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Universidad del País Vasco — Euskal Herriko Unibertsitatea

The transition towards low-carbon mobility: policies measures and consumer behaviour.

Author: *Alessandro Silvestri*

Directors: *Alberto Ansuategi* and *Sebastien Foudi*

Tutor: *Alberto Ansuategi*

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Abstract

The aim of this thesis is to analyse behavioural implications of low carbon mobility transition measures in order to identify potential barriers to and enablers of the successful implementation of mobility policies. To that end, three different types of measure are analysed: the introduction of a new mobility-as-a-service alternative; travel demand management strategies to shift away from private vehicle use; and restrictions on the most polluting vehicles. The three studies cover a wide range of potential strategies that are being implemented to bring about low carbon mobility. The analysis contributes by highlighting several barriers that have previously been overlooked in the existing literature.

The main results of the chapters demonstrate the need for specific policy measures to ensure the integration of car-sharing and its complementarity with public transport. It is also highlighted that those most sensitive to negative transport externalities are the drivers of private vehicles themselves, which suggests that policies aimed at raising awareness among drivers and habit breaking strategies can facilitate the modal shift towards public transport use and active travel. Lastly, the importance of guaranteeing the stability and application of low emission zones for the most polluting private vehicles in order to maintain their effectiveness is shown.

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Resumen extendido Tesis doctoral:

The transition towards low-carbon mobility: policies measures and consumer behaviour.

1. Introducción y objetivos

El cambio climático provocado por la emisión de gases de efecto invernadero es uno de los retos más urgentes a los que se enfrenta la sociedad moderna. Para limitar sus efectos negativos en el futuro se necesitan esfuerzos significativos en cada sector de la economía. En Europa, el transporte, especialmente el de carretera, es uno de los sectores que más contribuyen a las emisiones de gases de efecto invernadero.

La hoja de ruta europea para el consumo de energía baja en carbono prevé una reducción de 60% en la intensidad de emisiones del transporte para el 2050 con respeto a los niveles del 1990.

Para este objetivo, es necesaria una transición hacia una movilidad baja en carbono, lo que implica reducir las emisiones del transporte en términos de intensidad por viaje y/o reducir la duración y la frecuencia de los desplazamientos. Para garantizar el éxito de esta transición, se debe disponer de instrumentos que influyan en las decisiones de los consumidores en relación al modo de transporte elegido. Sin embargo, el éxito de estas medidas también dependerá de su aceptación por parte de la ciudadanía y de la disposición de esta para cambiar sus hábitos de transporte.

En este contexto, la presente tesis analiza las implicaciones en términos de comportamiento de algunas de las medidas más relevantes para impulsar la transición hacia una movilidad sostenible, con el objetivo de evidenciar potenciales barreras y facilitadores de la transición energética y extraer recomendaciones para mejorar las políticas para la transición hacia una movilidad baja en carbono.

Tres conjuntos de medidas han sido considerados con este propósito: el apoyo a la difusión de servicios de movilidad alternativos; medidas enfocadas en fomentar un cambio modal hacia un mayor uso del transporte público y de modos de transporte activo; y, restricciones directas al acceso en entornos urbanos de los vehículos más contaminantes para reducir los niveles de concentración de contaminantes locales y promover la renovación del parque móvil con vehículos de combustibles alternativos.

En el caso del apoyo a servicios de movilidad alternativos, se ha estudiado la reciente introducción y difusión del coche compartido (carsharing) en diferentes ciudades en España. A través de entrevistas en profundidad con usuarios y agentes relevantes del sector se ha procedido a identificar la contribución de esta alternativa a la movilidad baja en carbono con particular énfasis en la relación que ésta tiene con el transporte público.

En cuanto a las medidas de fomento del cambio modal, se ha realizado y analizado un cuestionario sobre costumbres de movilidad en 5 países europeos. El objetivo del análisis ha sido la identificación de actitudes y factores demográficos y de comportamiento que influyen en la toma de decisiones de movilidad. El análisis contribuye a la literatura en el tema considerando el impacto de la opinión sobre políticas de movilidad sostenibles y la percepción de externalidades negativas del transporte en las decisiones de modos con el que desplazarse.

Con respeto a las restricciones directas de acceso a zonas urbanas aplicadas a los vehículos más contaminantes, se ha analizado el impacto de la zona de bajas emisiones denominada Madrid Central en la reducción de las concentraciones de dióxido de nitrógeno y en la compra de vehículos alternativos. El objetivo del estudio ha sido la evaluación de la eficacia de este tipo de medidas para mejorar la calidad del aire en entornos urbanos e incentivar la compra de vehículos de combustibles alternativos.

2. La contribución del carsharing a la movilidad baja en carbono

Los servicios de vehículo compartido (carsharing) han atraído interés como alternativa al uso y la compra de coches privados en entornos urbanos y se ha implantado en diferentes ciudades de España. Para valorar su papel en la movilidad sostenible es necesario analizar en qué medida complementa o sustituye al transporte público y el coche privado.

A través de entrevistas en profundidad con usuarios de distintos modelos de coches compartidos en Madrid y Barcelona se ha analizado la relación entre el carsharing y los otros modos de transporte en ámbito urbano. Una serie de entrevistas con agentes relevantes del sector privado, el sector público y diversas asociaciones han servido para completar una visión panorámica del carsharing en España.

El estudio muestra la limitada complementariedad del carsharing con el transporte público, así como la escasa sustitución del coche privado con el coche compartido. En unos casos el servicio ha contribuido a crear nueva demanda de movilidad, facilitando el uso de un vehículo a segmentos de la población que en otras circunstancias no habrían elegido desplazarse. Por otra parte, se muestra que la presencia del servicio puede reducir la necesidad de tener un coche, y también ha permitido experimentar por primera vez el uso de vehículos eléctricos a la mayoría de los usuarios entrevistados.

Se concluye que para asegurar la contribución del carsharing a la movilidad baja en carbono son necesarias políticas directas que favorezcan la integración y complementariedad de éste con el transporte público, si bien es cierto también que las ventajas de fácil conexión y uso personal que el carsharing tiene con respecto al transporte publico tendrán que verse reflejadas en un mayor precio del servicio.

3. Reduciendo el uso del coche privado

Reducir el uso del coche privado en las áreas urbanas es otro paso necesario en la descarbonización de la movilidad. Para poder desarrollar políticas que puedan empujar a las personas a hacer este cambio de manera efectiva es fundamental una comprensión profunda de los determinantes de la elección del modo de viaje. Este capítulo analiza los factores socio-demográficos y las actitudes que influyen en las decisiones de los consumidores sobre su movilidad diaria.

El estudio analiza en particular la elección del modo en los desplazamientos al trabajo y en los viajes para las compras diarias, teniendo en cuenta las actitudes hacia la movilidad, los factores socioeconómicos y las características del viaje. Se realiza una regresión logística multinomial sobre datos de encuestas de 5028 hogares en cinco países europeos (Hungría, Italia, Polonia, Noruega y España) para describir la elección entre el vehículo privado, el transporte público y los modos de transporte activo.

El capítulo contribuye a la literatura sobre elección de modo de transporte, considerando medidas para la percepción de las externalidades negativas del transporte (es decir, los impactos negativos indirectos de la actividad del transporte por carretera) y el apoyo a las políticas de transición de movilidad sostenible.

Los resultados muestran que los viajeros más sensibles a las externalidades negativas del transporte prefieren los vehículos privados al transporte público o al viaje activo. Esto sugiere que puede existir una paradoja con respecto a la percepción de estas externalidades y es necesario dirigir las políticas a cambiar hábitos o sensibilizar sobre la contribución del vehículo privado a las externalidades del transporte para favorecer el cambio modal hacia el transporte público y los modos de transporte activo.

Otros factores, como las características del viaje, el apoyo a la intervención pública y el tamaño de la familia, también tienen una fuerte influencia en la elección del modo. El desarrollo de zonas mixtas residenciales y comerciales y servicios de compra online pueden ayudar en reducir el uso de coche privado en los viajes para las compras diarias.

4. El impacto de Madrid Central

Las Zonas de Bajas Emisiones (ZBEs) son instrumentos diseñados para mantener una buena calidad del aire en las ciudades restringiendo el acceso de los vehículos más contaminantes a determinadas áreas geográficas. Sin embargo, las ZBEs implican también un incentivo para la adquisición de vehículos que están exentos de las restricciones. Este estudio pretende analizar la eficacia de la ZBE implantada en Madrid en diciembre 2018, conocida como “Madrid Central”, en la reducción de las concentraciones locales de dióxido de nitrógeno (NO2) y en la adquisición de vehículos de combustibles alternativos en la ciudad y su área metropolitana. El estudio aplica el método de control sintético robusto, que permite comparar las concentraciones de NO2 y las ventas de coches de combustibles alternativos en el área en cuestión con una situación que representa cómo habrían evolucionado en ausencia de intervención. Los resultados muestran que la política fue efectiva a la hora de reducir las concentraciones de NO2 y aumentar las matriculaciones de vehículos de combustible alternativos en los primeros meses tras su introducción, pero el efecto desapareció casi por completo en la segunda mitad de 2019.

Una posible explicación de este resultado es que la nueva administración local, que se opuso a la política, generó una falta de credibilidad sobre la futura aplicación de la medida, lo cual anuló su efectividad. Por lo tanto, garantizar la credibilidad, la estabilidad y la aplicación firme de las restricciones al acceso de vehículos en zonas urbanas es fundamental para que surtan el efecto deseado. Es por ello importante que las ZBEs incorporen mecanismos que eviten su reversión prematura.

5. Conclusiones

El objetivo de esta tesis es analizar las implicaciones conductuales de las medidas de transición a la movilidad con bajas emisiones de carbono con el fin de identificar las posibles barreras y aspectos facilitadores para la aplicación exitosa de las políticas de movilidad. La tesis doctoral está compuesta por tres estudios que analizan diferentes medidas dirigidas a reducir el uso de vehículos privados con combustibles convencionales. Para cada una de estas medidas se han evidenciado diferentes barreras y factores que influyen en su eficacia.

Algunas recomendaciones de política de movilidad sostenible que se derivan del análisis de las diferentes medidas serían los siguientes: la necesidad de acompañar la introducción del vehículo compartido con intervenciones que promuevan la complementariedad entre el carsharing y el transporte público; la necesidad de políticas enfocadas a la concienciación de los conductores sobre los efectos externos generados por el vehículo privado; y garantizar la credibilidad, estabilidad y aplicación de las ZBEs incorporando mecanismos o procedimientos que eviten su reversión prematura.

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Chapter 1

Introduction

1. Background and Motivation

Climate change is one of the most urgent issues modern societies are facing. To maintain the global temperature-rise within the limits set by the Paris Agreement, that is below 2°C, and pursue efforts to limit it to a 1.5°C increase by 2100 with respect to pre-industrial levels, substantial efforts are required in reducing greenhouse gases (GHG) emissions in all sectors of the economy.

In Europe, the transport sector alone accounts for nearly 26% of total GHG emissions, of which about three quarters comes from road transport (European Commission, 2016). Moreover, road transport emissions have increased continuously since 1990, regardless of the efforts made in increasing vehicle efficiency and reducing emissions from fuel combustion (EEA Report No 5/2018). In this context, the role of urban mobility will be particularly crucial in the coming decades since 82% of the population is expected to live in urban areas by 2050 (United Nations, 2018). The European roadmap to low carbon energy consumption expects the emission intensity of road transport to be 60% lower by 2050 than in 1990 and to continue decreasing towards zero emissions (European Commission, 2021).

Future mobility will need to be low-carbon and sustainable, meaning that it should ensure the fulfilment of future generations' mobility needs while doing as little damage as possible to the environment in terms of both GHG emissions and other local air pollutants (Banister et al., 2011). Reducing the carbon intensity of road transport requires more efficient mobility, which entails two main complementary effects: an intensity effect, i.e. a reduction in the emissions intensity of the travel mode necessary for a given trip; and a scale effect, i.e. a reduction in the scale of mobility needs by reducing the frequency and length of trips, or by using tele-working or e-grocery.

In the long term, the intensity effect requires efforts to develop and disseminate suitable alternative vehicles with increased efficiency, such as electric and alternative fuelled vehicles, which can perform better than internal combustion engines[1]. Another way of reducing emissions from travel modes is to switch away from private vehicle use towards modes such as public transport and shared mobility or active travel (cycling and walking) (Cass and Faulconbridge, 2016).

The second effect entails reducing the scale of mobility needs. This might occur in the long term through the above-mentioned urbanisation process, but can also be influenced by developing mixed residential-commercial neighbourhoods (Cass and Faulconbridge, 2016). In an extreme case this pathway would include the total removal of the need for travelling, for instance through working-from-home solutions rather than commuting or e-grocery options (Bjørgen et al., 2021).

[1]Nonetheless, electric mobility may have different impacts in terms of reduced GHG emissions based on the specific energy mix used to produce electricity, with efficiency being severely affected in areas where electricity production relies heavily on burning coal and other fossil fuels (Ajanovic, 2015).

Nonetheless, specific short-term policy measures are fundamental in encouraging and ensuring a successful transition towards such a low carbon mobility. These policy efforts can be directed towards either demand- or supply-side management.

With respect to demand-side management, instruments can influence mobility choices by targeting private vehicles through fuel taxes and road tolls (Hilton et al., 2014; Ubbels et al., 2002). Similar interventions could favour public transport by reducing fares and giving special discounts to sensitive groups (Bachman and Katzev, 1982; Möser and Bamberg, 2008). Policy packages that reuse tax revenues from pricing private vehicle use so as to subsidise public transport have proven particularly effective (Brand et al., 2013; Harrington et al., 2001; Hilton et al., 2014). Moreover, policies can be directed at reducing demand for transport, for instance by favouring work from home and compressed workweeks or by reducing distances by promoting mixed commercial and residential or high-density urban development (Cass and Faulconbridge, 2016). Command and control measures, such as Low Emission Zones (LEZs), can also be implemented to restrict access to certain urban areas for the most-polluting vehicles and incentivise a switch towards more efficient vehicles or modes (Holman et al., 2015; Wolff, 2014).

With respect to supply side management, policy instruments can be directed at increasing public transport coverage and frequency and at improving its quality (Idris et al., 2015). They can also provide a grounding for extending carsharing and other mobility options as alternative services which can help shift the balance away from private vehicles (Ceccato and Diana, 2018). Apart from modal shifts, a reduction in road transport emissions can also be encouraged by improving traffic flow, as congestion is in itself a cause of additional emissions (Figliozzi, 2011).

The success of any low-carbon mobility transition policy heavily depends on how the public perceives and reacts to it. If there is one thing that low carbon transition policies have in common it is that they require consumers to make significant behavioural changes. Whether it is the embracing of multimodality, breaking private vehicle driving habits or the uptake of electric vehicles, much of the success of these policies depends on the actual predisposition of consumers to make such changes. Hence, a thorough understanding of consumer behaviour is fundamental in order to ensure these policies meet their goals.

2. Objectives and methodological approach

The main aim of this thesis is to investigate the behavioural implications of some of the main low carbon mobility transition measures in order to gain insights into potential barriers and enablers that they may encounter. The ultimate goal is to derive policy recommendations that can help ensure a successful transition to low-carbon mobility.

Three main measures have been identified as drivers of mobility transition in urban areas: support for the extension of mobility-as-a-service (MaaS) options; measures to foster a shift away from private vehicle use towards public transport and active travel; and direct restrictions on polluting vehicles to reduce local air pollution and incentivise the uptake of alternative-fuelled vehicles.

For each of these policies, an appropriate methodological approach has been selected to identify relevant behavioural aspects, taking into consideration the existing literature on the topic, data availability and specific research goals.

For the "support for MaaS" options, the recent introduction and extension in several Spanish cities of carsharing is analysed. This mobility alternative has attracted significant interest in recent literature as it can play a crucial role in shifting away from private vehicle use and can facilitate multimodality. However, the lack of publicly available data and monitoring limits the possibility of performing a quantitative analysis of their impact on urban mobility. An exploratory study based on in-depth interviews with carsharing users was therefore performed. The aim was to understand people`s motives and behaviour related to carsharing use in order to assess its the extent to which it can complement and replace other urban modes. In order to complete the description of this market, the study is supplemented by interviews of supply-side stakeholders from business, public administration and associations. The analysis highlights the complementarity and substitution properties of the different modes of CS in regard to public transport and private vehicle use.

In the case of measures to encourage a shift away from private vehicle use, a mobility survey has been conducted in five European countries (Hungary, Italy, Norway, Poland and Spain) to assess routine mobility choices and the attributes affecting them. First, an extensive analysis of descriptive statistics was undertaken to highlight differences and similarities in mobility between the five countries considered. Secondly, a discrete choice model approach was used to analyse the impact of different attitudes and demographic aspects on mode choice for commuting and grocery shopping. This analysis fits into a large body of literature on travel mode choice and contributes by specifically taking into consideration people's opinion on sustainable transition policies and perception of externalities and their connection with actual travel behaviour. This analysis highlights a paradox between the use of private vehicles and the perception of negative externalities: drivers who are highly sensitive to negative externalities continue to use their cars.

The last type of measure considered is direct restrictions on access to particular zones for the most-polluting vehicles. In this case, the impact of the recently implemented LEZ in Madrid is analysed. The aim of this case study is twofold: first, to determine the impact of the policy on reducing local concentrations of nitrogen dioxide, which was the main aim of the measure; and second, to assess its impact on the uptake of alternative fuelled vehicles, which contribute most to the transition to a low carbon mobility. The study takes into consideration the behavioural implications of the political debate concerning the policy since its implementation. It also provides a novel method in the context of LEZ and transport policy literature, as it uses the so-called synthetic control method rather than regression estimators. This enables us to track the level of effectiveness of the policy over time with extremely low data input, as it is robust to external confounders. This study is the first attempt at using this method for estimating policy impact on pollution and vehicle fleet renewal.

The structure of the thesis is the following: Chapter 2 analyses the contribution of carsharing to low carbon mobility through its interconnections with public transport; Chapter 3 investigates the role of the factors affecting routine mobility behaviour and travel mode choice in the transition towards low carbon mobility; Chapter 4 assesses the impact of Madrid's LEZ on local air pollution and the uptake of alternative-fuelled vehicles; and Chapter 5 discusses the behavioural and policy implications of the main outcomes of the three previous chapters. Chapter 6 reports the main conclusions of the thesis.

Chapter 2

The contribution of carsharing to low carbon mobility: complementarity and substitution with other modes

The research presented in this chapter has been developed within the H2020 project ENABLE.EU (Enabling the Energy Union), 2017-2019. The aim of the project was to define the key determinants of individual and collective energy choices in three key consumption areas - mobility, heating & cooling and electricity - as well as in the shift to prosumption.

The following publications derived from the research conducted in this chapter:

- ***Silvestri, A.**, Foudi, S., Galarraga, I., Ansuategi, A., 2021.* The contribution of carsharing to low carbon mobility: Complementarity and substitution with other modes. *Research in Transportation Economics*, 85, 100968.

