Index was obtained from the Oxford Coronavirus Government Response Tracker (OxCGRT), and price elasticities of demand were drawn from existing literature (see Table A2 in the Appendix for further details).

3.1.1. Fuel consumption

To quantify fuel consumption, we used the concept of gross inland deliveries (observed), representing the total energy supply within a country's territory, excluding international maritime bunkers. This measure was selected as data is available monthly and thus provides a reasonable proxy for assessing the short-term impact of COVID-19 policies on overall transport patterns. However, it is worth noting that domestically purchased fuels may also have been consumed outside the country's borders such as for international aviation or via "fuel tourism" in road transport (Eurostat, 2022).

The data encompasses the transport sector and includes motor gasoline (hereupon referred to as gasoline) and diesel[2] for motorised land transport as well as kerosene-type jet fuel (hereupon referred to as kerosene) consumption for aviation. While diesel is primarily associated with transport, it is also used in other sectors including households, services, agriculture, and forestry. However, the quantities consumed in these other sectors are marginal compared to the primary use of diesel in transport (Eurostat, 2023b).

We sourced data from the Eurostat (2023c) for the EU27 countries and from the UK's national statistics (UK Government, 2023a). Records were available monthly from 2008 until the first quarter of 2023. Population data from Eurostat and the UK government were also used to calculate per capita values. Fig. 2 shows per capita fuel consumption trends between these dates, indicating a marked decline at the onset of 2020.

The histograms in Fig. 3 depicting fuel consumption per million inhabitants in the EU highlight the considerable heterogeneity between countries in fuel usage patterns. Kerosene displays a clear right-skewed pattern, indicating much higher consumption in a few particular countries. For gasoline, the histogram reveals a more complex pattern with two peaks and a long tail towards higher values. The diesel histogram also demonstrates a long tail.

Luxembourg stands out as a notable outlier across all three fuel types, with exceptionally high per capita consumption levels compared to other EU countries. This anomaly is likely due to Luxembourg's relatively low energy taxes, which incentivise foreign commuters and truck drivers to refuel their vehicles within the country. Consequently, non-resident drivers account for approximately two-thirds of Luxembourg's transport fuel consumption (IEA, 2023c).

For our analysis, we converted the fuel consumption data into percentage changes relative to 2019 as a pre-pandemic baseline. This approach aligns with the prevailing practice in the literature (Le Quéré et al., 2020; Schulte-Fischedick et al., 2021; Bazzana et al., 2022; Echaniz et al., 2021). By focusing on percentage changes rather than absolute consumption levels, we effectively reduce the role of inherent country differences, enabling a clearer comparison of the trends and patterns across different countries.

Upon analysing the data, we identified abnormal values in Bulgaria, Estonia, Croatia, Malta, Romania, Slovakia, and Slovenia. For instance, Estonia consistently exhibited unusually low and high kerosene values, likely due to data rounding, resulting in a lack of data variation over time. Therefore, we excluded these seven countries from our primary sample. However, we conducted a robustness check, retaining them in the analysis, and found that the main findings were largely unaffected. We present these additional results in Appendix Tables A3 and A4 and Figure A1.

3.1.2. COVID-19 Stringency Index

The COVID-19 Stringency Index[3] (SI) database measures the stringency of governments COVID-19 containment policies worldwide with daily data from January 2020 to December 2022 (Hale et al., 2021). Data collection ceased after this period as many countries had relaxed their COVID-19 restrictions. The index ranges from 0 to 100, with higher values indicating stricter government policies. Since containment measures varied across countries, the index consolidates sub-indices into a daily score for normalisation. Each sub-index uses an ordinal scale based on stringency levels, with binary flags for some indicators representing if the measures were applied nationwide (1) or only to a specific region (0).

To generate each subindex score (I) for a given indicator (j) on a particular day (t), we use the function represented in Equation (1) based on the following parameters from Hale et al. (2021). Firstly, the maximum value of the indicator (N_j) is examined, which represents the upper limit of the measurement sale. Secondly, the presence of a flag for each indicator (F_j) is determined, with a value of 1 indicating its presence and 0 indicating its absence. Thirdly, the recorded policy value on the ordinal scale ($v_{j,t}$) is taken into consideration, representing the specific measurement at a given point in time (t). Lastly, if the indicator does have a flag ($f_{j,t}$), a recorded binary flag is noted.

$$I_{j,t} = 100\,\frac{v_{j,t} - 0.5\left(F_j - f_{j,t}\right)}{N_j} \tag{1}$$

After determining the sub-index scores, the SI is calculated by averaging all sub-indexes. Equation (2) illustrates this, where k is the number of indicators:

$$index = \frac{1}{k}\sum_{j=1}^{k} I_j \tag{2}$$

The measures included in the index and individually analysed for their impact on fuel consumption are.

- *School closures (C1).* Tracks the closure of schools and universities, accounting for factors such as in-person education for students, on-site preparation of work, and whether the school only opened for exams or the children of essential workers.
- *Workplace closures (C2).* Records official government policies regarding workplace closures regardless of compliance or voluntary closures by some workplaces.

[2] The term "diesel" in this paper represents diesel and gasoil interchangeably since they share fundamental similarities in composition and properties (IEA, 2022b). The data presented pertains to diesel and gasoil collectively.

[3] For detailed information about the construction of the COVID-19 Stringency Index, please refer to Hale et al. (2021).

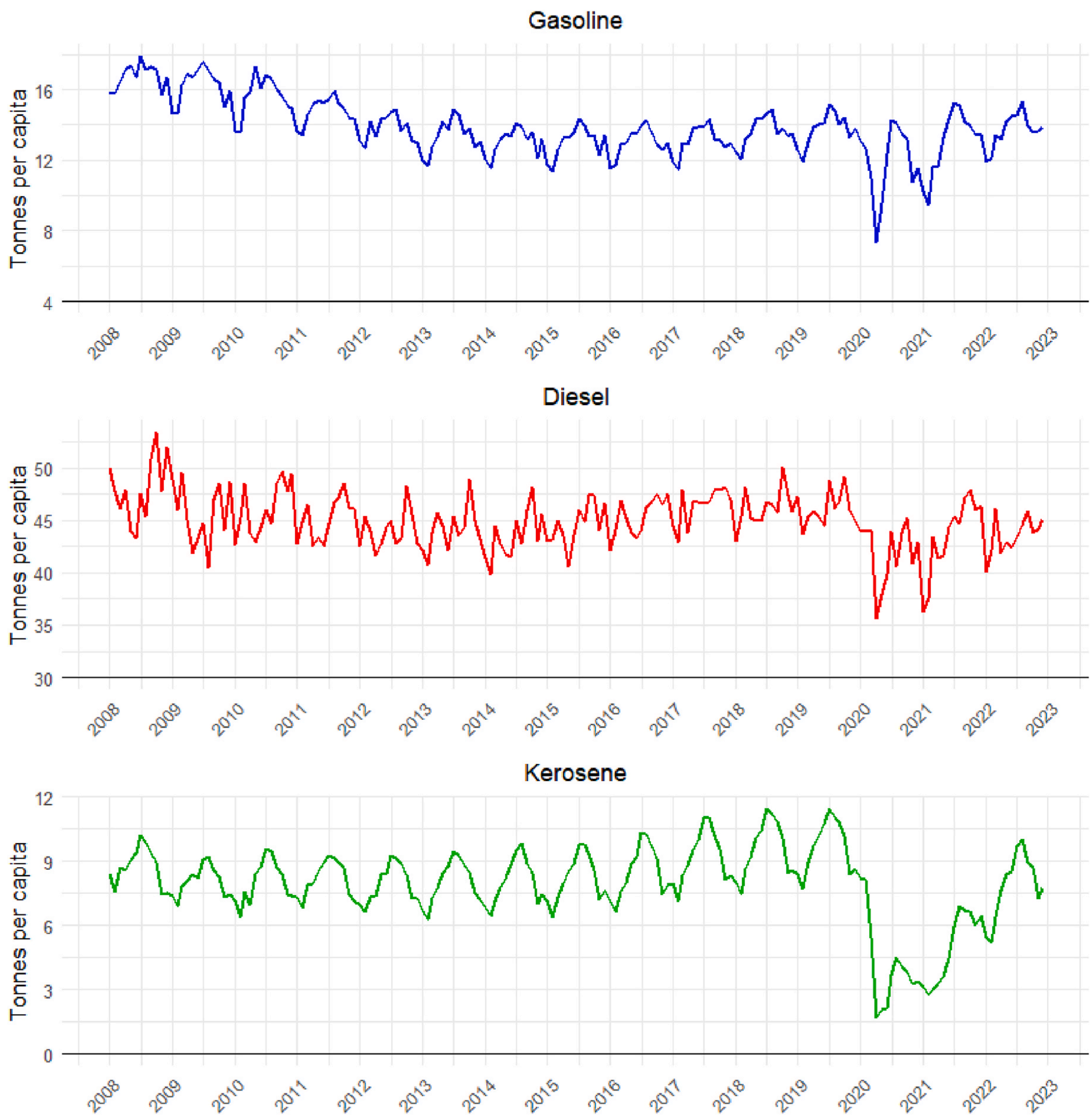

Fig. 2. Gross inland deliveries (observed) per capita by fuel in Europe. Illustrates fuel consumption per capita from 2008 to 2022.