- ***Silvestri, A.**, Foudi, S., Galarraga, I. (BC3), Schøyen Jensen, E., Kallbekken, S. (CICERO), Gaggi, S., Proietti, S. (ISINNOVA), Bieliszczuk, B., Skorupska, A. (PISM), Bartek-Lesi, M., Diallo, A., Felsmann, B., Vekony, A. (REKK). 2019.* D 4.2 Synthesis report on the "low carbon mobility" case study. *H2020 project Enable EU (Enabling Energy Union) deliverable.*

- *Foudi, S., **Silvestri, A.**, Galarraga, I. (BC3), Bartek-Lesi, M., Diallo, A., Csutora, M. (REKK). 2019.* D4.6 Final report on social and cultural factors impacting energy choices and behaviour. *H2020 project Enable EU (Enabling Energy Union) deliverable.*

1. Introduction

Carsharing is a short time automobile rental service where the users pay a fee proportional to the use of the vehicle (Shaheen and Cohen, 2013). The service operates mostly in urban areas and rental periods range from a few hours down to a few minutes ride. The mode has attracted interest as an alternative to private vehicle use, and also in areas where other modes are available (Millard-Ball, 2005). The need to decrease dependence on private and conventionally-fuelled vehicles for mobility, which are a primary source of GHG emissions in Europe (European Commission, 2016) suggests that this mode can potentially play a role in decarbonising the transport sector. The European Commission, in its strategy towards a low emission mobility, considers carsharing services to stand along with the actions that should be promoted by local authorities to reduce congestion and pollution (EC MEMO/16/2497).

Of particular interest is the analysis of how carsharing interacts with other modes, namely public transport and private vehicles, in the urban context. To contribute to lowering transport externalities, apart from substituting private vehicle use, this mode is expected to complement public transport and other mobility alternatives (Shaheen and Chan, 2016). The complementarity property refers to an increase in carsharing use being associated with an increase in public transport use. This implies that those who start using carsharing services should increase their use of public transport. However, as they are both urban travel modes, carsharing can instead substitute public transport use (Martin et al., 2011; Rotaris et al., 2019). Having people shifting away from public transport use towards carsharing instead of doing it from private vehicle use to carsharing, the carsharing's potential contribution to low carbon mobility is marked down.

The overall limited diffusion of carsharing makes it difficult to quantify its impacts on other modes' use. However, a deep understanding of carsharing users' perceptions and preferences towards the mode as well as the elicitation of the comparative advantages and disadvantages with respect to public transport and private vehicle can highlight the aspects that can favour or limit the complementarity with public transport as well as its potential to substitute private vehicle use.

The aim of this chapter is hence to contribute to the analysis of the complementarity and substitutability between carsharing services and public and private transport modes. Previous studies focusing on the relation between carsharing and other modes provide mainly quantitative-based evidence and are lacking a thoughtful explanation of the means behind mode substitution. A deeper understanding of the reasons why a mode is preferred to or complements other modes will contribute to highlighting the main drivers of the transport mode decision and providing guidance for low carbon mobility policies.

Qualitative analysis may give important insights into this aspect and enable us to consider the heterogeneity of users' preferences. A series of in-depth interviews have been conducted with carsharing users, capturing their experiences, opinions and preferences towards this mode and the relation with their use of public transport and private vehicles. To do so, deeper insights are gained into the motivations for adopting and using carsharing; and then, it is analysed how public transport and private vehicles are perceived and how their use has changed with carsharing use. It will be then possible to discuss how policy measures can support diffusion of carsharing services and limit the risk of shifting away from public transport rather than shifting away from private vehicle use.

Moreover, this study is accompanied by a series of interviews with stakeholders from administration, business and associations related with carsharing and urban mobility that help picturing the current development of carsharing in Spain as well as highlighting the economic and policy aspects that might influence its diffusion and complementarity with other modes. The focus of this analysis is the Spanish carsharing system as it offers a market with different carsharing operators in different cities.

The next section introduces the current status of carsharing in Spain. Section 3 reviews previous related works. Section 4 describes the methodology applied in this study. Section 5 presents the findings, which are discussed in section 6. Finally, section 7 draws the main conclusions.

2. Carsharing in Spain

The term carsharing comprises several business models in shared private transport services in urban areas that can differ with respect to the parking system and the type of journey. According to the parking system, business models can be classified in free-floating (FF), where vehicles are freely parked on the streets, and station-based (SB), where these occupy a specific reserved parking lot. The type of journey can be either "one-way", where users take the vehicle from a location and leave it at another within a restricted area, normally the urban centre, or "two-way" (or "round-trip"), where the vehicle must be returned to the same place where it was booked. Different modes are likewise often connected with different rates, with SB carsharing normally charging per-hour rates, whereas FF carsharing charges per-minute rates. Given that in the Spanish case FF carsharing is one-way and SB carsharing is two-way, this distinction will be maintained in the rest of this chapter.

At the time of conducting the interviews (2018), seven major companies were offering carsharing services to consumers in Spain. Four of them operated under a SB round-trip model. Users of this mode booked the vehicle by paying a constant rate per hour (ranging between 3-10€), plus an amount per kilometre depending on the vehicle fuel (around 0.30€ per kilometre for the gasoline). The service offered the possibility to pay a monthly fee to have lower prices per use as well as an alternative full day rental tariff. The four carsharing companies using this model (Avancar, Bluemove, Clickar and

Respiro) started to operate in the period between 2004 and 2010 in the cities of Barcelona, Bilbao, Madrid, Palencia and Seville.

From 2015 onwards, three other companies began operating in Madrid using an FF one-way model, exclusively based on 100% battery electric vehicles (BEVs). Users of this mode paid a rate of about €0.20 to €0.25 per minute (in 2018), with no specific costs per kilometre.

Madrid had approximately 1,500 FF carsharing vehicles and around 350 vehicles for SB carsharing. Barcelona had the second-largest concentration of vehicles with about 450 shared cars, while Bilbao, Seville and Palencia had a smaller number of vehicles.

From 2018, one new company (Wible) started offering a hybrid FF service in Madrid with an extended area with respect to competitors, while a company in in Barcelona (Avancar) stopped offering the service.

3. Literature review

FF and SB carsharing have been mostly analysed separately in the literature. However, Namazu and Dowlatabadi (2018) explored the impact of both these modes on vehicle ownership reduction. They found round-trip carsharing to be more effective in reducing car ownership, arguing that it directly substituted private car use, while FF carsharing represented an additional mode in multi-modal trips.

Carsharing is found to offer a cheaper alternative to private car use and ownership for households that have an average annual car use below 15,000 kilometres (Litman, 2000) and this could potentially contribute to the transition toward low-carbon mobility by reducing car use (Rabbitt and Ghosh, 2016). In fact, Nijland and van Meerkerk (2017) found carsharing users to reduce their car use by 20% compared with prior conditions, while Martin and Shaheen (2011) found vehicle kilometres travelled decreased by 27%. Carsharing could also reduce the need for owning a vehicle in households, especially with respect to a second and third vehicle (Le Vine and Polak, 2017; Mishra et al., 2015; Nijland and van Meerkerk, 2017).

A previous attempt at analysing carsharing usage motives could be found in Schaefers (2013), although no connection was provided towards the problem of complementarity and substitution with other modes.

In the urban context, carsharing cohabits with public transport. Common to both modes are the concepts of access-based mobility and shared mobility (Smith et al., 2018). The former refers to mobility being independent from the ownership of the vehicle, and whose cost is to a large extent proportional to the use of the mode. While it is ‘shared’, as different people can have access to it at the same time, as in the case of public transport, or in different moments, as in the case of carsharing, this also stands for other forms of shared mobility, such as bike-sharing. Several studies sought to assess the relationship between these modes. Ceccato and Diana (2018) stated that carsharing complemented well with bike-sharing, and to some extent, public transport as well, finding that carsharing users were more likely to use these modes. However, Martin et al. (2011), surveying carsharing users, found that a large part of them reduced their rail and bus use after joining the service. More recently, Rotaris et al., (2019) have found carsharing to mainly substitute private vehicle use, even though it has also a negative impact on public transport use, especially in the FF model. Furthermore, Tyndall (2019) has studied the effect of a transit outage in Vancouver on FF carsharing demand, finding evidence of an extemporaneous substitution between the two. Hence, shedding light on the relation between these two modes may help us assessing the resulting environmental benefits of carsharing (Jung and Koo, 2018).

4. Methodology

Data were collected with semi-structured interviews applied to two groups: the users and the stakeholders. The user group comprised individuals who regularly used the service during the last year. The stakeholder group included representatives of carsharing companies, public administration and sectorial association. Below, the subsampling method and the interview guideline of each group are presented, as well as the method of analysis.

a. Sample selection and description

Table 2.1 reports characteristics of the carsharing user sample. The sample of carsharing users consisted of 15 individuals selected in order to ensure the representation of different gender and age groups. Three age groups were defined: younger than 34 years old, from 34 to 45 and older than 45. The sample also included users with children and without children, as well as living or not living with their partner, given the different needs these groups might have. Each group was represented by at least three interviewees. 10 out of 15 individuals own or have a private car accessible to use in their household. The table also reports the stated use of public transport. Moreover, the study involved users from FF as well as SB carsharing, and covering 5 of the 7 main Business-to-Consumer companies operating in Spain (Car2Go, Emov, Zity, Avancar, Bluemove) in 2018.

Interviewees were recruited through a survey company (CPS)[2] and conducted between 19-26 February 2018. Interviews were conducted by the analyst, face-to-face in hotel lobbies or coffee shops at a convenient location for the interviewee and lasted for around one hour. The fifteen in-depth interviews were conducted in the cities of Madrid and Barcelona. A monetary remuneration was given to the interviewees to incentivize their active participation, as it added an additional motivation (Robinson, 2014).

[2] www.cps2000.com

Table 2.1 Carsharing user's sample

Interviewee	Gender	Age	Number of children	Living with Partner	Private car	PT use	Carsharing Type*
1	Female	31	2	Yes	Yes	Everyday	SB/FF
2	Male	36	2	Yes	Yes	Occasional	FF
3	Male	31	0	Yes	Yes	1-2/Week	FF
4	Male	46	0	Yes	No	Everyday	FF
5	Male	55	3	Yes	Yes	Occasional	FF
6	Male	45	0	Yes	Yes	Occasional	FF
7	Female	42	0	Yes	Yes	Occasional	FF
8	Male	25	0	No	Yes	Occasional	FF
9	Female	37	0	No	Yes	1-2/Week	FF
10	Female	25	0	Yes	Yes	1-2/Week	FF
11	Male	26	0	Yes	Yes	Occasional	FF
12	Male	35	0	Yes	No	Everyday	SB
13	Male	38	0	Yes	No	Everyday	SB
14	Male	33	0	No	No	1-2/Week	SB
15	Male	44	0	No	No	Everyday	SB

The age of the participants ranged from 25 to 55. Participants between 25 and 45 years old were almost evenly distributed, with at least 3 participants for each 5-year interval. There was a disproportion in gender with a majority of males (11) with respect to females (4). However, this can be considered in line with typical socio-demographic characteristics of carsharing users in Europe (Loose, 2010; Prieto et al., 2017). 11 out of 15 interviewees were living with their partner and 3 of them had children. The sample included representatives of both high school and graduate level education, with two of them currently studying at the university. All the interviewees were working, the majority of them as employees in public or private institutions, while two of them were freelance workers. The sample included 10 FF and 4 SB carsharing users. One interviewee was a recurrent user of both types of carsharing services. In both cities, the sample included people living in and outside the city centre.

Table 2.2 reports anonymised information on the final stakeholders' sample. Stakeholders were selected in order to represent three groups: the business sector, the public administration and associations. Each of these groups was represented by at least four stakeholders.

With respect to the business stakeholders, all carsharing companies operating in Spain in early 2018 were contacted, with the only exception being those businesses working exclusively with companies (company vehicle fleet management). 5 out of 7 operating companies positively answered the call.

With regard to public administration stakeholders, the regional, provincial and municipal authorities for the cities of Madrid, Barcelona and Bilbao were contacted. These three cities were selected because they could cover an area where all the 7 companies active in Spain operated (in

Seville and Palencia, the service was provided by companies headquartered and operating mainly in Madrid).

Table 2.2 Stakeholder sample

Business		
Code	**Type of Carsharing**	**Operating in**
B1	SB	Barcelona
B2	SB	Bilbao
B3	SB	Madrid-Barcelona-Seville
B4	SB	Madrid-Palencia
B5	FF	Madrid
Public Administration		
Code	**Area**	**Level**
P1	Bilbao	Province
P2	Barcelona	Province
P3	Madrid	Municipality
P4	Bilbao	Region
Associations/pressure groups		
Code	**Sector**	**Level**
A1	Carsharing	National
A2	Carsharing	Local
A3	Public transport	National
A4	Electric vehicles	National

The transport and environment authorities in the areas of Madrid, Barcelona and Bilbao were also contacted. For each of these areas, the institutions at municipal, provincial and regional levels were considered. 4 out of the 9 institutions contacted decided to participate in the study.

With respect to sectoral associations, all major national associations related to urban road transport were contacted: public transport association, car manufacturer association, taxi driver association.[3] Moreover, two carsharing associations were contacted, one operating at a national and the other at a local level; they ranged between a national and a local area of influence. A national company operating in the electric vehicle recharge infrastructure was also included.

The final sample comprised 13 stakeholders: 5 from carsharing businesses, 4 from public administrations and 4 from associations/pressure groups. Companies from both types of carsharing

[3] Taxi driver associations and car manufacturers were contacted but decided not to participate in the study

services were represented. All SB carsharing companies and 1 out of 3 FF companies participated in the study. Stakeholders' contacts were first identified online and then contacted via email to explain the study and its objective.

b. Interviewing process and topic guidelines

The users' interviews were semi-structured and based on a common topic guideline. The semi-structured nature of the interviews implied that there was not an explicit list of questions repeated in order in each interview, but rather a list of pieces of information reported in an interview guideline the interviewer made sure to retrieve with each person (Malhotra and Birks, 2007; Symon and Cassell, 2012).

A guideline was elaborated and several blocks were defined in order to gather the information necessary to understand the complementarity and substitutability of carsharing with other modes. The guideline consisted of 5 different blocks (see Appendix 1.I section A). The first block aimed at warming up the conversation, obtaining basic information on the interviewees, specifically their weekly routine and their typical use of the carsharing service. The second block focused on the factors influencing the subscription and the use of the service. Interviewees were asked to tell how they discovered the carsharing service and what made them start using it. The most important attributes affecting their use of carsharing were retrieved mainly in this phase, although the interview allowed for other factors to come up in the discussions. At the end of the interview, users were asked to relist and rank them by order of importance. The third and the fourth blocks were the central block of analysis of complementarity with other modes. The third block focused on the relation with public transport, aiming at understanding how different public transport modes were compared to carsharing and how their use changed after subscribing carsharing services. Users were first asked about the advantages and disadvantages of each public transport mode (metro/tram, bus and taxi) by itself, and then to compare carsharing with each of them. The fourth block focused on the relation with the private vehicle. In particular, they were asked whether their use of the private vehicle changed after joining a carsharing service and how this service could influence their need for a private vehicle. Also in this case, users were asked about the advantages and disadvantages of private cars, and to compare the mode with carsharing directly. The fifth block closed the interview and focused on possible future developments of the service[4].

Topic guidelines for stakeholders' interviews consisted of 5 sections (see Appendix 1.I section B). The first block was aimed at warming up the conversation and gathering information on the

[4] Users were also asked in this section about advantages and disadvantages of electric vehicles and whether they preferred them compared to conventional ones. Users were specifically asked whether they would have been willing to pay a price premium for the service offered with electric vehicles compared to the conventional one.

stakeholders and the institution they represented as well as their view of the carsharing sector and its development. The second block explored the facilitation of carsharing. In particular, it focused on the motivations to implement and develop this service further, the main policies and social characteristics that could facilitate its success and its contribution to urban mobility. The third block looked at the relation between carsharing and other modes of transport within the urban context and what changes the introduction of carsharing could imply. The fourth section was specific to the stakeholder group. The Business stakeholder group was asked about details on the carsharing market, whether they benefited from any support, whether they targeted a specific group of people and if they had specific aims to provide an environmentally-friendly service. The Public Administration group was asked about measures to combat transport-related problems, how the decisions were made in this context and what role was intended for electric carsharing in urban mobility planning. The pressure groups were asked about the mission and vision of their institutions and about their strategy to achieve it. Finally, all stakeholders were asked how they perceived the relation with the other actors in the field and about their vision regarding the future of the sector. The interviews were conducted in the cities of Barcelona, Bilbao and Madrid, usually at the offices of the companies/institutions.

c. Method of analysis

Interviews were digitally recorded and then transcribed. For carsharing users, these were analysed following a template analysis method (Symon and Cassell, 2012). This methodology consists in developing an a priori and hierarchical set of codes: labels for indexing sections of text related to a specific theme. This set of codes forms an initial template into which the information flows. The template is flexible and can be adapted to include information the analyst did not expect. New codes are added to the template upon the first analysis of the transcripts, then a second analysis ensures the new codes have been considered for each interview. This allows including important themes in the analysis that were not initially considered by the analyst. In this case, the *a priori* codes were set after the first transcription of interviews with the highest hierarchical level following the topic guidelines structure. After a deeper review of the transcripts more detailed codes were set to better account for heterogeneity of preferences, in particular with respect to alternative travel modes available. A table was developed following the topic guidelines to include all comparable information in the same structure. Each row in the table referred to a single interviewee, while each column was dedicated to collecting information on a specific code. Appendix 1.II reports the final template coding of the interviews.

When discussing the advantages and disadvantages of the different travel modes, as well as motives for carsharing use, interviewees were asked to list a series of attributes. In most cases, interviewees used different wording to express the same attribute. Hence, these went through a homogenisation process and were then categorised into common groups.

Given the different nature of the interviewed stakeholders, topic guidelines were adapted by developing a section with different questions for the three stakeholder types (See Appendix 1.I.B section d.). While for business stakeholders the discussion remained close to the selected topics, the discussions with public administration and associations were highly influenced by the specific area of expertise of the interviewees. Hence, a uniform, data-driven analysis of the interviews, to find similar patterns and concepts, was conducted for stakeholders: main contributions from each transcript of records were summarised and collected into a single document. Then, each contribution was grouped under common topics, keeping track of the stakeholder who mentioned it. The different contributions fed section 2.2 on the current development of carsharing in Spain and contributed to complete insights coming from carsharing users with respect to use, comparison with other modes and electrification of carsharing. The complete topic guidelines for stakeholders can be found in Appendix 1.I section B.

5. Results

a. Carsharing use

FF consumers appeared to be more frequent users of this mode than SB users. 7 out of the 11 FF carsharing interviewees stated they used it around 3 times per week; SB carsharing interviewees used the mode more on a monthly basis and sometimes even more occasionally. Regarding the journey length, most FF users had a normal range of 10 km or 15-30 minutes, normally affected by traffic congestion. SB carsharing instead, was generally booked for 2-3 hours, although in some cases users stated to book it for a full-day or weekend. Some users of both systems also stated their use to be dependent on the period of the year, with a higher frequency during summer or holidays. The higher frequency in these periods was due to the higher number of “out-of-routine” activities, as for normal routine activities most interviewees used other modes. In fact, users stated that they used shared cars especially on weekends, at night when the public transport stops or using the latter when going to locations that were not easy to reach. Other uses mentioned were to replace their own car while it was being repaired and the need to move equipment from one place to another. Some FF carsharing users, given the limited area where this system operates, mainly used the mode to reach the city centre from the periphery, where they could park for free, or to move from one place to another within the centre. SB users mainly booked vehicles for weekend trips and mainly used the system to reach outer places such as mountains, the seaside or nearby villages.

Age seemed to influence the propensity to use different modes; younger interviewees of both carsharing models used a wider range of modes in their normal routine, mainly due to a higher number of activities and a less structured schedule. It is interesting to note that most young interviewees in Madrid were subscribed to more than one carsharing company, while older ones would normally be subscribed to a single operator. In some cases, this seemed to be due to a higher ability (and willingness) to use smartphones and adopt new technologies by younger generations. However, some older interviewees stated they were registered with a single company because of the higher availability of their vehicles in the area where they lived. Some younger interviewees also stated they registered because they were attracted by the 20€ travel credit incentive upon subscription and the immediacy of the registering process.

b. Attributes motivating carsharing use

For many interviewees, the motivation to start using carsharing was either a specific external condition, for instance the unavailability of their own car, or a specific unusual trip they had to do out of their usual routine, or a change in city mobility due to an event or holiday. Some users stated they had also been curious about the type of vehicle and the way the system functioned.

Figure 2.1 reports the distribution of the importance of homogenised attributes motivating carsharing use, divided by carsharing type. The importance was derived based on the ranking position of the attribute and the times it was cited. That is, the sum of weights of the attributes of each individual was set to one. Moreover, for a single individual, attribute weights were set in order to keep the distance between ranking positions constant. Then, homogenised attributes were summed across interviewees. To make them comparable across types of carsharing users, the sum of the attributes' importance was standardised to 100% for each carsharing type.

Based on the interviewees' responses, four main categories were defined, covering the different homogenised attributes: convenience in use, technological attributes, economic attributes and environmental attributes. Convenience in use included factors that identify carsharing as a more practical alternative. This included the comfort feeling, the high availability of vehicles around the city and the possibility of going exactly from and to where you need to go. Technological factors included considerations of the type of vehicle, the fact that it is electric, the quality and the small car size. Other attributes mentioned were the possibility to control everything by smartphone and the possibility to pay by card instead of cash. The economic factors category dealt with the price, which for most of users was considered as affordable. Some other interviewees mentioned the advantages compared to the costs related to a private vehicle, the possibility to pay according to the use of the mode and the avoidance of purchasing, maintenance and parking costs.

Then, the environment category included motivations related to the perception of carsharing as an environmentally-friendly practice.

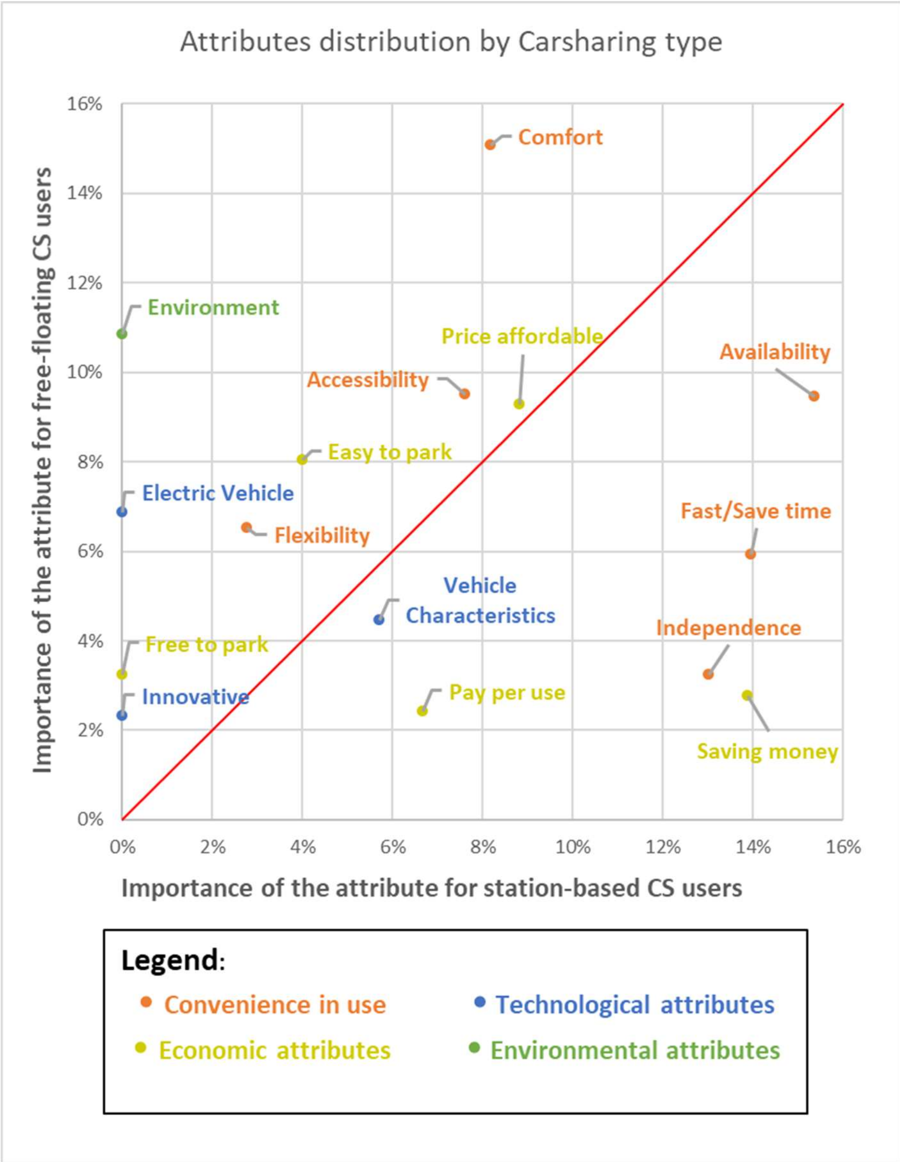

Figure 2.1: Distribution of the attributes of carsharing use by carsharing (CS) type. The dashed line is the 45º line which separates the FF and the SB prevalence areas.

When looking at how these attributes were distributed in terms of importance, it was clear that aspects related to convenience in use ranked at the top. In particular, comfort was the most important factor for FF carsharing users, whereas availability of vehicles was the most important factor for SB users, followed by saving time and being independent. Economic attributes were also important, especially the possibility of saving money for SB carsharing users and considering the price affordable for FF carsharing users. Only FF electric carsharing users mentioned the advantage of being environmentally friendly as a valuable aspect of carsharing. This attribute seemed therefore deeply linked to the type of vehicles involved. In fact, these users believed the service was environmentally-friendly because of the battery electric vehicles. SB carsharing users did not see this aspect of the service because vehicles were not low-carbon fuelled, especially considering that public transport was the main travel alternative for most of them. Also, most SB carsharing users would have preferred to have hybrid or electric vehicles. Only a couple of interviewees expressed indifference in this regard. Regarding technological factors, appreciation for being innovative and based on electric vehicles only came from some FF users, while both types of users valued vehicle characteristics such as size and quality.

c. Relation with other modes

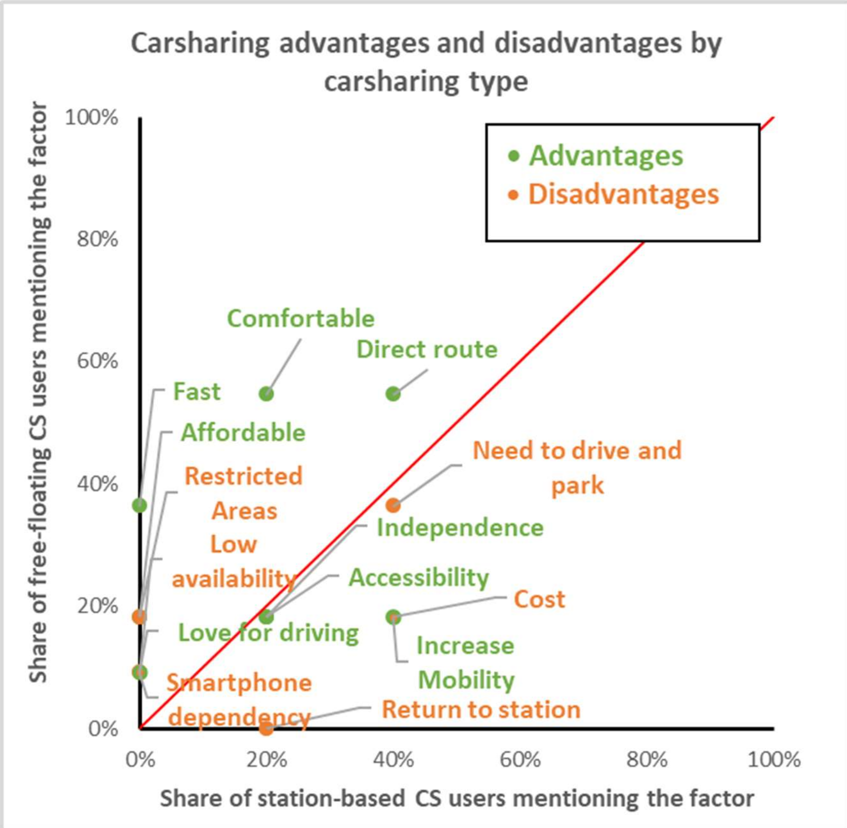

Figure 2.2: Distribution of advantages and disadvantages of carsharing compared to other modes by type of carsharing (CS) user. The dashed line is the 45º line which separates the FF and the SB prevalence areas

Figure 2.2 reports the distribution of homogenised comparative advantages and disadvantages of carsharing compared to other alternatives modes available to users. Carsharing was valued as more comfortable and flexible, as well as allowing the user to choose the route. Almost 40% of FF users considered carsharing faster than other modes (Fig. 2.2), while 60% of SB users stated public transport to be faster (as shown in Fig. 2.3 below). Some young interviewees also mentioned the advantage of having more independence and being able to reach other places, stating that somehow this mode increased their mobility possibilities. One interviewee also mentioned the love of driving rather than being driven as an advantage of carsharing. With respect to the disadvantages of carsharing, users complained about the need to find parking, having to drive and the cost of the service. FF users also mentioned the constraint given by the restricted geographical area, while SB users spoke of the limitation of having to return the vehicle to the station. One user also mentioned the disadvantage of being smartphone-dependent.

d. Relation with Public transport

6 out of the 15 interviewees stated they used public transport less than once a month, three interviewees used it around once a week, and 6 used it more often as the main transport mode. It was striking that all 6 users with low public-transport use came from the FF carsharing group, while 4 out of the 5 SB carsharing users stated they used public transport on a daily basis. This is probably related to the fact that the SB carsharing interviewees did not own a car and only one of them had access to it within the household. On the contrary, all FF interviewees either owned or had access to a private vehicle.

Carsharing was competing with some specific public transport modes. Indeed, within public transport modes, the majority of users preferred the metro to the bus. Their opinion regarding the metro was that it was cheap and relatively fast, while the bus was considered too slow. Taxi use was limited to emergencies, occasions where it was not possible to drive and for mobility at night, but it was considered extremely expensive.

Figure 3 reports the distribution of homogenised comparative advantages and disadvantages of public transport. Competitive advantages of public transport were identified as not having to drive, which included not being directly subject to the stress of driving and the possibility of doing something else meanwhile, such as reading or talking. Moreover, some users, mainly from SB carsharing, stated public transport, in particular the metro, as faster than carsharing, as it was not subject to congestion. Being affordable was also cited by some, and one FF user mentioned having a fixed monthly ticket as an advantage. On the other hand, being crowded, not allowing for direct connection and poor timetables were the most oft-cited disadvantages. Some users also criticised the rigidity of route, the payment method and limits for animal access.

When asked how their use of public transport changed after subscribing to carsharing, all FF carsharing users except one stated that their use decreased. Those of them using public transport as their main mode said that it fell slightly on occasions where many transit changes were needed, when not knowing about when they would have to return, or in case of emergencies. Moreover, most of them also stated that this mode increased their mobility possibilities. Conversely, all SB carsharing users said that, given the occasional use, it did not greatly influence their behaviour with respect to public transport. Indeed, a couple of them said they rather completed each other, leading to greater independence because an alternative mode existed.

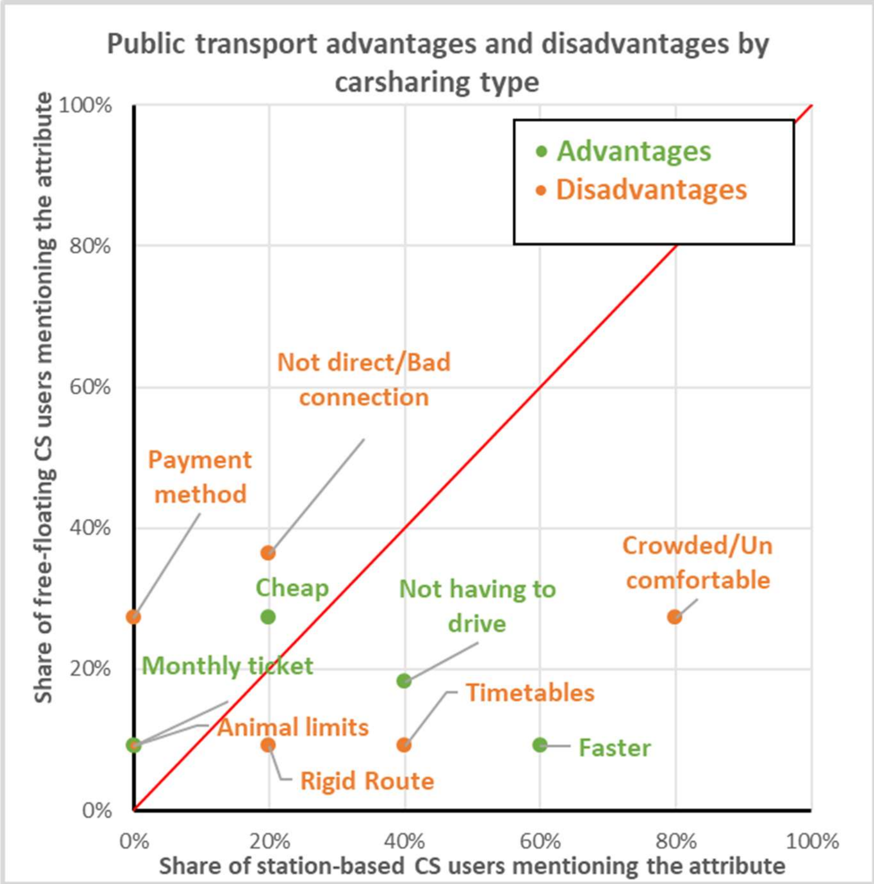

Figure 2.3: Distribution of advantages and disadvantages of public transport compared to other modes by type of carsharing (CS) user. The dashed line is the 45º line which separates the FF and the SB prevalence areas.

e. Relation with private vehicle

Among carsharing users, most FF carsharing users owned at least a car, a motorbike or had access to a vehicle within their household, or through their parents. However, the majority of them only had one vehicle in their household. None out of the five SB carsharing users personally owned a car, although one of them owned and mostly used a motorbike and another one could have access to his/her partner's vehicle. Most owners of a private vehicle used it to go to work every day, while preferring to take a shared car when needing to go to the city centre. Some of them also expressed the need for a vehicle when going on a longer journey for holidays or during weekends.

Figure 2.4 reports the advantages and disadvantages of private vehicles compared to carsharing. The first noticeable aspect is the difference between the perception of FF and SB users. Most of the private vehicle's advantages were mentioned exclusively by FF users. In particular, they acknowledged the advantage of being always available, not having a limited area, facilitating household needs, being useful for emergencies, love for the car and growing affordable with frequent use. The only exception was the increased independence, which was indeed in the SB prevalence area. Conversely, all private vehicle disadvantages fell in the SB users' prevalence area, meaning they had a more critical view with respect to the mode. This might depend on the fact that SB users did not own private vehicles. Both types of users cited the disadvantages of maintenance and the purchase cost, as well as the struggle to find and pay for parking. SB users also cited cars to be stressful and inefficient in urban areas compared to public transport, due to traffic congestion and parking costs.

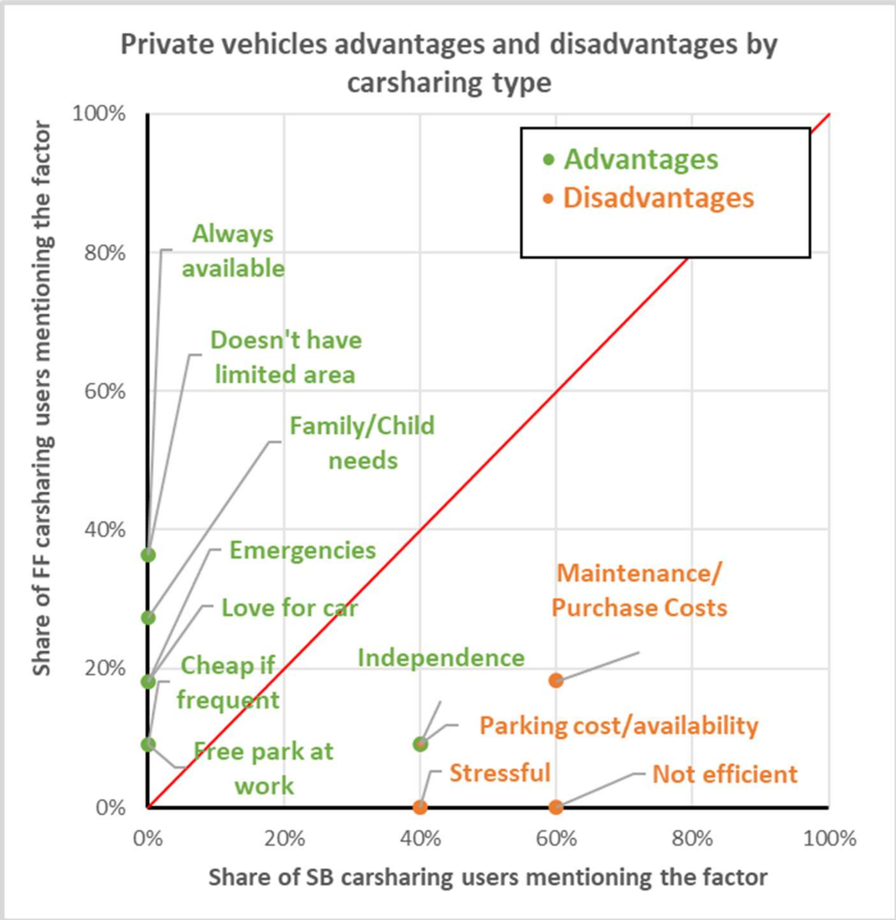

Figure 2.4: Distribution of advantages and disadvantages of private vehicles compared to other modes by type of carsharing (CS) user. The red line is the 45º line, which separates the FF and the SB prevalence areas.

Most of the interviewees stated they had partially reduced the use of their private vehicle since using carsharing, although they normally had different uses. Some users living in suburbs stated that when they needed to go to the city centre, they used their own car to the closest point where they could park for free, and then changed to a shared car as it would be more expensive to pay for several hours' parking than to pay for a shared car.

Finally, the vast majority of the respondents who owned a car were open to at least reducing the number of cars to one for the whole household, and directly connected this possibility to the existence of the carsharing service. This was mainly because of its high availability in the urban area, the immediateness of reservation and the possibility of free access and parking in the city centre. Most of them related the decision of whether or not to own a vehicle to the change in daily routine, to the area where they lived or to having children. Most of the interviewees stated they had had the car since before discovering carsharing, and a couple of them stated they would not have bought one if they had known about carsharing before. A barrier to reducing the number of cars cited by some of the respondents was the low market value of their vehicle, while the disposal of the vehicle through scrappage programs was connected to the purchase of a new one. Hence, some of the interviewees said they were waiting for the car to stop working to scrap it. All interviewees who did not own a private car stated they would not buy one if their routine at the time or living place did not change.

f. Considerations from Stakeholders

Carsharing providers considered that the market was emerging and a large share of users could be captured. They considered the level of 15,000 kilometres per year to be the cut-off point above which private vehicles were more cost-efficient than carsharing. This level is also reflected in literature (Litman, 2000). They argued that carsharing, in exchange for a higher price per kilometre, gave door-to-door solutions that facilitated citizen independence from private vehicles. They also stated that the vast majority of citizens living in urban areas drove their car for less than that amount and were hence potential carsharing users. Most of the stakeholders said carsharing helped users to avoid buying a car, or at least to reduce the number of cars per household. They were also convinced that the private vehicle was losing its symbolic value (i.e., vehicle as a mean to express identity or social position), especially among young people who were given new ways of gaining their independence, one of which was access to a shared vehicle.