- *Cancel public events (C3).* Prohibition of public events, considered as gatherings of 10+ people. Religious gatherings were often considered an exception but are still counted as the highest restriction level.
- *Restrictions on gatherings (C4).* Captures limitations on the types and sizes of both indoor and outdoor gatherings.
- *Public transportation (C5).* Ranges from a total shutdown of public transport to operations with social distancing requirements in place.
- *Stay-at-home order (C6).* Measures stay-at-home requirements, including curfews. It and allowances to engage in non-essential activities.
- *Restrictions on internal movement (C7).* Records restrictions on inter-regional travel, including highway closures or recommendations against visiting neighbouring cities.
- *International travel controls (C8).* Records policies affecting incoming travellers to a jurisdiction without differentiating between passenger travel and freight transport.[4]
- *Public information campaigns (H1).* Measures coordinated campaigns, including via websites, announcements, and government social media.

Fig. 4 illustrates the chronological evolution of the average SI and its constituent elements from 2020 to 2023, illustrating the variances among policies implemented in Europe.

[4] According to the European Commission's guidelines for border management (2020), the EU emphasised the free circulation of goods in the Single Market, exempting transport workers from border restrictions. This clarifies that freight transport falls outside the scope of variable C8.

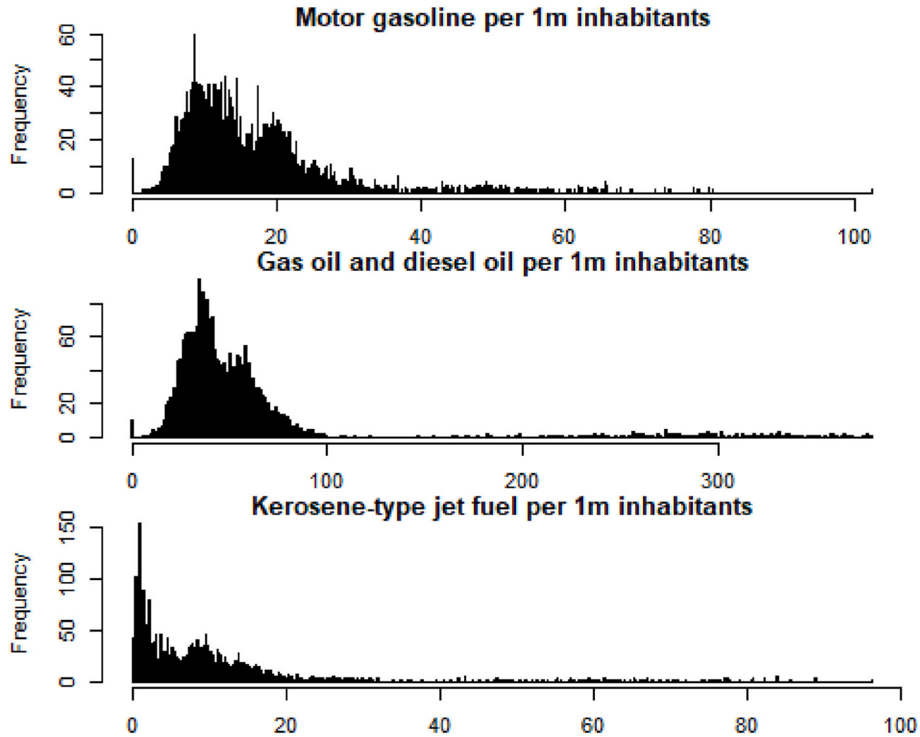

Fig. 3. Histograms of fuel consumption per fuel per one million inhabitants. Histograms illustrate fuel consumption per one million inhabitants in Europe.

Fig. 4. Evolution of the Stringency Index and its constituent elements in Europe. The left-most graph illustrates the progression of the overall Stringency Index. The graphs on the right detail the trends for each constituent element. The lines illustrate the progression of the specific element over the years studied, with the Y-axis consistently representing the maximum scale for each indicator.

3.2. Methods

3.2.1. Changes in fuel consumption during COVID-19

To analyse changes in fuel consumption, we employed descriptive statistics and data visualisation techniques, calculating the average percentage change in fuel consumption for each month from 2020 to 2022 compared to the respective month in 2019.

3.2.2. Impact of COVID-19 policies on fuel consumption

Given the skewed distribution of our dependent variables (fuel consumption), we utilised quantile regression analysis. Unlike ordinary least squares regression, which is sensitive to outliers, quantile regression is better suited to empirical economics when the data is not normally distributed (Marson and Savin, 2022; Koenker and Bassett, 1978). This method allows us to effectively address the higher fuel consumption levels observed in certain countries while examining the relationship between consumption and other factors. Additionally, quantile regression allows the heterogeneous effects of COVID-19 confinement policies on fuel consumption to be revealed depending on the percentile a particular country is occupying in the dependent variable (Drews et al., 2022b).

The plot in Figure A2 of the Appendix shows strong positive correlations among COVID-19 policies (C1 to C8), indicating that an increase in one policy often corresponds with increases in others. This high multicollinearity complicates analysing them together in a single regression equation as this can cause fluctuations in coefficient estimates, making it challenging to interpret the specific impact of each policy on fuel consumption. Additionally, this reduces the precision of coefficient estimates, leading to unreliable p-values and difficulty in identifying which predictor variables are statistically significant. To address this, we ran separate regression analyses for each fuel type and COVID-19 policy while including country and monthly fixed effects.

Given the multicollinearity challenge mentioned above, we also used the gradient boosting machines (GBM) algorithm to rank the importance of each COVID-19 policy on fuel consumption. GBM is an advanced machine-learning algorithm that combines gradient boosting and decision trees to create an ensemble model (Savin et al., 2021; Natekin and Knoll, 2013). It constructs the model iteratively by sequentially adding weak learners (decision trees) sequentially to refine predictions.

The initial decision tree fits the data to predict the response variable ($F_1(x) = y$), while each subsequent tree is trained to capture the residuals of the previous model ($h_1(x) = y - F_1(x)$), and its predictions are added to the ensemble model ($F_2(x) = F_1(x) + h_1(x)$). The resulting model is essentially a cumulative addition of individual regression trees, progressing step by step. This allows for the refinement of predictions by iteratively improving the model's ability to capture the remaining errors in the data, ultimately enhancing its predictive performance.

We use the associated GBM package in R (Greenwell et al., 2019), training 10,000 trees to build a predictive model. Validation was achieved via 10-fold cross-validation, which randomly splits the sample into training and testing sets ten times, trains the model on the first set and then evaluates its performance on the testing set, reporting average results. As an outcome, GBM ranks the nine confinement policies together with country and seasonal dummies based on their explanatory power.

By utilising an ensemble of decision trees, GBM handles multicollinearity effectively by reducing the influence of correlated predictors (Levi, 2021). Therefore, using this technique allows us to assess the relative importance of each policy in reducing fuel consumption during the COVID-19 pandemic while accounting for non-linear effects and the interplay between variables.

To determine the impact of how COVID-19 policies influenced fuel consumption, we conducted regressions covering 2019–2022 to quantify the magnitude and significance of these influences. The impact of the COVID-19 policies on fuel consumption was estimated with the following regression model:

$$FC_{i,t} = \alpha + \beta \cdot COVID\ POLICIES_{i,t} + \gamma C + \delta M + \varepsilon_{i,t} \quad (3)$$

The dependent variable, *FC*, represents the percentage change in per capita fuel consumption relative to the corresponding month in 2019 for each country *i* in period *t*. The independent variables are COVID-19 policies, represented by either the SI or one of its constituent elements (C1, C2, C3, C4, C5, C6, C7, C8, and H1). To control for country-specific and seasonal fixed effects, the model includes country (*C*) and monthly (*M*) dummy variables.