With respect to economic aspects of the service, carsharing providers highlighted the importance of having a mix of private users and companies as their demand covered different hours during the day and private users mainly used carsharing for leisure activities. For SB carsharing this implied that they were most interested in having the station in mixed neighbourhoods accessible by both type of users. FF carsharing users needed instead to have a capillary distribution of vehicles, so that over the whole area of service users could find a vehicle within 5 minutes walking. FF carsharing hence incurred in other costs due to relocations of vehicles over the service area. Some stakeholders expressed that profitability of the service was on average guaranteed by a 5 hours daily use per vehicle.

Looking at the location aspects and relation with local institutions, providers mentioned the importance of parking availability and car access restrictions as main tools driving the existence of this type of service. Especially, providers believed that for FF carsharing the possibility of freely parking on the streets and access over the whole area of service was a pre-condition for economic viability, since the vehicles might be parked on a spot for several hours between uses. FF providers noted that in Madrid these pre-conditions were met not because of being a carsharing service but because this was guaranteed to all electric vehicles. In fact, this seemed to be the main reason why they decided to offer only electric vehicles. SB carsharing, instead, was typically paying for the parking spaces they occupied in the stations and would benefit from a lower price due to a recognition of the benefits linked to their service. They stated that electric vehicles were not a viable option for their service given the large range of their trips.

An important area for policy intervention highlighted by both carsharing providers and the public administration authorities was to improve the connection of carsharing services with public transport. For most stakeholders, public transport and carsharing were deeply interconnected and should be considered part of one same service, even if managed by different operators. Stakeholders of different groups agreed that carsharing's main contribution to low-carbon mobility depended on the positive impact it could have on exploiting synergies with public transport in order to reduce the need to own a private vehicle.

The Public Administration group considered public transport to be the main tool to deal with mobility and congestion, availability of parking space and preservation of air quality, because of the size of its impact on urban mobility. They believed that the relative impact of carsharing was limited, as it serviced a lower number of users than public transport, but it was considered to contribute to the transition to low-carbon mobility.

According to different stakeholders, SB and FF carsharing could supplement the supply of public transport, especially when a vehicle was needed to carry packages, when the public transport timetables did not cover the journey or when the location was poorly connected. The connection between the services could be improved, according to providers, by the joint development of hubs, stations where it was possible to switch between public transport and shared modes, bicycle and car. Also, it would be important for carsharing companies to rely on the same public transport card and a unique app that could show public transit routes and position of shared vehicles. This view supported the need for a Mobility-as-a-Service (MaaS) type of offer (Jittrapirom et al., 2017) which would increase visibility of the mode and facilitate complementarity between carsharing and other collective and shared modes (Ambrosino et al., 2016; Smith et al., 2018).

6. Discussion

What can be drawn from how the interviewed households described their use of carsharing is that those cases where carsharing could be considered a complement to public transport are rather limited. None of the users stated that their use of public transport increased upon joining the carsharing service. In fact, most of the FF users stated, in line with the findings of Martin et al. (2011), that their use of public transport had decreased instead. It is also true that SB users stated that their use of public transport did not change much due to their occasional use of the shared cars. However, it has to be noted that for most of them public transport was the only alternative travel mode, and carsharing ended up being used for trips that were formerly conducted with public transport.

Both SB and FF business stakeholders argued that users of carsharing services had a higher use of public transport compared to other people. However, this does not necessarily prove complementarity between carsharing and public transport as this could merely be interpreted as a sign of reverse causality, i.e., people with higher public transport use are more likely to start using carsharing. In these interviews, this seemed to be the case, especially for SB carsharing. Some recent studies are also finding difficulties when trying to shed some light on the connection between carsharing and public transport use. Thus, Clewlow and Mishra (2017) and Mishra et al. (2017) reach the conclusion that connecting carsharing use with higher public transport use may be affected by self-selection and simultaneity biases of carsharing users.

Ceccato and Diana (2018) recognize the difficulty to prove complementarity between public transport and car sharing when comparing public transport use before and after subscribing carsharing services because beginning to use carsharing could be connected to changes in mobility needs, or so-called «life events» (e.g., marriage, birth of a child).

Overall, the interviewees cited motivations for using carsharing in line with the previsions made by stakeholders. In particular, most of the SB carsharing users moved mainly by public transport and used the shared car on a monthly basis to reach outside leisure locations or furniture stores. This is in line with the stakeholders' view and findings by Rotaris and Danielis (2018). However, most FF users had a low use of public transport and this did not increase after joining the service. Conversely, some of them stated that they reduced public transport use. Given that shared vehicles could be parked for free in the city centre, some of them used the service as a "park and ride" solution, in substitution of public transport. For some interviewees, carsharing somehow increased their mobility rather than substituting other modes. This allowed them to perform trips which they would otherwise avoid because they "couldn't be bothered," the "complexity of using other modes" or external conditions (e.g., weather, time of the day). In this sense, carsharing created more mobility in cases where public transport was considered inefficient. However, the majority of car owners interviewed stated that they have also reduced private vehicle use, substituting it with carsharing.

Since both carsharing models were perceived as a more comfortable and more direct solution than public transport, increasing user independence and possibilities, they should have implied a price premium with respect to public transport. However, FF carsharing was considered affordable and even cheaper when sharing the price between more people. Hence, in order for a complementarity between this mode and public transport to exist, policies might ensure this price premium for carsharing use, or incentivize complementarity through policies aimed at connecting the two modes. SB carsharing incurred less in the risk of competing with public transport in urban areas. Indeed, the interviewed users of this mode were using this service occasionally, complementing a public-transport and active mode-based mobility. However, this mode might compete with medium-distance trips by bus or train if it did not imply a sufficiently high price premium.

The complementarity between carsharing and public transport could benefit from joining effort with public transport, developing a network to facilitate use and connection between both modes. This could be done by using a common payment method, by including stations and car parks in the public transport information system and by involving carsharing to serve urban areas without a critical mass of public transport users. This aspect was primarily raised by carsharing operators and seemed to be reflected in public administration and sectoral pressure group opinions. This could be done through MaaS type of service with integrated offer of different mobility alternatives (Jittrapirom et al., 2017). This includes developing a higher-level service, which can be provided by public administration or private entities that facilitate a seamless mobility by allowing users to purchase a trip with different modes at once with a single subscription. Services of this type have been already developed in some European cities and they have been proved effective in improving the complementarity between carsharing and public transport (Ambrosino et al., 2016; Smith et al., 2018). Facilitating multimodality and the specific places where modal shifts are possible might hence make it easier to avoid private vehicle use. According to users, the most valued factors of carsharing were in fact related to its simplicity and immediateness, making it more convenient compared to its alternatives, rather than economic or other advantages. In the same way, access-based mobility was likely to be more successful than private vehicle-based mobility only if it was seen as more convenient in these terms.

Parking and road pricing are important factors, as they seem to be a deterrent for car use in urban areas (Garling and Schuitema, 2007). Certainly, carsharing diffusion would benefit from being exempt from such restrictions, but this might also trigger competition between carsharing and public transport if the difference in prices between the two trips is marginal and if there is no connection between carsharing and public transport offerings. Especially in areas as the city centres, where public transport offer is more capillary, allowing free parking and access to carsharing vehicles might favour this competition and lead to substitution. Conversely, carsharing would play a complementary role in outer urban areas where public transport might be sparser.

As envisaged by business stakeholders and expressed by users, both modes seemed to reduce the stated need for private vehicle use and ownership. SB users were found to have a more negative opinion of private vehicles, and most of them did not use a car in their daily routine. Moreover, users owning cars stated that the service could help them reducing the number of vehicles in their household, in line with findings by Nijland and van Meerkerk (2017). A policy that might incentivise the switch from private car to carsharing might be to provide stronger incentives to get rid of old vehicles and use carsharing than to the purchase of a new one. This could also add qualitative insights to the findings of Namazu and Dowlatabadi (2018), who discovered that round-trip carsharing was more effective in reducing ownership. The switch from private car to carsharing might be encouraged by enforcing restrictions to private vehicle use and parking.

7. Conclusion

This chapter sought to understand how carsharing systems could contribute to low-carbon mobility. It particularly focused on understanding its complementarity or substitutability with its alternatives in the urban context. For this a qualitative analysis was carried out based on semi-structured interviews with users and stakeholders in Spain. The analysis gathered a total of 28 in-depth interviews with carsharing users, experts from all the Spanish carsharing companies, public administration and associations.

Currently carsharing covers mainly users' journeys in the evening and at the weekend for leisure. Factors influencing its use appeared to be primarily related to its convenience with respect to other modes, in particular, the possibility of easily travelling directly to the desired destination, independence and the comfort during the journey. Economic attributes, such as the cost of the service and savings related to the avoidance of private vehicle purchase and maintenance costs, were also shown to be relevant, in particular with respect to avoiding private car maintenance costs and the generally affordable price of the service. To a lesser extent, technological aspects related to vehicle quality and the functioning of the entire carsharing service were also cited. Moreover, environmental friendliness of the use of electric vehicles was also cited as a motivating factor by FF carsharing users.

These attribute groups can be connected to the ones found in Schaefers (2013)[5], namely, value-seeking (economic attributes), convenience (convenience in use), and environmentalism (environmental attributes). In this study, a strategy to assess their relative importance has been provided by aggregating interviewees' ranked motives for carsharing use. This analysis also allowed us to highlight differences between carsharing modes.

In principle, carsharing can supplement the supply of public transport both for urban and extra-urban areas. SB carsharing often serves as an occasional alternative to public transport for people who do not own vehicles and mainly move by public transport and active modes. FF carsharing is an urban mode which can complete public transport supply in poorly-serviced areas, at night and for multi-destination trips.

[5] The only exception would be "lifestyle", although within technological attributes considerations on the service being innovative were also included.

However, this complementarity seems to be rather limited at the moment. Carsharing, especially the FF type, is likely to compete with public transport instead, as it is considered more comfortable, flexible and direct. These features should be reflected in a price premium. However, this did not seem to be the case in this study as many interviewees considered it affordable, and by some, even cheaper when shared between multiple passengers. SB carsharing seems to be mainly directed to those who do not own and use a private car. Moreover, there is also evidence that in some cases carsharing generates new demand for mobility.

Thus, additional policies seem to be necessary to ensure the complementarity of these two modes in order to successfully provide an alternative to private-car use, which should be the main mode substituted by carsharing. Measures aimed at connecting carsharing with public transport services can play a role in facilitating this process. For instance, the complementarity could benefit by an integrated MaaS offer facilitating a seamless trip planning. Moreover, restrictions on private car use in urban areas could also contribute to the development of this alternative.

This approach allowed us to consider heterogeneity of preferences and experiences and highlight motivations which would otherwise be overlooked by quantitative studies. Nonetheless, these findings could be complemented and supported by a quantitative based analysis which could evaluate at a larger scale some of the policy instruments that have been discussed.

Chapter 3

Shifting away from private vehicle use: determinants of mode choice and the impact of policy support and externality perception

The research presented in this chapter has been developed within the H2020 project ENABLE.EU (Enabling the Energy Union), 2017-2019. The aim of the project was to define the key determinants of individual and collective energy choices in three key consumption areas - mobility, heating & cooling and electricity - as well as in the shift to prosumption.

The following publications derived from the research conducted in this chapter:

- ***Silvestri, A.,*** *Foudi, S., Galarraga, I., (2022).* How to get commuters out of private cars? Exploring the role of perceived social impacts in mode choice in five European countries*. Energy Research & Social Science. Vol. 92.*

- ***Silvestri, A.****, Foudi, S., Galarraga, I., 2020.* Determinants of travel mode choice in Europe: Results from a survey on routine mobility*. Papeles de Energia 9.*

- ***Silvestri, A.****, Foudi, S., Galarraga, I. (BC3), Schøyen Jensen, E., Kallbekken, S. (CICERO), Gaggi, S., Proietti, S. (ISINNOVA), Bieliszczuk, B., Skorupska, A. (PISM), Bartek-Lesi, M., Diallo, A., Felsmann, B., Vekony, A. (REKK). 2019.* D 4.2 Synthesis report on the "low carbon mobility" case study*. H2020 project Enable EU (Enabling Energy Union) deliverable.*

- *Foudi, S.,* ***Silvestri, A.****, Galarraga, I. (BC3), Bartek-Lesi, M., Diallo, A., Csutora, M. (REKK). 2019.* D4.6 Final report on social and cultural factors impacting energy choices and behaviour*. H2020 project Enable EU (Enabling Energy Union) deliverable.*

1. Introduction

Shifting away from private vehicles (PV) use is a crucial step towards decarbonising the transport sector, because in Europe it is the biggest single contributor to total road transport emissions (European Commission, 2016). Electrifying vehicles might substantially reduce the impact on greenhouse gases emissions, but discouraging private vehicle use altogether can help reduce several negative externalities (Banister et al., 2011; Sovacool et al., 2021) such as safety and health problems, congestion and occupation of public space. Considering these externalities, the European Union has set up a specific strategy to reduce transport related emissions and dependence on PV and encouraged cities and local authorities to favour modal shift towards active modes (AM) (cycling and walking) and public transport (PT) (European Commission, 2016).

Moreover, understanding the motives and factors that affect the specific choice of travel mode in recurrent trips has long been a matter of study in transport research. However, there seems to be a lack of research into the link between travel mode choice and consumers' perception of negative transport externalities (e.g. congestion, noise, pollution, unsafety) and their opinions of the policy options presented to encourage modal shift (e.g. car use pricing, investment in infrastructures, reducing travel demand)(Huber and Wicki, 2021). These make it possible to determine whether concerned consumers make decisions consistent with their opinions on the transition towards low carbon mobility. Depending on their perception of negative transport externalities, people may be more reluctant to take a specific mode of transport, either out of social responsibility or because it may be more exposed to such externalities.

In this context, the aim of this chapter is to understand citizen's mobility behaviour, choices and preferences, as well as identify what are the key drivers and barriers to lowering carbon intensity of mobility. To do so, a mobility household survey has been conducted, which analyses citizen travel behaviour, travel mode choices and the factors influencing them. The survey provides a comparative analysis between 5 countries from both eastern and western Europe. The participating countries are Hungary, Italy, Norway, Poland and Spain. The analysis of the survey is divided into two parts. The first part provides a descriptive analysis of the survey result with a focus on the comparative cross-country results. This second part seeks to contribute with an analysis of transport mode choice (PV, PT and AM) by including perception of negative externalities and opinions towards policy measures, and by considering socio-economic and journey characteristics. The analysis focuses on two of the destinations monitored in the survey, the commute to work and grocery shopping, and is based on a conditional multinomial logit model.

Section 2 provides a review of the current literature on determinants of travel mode choice. Section 3 details the methodology, including the survey design and implementation, the theoretical framework for the conditional multinomial logit model and the model specification. Section 4 presents the descriptive statistics of the survey results. Section 5 presents the results of the travel mode choice model. Section 6 discusses the results of the two previous sections. Section 7 reports some concluding remarks.

2. Literature review

Over time, a broad body of literature has analysed determinants of travel mode choice. Built environment aspects such as city size and whether household activities are located within or outside urban areas determine different needs and travel possibilities. For instance Dargay and Vythoulkas (Dargay and Vythoulkas, 1999) find higher car use levels outside cities. Indeed, the higher population density in urban areas is likely to be accompanied by greater availability of public transport (Ahlfeldt and Pietrostefani, 2019; Limtanakool et al., 2006). Moreover, congestion, driving limitations and the costs and availability of parking may deter people from moving by PV. By contrast, using AM can be more complicated to use in suburban and outer areas where distances are larger (Marquet and Miralles-Guasch, 2014). Aditjandra et al. (Aditjandra et al., 2013) argue that households can be sorted based on their preferences for living in urban or suburban areas as different travel behaviours are observed, which underlines choice differences that go beyond infrastructural restrictions. Hence, people living in the same place might, to some extent, have similar transport preferences and behaviours that can be tackled by specific policies or investments, e.g. in public transport infrastructure or car access and parking restrictions. The point of destination of journeys also matters. For instance, local distribution of shopping facilities and large-scale outlets might give rise to different travel behaviours (Achen, 2005; Handy and Clifton, 2001).

One stream of the literature analyses travel behaviour from a social psychology point of view and has developed a framework for assessing the influence of attitudes, social norms and perceived behavioural control (Bamberg et al., 2003; Thøgersen et al., 2021). This framework is known as the theory of planned behaviour (Ajzen, 1991), and it has been widely adopted in travel mode choice studies. Attitudes towards PT and AM are found to play a significant role in travel mode choice (Spears et al., 2013). Lanzini and Khan (Lanzini and Khan, 2017) provide a comprehensive meta-analysis of the role of psychological and behavioural factors in travel mode choice. They find significant influence of habits and past mode use in current travel mode choices and a significant role of environmental values and concerns in intentions to adopt eco-friendly alternatives.

Studies have investigated attributes of different mobility options that influence travel mode choice (Anable and Gatersleben, 2005). Economic aspects such as mode-associated costs and convenience aspects such as shorter travel times and greater comfort and privacy are important in deciding between travel modes (Silvestri et al., 2021). Sensitivity to travel time can increase the propensity to move by private vehicle, while price sensitivity is considered to reduce it (De Borger and Fosgerau, 2008). Likewise, people concerned about environmental issues are found to be more likely to accept car use reduction policies and to actually reduce car use, mainly by changing personal norms (Eriksson et al., 2006; Nordlund and Garvill, 2003). Safety and security perceptions are also found to influence whether people opt for active travel modes (Singleton and Wang, 2014; Willis et al., 2013) and public transport in the case of women and higher income groups (Kamargianni et al., 2015).

Several studies highlight differences in travel behaviour related to socio-economic characteristics. Travel demand is believed to change with age following what Dargay and Vythoulkas (1999) describe as a 'lifecycle effect': that is, car use increases with age until around the age of 50, and then starts decreasing. Young people might not be able to afford a private vehicle, and after a certain age health problems might limit the possibility of moving by active mode or the ability to drive a car (Santos et al., 2013). Education, income and employment are also considered to be associated with different travel behaviours. Highly educated and wealthier people and those in work are likely to have a preference for minimising travel time and thus opt to use private vehicles (DeSalvo and Huq, 1996; Santos et al., 2013; Schwanen et al., 2002). However, they are also found to be more likely to use alternative-fuelled and electric vehicles (Hackbarth and Madlener, 2013; Hidrue et al., 2011) and to be more sensitive to transport problems such as congestion, safety and environmental issues (Golob and Hensher, 1998; Rienstra et al., 1999). Women tend to be more concerned about transport problems than men (Rienstra et al., 1999; Vance and Lovanna, 2007) and to have lower levels of car use and ownership and higher use of PT (Golob and Hensher, 1998; Nolan, 2003).