To verify the parallel-trend assumption, we performed a placebo analysis using historical fuel consumption data for previous years. Following the methodology of Angelov and Waldenström (2023), we recalculated *FC* from Equation (3) over 2017–2019 relative to the respective month in 2016. Then, we estimated Equation (3) for this earlier period assuming that the COVID-19 pandemic took place exactly three years earlier (placebo effect). If the estimate for the confinement policies is small in size and not significant, this will support our empirical approach.

3.2.3. Lasting effect post COVID-19

After March 2022, the SI was very low across many countries, indicating minimal impact from policies that could affect fuel consumption. To evaluate the lasting effect of COVID-19 confinement policies, we forecasted fuel consumption from April 2022 to December 2022 using estimated effects ($\hat{\cdot}$) of the overall COVID-19 SI on the respective consumption from the preceding period (January 2020 to March 2022), following Equation (4):

$$\widehat{\mathrm{FCI}_{i,t}} = \widehat{\alpha} + \widehat{\beta} \cdot COVID\ POLICIES_{i,t} + \widehat{\gamma} C + \widehat{\delta} M + \varepsilon_{i,t} \quad (4)$$

Our primary objective was to compare projected fuel consumption with observed consumption during the forecasted period. If projected fuel consumption is higher than observed consumption, this would indicate sustained positive behavioural changes in fuel usage. Conversely, if projected fuel consumption is lower than the observed level, we can conclude that the respective countries exhibit a "post-pandemic rebound", which we define as post-pandemic energy consumption exceeding 2019 levels.[5]

When assessing the lasting effect of COVID-19 on fuel consumption, we also considered the influence of prices via their respective price elasticities to evaluate how sensitive fuel consumption was to price fluctuations. Price elasticity of demand measures how responsive demand is to changes in price. By using price elasticities alongside the COVID-19 SI, we can distinguish between the role of prices and behavioural change. This is particularly relevant given the high inflation rates in the energy sector in Europe during 2022. Higher fuel costs can discourage people from using certain transport modes or encourage alternatives like public transport or remote work.

We report two forecasts ($\widehat{\mathrm{FCI}_{i,t}}$ and $\widehat{\mathrm{FCII}_{i,t}}$). In the former (Equation (4)), we assume transport fuel consumption is perfectly inelastic, unaffected by price changes. In the latter (Equation (5)), we add the price effect by estimating the difference in fuel prices between the corresponding month in 2019 and the forecasted period *t,* and multiply the change by the price elasticity of demand:

$$\widehat{\mathrm{FCII}_{i,t}} = \widehat{\mathrm{FCI}_{i,t}} + \left(Fuel\ price_{i,t} - Fuel\ price_{i,2019}\right) \times Price\ elasticity \quad (5)$$

For example, if the price of kerosene in Spain was 100 in May 2019 and 119 in May 2022, with a price elasticity of demand for flights of -0.8, expected kerosene consumption in May 2022 would be 90% $\times$ $-0.8 = -15.2\%$. Thus, we would expect lower kerosene consumption as its price has increased.

We obtained prices of gasoline, diesel, and passenger air transport for the EU27 countries from the harmonised index of consumer prices provided by Eurostat, adjusted for relative comparisons to 2019 prices to provide consistent reference points (Eurostat, 2023dd). It is worth noting that significant price variations exist for passenger air transport among European countries. For the UK, we sourced equivalent data from the UK government's consumer price inflation tables (UK Government, 2023b).

Based on a review of the literature published from 2000 to 2020, we determined the average short-term price elasticity of demand for gasoline to be -0.2714 and for diesel to be -0.1386 (Table 1).

To determine the price elasticity of demand for aviation in Europe, we used data from the International Air Transport Association (IATA, 2008). To capture the unique dynamics of the European market, we

[5] Not to be confused with the concept of energy rebound effects in conservation and energy economics.

Table 1
Elasticity demand studies from 2000.

Study	Energy product	Short term elasticity
Graham and Glaister (2002)	Gasoline	[-0.2; −0.3]
Graham and Glaister (2004)	Gasoline	−0.25
Basso and Oum (2007)	Gasoline	[-0.2; −0.3]
Brons et al. (2008)	Gasoline	−0.34
Dahl (2012)	Gasoline	−0.18
Havranek et al. (2012)	Gasoline	−0.09
Ajanovic et al. (2012)	Gasoline	[-0.2; −0.3]
Labandeira et al. (2017)	Gasoline	−0.293
Aklilu (2020)	Gasoline	−0.24
Average		**−0.2714**
Basso and Oum (2007)	Diesel	−0.13
Dahl (2012)	Diesel	−0.16
Ajanovic et al. (2012)	Diesel	−0.1
Labandeira et al. (2017)	Diesel	−0.153
Aklilu (2020)	Diesel	−0.15
Average		**−0.1386**

selected elasticity values employed by IATA for pan-national demand. We considered three flight categories to approximate an average elasticity: short-haul intra-Europe, long-haul North America-Europe, and long-haul Europe-Asia. These categories were then weighted based on the composition of air traffic within the EU, where approximately 37% of flights are extra-EU and the remaining 62% comprise national or intra-EU flights (Eurostat, 2022). By incorporating these weightings, we derived an average price elasticity of −0.8 to represent demand responsiveness for aviation within Europe.

4. Results

4.1. Changes in fuel consumption during COVID-19

Fig 5 and 6 illustrate changes in fuel consumption across countries for the three fuel types. In Panel A of Fig. 5, we can observe that the aviation sector experienced the most significant decline in fuel consumption compared to 2019. Motorised land transport also experienced a decrease, although less pronounced than aviation (see Table A5 in the Appendix for more details). Panel B of Fig. 5 shows the contrasting recovery patterns between motorised land transport and aviation. While motorised land transport quickly recovered and started fluctuating around the 2019 average by June 2021, the recovery in the aviation sector was more gradual (see Figure A3 in the Appendix). As can be seen in Figs. 5 and 6, Austria, Sweden, and the UK exhibited the largest reductions in fuel consumption.

Regarding gasoline consumption, Ireland, Sweden, and the UK showed substantial reductions, while Lithuania and Italy had higher overall consumption levels. For diesel, Luxembourg, the Netherlands, and the UK reported the lowest overall consumption levels. Conversely, only Poland and Cyprus increased their consumption from the 2019 baseline levels.

Due to the largely international nature of the aviation sector and the severe impact COVID-19 restrictions had on it, it is unsurprising that all countries reported kerosene consumption well below 2019 levels. Finland, Czechia, Sweden, and Austria saw reductions of over 50% compared to 2019. Belgium and Luxembourg experienced the smallest declines at 18% and 12%, respectively.

4.2. Impact of COVID-19 policies on fuel consumption

When analysing the impact on gasoline, the factors of “Restrictions on Internal Movement”, “Stay-at-Home Order”, and “School Closures” exerted the most prominent influence. For diesel, “Restrictions on Internal Movement”, “Public Information Campaigns”, and “Stay-at-Home Order” played substantial roles. In the case of kerosene, the main factor was “Public Transportation”, followed by “Cancelling of Public Events” and “Restrictions on Internal Movement”.

Table 2 presents the results of the quantile regression, revealing the relationships between fuel consumption and COVID-19 policies, and Table 3 shows the results of the GBM analysis. In both analyses, the SI consistently demonstrates explanatory power for reducing fuel consumption, illustrating its validity as an aggregate proxy for COVID-19 confinement policies.

The results presented in both Tables 2 and 3 account for country and seasonal factors. The variables demonstrating the highest R^2 in Table 2

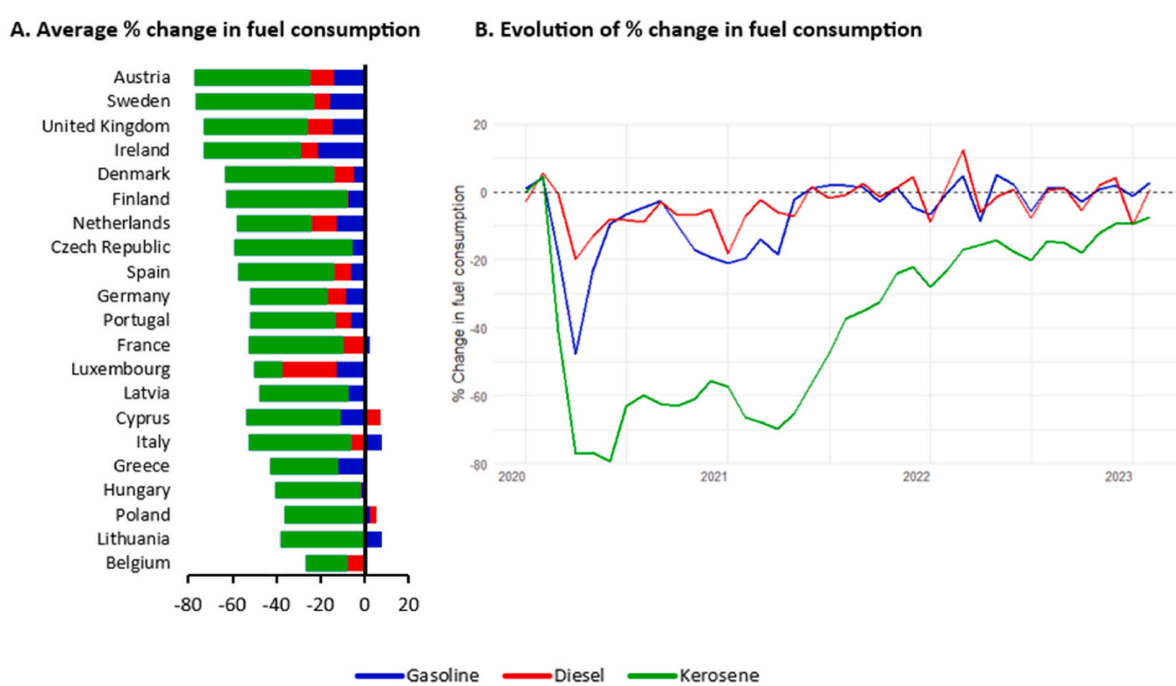

Fig. 5. Fuel consumption per capita in the EU27 + UK. Panel A shows the average overall percentage change from 2020 to 2023 in fuel consumption across countries and Panel B shows the evolution of total fuel consumption across the studied years.

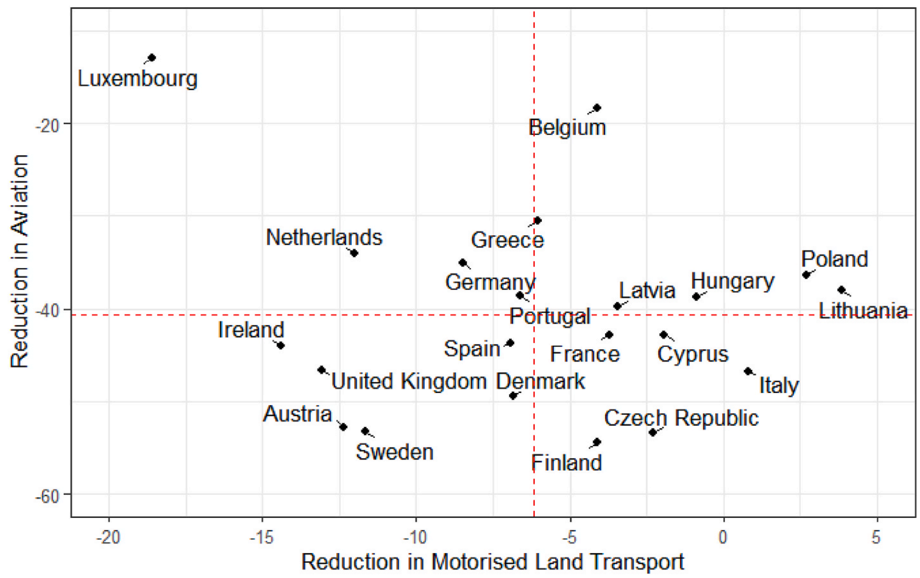

Fig. 6. Reduction in Aviation vs. Motorised Land Transport. The scatter plot illustrates aviation and motorised land transport reductions per capita for each country. Dashed lines represent average values for these variables.

Table 2
Results of quantile regressions.

	SI	C1	C2	C3	C4	C5	C6	C7	C8	H1
Gasoline										
COVID-19 SI	−0.271	−7.776	−6.068	−6.490	−2.657	−6.244	−9.421	−10.504	−2.929	−5.030
R^2	0.536	0.553	0.499	0.491	0.460	0.381	0.532	0.547	0.413	0.359
AIC	328.4	327.3	331.0	331.5	333.5	338.0	328.8	327.7	336.2	339.1
N of obs	729	729	729	729	729	729	729	729	729	729
Diesel										
COVID-19 SI	−0.088	−2.532	−2.164	−1.637	−0.660	−2.277	−2.672	−3.450	−1.115	−2.816
R^2	0.427	0.428	0.422	0.409	0.404	0.407	0.423	0.430	0.406	0.396
AIC	320.2	320.2	320.5	321.3	321.6	321.4	320.5	320.1	321.5	322.0
N of obs	729	729	729	729	729	729	729	729	729	729
Kerosene										
COVID-19 SI	−0.983	−23.297	−24.312	−27.099	−12.439	−35.099	−24.787	−25.898	−16.782	−23.872
R^2	0.764	0.653	0.668	0.708	0.634	0.327	0.521	0.477	0.668	0.272
AIC	345.6	358.4	356.9	352.7	360.1	380.2	369.0	371.9	356.9	382.8
N of obs	729	729	729	729	729	729	729	729	729	729

Notes: Country and monthly dummies are consistently included in the analysis. All coefficients are significant at the 0.1% level.

Table 3
Results of GBM analysis.

	Gasoline	Diesel	Kerosene
Country dummies	*39.23*	*48.38*	*27.49*
Seasonal (monthly) dummies	*17.14*	*24.93*	*10.31*
C1: School closures	*12.68*	*8.56*	*9.24*
C2: Workplace closing	*10.31*	*6.44*	*4.42*
C3: Cancel public events	*5.27*	*0.64*	*10.45*
C4: Restrictions on gatherings	*1.37*	*1.75*	*8.96*
C5: Public transportation	*0.84*	*0.99*	*0.29*
C6: Stay at home order	*2.29*	*1.99*	*0.75*
C7: Restrictions on internal movement	*7.91*	*1.95*	*2.00*
C8: International travel controls	*2.75*	*3.05*	*24.72*
H1: Public information campaigns	*0.23*	*1.31*	*1.37*

correspond to the greatest relative importance observed in GBM, highlighting the significance of these policies. Through separate and combined testing, it is evident that the most important policies were “School Closures”, “Cancelling of Public Events”, and “International Travel Controls”. The ranking of policies by GBM in Table 3 differs slightly from the magnitude of the R^2 values in Table 2 because we tested COVID-19 policies separately in the regression analysis without accounting for their interplay and non-linear effects (see Section 3.2.2). Therefore, the results from Table 3 should be considered more reliable.

As described in Section 3.2.2, we conducted a placebo test by estimating the regression equation on the period 2017–2019 instead of 2020–2022 to see if we could find any significant estimates for imaginary confinement policies present in that period. Table A7 of the Appendix shows that no estimate of the COVID-19 polices is significant for gasoline, few are significant for diesel, and only one for kerosene. When these coefficients are significant, they are always positive, and their absolute values are always much smaller than their counterparts in Table 2. Additionally, the corresponding R^2 values drop dramatically, indicating little explanatory power for the placebo effect. Based on these results, we can conclude that the placebo robustness test supports our findings on the significant role of COVID-19 confinement policies in the period 2020–2022.