Journey characteristics such as purpose, distance and frequency are also acknowledged to be major determinants of travel behaviour, in particular for AM (Keyes and Crawford-Brown, 2018). The purpose of a journey is generally associated with different mode choices. The frequency and regularity of trips to work, for instance, are connected with greater use of public transport (Ortúzar and Willumsen, 2011). By contrast, the possibility of storing products in the car can make car use more likely for grocery shopping. Connecting trips, for instance by taking children to school before going to work can also be a reason to choose a car (Dieleman et al., 2002; Salonen et al., 2014). Distance in itself influences mode choice: active travel for most people is an option only for short distances, while the availability of direct public transport connections is often lower (Limtanakool et al., 2006).

Despite extensive studies of people's mode choices, their links to perceptions of negative transport externalities and support for sustainable transport policies have been largely neglected in previous literature. Nonetheless, Rousseau et al. (2020) find a positive relation between stated subjective perceptions of externalities (noise, air and odour pollution) and willingness to pay for changes in city's mobility policies. Although, the authors find as well little to no evidence of this willingness to pay being determined by objective exposure to these externalities.

3. Methodology

a. Survey design and implementation

The analysis of travel behaviour relies on a mobility household survey conducted in winter 2017-2018. The survey has been implemented in Hungary, Italy, Norway, and Poland with more than one thousand respondents per country while 760 interviews in Spain. Interviews have been conducted face to face in all countries apart from Norway, which implemented the survey online. In all countries, participants were selected in order to ensure national representativeness.

The survey consists of two sections: a mobility section, which includes questions related to routine travel behaviour and preferences, while the second a series sociodemographic question (See Appendix 2.I). The whole mobility section can be characterised by three blocks of questions: (i) the description of the routine trips, (ii) preferences towards mode attributes and (iii) a series of attitudinal questions.

Routine trip description is covered by 4 questions (M1-M4) that focus on 5 typical destinations: the workplace (or university for students), children's school, children's activities' location, grocery shopping and recurrent leisure activities. Participant are asked not to consider a specific week but rather what they consider to be their most typical weekly mobility behaviour. First, they are asked the weekly frequency of travel to these destinations from 1 to 7 days. Second, households are asked to describe in detail for each destination which modes they used to take for each destination and for how long. And third, they are asked about the distance between the destinations. The way in which these questions are designed also allow describing connected trips, for instance if one uses to go to work directly after bringing children to the school.

The second block of questions elicits preferences and attitudes towards mobility alternatives. Interviewees are asked about the importance of different factors when choosing the travel mode. Factors have been selected according to the literature review presented in the previous section and include cost, travel time, comfort, flexibility, safety, privacy, environmental impact, on both air quality and CO2 emissions, reliability, availability of the mode, and reputation. For each of these, participants assess the importance based on a 5-level Likert scale ranging from 1 = not at all important, to 5 = very important. In this study, answers are grouped to distinguish between sensitive (4, 5) and insensitive (1, 2, 3) to the attribute. The third block include attitudinal questions on policies, transport externalities and infrastructure. In the first of these, participants are asked to evaluate the support to a series of policies towards a transition to a sustainable mobility. These include: (a) improving traffic flow; (b) discouraging automobile use; (c) developing walkers and cyclists' friendly neighbourhoods;

(d) enforcing emissions standards; (e) giving public transport dedicated traffic lanes; (f) reduce fares, increasing frequency, and expanding route coverage of public transport; (g) promote mixed commercial and high-density development to reduce distances; (h) encourage working from home to reduce travel needs. Interviewees are also asked about their perception of transport externalities like (a) congestion, (b) traffic noise, (c) space occupation, (d) air quality impact, (e) accidents, (f) impact on global warming and (g) unsafe communities. Moreover, they are asked about their level of satisfaction with the following transport facilities: parking space, public transport timetables and coverage, bike and pedestrian lanes, public shared bikes and cars.

The survey also includes a series of questions on household social and economic characteristics. In this section, respondents are first asked about their age, level of education, gender and residence city size. Respondents are also asked about their vehicle holdings. Finally, income is assessed by asking for the ability of present income to cover current costs through a 4-level question from "living comfortably" to "finding it very difficult" on present income.

b. Theoretical framework

The theoretical framework used in this study draws on literature from both economics and social psychology. In particular, it is assumed that commuters are rational and maximise a random utility function (Train, 2009). According to the literature on social psychology related to the theory of planned behaviour (Ajzen, 1991; Bamberg and Schmidt, 2003), choices are maximised for the long-term and the mode used to commute daily is habitual and remains stable in the routine. Therefore, other choices made in response to occasional events (e.g. public transport strikes, unavailability of PV, weather conditions) are excluded and the most recurrently used mode is considered for the analysis.

Conditional multinomial logistic regression (CMNL) was introduced by McFadden in 1973 and is one of the most widely used discrete choice models (McFadden, 1974, 1973; Train, 2009). The model enables choices by decision makers from certain options to be described.

Formally, a decision maker n faces J options and maximise utility U_{nj}. The utility can be divided into a known component V_{nj} and a random error term ε_{nj}, which is an independently, identically distributed extreme value (Train, 2009).

According to the CMNL theory the probability of decision maker n choosing option i (i ∈ J) can be expressed as:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}} \quad (1)$$

In this analysis, the known component V_{nj} is represented by:

$$V_{nj} = \beta_{1j}X_n + \beta_{2j}Z_n + \beta_{3j}C_n + \beta_{4j}TT_{nj} \quad (2)$$

where X is a vector of attributes representing attitudes towards mobility, Z a vector of socio-demographic characteristics and C a vector of journey characteristics based on the previous literature presented. TT_{nj} is the travel time required for individual n to reach his/her destination with option mode j. β1j, β2j and β3j are the respective vectors of parameters which are constant for each observation. β4j is the coefficient of travel time with option j.

The set of options J is PV, PT and AM (bicycle and walking) for the two journeys (commuting and grocery shopping).

c. Model specification and data management

The empirical analysis of travel mode choice relies on the combination of two main methodological approaches: latent-class analysis (LCA) (Lazarsfeld, 1950) and conditional multinomial logistic regression (CMNL) (McFadden, 1974, 1973).

First, LCA is used to identify two unobservable variables: support for sustainable transport policies and the perception of negative transport externalities. LCA identifies classes of a categorical latent variable based on responses to a set of indicators (Lazarsfeld and Henry, 1968; Rhead et al., 2018), here the items P1-P8 for the sustainable policy support topic and E1-E7 for the externality topic described in the previous section. The set of items are expressed on a 5-level Likert scale. Membership of a specific class is determined a posteriori using the modal a posteriori assignment procedure (Bolck et al., 2004). Each observation is then assigned to the class with the greatest likelihood of membership. LCA was performed using ordered logit measurement type. In order to determine the number of classes, LCA models from 1 to 6 classes were compared. A 3-class solution has been chosen as adding more classes resulted in poorly identifiable solutions with further classes comprising observations that were few in number and not significantly different from the others. Akaike (AIC) and Bayesian (BIC) information criteria consistently showed lower values, probably due to the wide range of possible response patterns provided by the 7 items with 5 levels used to identify latent classes. Nonetheless, AIC and BIC 3-classes solution where relatively close to the 6-class solution, within 5 points.

These classes are then treated as categorical explanatory variables in the CMNL, describing the choice of mode to commute to work or to grocery shopping. Final standard errors of the CMNL were derived using bootstrap estimation with 100 repetitions. The validity of the Independence of Irrelevant Alternatives (IIA) was verified using the Hausman test[6]. Potential multicollinearity issues were excluded by checking the variance-covariance matrix for any relevantly high correlation between explanatory variables.

[6] A Hausman test for IIA identification was conducted against a consistent and efficient 2 alternative conditional logit model (PV-AM). Results of the test are chi2(31) = 18.87 with Prob>chi2 = 0.9570 for the workplace trip and chi2(30) = 1.60 with Prob>chi2 = 0.999 for the shopping trip. In both cases the null hypothesis that the coefficient in the 3 alternatives model is the same cannot be rejected and the assumption on the IIA is valid.

The survey addressed support for transport policies as well as perception of negative transport externalities with a series of Likert-scale questions that were then used to draw up latent classes. In the case of support for transport policies the questions referred to: (P1) improving traffic flow by building and expanding roads; (P2) discouraging automobile use with road tolls, fuel taxes and vehicle surcharges; (P3) making neighbourhoods more attractive to walkers and cyclists by using bike lanes and speed controls; (P4) reducing vehicle emissions via regular testing and manufacturer emissions standards; (P5) making public car-sharing and PT faster by giving them dedicated traffic lanes and priority at intersections; (P6) making PT more attractive by reducing fares, increasing frequency and expanding route coverage; (P7) reducing transportation distances by promoting mixed commercial and residential land use and high density development; and (P8) reducing transportation needs by encouraging compressed working weeks and working from home. A 5-level Likert scale was used: from "Opposed to the policy" (level 1) to "Strongly supports the policy" (level 5).

For perception of negative transport externalities, the questions referred to: (E1) traffic congestion experienced while driving; (E2) traffic noise perceived at home or while engaged in activities; (E3) too many vehicles occupying urban spaces; (E4) vehicle emissions which impact local air quality; (E5) accidents caused by aggressive or distracted drivers; (E6) vehicle emissions which contribute to global warming; and (E7) unsafe communities due to speeding traffic. A 5-level Likert scale was used: from "Not at all important" (level 1) to "Very important" (level 5).

Table 3.1 outlines the statistics used in the CMNL model. The travel-diary style questions were used to derive how they most often travelled to their workplace (or university) and their grocery shopping locations. Each observation for both types of journeys is assigned to one of the three options used based on the response to the travel-diary question. For multimodal trips, observations were assigned to either PV or PT based on the mode which covered the largest proportion of the trip. They were assigned to AM if and only if respondents travelled exclusively on foot, by bicycle or by a combination of the two. This assignment rule may overlook potential park-and-ride commuters. However, the number of observations with a mix of PV and public transport was relatively small at just 3.1% for the commute to work and 0.8% for grocery shopping journeys. Hence, including a fourth mode in the analysis for park-and-ride was deemed to be an unnecessary complication of the model. The analysis uses country dummy variables to reflect country effects.

The model required travel time to be known for modes other than the chosen one. Hence, for PV and PT travel time was derived by multiplying individual specific trip distances by the average speed of the relevant option in the surrounding area as indicated by individuals who used that option. This speed was obtained dividing the distance between locations by total travel time using the mode, with values then averaged at NUTS3 level. AM speed was assumed to be constant at 4km/h.

Table 3.1 Summary of descriptive statistics of the variables used in the MNL

Variable	*Description*	*Stat*
Workplace/University Mode	Categorical variable indicating the main mode used for the workplace /university journey. Categories: PV= Private Vehicle; PT = Public Transport; AM = Active modes.	PV = 58% PT = 25% AM = 17%
Grocery/Shopping Mode	Categorical variable indicating the main mode used for the grocery/shopping journey. Categories: PV= Private Vehicle; PT = Public Transport; AM = Active modes.	PV = 52% PT = 4% AM = 44%
Attitudes towards mobility		
Choice Attributes	Dummy variables indicating the importance (1= "important" or "very important") of the specific attribute in the decision as to what mode to take.	
Cost	Cost of the journey	64,1%
Duration	Duration of the journey	72,6%
Comfort	Comfort provided by the travel mode	67,2%
Safety	Feeling of safety provided by the travel mode	78,2%
Privacy	Feeling of privacy provided by the travel mode	52,9%
Environmental Impact	Concerns about the travel mode's impact on CO2 emissions	57,6%
Infrastructure satisfaction	Dummy Variables indicating a high or very high satisfaction level with respect to different transport related infrastructures	
PT satisfaction	Value averaged over satisfaction with the PT timetables and coverage	34,6%
Parking presence	Satisfaction with the amount of parking space in the area where activities take place	39%
Socio-economic characteristics		
Young (<30)	Dummy variable which takes a value of 1 if the interviewee is aged below 30	16,0%
Fulltime Worker	Dummy variable which takes a value of 1 if the interviewee is a full-time worker	49,3%
Gender (female)	Dummy variable taking a value of 1 if the interviewee is female	54,6%
Children	Dummy variable indicating whether the household includes at least one child	39,1%
Household size	3-level categorical variable taking a value of 1 if the household comprises one person (base level), 2 for 2 persons, 3 for more than two persons	1= 19,0% 2= 35,3% 3= 45,7%
High Education	Dummy variable which takes a value of 1 if respondent has completed first stage tertiary education (bachelor´s/master´s degree)	29,7%
High Income	Dummy variable taking a value of 1 if the respondent states their present income enables their household to live in a sufficiently comfortable manner.	71,8%
Journey Characteristics		
Leaving from home	Dummy variable indicating whether the journey to workplace (Work.) and to grocery shopping (Shop.) begins from home	Work. = 95% Shop. = 85%
Frequency	For workplace trip (Work.), 3-level categorical variable, taking value 1 for 5 days a week, 2 for less and 3 for more than 5. For grocery shopping trip (Shop.), 2-level categorical variable, taking a value of 1 if the trip is made more than 2 times per week, 0 otherwise.	(mean) Work. = 4,9 Shop. = 3,2
Home within urban area	Dummy variable indicating whether the house is located within the urban area	1= 57.8%
Rural/small village	Dummy variable indicating whether the household is located in a rural area or small village compared to a medium or a large town/city	1= 26,4%
Travel time	Travel time in tens of minutes by PV, PT and AM respectively	

4. Determinants of routing travel behaviour in Europe.

a. Trip frequency and mode choice

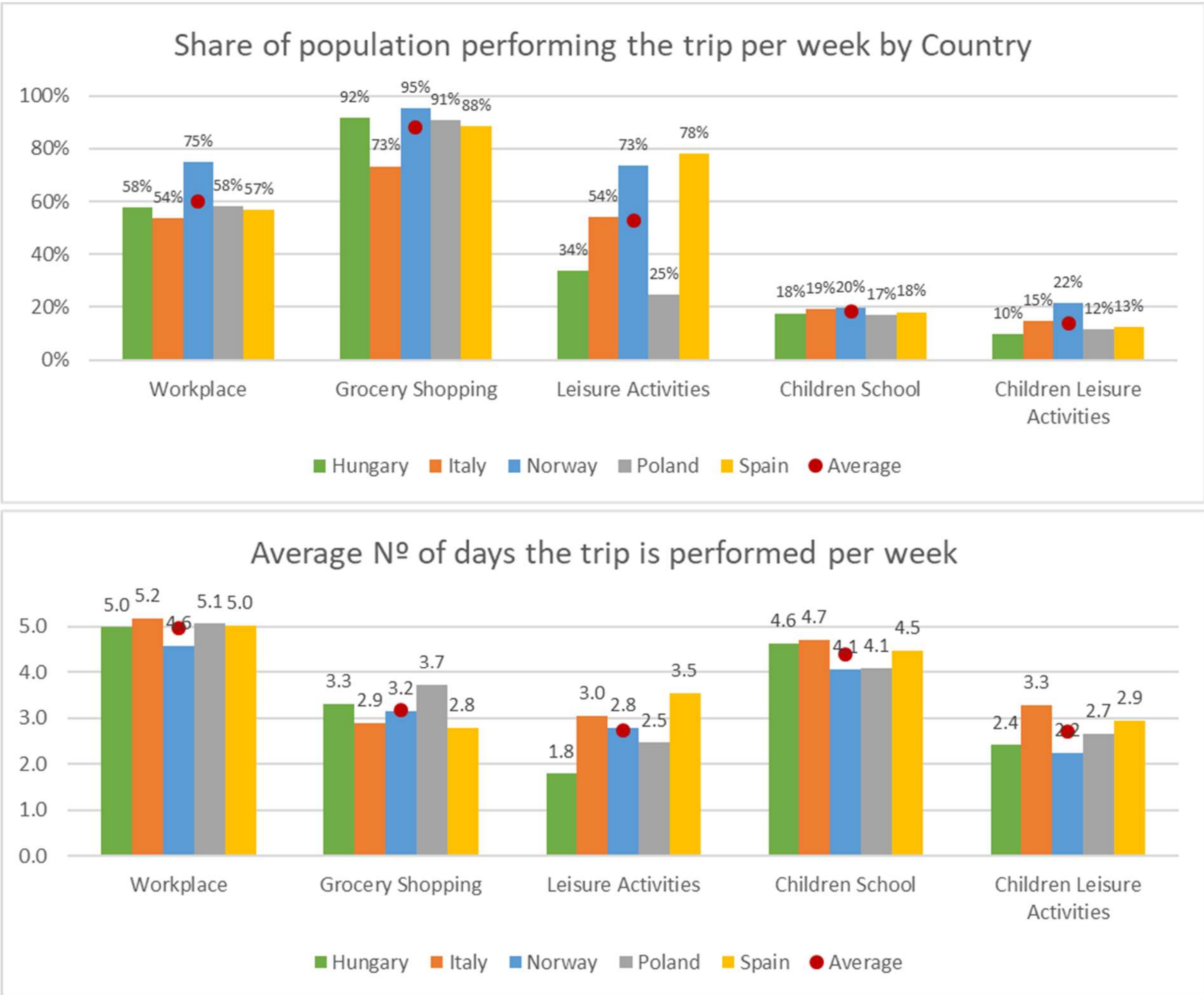

Figure 3.1 Trip frequency: a) Share of population travelling to the selected destinations at least once in a week; b) Average number of days per week the destination is reached by households who perform the trip

Figure 3.1 below shows the share of population performing the trip in each of the countries analysed and its frequency. Overall, patterns are quite similar across countries with the workplace trip being the most recurrent and trip to grocery being the one performed by the highest share of population. Leisure activities show substantial difference across countries: in Norway and Spain this is performed by over 70% of the population, while in Hungary and Poland by, respectively, 34% and 25%. Trips related to children needs are performed only by households with minors. This explains the relatively lower shares of population performing the trip.

Workplace trip frequency is close to five days per week, suggesting most of the population tend to work full-time and do not work from home at the time of the survey. Bringing children to school is the second most frequent trip in each country. Grocery shopping is done normally around 3 times per week, similar to leisure activities of both adults and children. In most cases, the trips are performed starting from home, although some differences in this can be found across countries (See Figure 11 in Appendix 2.II). For instance, Hungary and Norway show a higher tendency to connect shopping and children's school trips compared to other countries. While Hungary, Italy and Spain have higher tendency to connect trips related to Children's activities. Average distances and travel time for each trip (Table A1 in the Appendix 2.II) are highest for the workplace trip in all countries. Spain, compared to the others, presents lower levels for each destination of both distance and travel time, while Hungary the highest values.

Figure 3.2 Shares of mode use in each Country by trip destination

Figure 3.2 shows, for each destination, the shares of population performing the trip by private vehicle, public transport or active modes. Except for Spain where for most of the destinations active modes present the highest share (over 60%), in the other countries private vehicles seem to dominate in most of the recurrent trips.

Overall, the trip to workplace shows the highest rate of time spent travelling by public transport, followed by leisure activities and children's school, while the lowest levels are shown for the grocery shopping and children's activities destinations. In this case, there seems to be more differences between trip destinations rather than countries. In most of the cases active modes represent the second higher mode type after private vehicle, with the exception of the trip to workplace where these values are lower compared to public transport ones.

b. Relation of mode choice with socio-demographics

Changes in mode choice are then analysed in conjunction with several socio-economic characteristics. Figure 3.3 reports the share of trips by private vehicles by age. The red line represents a local-linear regression and shows the evolution of private vehicle use by age. In all trips, private vehicles' use increases with age up to around 40 years where it becomes steadier. Behaviour changes with older age by trip. In the case of workplace, private vehicle' use starts rising again after 60. In the grocery and leisure trips it lowers. Trips related to children needs have also different trends, where school trips keep increasing with age while activities trip decreases. It is to note however that in these last two graphs the lower number of observation (respectively 905 and 704 out of the 5028 sample) might affect the estimation of mean values, especially for household with age below 30 and over 50. The same effect might affect the workplace trip after age 65 (the average age of retirement).