4.3. *Lasting effect post COVID-19*

We initially derived an estimate for Equation (4) covering January 2020 to March 2022. To ensure accuracy and consider multicollinearity, we focused solely on the SI, as it demonstrates the strongest explanatory capability (see Table 2). Fig. 7 provides an overview of the lasting effects

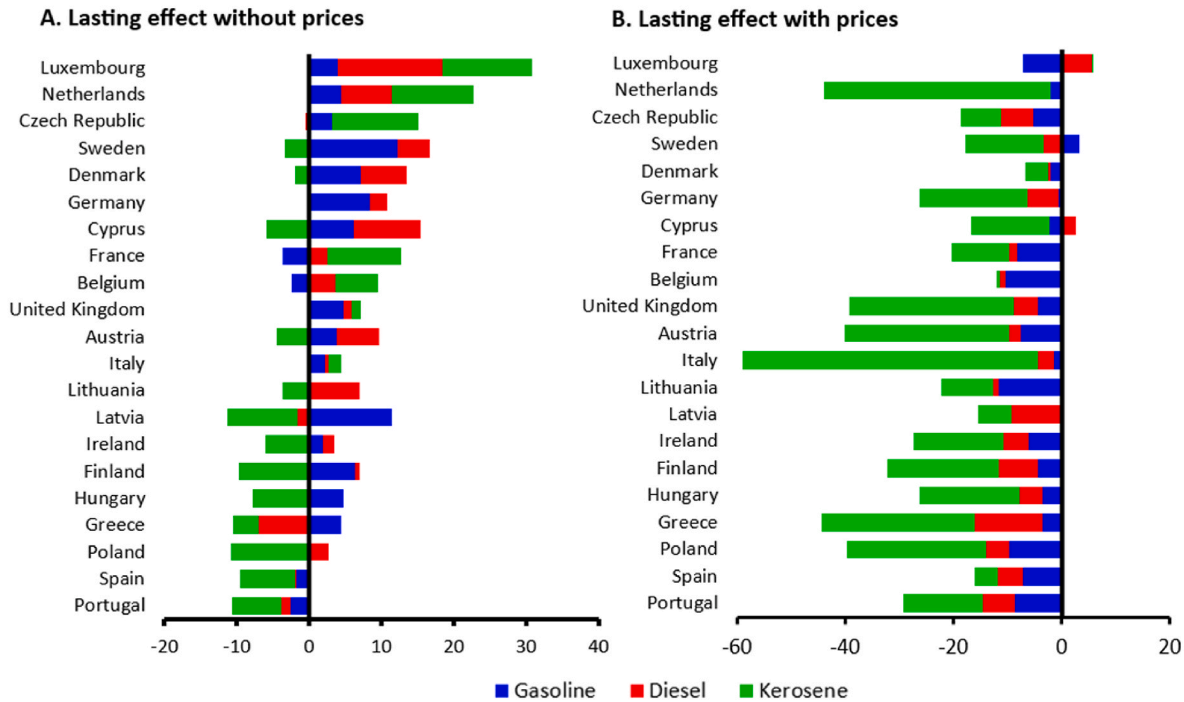

Fig. 7. Lasting effect with and without prices. Panel A shows the lasting effect without the price effect and Panel B with the price effect included. Both graphs show the calculated lasting effect for the three types of fuels and the studied countries. Positive values indicate a lasting effect, while negative values indicate a rebound.

of the pandemic on fuel consumption, categorised by fuel type and country (results with countries excluded from the main analysis are provided in Figure A2 of the Appendix). Results are provided both with (panel B) and without (panel A) the impact of prices. Within these graphs, positive values indicate a lasting effect, where fuel consumption in a particular country was lower than predicted. Conversely, negative values imply a rebound, where fuel consumption exceeds the projected levels. Overall, a moderate rebound can be observed for motorised land transport, while aviation exhibits a significant rebound in fuel consumption (see Table A6 in the Appendix for more details).

Considering the results without the price effect, most countries exhibit a lasting effect with gasoline and diesel. However, Lithuania, Spain, Belgium, Portugal, and France experienced a rebound in gasoline consumption, while Spain, Hungary, Czechia, Portugal, Latvia, and Greece saw a rebound in diesel consumption. Kerosene consumption rebounded in most countries but one-third of the countries, namely Luxembourg, Czechia, the Netherlands, France, Belgium, Italy, and the United Kingdom, showed a lasting effect.

When accounting for the price effect, Sweden is the only country demonstrating a lasting effect on gasoline consumption. For diesel, Luxembourg and Cyprus were the only countries exhibiting a lasting effect. Regarding kerosene, despite flight prices on average rising substantially by 19% relative to 2019, fuel demand still reached almost the same level as in 2019. Luxembourg was the only country to demonstrate a slight lasting effect with kerosene; however, Luxembourg's results should be interpreted cautiously due to the high role of non-residents in its fuel consumption.

5. Discussion

During the initial stages of the COVID-19 pandemic, there was a notable decrease in fuel consumption and transport usage due to strict confinement measures. As these measures were gradually lifted, motorised land transport experienced a rapid recovery, while the aviation sector took longer to recover. This resurgence in transport consumption reflects the interplay between COVID-19 policies and individual behaviours. While some countries returned to their pre-pandemic fuel consumption patterns, others exhibited a moderate reduction in consumption as restrictions were lifted. These circumstances lead to the identification of four distinct scenarios surrounding specific types of transport use concerning the stringency of COVID-19 measures. Fig. 8 provides an overview of the country distribution (see Figure A4 in the Appendix for results including countries excluded from the main analysis).

The first group of countries fall under the category of high stringency and high fuel reductions, containing countries such as Austria, Germany, and the UK. It is plausible that amid the elevated restrictions, people embraced alternative lifestyles and activities that reduced their dependence on transport. This behavioural shift may have occurred because individuals perceived the adoption of these new routines as both feasible and desirable.

Based on our observations, the UK exhibited lasting effects, consistent with O'Garra and Fouquet's (2022) findings that indicated a willingness to reduce post-pandemic travel consumption. However, the lasting effects we observed are not as substantial as the 20–30% (range depending on the transport mode) reduction implied in their study. Lewandowsky et al. (2021) also suggest that UK citizens preferred a more sustainable future after COVID-19 rather than returning to "normal". Despite this willingness, some individuals may lack the necessary means to reduce travel effectively. Compulsory return to the office, limited remote work opportunities, lack of affordable transport alternatives, or family obligations may hinder them from transforming their willingness into action.

In Austria and Germany, we observed lasting effects in motorised land transport but aviation rebounded significantly in Austria and slightly in Germany. This suggests that people in these countries may have made changes to their daily routines such as teleworking or cycling more frequently. According to a recent study by Jacobsen et al. (2023), some people believe that holidays taken at home countries do not feel like proper holidays. This perception could be a contributing factor to the increase in air travel for tourism, suggesting that people still prefer flying for vacations.

Countries like Czechia, Sweden, and Denmark exhibited low stringency measures during the COVID-19 pandemic yet reported substantial

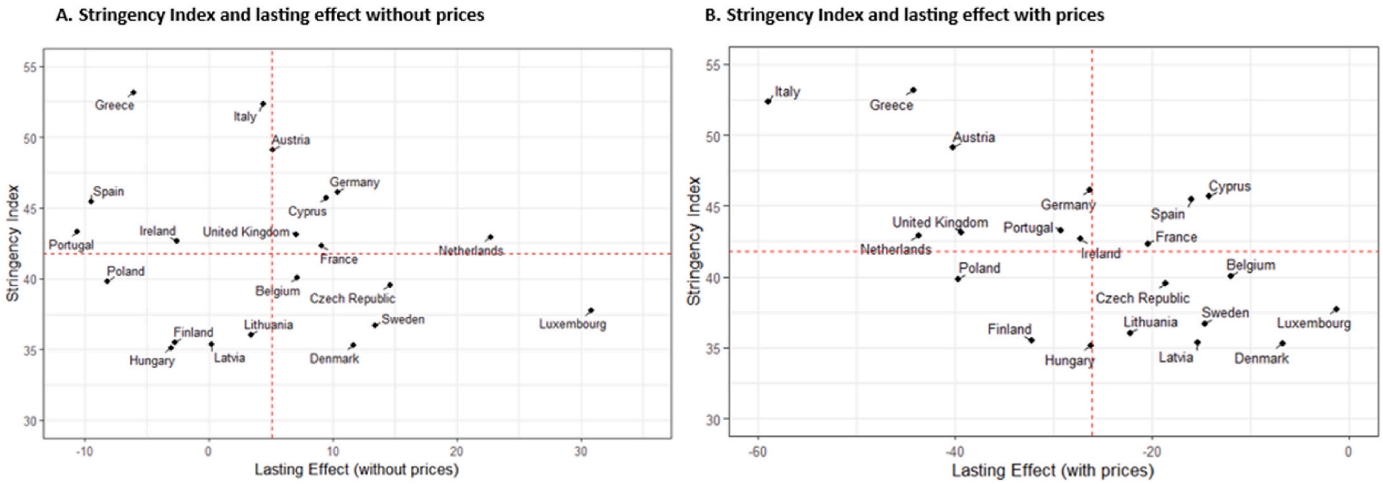

Fig. 8. Stringency Index and lasting effect. The scatter plot illustrates the Stringency Index and its lasting effects. Panel A shows the lasting effect without prices, and Panel B with the price effect. The dashed lines represent average values for both variables.

reductions in fuel consumption. For all three countries, the overall lasting effect is high despite minor rebounds for aviation in Sweden and Denmark and diesel in Czechia. This lasting effect can be attributed to the comparatively limited impact of COVID-19 policies on daily routines in these countries. As reported by Lindgren et al. (2023), participants in Sweden indicated that daily activities were only affected to a minor extent. As a result, individuals were able to maintain a semi-normal lifestyle without experiencing a strong sense of deprivation or the need to compensate for lost time after restrictions were lifted.