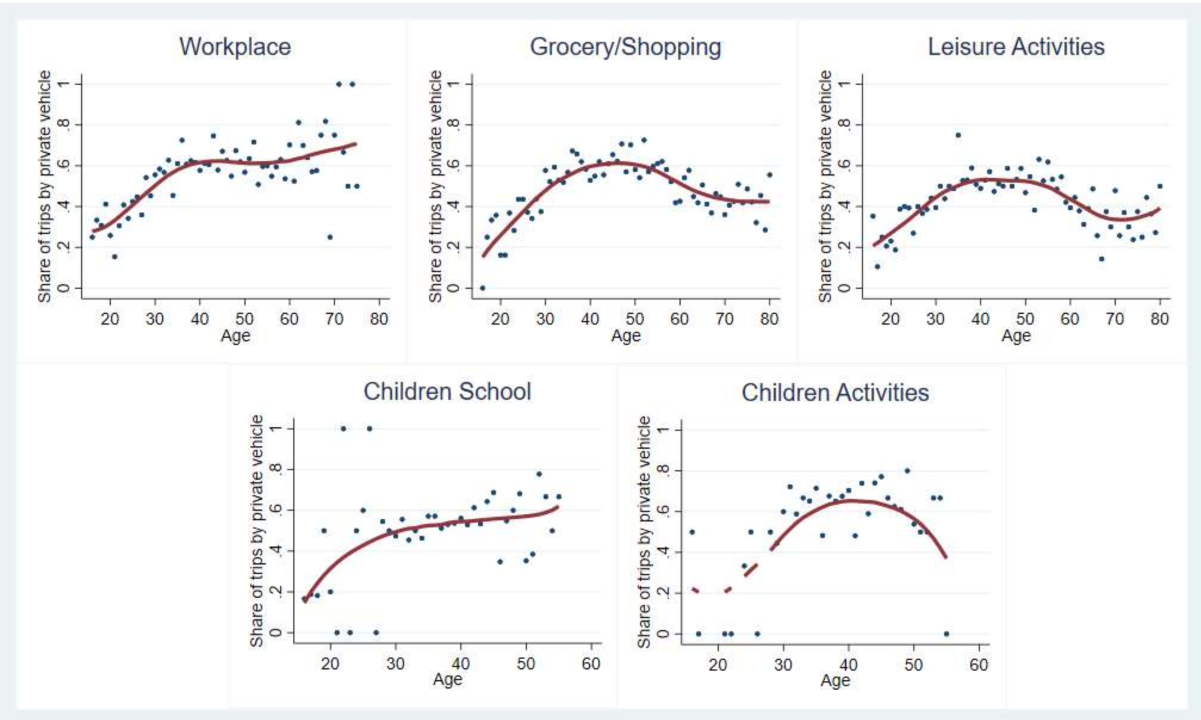

Figure 3.3 Average private vehicle use (%) by age. (In red, non-parametric local linear regression, kernel = Epanechnikov, bandwidth= 5)

Figure 3.4 shows private vehicle use by household location differentiating by large, small cities and country villages in each country. As shown in the previous section, Italy shows higher levels of private vehicle use than other countries, while Spain the lowest for non-work-related trips. For most cases, private vehicle use seems to be lower in large cities and higher in country villages. This is in line with what one might expect given the limited supply of transport alternatives and the higher distances between locations. However, Italy and Hungary seem to behave differently from other countries with similar use across city sizes, if not even a higher use of private vehicles in large cities.

Figure 3.4 Heat maps of average private vehicle use (%) by household location. Colour ranges from yellow (= 0%) and blue (100%).

As shown in Figure 3.5, private vehicle use seems to be different across men and women. Men have in most cases a higher private vehicle use than women. The difference seems to be sharper in commuting to work, while for the other destinations, behaviours are rather similar, especially in Poland where the shares for leisure and children's activities are equal.

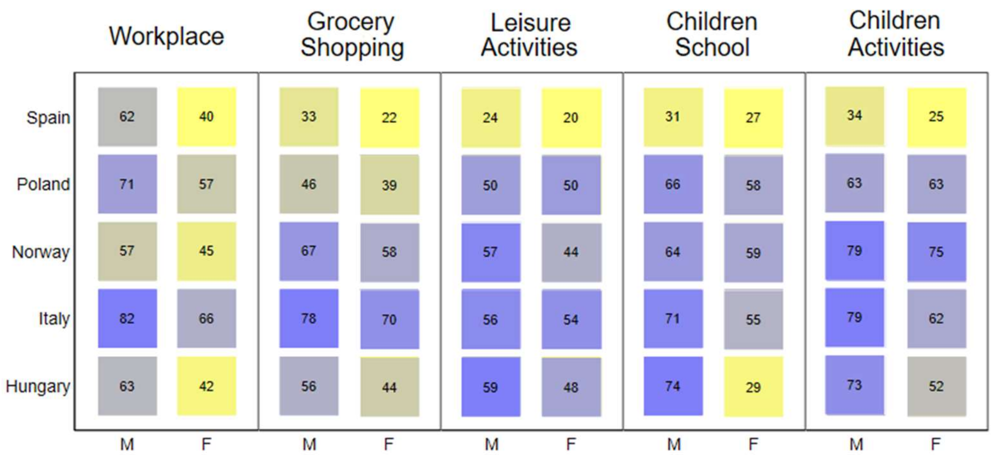

Figure 3.5 Heat maps of average private vehicle use (%) by gender. M= Male, F= Female. Colour ranges from yellow (= 0%) and blue (100%).

Figure 3.6 shows that changes in private vehicle use with education seem to differ between countries. In Hungary, higher level of education seems to be very much connected with higher private vehicle use. However, in Spain private vehicle use decreases with education in commuting to work but increases for grocery shopping and children related trips. In general, in the grocery shopping trip higher education is related to higher private vehicle use.

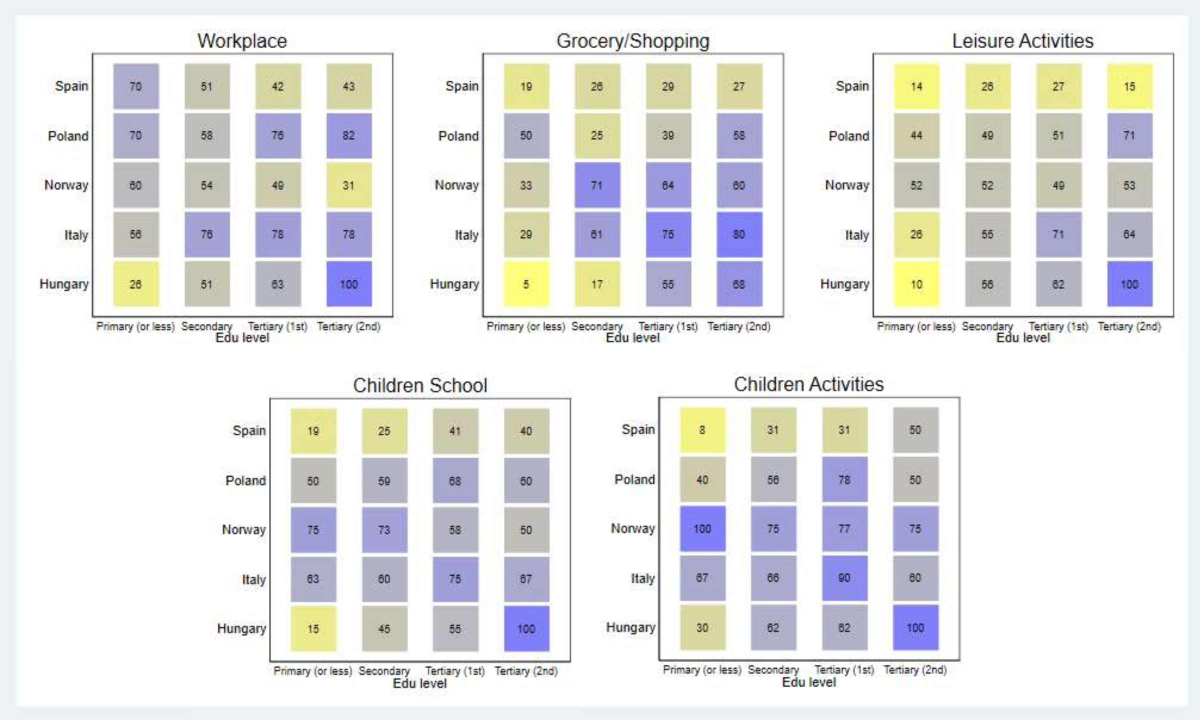

Figure 3.6 Heat maps of average private vehicle use (%) by education level. Colour ranges from yellow (= 0%) and blue (100%).

Figure 3.7 Heat maps of average private vehicle use (%) by income. Colour ranges from yellow (= 0%) and blue (100%).

With respect to income (Figure 3.7), patterns show private vehicle use tends to increase with higher income groups[7]. However, in some cases the lowest income group also presents a relatively

[7] The information used to distinguish income classes refers to a question on how the household perceive the present income allow them to live, ranging from comfortable to very difficultly.

high private vehicle use. This is the case for commuting to work in Italy or children and leisure activities in Poland. Commuting to work in Spain Norway and Italy seems to be rather similar across income groups, while it is increasing in Poland and Norway.

c. Households' beliefs and choice attributes.

Several attributes influence the choice of travel mode. Figure 3.8 shows the average and country specific evaluation of the importance of a predetermined list of factors. Patterns across countries have some similarities. In almost all countries factors of safety, reliability and availability have been considered a priority, followed by travel time, cost, flexibility and comfort. On the other side, factors related to reputation, privacy and environmental impacts on local air quality and CO2 emissions are the ones valued less importantly.

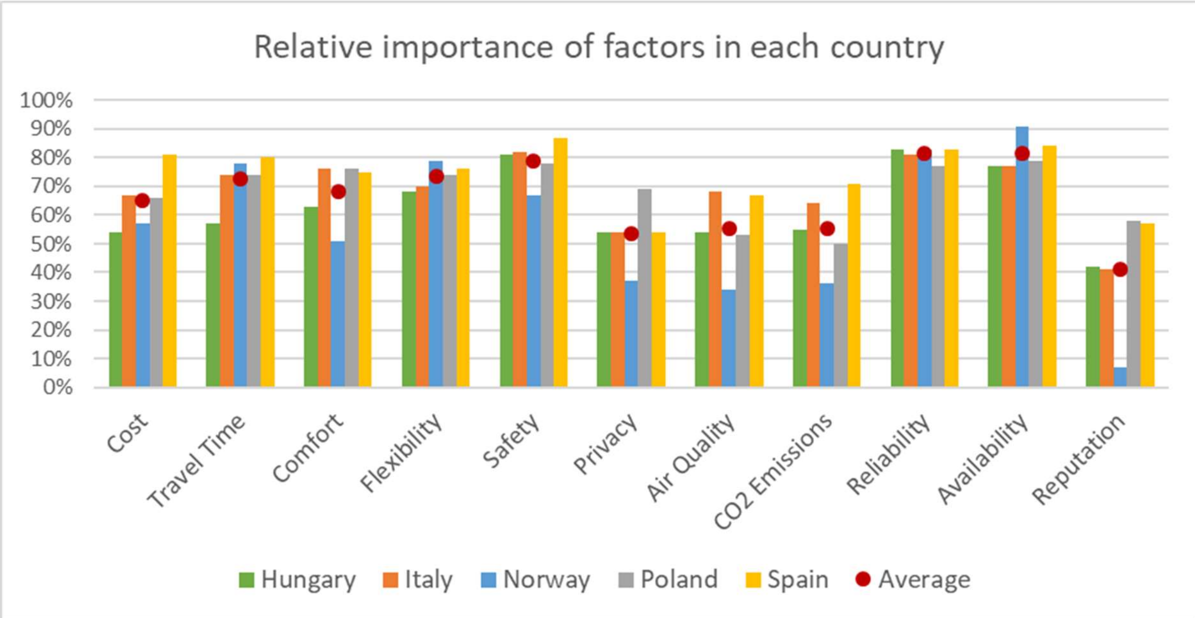

Figure 3.8 Shares of population valuing the factor as important or very important in each country

Cost factors have been stated to be fairly decisive in all countries, especially in Spain, Poland and Italy, while received less importance in Norway and Hungary. Travel time seems in general to be evaluated even more important than cost, with the only exception of Spain where a similar importance is perceived. Comfort also ranked high in the household preferences apart from Norway where it scored sensibly lower respect to the others. Flexibility received similar votes in each country with around 70 to 80% of the population stating the factor to be 'important' or 'very important'. Safety was evaluated as influential by at least 80% of the sample with the only exception of Norway where it scored less (68%). Privacy scored fairly low compared to other factors apart from Poland where it reached 70% of people voting the two highest importance levels. Environmental factors performed quite low and there seems not to be much difference between local air quality and CO2 emissions. The lowest levels of concern for these factors have been found in Norway, while southern European countries, Italy and Spain, present a bit higher level. Reliability and availability scored high and similarly across countries, with around 80% of the population valuing them at least as important. Finally, reputation is the least evaluated factor in almost all countries, hitting the lowest values in Norway, although in Poland it dominates environmental factors.

Figure 3.9 shows preferences towards transition policies, transport externalities and satisfaction with infrastructure. With respect to support to transition policies (Figure 3.9A), the development of more stringent regulation for emission standards and the development of mixed neighbourhoods to reduce transport distances seem to be the most supported policies, especially in Norway and Spain. Nonetheless, high shares of the population seem to favour also improvement of roads as well as public transport and bike lanes. The lowest levels of support in all countries are related to discouraging private vehicle use through road and vehicle pricing. In most cases, answers are similar across countries, with values close to the average. On the contrary, more difference between countries is found in relation to the perception of transport externalities (Figure 3.9B). Norway presents the lowest share of people feeling affected by any of the listed externalities, while these shares are highest for Poland and Italy. The overall average values are quite similar for all externalities, scoring between 50% and 60%, the only exception being noise that is the least perceived in each country. Satisfaction with infrastructure (Figure 3.9C) is also, on average similar across the various options, with exception of public shared bikes and cars which set on a lower level. Overall, average values are below 50% for each infrastructure. Some differences can be found from country to country, with Spain being mainly satisfied with public transport timetables and coverage, while Norway and Hungary with parking space and pedestrian lanes.

In Figure 3.10, mode choice is analysed in conjunction with some of the choice attributes presented in the previous section. The sensitive group includes those households stating the attribute is either important or very important in their choice. Private vehicle uses decreases with cost sensitivity and concerns for environmental impact[8], while it increases with travel time, comfort, flexibility, safety and privacy. In particular, comfort and privacy are associated with the largest increases. Public transport use increases mainly with cost sensitivity and in a minor grade with travel time and environment. It reduces with the sensitivity to comfort, flexibility, safety and, especially, with privacy attributes. Active modes slightly increase with the sensitivity to cost and environmental impact attributes, while decreases in all other cases, with travel time, comfort and privacy.

[8] Derived as the mean value between local air pollution and CO2 emissions sensitiveness.

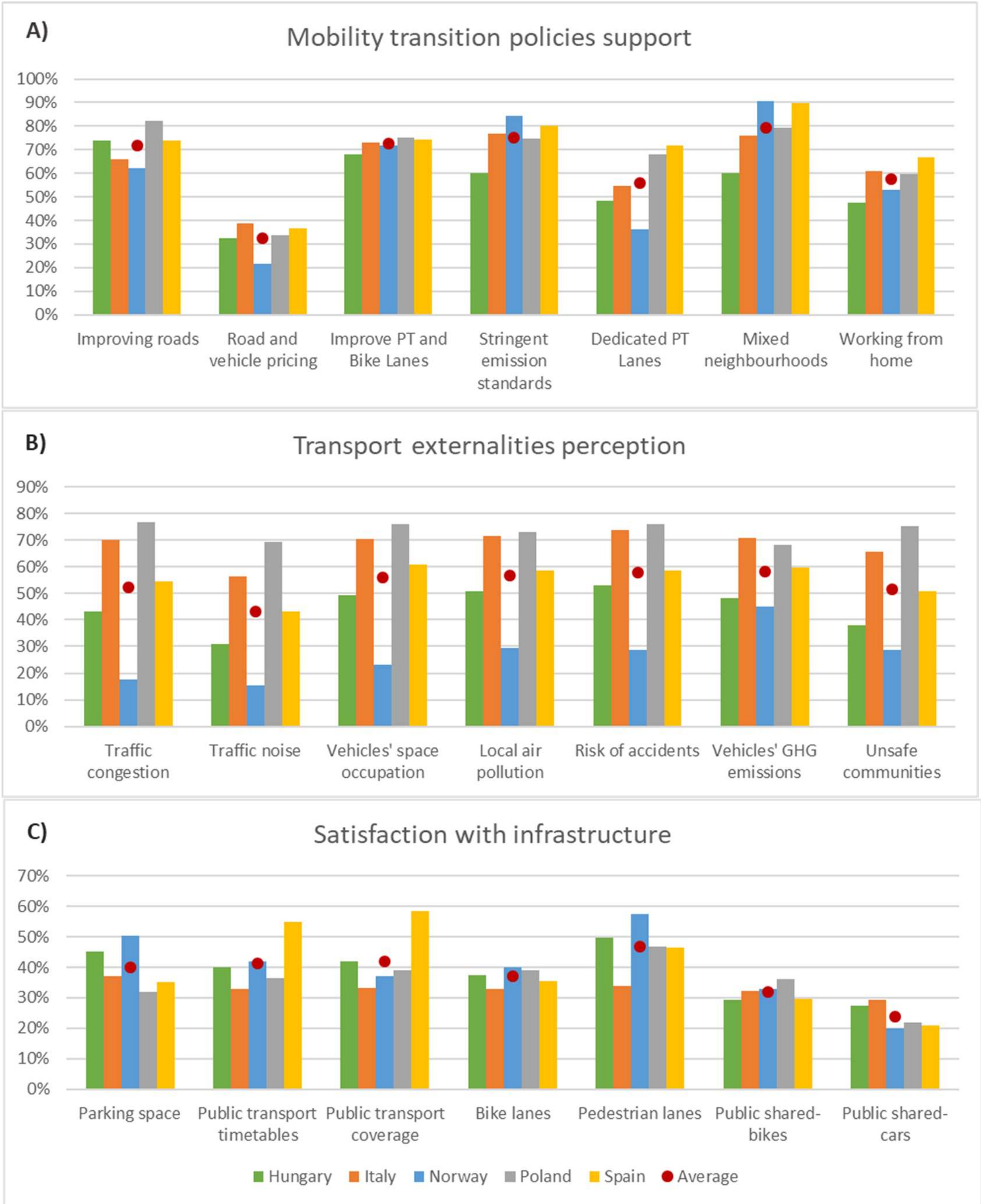

Figure 3.9 A) Shares of population supporting potential transition policies; B) Shares of population sensitive to transport externalities; C) Shares of population satisfied by local transport infrastructure

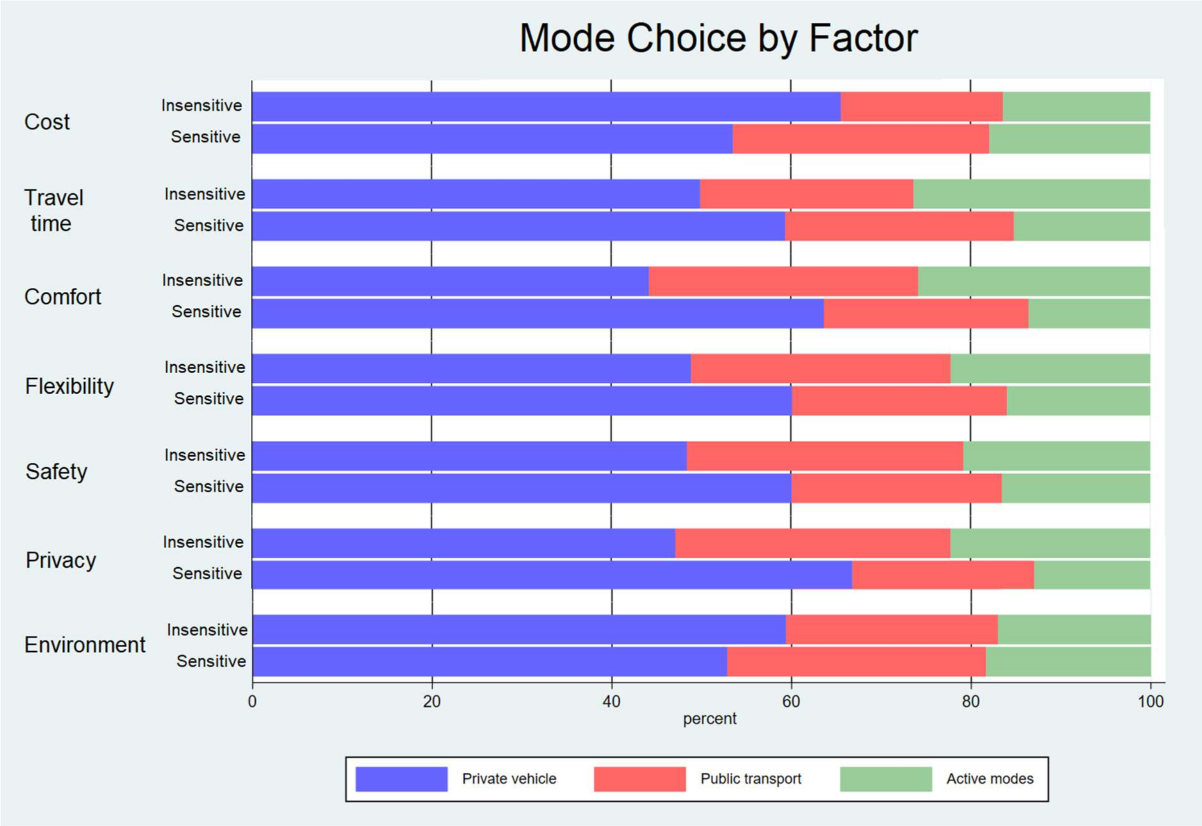

Figure 3.10Mode choice by choice attribute, comparison between sensitive and insensitive.