Given the differences in transport use across Europe, it is important to consider underlying factors beyond COVID-19 policies such as cultural and behavioural changes. An example is the emergence of the "flight shame" (*flygskam*) phenomenon originating in Sweden, which describes a sense of guilt associated with the carbon footprint of air travel (Gössling et al., 2020). According to Gössling et al. (2020), a growing number of individuals are experiencing "flight shame" but the effectiveness of it as a motivator for change depends on individuals' willingness to alter their travel behaviour and the availability of alternatives.

Countries like Greece, Portugal, Italy, and Spain experienced both high stringency and high rebounds in fuel consumption. Strict lockdowns in these countries likely heightened the adverse effects of confinement, leading to an increased desire for travel and a sense of normality once restrictions were lifted. The resumption of tourism also played an important role in these countries as it is closely linked to the economic well-being of Mediterranean countries. Therefore, the rise in fuel consumption within these countries' borders can be partially attributed to visitors from Northern and Central Europe, who frequently favour Mediterranean countries as tourist destinations. Additionally, Italy's explicit dismissal of remote work, as noted in Battisti et al. (2022), may further explain the outcomes in Italy and other countries with a similar approach.

Other countries, such as Hungary, Poland, Latvia, and Lithuania, presented low stringency measures and limited reductions in fuel consumption. These countries conformed to the inertia of the existing consumption trajectories and predictably showed an overall rebound. As relatively low-income countries within the EU, they may have faced economic challenges in adapting during and after the pandemic, potentially limiting their capability to reduce consumption.

Considering the influence of prices on lasting effects, actual fuel consumption exhibited a considerably higher price inelasticity than our modelled assumptions. This could be because many individuals maintained steady incomes during the pandemic while their ability to spend on leisure activities was reduced due to restrictions, leading to increased personal savings. With the relaxation of these restrictions, individuals found themselves with both the desire and the financial means to bear the elevated fuel and air travel costs. Therefore, repeating our analysis when data for 2023–2024 becomes available would be beneficial to explore long-term behavioural changes free from the influence of savings made during confinement.

This study has certain limitations, primarily due to unaccounted confounding factors. Notably, we did not include meteorological variables, which may affect diesel-based heating. Additionally, we did not consider the changing landscape of vehicle technology, specifically the potential growth of electric and hybrid vehicles during this period, as monthly data on this is not readily available for all countries and years of our analysis.

While gross inland deliveries of gasoline, diesel, and kerosene serve as reasonable proxies for assessing the short-term impact of COVID-19 policies on overall transport patterns, their direct correlation with public engagement with transport modes may lack precision. Future research may explore alternative data sources that reflect more specific changes in transport behaviour during and after the pandemic.

Future research could also focus on country-specific factors that involve qualitative and quantitative studies aimed at exploring a broader range of determinants beyond policy strictness. Investigating societal norms, individual behaviours, transport infrastructure, adaptability to remote work, and public attitudes could provide policymakers with valuable insights into the underlying dynamics influencing transport use.

6. Conclusion and policy implications

This paper investigated transport use within Europe during the COVID-19 pandemic and its lasting effects. By analysing different transport modes, we revealed significant reductions in motorised land transport and aviation use during COVID-19 across Europe. Moreover, these transport modes showed distinct recovery patterns after restrictions were lifted: motorised land transport swiftly rebounded and began oscillating around the 2019 average by June 2021, while aviation experienced a slower recovery to pre-pandemic levels.

Additionally, utilising quantile regressions and GBM analysis, we examined the relationship between stringency of COVID-19 confinement policies and transport use. Results indicated that "school closures", "cancelling of public events", and "international travel controls" had the most substantial influence on overall transport use. Furthermore, "restrictions on public transport" also impacted aviation, while "workplace closures" and "restrictions on internal movement" significantly impacted motorised land transport.

Our ultimate aim was to determine whether there were lasting effects on transport use in Europe after COVID-19 restrictions were lifted. While most countries exhibited lasting effects, factoring in the price effect from the high energy price inflation experienced in Europe during 2022 translated these to substantial rebounds in almost all cases. These results imply that transport was more price inelastic in the post-pandemic period than suggested by literature estimates of elasticities. Increased savings during the pandemic likely enabled the public to afford the higher fuel and air travel costs alongside a desire to compensate for "lost" travel during the pandemic.

The overall findings highlight that a behavioural shift towards reduced travel use after the pandemic, as suggested by survey data in the UK (O'Garra and Fouquet, 2022), is unlikely to occur uniformly across Europe. However, important lessons can be learned from countries that do show lasting effects as their transport and energy policies might have contributed to these outcomes. Similarly, countries with high rebounds may offer insights into challenges that need to be overcome to promote sustainable transport behaviour.

Some countries with high stringency of COVID-19 policies, such as Austria, Germany, and the UK, experienced significant reductions in fuel consumption that persisted to some extent after restrictions were lifted. However, these changes were limited, possibly because people's willingness to adapt to new routines was not matched by their capacity to do so. Conversely, other countries with high stringency, including Greece, Portugal, Italy, and Spain, experienced a notable rebound after restrictions were lifted. This rebound might not only be due to an increased desire for travel among citizens in these countries but also reflect the attractiveness of Mediterranean destinations for international tourists.

Hungary, Poland, Latvia, and Lithuania implemented COVID-19 measures with low stringency and showed an overall rebound. The relatively lower incomes of this group of countries may partly explain why they quickly returned to normality. In contrast, despite also implementing limited measures, Sweden, Denmark, and Czechia exhibited lasting reductions in transport consumption. These countries offer potential policy lessons for promoting sustainable transport practices.

In Sweden, some sectors, particularly information and communication technology, already had a relatively high and growing percentage of remote workers before the pandemic (Milasi et al., 2020). This trend continued post-pandemic as teleworking increased by 12.2%, going from 5.9% of employees in 2019 to 18.1% in 2022 (Eurostat, 2024). Moreover, the Swedish government has expanded the remote work regulations to ensure a safe work environment (SAWEE, 2021). In contrast, other countries such as Hungary have only a seen marginal increase in remote work, rising from 1.2% of the workforce in 2019 to 2.8% after the pandemic (Eurostat, 2024).

Since 2010, outdoor recreation has been a political goal in Sweden, aiming to improve accessibility to natural environments and spread knowledge about outdoor activities (Hansen et al., 2022). These goals were reinforced during the COVID-19 pandemic when emphasis was placed on providing adequate outdoor recreation opportunities for everyone. Promoting and preserving local natural areas could impact transport mobility by encouraging citizens to choose physically active leisure activities and transport options.

Denmark, despite already having widespread use of bicycles in daily activities (Pucher and Buehler, 2008), continues to promote and invest in cycling. The Danish National Reform Programme for 2022 includes funds for cycling and e-bike infrastructure on main roads and municipal projects (Danish Government, 2022). Additionally, Czechia, particularly Prague, has some of the cheapest public transport tickets in Europe (Greenpeace, 2023), which can also help people transition towards less carbon-intensive transport.

Conversely, Latvia and Lithuania face challenges with the state of their train lines and connectivity to international lines, mainly due to the different structure gauge of the railway inherited from Russia (Jurušs et al., 2016). The "Rail Baltica" project aims to connect Estonia, Latvia, Lithuania, and Poland by high-speed train (Rail Baltica, 2023). However, since its first policy proposal in 1994, the project has faced delays, with initial construction projected to start in the spring of 2024 (Bautre, 2023). These implementation problems force passengers to opt for other, less sustainable, transport modes.

To meet their Paris Agreement targets, European countries need to profoundly transform their transport sectors over the coming decades. Developing green transport options such as public transit, cycling, and electric vehicles, alongside promoting behavioural change, is essential. The lasting reductions in energy consumption observed in some countries following the COVID-19 pandemic offer valuable lessons for fostering sustainable transport choices. Nonetheless, the swift rebound in fuel consumption seen elsewhere underscores the need for more comprehensive efforts to make sustainable transport not just an option but the preferred choice for the public.

CRediT authorship contribution statement

Helena Patino-Artaza: Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Lewis C. King:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Ivan Savin:** Writing – review & editing, Visualization, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Table A1
Descriptive statistics

Name	Unit	Obs.	Average	Min	Max
Gasoline	Thousand tonnes	5059	253.1	0	1895.9
Diesel	Thousand tonnes	5059	817.6	0	5784.0
Kerosene	Thousand tonnes	5053	144.63	0	1238.84
COVID-19 Stringency Index	Index (0–100)	1064	38.54	0	95.43
School Closures	Index (0–3)	1064	0.22	0	3.00
Workplace closing	Index (0–4)	1064	0.22	0	3.00
Cancel Public Events	Index (0–2)	1064	0.19	0	2.00
Restrictions on gatherings	Index (0–4)	1064	0.40	0	4.00
Public Transportation	Index (0–2)	1064	0.05	0	2.00
Stay at Home Order	Index (0–3)	1064	0.11	0	2.52
Restrictions on Internal Movement	Index (0–2)	1064	0.07	0	2.00
International Travel Controls	Index (0–4)	1064	0.34	0	4.00
Public information campaigns	Index (0–2)	1064	0.37	0	2.00

Table A2
Variables description

Name	Description	Data source
Gasoline	Gross inland deliveries - observed of Motor gasoline	Eurostat: Supply and transformation of oil and petroleum products - monthly data https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_OILM_custom_6046553/default/table?lang=en UK government: National statistics - Energy Trends: UK oil and oil products https://www.gov.uk/government/statistics/oil-and-oil-products-section-3-energy-trends
Diesel	Gross inland deliveries - observed of Gas oil and diesel oil	
Kerosene	Gross inland deliveries - observed of Kerosene-type jet fuel	
COVID-19 Stringency Index	The index records the strictness of "lockdown style" policies that primarily restrict people's behaviour. It is calculated using all ordinal containment and closure policy indicators, plus an indicator recording public information campaigns.	OXFORD COVID-19 Government Response Stringency Index https://data.humdata.org/dataset/oxford-covid-19-government-response-tracker
School Closures	Record closings of schools and universities	
Workplace closing	Record closings of workplaces	
Cancel Public Events	Record cancelling public events	
Restrictions on gatherings	Record limits on gatherings	
Public Transportation	Record closing of public transport	
Stay at Home Order	Record orders to "shelter-in-place" and otherwise confine to the home	
Restrictions on Internal Movement	Record restrictions on internal movement between cities/regions	
International Travel Controls	Record restrictions on international travel	
Public information campaigns	Record presence of public info campaigns	

Table A3
Results of quantile regressions with all countries

	SI	C1	C2	C3	C4	C5	C6	C7	C8	H1
Gasoline										
COVID-19 SI	−0.282	−8.078	−5.483	−6.461	−2.663	−7.571	−9.590	−11.198	−3.070	−5.243
R^2	0.389	0.395	0.342	0.347	0.333	0.291	0.380	0.396	0.312	0.254
AIC	424.6	424.2	427.6	427.3	428.1	430.6	425.2	424.2	429.3	432.6
N of obs	1008	1008	1008	1008	1008	1008	1008	1008	1008	1008
Diesel										
COVID-19 SI	−0.112	−3.326	−2.707	−2.614	−1.038	−2.990	−2.643	−3.928	−1.618	−3.073
R^2	0.393	0.410	0.389	0.387	0.374	0.363	0.378	0.389	0.380	0.350
AIC	404.2	403.1	404.5	404.6	405.4	406.1	405.2	404.5	405.0	406.9
N of obs	1008	1008	1008	1008	1008	1008	1008	1008	1008	1008
Kerosene										
COVID-19 SI	−0.992	−23.041	−23.907	−26.250	−12.530	−30.746	−24.332	−24.445	−16.669	−23.452
R^2	−0.183	−0.388	−0.432	−0.316	−0.454	−1.138	−0.768	−0.858	−0.358	−1.298
AIC	451.0	457.4	458.7	455.3	459.3	474.7	467.1	469.1	456.6	477.6
N of obs	1008	1008	1008	1008	1008	1008	1008	1008	1008	1008

Notes: Country and monthly dummies are consistently included in the analysis. All coefficients are significant at the 0.1% level.

Table A4
Results of GBM Analysis with all countries

	Gasoline	Diesel	Kerosene
Country	*47.66*	*53.23*	*35.01*
Month	*22.48*	*22.15*	*16.05*
C1: School closures	*9.56*	*7.87*	*7.27*
C2: Workplace closing	*2.27*	*4.21*	*4.94*
C3: Cancel public events	*3.15*	*1.67*	*4.37*
C4: Restrictions on gatherings	*1.74*	*2.01*	*12.28*
C5: Public transportation	*0.46*	*0.45*	*0.19*
C6: Stay-at-home order	*1.40*	*1.08*	*0.44*
C7: Restrictions on internal movement	*8.57*	*1.66*	*1.59*
C8: International travel controls	*2.33*	*4.15*	*16.90*
H1: Public information campaigns	*0.37*	*1.52*	*0.95*

Table A5
Average percentage change in overall fuel consumption per country

Country	*Gasoline*	*Diesel*	*Kerosene*
Austria	−13.926	−10.773	−52.771
Belgium	0.028	−8.256	−18.319
Cyprus	−10.681	6.848	−42.779
Czechia	−5.534	0.978	−53.445
Germany	−8.723	−8.213	−35.136
Denmark	−5.119	−8.576	−49.404
Spain	−6.190	−7.626	−43.680
Finland	−7.168	−1.015	−54.434
France	2.083	−9.525	−42.853
United Kingdom	−14.680	−11.409	−46.720
Greece	−11.944	−0.165	−30.485
Croatia	−6.683	9.431	−40.105
Hungary	−1.604	−0.131	−38.692
Ireland	−21.454	−7.288	−44.049
Italy	7.624	−5.985	−46.755
Lithuania	7.812	−0.147	−38.013
Luxembourg	−12.921	−24.278	−12.997
Latvia	−7.614	0.762	−39.790
Netherlands	−12.536	−11.454	−34.054
Poland	2.297	3.077	−36.330
Portugal	−6.178	−7.044	−38.657
Sweden	−15.723	−7.575	−53.283

Table A6
Lasting effect with and without price effect per country

	Gasoline		Diesel		Kerosene	
Country	lasting effect without prices	lasting effect with prices	lasting effect without prices	lasting effect with prices	lasting effect without prices	lasting effect with prices
Austria	3.797	−7.646	5.886	−2.123	−4.485	−30.404
Belgium	−2.453	−10.422	3.712	−0.942	5.888	−0.661
Cyprus	6.222	−2.196	9.121	2.628	−5.838	−14.578
Czechia	3.234	−5.272	−0.404	−5.996	11.795	−7.306
Germany	8.476	−0.495	2.261	−5.719	−0.367	−20.094
Denmark	7.167	−2.006	6.365	−0.515	−1.837	−4.21
Spain	−1.725	−7.151	−0.11	−4.757	−7.644	−4.121
Finland	6.319	−4.42	0.684	−7.262	−9.729	−20.543
France	−3.666	−8.272	2.461	−1.502	10.276	−10.644
United Kingdom	4.719	−4.45	1.232	−4.307	1.134	−30.562
Greece	4.461	−3.642	−6.958	−12.483	−3.554	−28.137
Hungary	4.821	−3.503	−0.25	−4.347	−7.607	−18.356
Ireland	1.9	−6.161	1.556	−4.713	−6.05	−16.418
Italy	2.298	−1.375	0.346	−3.029	1.784	−54.577
Lithuania	−0.056	−11.628	7.011	−1.067	−3.543	−9.506
Luxembourg	3.956	−7.122	14.5	5.647	12.416	0.218
Latvia	11.435	−0.178	−1.552	−9.165	−9.66	−6.023
Netherlands	4.514	−1.961	6.852	0.305	11.36	−42.057
Poland	0.206	−9.653	2.505	−4.221	−10.842	−25.792
Portugal	−2.524	−8.597	−1.282	−5.979	−6.803	−14.68
Sweden	12.161	3.179	4.553	−3.287	−3.322	−14.532

Table A7
Results of the placebo test using quantile regressions and the period 2017–2019

	SI	C1	C2	C3	C4	C5	C6	C7	C8	H1
Gasoline										
COVID-19 SI	0.007	0.079	0.368	0.689	0.144	1.342	−0.209	−0.743	0.110	−0.061
R^2	0.404	0.404	0.405	0.405	0.404	0.406	0.404	0.405	0.404	0.404
N of obs	756	756	756	756	756	756	756	756	756	756
Diesel										
COVID-19 SI	0.031***	−0.444	0.742***	1.325***	0.286**	−0.163	−0.482	0.564	1.124***	2.602
R^2	0.315	0.314	0.306	0.319	0.315	0.313	0.313	0.314	0.319	0.321
N of obs	756	756	756	756	756	756	756	756	756	756
Kerosene										
COVID-19 SI	0.031	0.983	1.403**	0.743	0.340	−0.244	−0.383	0.561	−0.272	−2.504
R^2	0.282	0.283	0.284	0.282	0.282	0.282	0.282	0.282	0.282	0.283
N of obs	756	756	756	756	756	756	756	756	756	756

Notes: Country and monthly dummies are consistently included in the analysis. Asterisks ***, ** and * denote 1%, 5% and 10% statistical significance, respectively.