5. Mode choice, urban transport externalities and sustainable mobility policies.

a. Latent Class Analysis

An initial latent class analysis was run to identify support for policies for a transition to low-carbon mobility and perception of negative transport externalities.

With respect to sustainable transport policies, 3 classes of supporters have been identified: mild supporters, strong supporters of interventions and indifferent to intervention. Members of the "mild supporters of intervention" group showed a greater likelihood to agree somewhat with sustainable transport policies, with the exception of taxing car use, for which there was not a clear support. Members of this group were also more likely to support strongly policies that did not entail a direct cost or a disruptive change in their current lifestyles and in the built environment. Members of the "strong supporters of intervention" group are highly likely to strongly support all policies, with the sole exception of taxation of car use. The third group showed overall indifference towards either policy with a tendency to oppose the taxing of car use, and is hence defined as "indifferent to intervention". Figures A.1, A.2 and A.3 in Appendix 2.III A summarise response probabilities for support for low carbon mobility policies using heat maps.

In the case of perception of externalities, 3 classes have been identified. The class "somewhat sensitive" to externalities regroup respondents more likely to choose the scales 3 and 4 (among the 5 scales) on the sensitiveness level for most externalities. The class "highly sensitive" to externalities regroups members most likely to indicate a high sensitivity to all externalities (highest values of the Likert scale for the different items). The group "insensitive to externalities" contains people whose level of sensitiveness mostly set between 1 and 2 in the Likert scale. Figures B.1, B.2 and B.3 in Appendix 2.III B report heat maps for response probabilities for perception of transport externalities. Table 3.2 summarises membership ratios for the 3 classes in each of the two latent class variables described.

Table 3.2 Membership ratios of the two latent classes identified (N=5028)

Support for low carbon mobility policies		**Perception of negative transport externalities**	
Class name	Proportion	Class name	Proportion
Mild supporters	44.7 %	Somewhat sensitive	50.6 %
Strong supporters	33.2 %	Highly sensitive	27.0 %
Indifferent	22.1 %	Insensitive	22.4 %

b. Commute to work

Table 3.3 reports the outcomes for the model and, for ease of interpretation, the average marginal probabilities for mode choice in the commute to work. Coefficients of marginal probabilities represent the percentage changes in the likelihood of mode choice associated with the explanatory variable. As shown in section 4.a the trip was performed by about 60% of the total sample. Once observations with missing values are removed the final sample for the commute to work resulted in 2114 observations.

A relation exists between the mode choice and the level of support to sustainable transport policy intervention and to the sensitiveness to negative transport externalities. Individuals indifferent to policy intervention are 5.2% less likely to choose PT. Sensitivity to transport externalities is associated with a 4.6% lower use of PT while insensitivity is also associated with 5.7% lower PT use and 2.4% AM use. Marginal effects are calculated for latent class membership at country level to check whether the result held true for all countries. The impact in most countries is similar to the overall results, with Hungary showing slightly higher values and Italy substantially lower ones. The result for AM use under insensitive to externalities is only significant for Italy and Poland (Appendix 2.IV B).

With respect to mode attributes, considering the cost attribute as important is associated with a 7.1% greater likelihood of choosing PT. Comfort, by contrast, is associated with a 6.4% lower probability of choosing AM, while Privacy seekers are 6.1% less likely to choose PT. People concerned with environmental impact are 5.8% less likely to use PV. Preference for shorter duration and the perception of safety are not significant. Satisfaction with PT infrastructure is related to a significant, 10.1% greater likelihood of using PT, while satisfaction with parking space availability is associated with a reduction in commuting by PT.

Young workers tend to use PT more than older ones. Women are 5.8% more likely to use PT. Having children per se does not significantly affect mode choice, but larger households are around 3.1% more likely to use PT and 5.0% more likely to use AM than single person households, while two-person households do not show a significantly different behaviour. Full-time workers tend to use PV more than PT and AM. Households with higher income levels are less likely to use AM but higher education does not seem connected to specific travel behaviour.

With respect to journey characteristics, people leaving from home (the vast majority) are more likely to commute by AM, while commuting on more than 5 days per week is associated with a lower likelihood of using PT. Living within the urban area of a town is associated with a higher likelihood of commuting by AM. By contrast, the figures for rural/small villages show lower PT use. Finally, as might be expected, people are more likely to switch to other modes as relative travel time increases.

Table 3.3 Parameters and average marginal predicted probabilities in the MNL model for mode choice in commutes to workplace (or university).

Workplace trip	**Conditional multinomial logit**			**Average marginal effects**		
	PV (base outcome)	**PT**	**AM**	**PV** %	**PT** %	**AM** %
Attitudes towards mobility						
(2d) TP Strong Supporters[a]	-	-0.164	0.189	-0.4%	2.5%	2.2%
(3d) TP Indifferent[a]	-	-0.456**	0.0702	3.1%	-5.2%	2.1%
(2d) TE Highly Sensitive[b]	-	-0.433**	-0.25	4.6%	-4.0%	-0.6%
(3d) TE Insensitive[b]	-	-0.723***	-0.615***	8.1%	-5.7%	-2.4%
Mode Attributes						
Cost	-	0.739***	0.374*	-7.1%	6.7%	0.4%
Duration		-0.259	-0.325	3.4%	-1.8%	-1.6%
Comfort	-	0.0743	-0.696***	3.0%	3.4%	-6.4%
Safety	-	-0.182	0.0441	1.2%	-2.2%	1.0%
Privacy		-0.658***	-0.383**	7.0%	-6.1%	-1.0%
Environmental Impact	-	0.489***	0.440**	-5.8%	3.8%	2.0%
PT Infrastructure Sat.	-	1.009***	0.408**	-10.0%	10.1%	-0.1%
Parking presence	-	-0.263*	-0.27	3.4%	-1.8%	-1.6%
Socio-economic characteristics						
Young (<30)	-	0.735***	0.327	-7.6%	7.4%	-0.2%
Gender (female)	-	0.686***	0.353**	-6.9%	6.4%	0.5%
Having Children	-	-0.123	-0.287	2.2%	-0.3%	-1.9%
2-person household	-	0.424*	0.398	-4.6%	3.2%	1.3%
>2-person household	-	0.571**	0.907***	-8.0%	3.1%	5.0%
Fulltime work	-	-0.701***	-0.381*	7.4%	-6.7%	-0.7%
High Income	-	-0.148	-0.378*	3.0%	-0.3%	-2.7%
High Education		-0.038	-0.0404	0.5%	-0.3%	-0.2%
Journey characteristics						
Leaving from home	-	0.634	1.047**	-8.7%	3.0%	5.6%
Freq. <5 times a week	-	-0.0727	-0.207	1.7%	-0.0%	-1.7%
Freq. >5 times a week		-0.425*	-0.0243	3.3%	-4.5%	1.2%
Home within urban area		0.096	0.497**	-3.0%	0.6%	3.7%
Rural/small village	-	-0.512**	0.414	3.5%	-6.6%	3.1%
Travel time						

Private Vehicle				-2.6%	1.6%	1.0%
Public Transport	-0.208***			1.6%	-2.3%	0.8%
Active Travel				1.0%	0.8%	-1.8%
Country effect (base = Norway)						
Hungary		-0.564**	-0.284	4.3%	-5.1%	0.8%
Italy		-0.630*	-1.488***	10.3%	-1.8%	-8.5%
Poland		-0.663**	-0.376	5.8%	-5.8%	-0.0%
Spain		-1.465***	-0.781**	11.6%	-11.9%	-0.3%
Constant		-0.925	-0.973			
Observations (cases)		2114				

*** p<0.01, ** p<0.05, * p<0.1

[a] Percentages refer to the difference with respect to class 1: *mild intervention supporters*.

[b] Percentages refer to the difference with respect to class 1: *somewhat sensitive to externalities.*

c. Travel for grocery shopping

Table 3.4 reports the results of the CMNL and the relative average marginal predicted probabilities for travel for grocery shopping. As reported in section 4.a the trip was performed by nearly 90% of the respondents. Once observations with missing values are removed, the final sample for the grocery shopping trip resulted in 2798 individuals.

In this case strong supporters of transport policies are 5.4% more likely to use AM. Those insensitive to transport externalities are significantly less likely to use AM compared to PV instead. These results hold at largely similar levels for all countries, except Italy which shows lower values. (Appendix 2, IV B)

Cost is associated with a greater likelihood of choosing PT and AM over PV, although in this case AM use increases by 6.7% and PT by 2.9%. By contrast, comfort is associated with a lower likelihood of using AM. Again, environmental impact concerns decrease the likelihood of using PV and increase that of PT and AM, while both privacy and safety concerns increase the likelihood of using PV. As for commutes to work, satisfaction with PT infrastructure reduces PV use while parking space availability reduces PT use. Again, preferences for trip duration do not significantly affect decisions.

Regarding socio-demographic characteristics, having children is again not associated with a specific mode choice. However, both couples and larger households are more likely to use PV than PT and AM. Younger people and women are more likely to use AM to go shopping, while fulltime workers and higher income households are more likely to use PV. Again, higher education shows no significant link to any specific mode choice.

Living within the urban area or in rural/small villages increases the likelihood of going by AM. Interestingly, as the number of shopping trips per week increases so does the likelihood of going by AM, suggesting that shopping more often for smaller purchases might be less private-vehicle-dependent than doing a less frequent major shop. Finally, as might be expected, people are more likely to switch to an alternative mode as the travel time of the selected mode increases.

Table 3.4 Parameters and average marginal predicted probabilities of the MNL model for mode choice for grocery shopping.

Shopping trip	Conditional multinomial logit			Average marginal effects		
	PV (base outcome)	PT	AM	PV %	PT %	AM %
Attitudes towards mobility						
(2d) TP Strong Supporters[a]	-	-0.340	0.306***	-3.5%	-1.9%	5.4%
(3d) TP No Indifferent[a]	-	-0.395	0.0519	-0.2%	-1.7%	1.5%
(2d) TE Highly Sensitive[b]	-	-0.0454	0.0556	-0.7%	-0.3%	1.0%
(3d) TE Insensitive[b]	-	0.0586	-0.284**	3.8%	-0.7%	-4.6%
Mode Attributes						
Cost	-	1.013***	0.530***	-9.6%	2.9%	6.7%
Duration		-0.281	-0.147	2.7%	-0.9%	-1.8%
Comfort	-	-0.370	-0.761***	11.7%	-0.2%	-11.5%
Safety	-	-0.771***	-0.268**	5.7%	-3.0%	-2.7%
Privacy		-0.880***	-0.578***	10.3%	-2.6%	-7.7%
Environmental Impact	-	0.480**	0.335***	-5.8%	1.3%	4.4%
PT Infrastructure Sat.	-	0.830***	0.616***	-10.7%	2.3%	8.4%
Parking presence	-	-0.536**	-0.114	2.8%	-1.9%	-0.9%
Socio-economic characteristics						
Young (<30)	-	0.136	0.478***	-7.1%	-0.3%	7.4%
Gender (female)	-	0.173	0.204**	3.3%	-0.3%	-2.9%
Having Children	-	-0.440	-0.211	-3.9%	1.3%	2.6%
2-person household	-	-0.562**	-0.627***	10.1%	-1.3%	-8.8%
>2-person household		-0.972**	-0.597***	10.6%	-2.9%	-7.7%
Fulltime work	-	-0.536**	-0.367***	6.6%	-1.7%	-4.8%
High Income	-	-0.574**	-0.757***	12.2%	-1.0%	-11.2%
High Education		-0.385	-0.119	2.5%	-1.3%	-1.2%
Journey characteristics						
Leaving from home	-	-1.367***	0.558***	-3.1%	-8.9%	12.0%
Freq. >4 times a week	-	0.256	0.530***	-8.0%	0.1%	7.9%
Home within Urban area		-0.243	0.332**	-4.1%	-1.6%	5.7%
Rural/small village	-	-0.522	0.349**	-3.9%	-2.4%	6.3%
Travel time						
Private Vehicle				-3.1%	0.4%	2.6%
Public Transport	-0.189***			0.4%	-0.8%	0.3%
Active Travel				2.6%	0.3%	-3.0%
Country effect (base = Norway)						
Hungary		1.507***	0.713***	-13.2%	5.0%	8.2%
Italy		0.660	-1.105***	11.9%	5.9%	-17.9%
Poland		0.580	1.192***	-18.2%	-0.0%	18.2%
Spain		-0.0519	1.238***	-18.1%	-1.9%	20.0%
Constant		-0.394	-0.810***			
Observations (cases)		2798				

*** p<0.01, ** p<0.05, * p<0.1

[a] Percentages refer to the difference with respect to class 1: *mild intervention supporters*.

[b] Percentages refer to the difference with respect to class 1: *somewhat sensitive to externalities.*

6. Discussion

a. Comparative cross-country analysis of travel behaviour

Across the different determinants of travel behaviour analysed in section 4, trip purpose seems to substantially affect frequency of trips and mode choice. However, in the case of frequency of trips, countries seem to behave rather similarly: work trip is performed on average around 5 days a week, grocery shopping 3 days a week and Children to school between 4 and 5 days a week. Only leisure activities show some country differences, with Hungary and Poland showing a sensibly lower share of people performing these trips. More differences are found in mode use across the different countries. Italy and Poland seem to have a larger private vehicle use for commuting, while Norway for children related activities. Spain largely dominates in active travel for non-work related trips. In fact, it also shows shorter average distances and lower travel times in all trips. This may be also depending on more favourable weather conditions compared or higher urban densities. The main distinction in mode choice is however related to work and non-work related trips. In fact, public transport use is rather low in non-work related activities in all countries, especially in Italy. This, may be due to the fact that public transport use might be limited because of restricted timetables at evenings and being less comfortable when moving with grocery or bags (Dieleman et al., 2002; Ortúzar and Willumsen, 2011; Salonen et al., 2014).

Results also generally confirm the influence of city size, with lower use of private vehicle in large cities (Dargay and Vythoulkas, 1999). However, Italy and Hungary seem to go against this finding, showing higher private vehicle use. A deeper consideration of contextual factors, such as local transport policies, city structure and road infrastructure, might need to be taken into account. However, this could also underline some differences in cultural attitudes towards car use.

Private vehicle use seems to change with age as also argued by Dargay and Vythoulkas (1999), with an increasing tendency of use until 40 years. However, while this seems to be reduced for older people in grocery and leisure activities, for commuting it continues to increase. Gender influence seems substantially in line with the literature (Nolan, 2003; Vance and Lovanna, 2007); women having a lower use of private vehicles in all countries and for all trip purposes. Also, the effect of education and income seem to be generally in line with literature, which associates a positive relation of these with private vehicle use. However, highly educated people in Norway and Spain seem to behave differently, using car less for commuting to work. The reason behind this would need more investigation. It may be associated with more environmental concern, as argued by (Rienstra et al., 1999), or because the level of education might be higher in larger cities.

When associating attributes sensitivity to actual mode choice, interviewees seem to act consistently with their preferences. Comfort seekers and privacy seekers are associated with the largest increase in private vehicle use, while cost sensitivity and environmental concern increases with public transport use and active travel (De Borger and Fosgerau, 2008; Eriksson et al., 2006). The survey also highlights the importance, of safety and reliability considerations across all countries (Kamargianni et al., 2015; Singleton and Wang, 2014; Willis et al., 2013). In fact, not only a high share of population stated to be sensitive to these factors in all countries, but they seem also to have a lower public transport use and active travel. These results highlight that public transport is perceived as a less comfortable, safe and reliable alternative to private transport. Policies should target these limitations in order to facilitate shifting away from private vehicle use.

Countries have in general similar support to mobility transition policies. Road and vehicle pricing are the least supported, followed by dedicated public transport lanes in most countries. Mixed neighbourhoods, more stringent emission standards and controls and improvements of mobility infrastructure seem the most supported. Countries that have higher use of private vehicle for workplace trip (Italy and Poland) seem more affected by externalities. This may suggest higher private vehicle use make them perceive externalities more intensively. Conversely, Norway and Hungary, which have the highest public transport use, have a sensibly lower sensitiveness to these externalities. Spain seems to have higher satisfaction with public transport infrastructure. However, it does not seem to use it more than other countries. Similarly, in Norway, the higher parking space and pedestrian lane satisfaction does not seem to be associated with more private vehicle use or active travel. Satisfaction towards shared mobility infrastructure is generally the lowest. This might suggest that perception of transport externalities might be more connected with different travel behaviour than satisfaction with infrastructure.