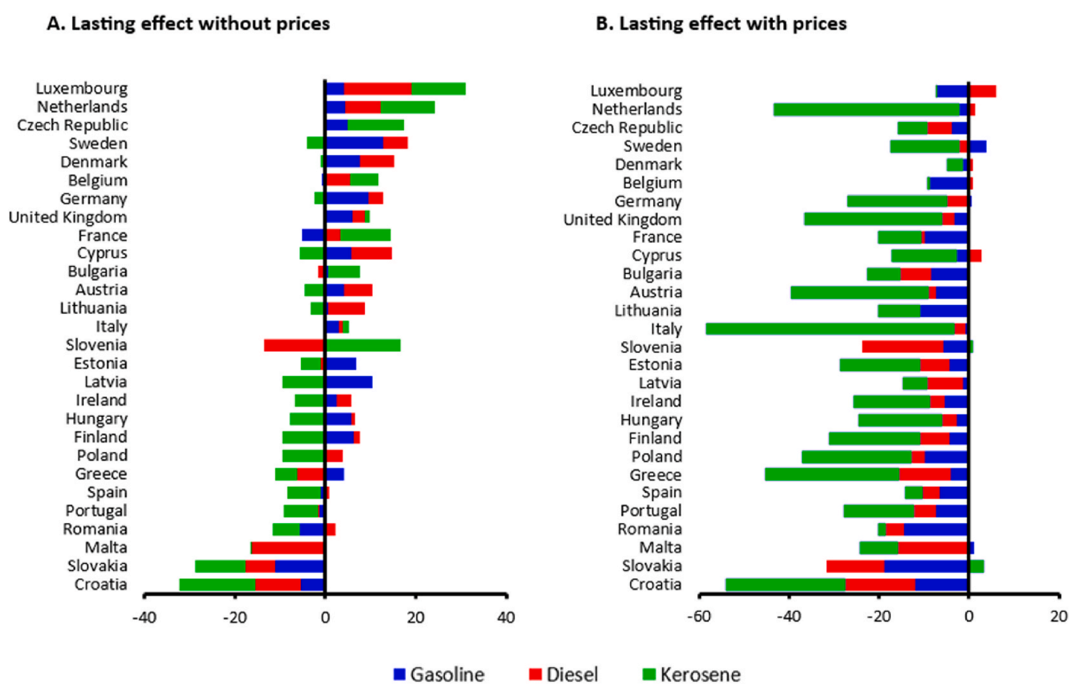

Fig. A1. Lasting effect with and without prices for all countries.

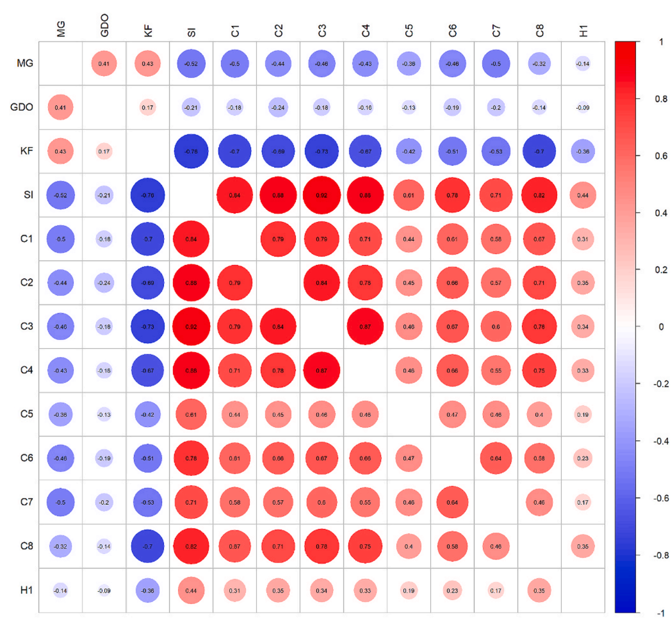

Fig. A2. Correlation plot of fuels, Stringency index and its component elements.

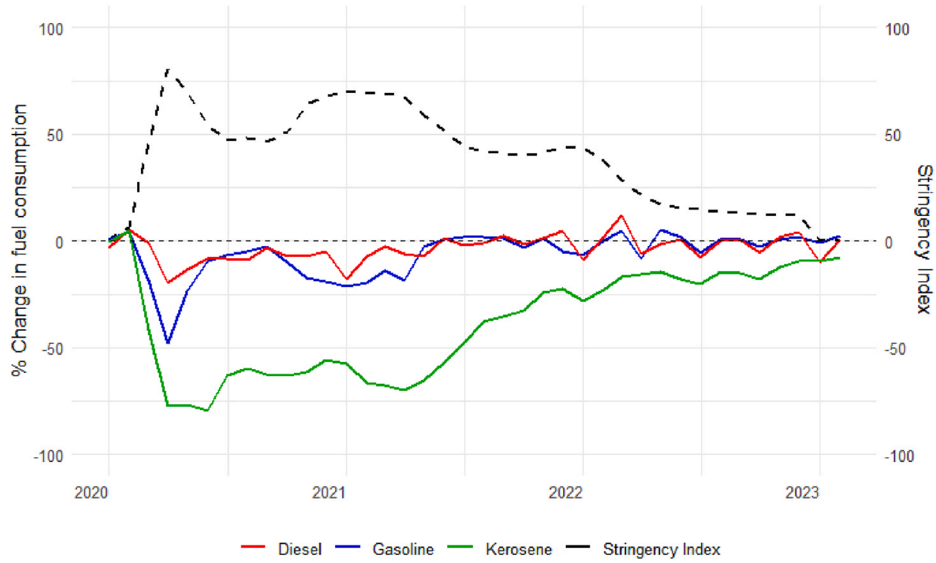

Fig. A3. Stringency Index and fuel consumption per capita in the EU27 and UK.

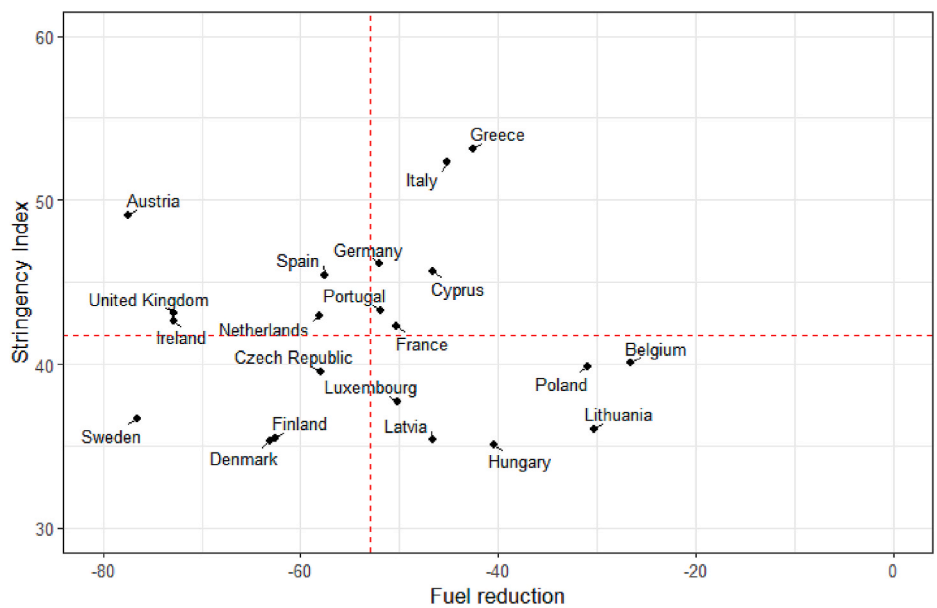

Fig. A4. Stringency Index and total fuel reduction.

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