Causal relations (e.g. income and education, distance and mode choice) must be further investigated. This analysis presented the descriptive results of travel behaviour in five European countries and put the attentions on aspects to consider when analysing travel behaviour. First, the importance of considering country specific behaviour when considering factors as education and city size. Meanwhile, the relative importance with respect to choice attributes and attitudes regarding externalities and transport policies seem to be similar across countries and seem to be associated with consistently different travel behaviour.

b. Travel mode choice, policy support and perception of externalities

Several insights can be drawn from a comparison of the two journeys under analysis in section 5. Overall, support for a transition to sustainable mobility indicates that people's mode choice is quite consistent with their opinions on these policies, with strong supporters of intervention using AM more for grocery shopping, and those indifferent to intervention using PT less for commuting.

In the case of perception of negative externalities, it is interesting to note that both the insensitive and highly sensitive to externalities groups tend to move more by PV to commute to work. In the case of the highly sensitive group, this may highlight a very interesting paradox with respect to the perception of negative transport externalities. Since private vehicles are the most exposed mode to these externalities, one would expect that those aware of these externalities might prefer other modes. However, this research seems to indicate the opposite. This result may highlight that PV drivers find it difficult to accept or acknowledge that they are major contributors to the very externalities that they perceive (Miralles-Guasch et al., 2014; Van Exel and Rietveld, 2009). Those drivers act as free-riders to the contribution to public goods of sustainable mobility environment. Voluntary-based policy measures are thus not likely to be effective for this category of drivers. On the longer term, policies framed to make private car drivers aware they contribute to the externality they complain to would raise help to change. The result may also indicate that commuting behaviour to work is governed by habits, with people preferring to move by PV regardless of their sensitivity, as found as well in Lanzini and Khan (Lanzini and Khan, 2017). If this is the case, policies aimed at habit-breaking, such as PT incentives or ride-to-work programmes, may prove effective in helping shift people away from PV use. However, it could be that people chooses PV because they have no efficient alternative to reach their workplace (Vermesch et al., 2021). In that case, increasing PT coverage and improving timetables might help overcome this barrier. Nonetheless, the lack of alternatives might as well be only a perception, undermining one of the main determinants of intention to change behaviour according to the theory of planned behaviour: perceived behavioural control (Ajzen, 1991). This refers to the perceived ability to have different choices with respect to current behaviour and relative easiness to adopt them.

In the case of the insensitive group, the result is more straightforward and highlights a lower willingness to contribute to environmental quality and health: pollution, noise, accidents, climate change.

Socio-economic characteristics seem to be similarly connected to both trips and can help to identify groups that could be targeted with specific transition policies. Full-time workers tend to use PT less, so cheaper PT for commuters in the form of tax credits or company refunds for tickets might help them switch to less polluting modes (Hilton et al., 2014; Steinsland et al., 2018). Larger households seem to show a greater likelihood to move by PV for grocery shopping, which is expected since they are likely to need larger amounts of products. In this case, e-groceries could provide a sustainable last mile solution to using PV for larger families (Bjørgen et al., 2021; Heldt et al., 2021).

Journey characteristics appears to be connected to mode choice more in the grocery shopping trip than in the commute to work. In particular, a tendency to make more frequent trips and leave from home is clearly associated with a greater likelihood of using AM rather than motorised vehicles. This can be seen as an argument in favour of providing such facilities closer to residential areas rather than on industrial estates, as is often the case with large malls (Achen, 2005; Handy and Clifton, 2001).

Overall, the connections between choice attributes and travel mode choice in both trips indicate that people's mode choice is consistent with their preferences. Those who seek to minimise costs seem to favour PT over PV, meaning that the latter is rightly associated with higher spending. Respondents concerned about the environmental impact of modes tend to avoid PV more. By contrast, comfort, privacy and safety seekers tend to prefer travelling by PV.

Behaviour consistent with preferred mode attributes suggests that policies and recommendations aimed at raising awareness of environmental impact or the cost benefits of shifting away from PV use could potentially be effective (Anable and Gatersleben, 2005; Eriksson et al., 2006).

Finally, there seem to be significant differences from country to country, especially in the grocery shopping trip, where there may be variations of up to 20% in likelihood responses to mode choice. This suggests that these policies may need to be specifically tailored to the country where they are applied, which calls for a deep knowledge of citizens' behaviour on the part of the public administration. However, results on policy support and perception of negative externalities seem to hold across all countries at similar levels except in Italy, where the connection is smaller.

The analysis presented here has certain limitations. First, travel time is approximated for other options based on distance and mode speed at NUTS3 level. This is a relatively major assumption. Other methods such extended travel diaries were ruled out to avoid extending the duration of the interview. Second, the current study design and analytical approach also limits some specific causal inference. Another substantial limitation with respect to assessing causality comes from the two-way connection between attitudes and behaviour, i.e. the possibility that choosing a specific mode also influences opinions on policy and attitudes (Kroesen et al., 2017).

7. Conclusions

The descriptive statistics reveal that transport policies received different support from citizens. As expected, those policies implying a direct financial cost for users are much less supported than infrastructure or technology-based policies. Citizens are much less supportive with road and vehicle pricing instruments and would rather support mixed neighbourhood development. On this last point, the survey results show that in some countries active travel is commonly used for grocery shopping. This choice is likely to be motivated by the presence of corner shops in cities. However, citizens are also supportive with policies dedicated to improving road traffic and expansion while it is well known that expanding roads does not solve congestion problems in the long run (Duranton and Turner, 2009). Informational gaps regarding the effectiveness of some instruments to change travel behaviour are thus present. Hence, successful mobility transition should have to address them so that citizens can accept them and would revise their mobility behaviours.

The analysis of travel mode choice shows that people act consistently with their opinion towards sustainable transport policies and preferred mode specific attributes but rather inconsistently with their perception of negative externalities. Supporters of sustainable transport policies are more prone to use active mode of mobility, at least for grocery shopping. And a rational relation is observed between the mode choice and mode attributes such as cost, privacy, safety, comfort and environmental impact. However, people who are most sensitive to negative transport externalities are also most likely to be private vehicle drivers. This is a rather interesting outcome which might suggest the presence of habits in commuting or a perceived lack of alternatives and suggests that sustainable mobility policies should also act on driver responsibility in negative transport externalities.

Dealing with mobility for grocery shopping is also a challenge for a low carbon mobility. Mode choice for grocery shopping appears to depend more than the commute to work on journey characteristics, such as frequency and starting point and also on family size. This suggests measures such as setting up mixed residential and commercial neighbourhoods and e-grocery shopping might contribute to low carbon mobility and would deserve to be further investigated to assess their effectiveness in changing mobility habits.

Chapter 4

The impact of Madrid Central low emission zone on NO_2 concentrations and alternative-fuelled vehicles' adoption

The research presented in this chapter has been developed within the la Caixa social research project ENERPOLIS (Energy Efficiency Policies in Spain: analysing consumer choices), 2019-2022. The aim of the project was to understand the effectiveness of market based (energy efficiency labels) and command and control instruments (Low emission zones) in Spain and subsequently provide insights on the effectiveness of regulatory and economic instruments in the transition towards an energy efficient economy.

The following publications are derived on the content of this chapter:

- ***Silvestri, A.****, Galarraga, I., Ansuategi, A., (Under review)* Assessing the impact of a Low Emission Zone (LEZ) on NO2 concentrations using the synthetic control method: the case of Madrid Central*.*

- ***Silvestri, A.****, Foudi, S., Galarraga, I., Ansuategi, A., (Under review)* The impact of Low Emission Zone on the purchasing of alternative fuelled vehicles: the case of Madrid central.

1. Introduction

Road transport causes many negative externalities, some of which affect environmental quality and public health in European cities. In particular, poor air quality deriving from vehicle emissions is a major concern for large urban areas as exposure to the pollutants emitted[9] is connected with serious health threats such as respiratory, cardiovascular and nervous system problems resulting in premature mortality and morbidity (Ballinger et al., 2017; Gehrsitz, 2017). Some of the pollutants concerned are also GHGs, and thus contribute to anthropogenic climate change. Moreover, congestion due to excessive private vehicle use is a source of inefficiency in mobility and a cause of further emissions per kilometre driven (Bernardo et al., 2018).

To tackle some of these externalities, the EU published the EU Air quality Directive in 2008 (2008/50/EC, 2008). This directive was then enforced by the Clean Air programme (COM(2013) 918), which set air quality standards in terms of concentration levels for several pollutants. According to the European Environmental Agency (EEA), these air quality standards have partially mitigated emission levels in many European cities in the last ten years. However, the EEA estimates that at least one third of the EU population is still exposed to concentrations of pollutants above acceptable thresholds.[10] There is therefore a need to implement mobility management policies in urban areas aimed at reducing private vehicle use and improving overall emission levels in the existing vehicle fleet.

These mobility management policies are part of a raft of measures that urban governments can use to reduce "pollution-type" urban traffic externalities. According to De Borger and Proost (2013), a Pigouvian emission tax set at the value of the external marginal damage would be the optimal measure for reducing both emissions per kilometre driven and the number of kilometres driven. However, such a policy is hard to implement, mainly due to its unpopularity. Thus, they provide and assess a full range of second-best policy options, including LEZs.

A LEZ limits access by the most polluting vehicles to certain areas, typically historical city centres and/or city business districts; although in some cases it may be extended to full metropolitan areas or provinces. LEZs are expected to provide positive health impacts (Gehrsitz, 2017; Malina and Scheffler, 2015a; Mudway et al., 2019) by reducing emissions of local air pollutants from traffic and incentivising the purchase of more efficient vehicles (Browne et al., 2005; Kelly and Kelly, 2009; Wolff, 2014).

In 2018, the city of Madrid (Spain) announced a plan to implement a LEZ to reduce its excessive levels of nitrogen dioxide (NO2). The policy was called Madrid Central (MC hereafter) and came into effect in December 2018 with a plan to progressively restrict vehicle access to the historical central

[9] Mainly particulate matter (PM_{10} and $PM_{2,5}$), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2).
[10] https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-2/assessment

area. MC was the first LEZ to be implemented in Spain and it opened up the path to similar policies in cities elsewhere in the country. Indeed, Barcelona also set up a LEZ in September 2020 and the central government in Spain has announced that by 2023 LEZs must be adopted in all cities with more than 50,000 inhabitants and in those with more than 20,000 inhabitants where there are exceeding concentrations of certain pollutants (BOE 121 21/05/2021). It is therefore extremely important to estimate the effectiveness of LEZs in reducing pollutant concentrations.

The objective of this chapter is twofold: first, to analyse the impact of Madrid Central on local air pollution; and second, to assess the policy impact on the purchasing of AFVs. In both cases, a robust synthetic control method is employed which allows creating a baseline "No policy scenario" for the two cases to compare the "Policy scenarios" relative to the local concentrations of NO2 and the share of AFV sales on total private vehicle sales.

The next section overviews the literature on LEZ impact on local air pollutants and on vehicle fleet renewal. Section 3 presents the common methodology to both the case studies. Then, Section 4 will present and discuss the case study on the LEZ effectiveness on reducing local concentrations of NO2. Finally, Section 5 will present and discuss the results of the LEZ impact on sales of AFV.

2. Literature review

a. LEZ impact on local air pollutants

Most studies in the literature conclude that LEZs lead to reductions in concentrations of local air pollutants. However, the size of those reductions, and thus the effectiveness of LEZs, is still a matter of discussion (Malina and Scheffler, 2015a, 2015b; Morfeld et al., 2015a, 2015b). Estimates of the effectiveness of LEZs vary according to the method of analysis used, the volatility of the measurements of the concentrations of the pollutant under study and the specific characteristics of both the city and the policy applied. In addition, it must be taken into account that pollutant concentrations are also influenced by other factors such as traffic congestion (Bernardo et al., 2018), industry, domestic heating systems and external factors such as the economic situation and the mobility restrictions and emergency regulations in response to the health crisis that have been recently experienced. Hence, it is not easy to isolate policy-specific impacts and particular care is needed in selecting the methodology.

Table 4.1 reports the results of ex-post studies conducted in European capitals to address the effectiveness of LEZs in reducing nitrogen oxide (NOx) concentrations. Several reasons such as differences in characteristics between cities, the intervention period and the type of vehicles targeted make it difficult to compare results directly.

Table 4.1 Ex-post evaluation studies on LEZs in Europe analysing impact on Nitrogen oxide (NOx) concentrations

CITY	TARGETED VEHICLES	YEAR INTRODUCED	NITROGEN OXIDES (NOX) REDUCTION	REFERENCE(S)
STOCKHOLM	Heavy duty	1996	4% [NO2]	Rapaport (2002)
LONDON	Light and Heavy duty	2008	No effect [NOx] 3-7% [NOx] (TC) No effect [NO2] (TC)	Ellison et al. (2013) Barratt et al. 2014 [reported in Holman et al. (2015)]
AMSTERDAM	Heavy duty (Euro 0, I and II)	2009	4.9% [NO2] (TC) 5.9% [NOx] (TC)	Panteliadis et al. (2014)
COPENHAGEN	Heavy duty	2008	No effect [NOx](TC)	Jensen et al. (2012) [reported in Holman et al. (2015)]
ROME	All non-resident vehicles during working hours (excluded public transport)	2001	Within LEZ: 24% Surrounding LEZ: 22% [NO2] (TC)	Cesaroni et al. (2012)
BERLIN	All vehicles [petrol Euro 1, diesel Euro 4]	2008	No effect [NO2]	Gu et al. (2022)
LISBON	All non-resident vehicles: - Euro 2 in Zone 1 - Euro 1 in Zone 2	2009	12% [NO2] Zone 1 13% [NO2] Zone 2 22% [NO2]	Ferreira et al. (2015) [Data until 2013] Santos et al. (2019) [Data until 2016]
MADRID	All non-resident vehicles [petrol Euro 3, diesel Euro 4]	2019	23-34% [NO2]	Salas et. al (2021)

Moreover, some studies assess total reductions in air pollutant concentrations while others focus on reductions in the contribution of traffic to air pollution. Differences in results may also emerge depending on methodological approaches and data availability. Thus, in some cases data from only a few meteorological stations are available for the study (Holman et al., 2015; Panteliadis et al., 2014). Some studies look not only at the impact within the LEZ area but also at the surrounding area to check for so-called spillover effects, i.e. either a positive or negative[11] impact on pollutant concentrations dependent on the policy being active (Salas et al., 2021).

The earliest LEZs, such as those in Stockholm, London, Copenhagen and Amsterdam, only targeted commercial vehicles, trucks or buses, so their estimated impact on pollutant concentrations is rather small (Ellison et al., 2013; Holman et al., 2015; Panteliadis et al., 2014; Rapaport, 2002). All the studies on these four cities find some degree of reduction in other pollutants such as particulate matter, but the effect on nitrogen oxides is not always confirmed. In fact, Ellison et al. (2013) and Jensen et al. (2014) find no significant effect on nitrogen oxides.

In determining the effect of the policy, a simple comparison between pre- and post- intervention data alone cannot provide insightful results, as it would incorporate a confounding effect from other variables not directly related to the policy itself. Studies employ different methodologies to identify the specific effect of the policy. Ellison et al. (2013) and Panteliadis et al. (2014) use regression techniques to control for the impact of meteorological (i.e. wind, temperature, pressure) and traffic related (i.e. number of vehicles on the streets, working days or weekends, holidays) effects. Rapaport (2002) and Jensen et al. (2014) instead derive the effect by comparing real data to scenarios drawn up using different modelling tools (AIR VIRO[12] and OSPM[13]).

The cases of Rome and Lisbon (Cesaroni et al., 2012; Ferreira et al., 2015; Santos et al., 2019) are closer to MC than the four mentioned above, as the policy targets both commercial and also non-commercial vehicles. In both cases there is evidence that the policy led to substantial reductions in NO2. Cesaroni et al. (2012) use a full chain approach[14] to determine policy impacts on health and pollutant concentrations. Their study estimates the contribution of traffic to NO2 concentrations using a distributional model that uses traffic volume and street geometry (CAR-2). The two studies on Lisbon's LEZ use linear models to estimate the impact of the policy. Specifically, Ferreira et al. (2015) use a Generalised Additive Model while Santos et al. (2019) use linear regression to determine temporal trends between the annual average concentrations. Despite the different methodologies and periods under scrutiny, the policy resulted in a reduction in NO2 concentrations in the range of 12- 13% within the area, while Santos et al. (2019) estimate an even greater reduction of 22% for the larger zone. Conversely, Gu et al.(2022) use a general additive mixed model and find no reduction in NO2 in Berlin. This is the only case in the study considered in which a LEZ that also targeted private vehicles did not lead to a reduction in pollutant concentrations.

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[11] Positive *spillover* means the increasing presence of cleaner vehicles on the surrounding streets, while negative spillovers could arise if the LEZ redirects polluting traffic towards the surrounding areas.
[12] https://www.airviro.com/airviro/
[13]https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/the-monitoring-program/air-pollution-models/ospm/
[14] See the INTARASE project described in Briggs (2008).

A few studies have already sought to analyse the impact of MC on the concentrations of local air pollutants. Prior to the implementation of the policy, Izquierdo et al. (2019) studied the potential impacts of the plan in terms of reducing NO2 concentrations and the relative impact on mortality. They compared data on pollutant concentrations in 2012 with predicted data for 2020 with the policy in place. They used a Eulerian chemical-transport model for predictions. They expected the policy to reduce citywide concentrations of NO2 by 4.0 µg/ m3 and bring about appreciable health-related benefits, cutting premature deaths by over 500 per year, with the highest impacts being found within the city centre.

Salas et al. (2021) use a difference-in-difference approach to compare pre- and post-implementation impacts on NO2 concentrations at the meteorological station within the LEZ area with those at 10 other stations around it. They find a significant reduction of between 23% and 34% within the LEZ, taking the area to below the 40 µg/ m3 mark set by the EU. This reduction is in line with the expected figures calculated by Izquierdo et al. (2019). They also find significant reductions in 9 out of the 10 stations around the area suggesting that there is no negative spillover effect.

Lebrusan and Toutouh (2020a, 2020b) and Toutouh et al. (2020) also analyse the effectiveness of MC using different methodologies and conclude that the policy brought about a reduction in NO2 concentrations with no negative spillover effects in outlying areas. Their studies use smart city tools (Lebrusan and Toutouh, 2020a), analysis of variance on the difference between pre- and post-intervention concentrations (Lebrusan and Toutouh, 2020b), polynomial regression and computational intelligence (Toutouh et al., 2020). In line with the results of Salas et al. (2021), they conclude that MC brought about a reduction in NO2 concentrations. However, they also find a reduction in the areas surrounding the LEZ.

b. LEZ impact on vehicle fleet renewal

Despite the extensive recent literature analysing LEZs and local air pollutants, the impact of LEZs on the renewal of vehicle fleets has been explored far less than their impact on air pollution.

In one of the first attempts at analysing vehicle fleet changes following the introduction of an LEZ, Ellison et al. (2013) find substantial reductions in London registrations of duty vehicles targeted by the London LEZ. By comparing shares of vehicles registered that do not meet the LEZ requirements in London, neighbouring counties and the rest of the UK, they estimate an extra 20% reduction in London for pre-Euro III vehicles in 2008 above the natural vehicle replacement rate. Furthermore, just before being targeted in 2011, the registration of non-compliant light commercial vehicles dropped by 10% compared to the national average. In a study of German cities, Wolff (2014) estimates a drastic change in spatial fleet composition following the announcement of the introduction of LEZs. This occurred particularly in areas closer to the LEZs and is identified by the author as a main driver of the effectiveness of the policies in reducing pollutant concentrations.

Prior to the present study, an attempt at estimating the impact of MC on AFV registrations was made by Peters et al. (2021). Their paper is also the only previous study analysing the impact of LEZs on the uptake of AFVs. In their study, a difference-in-difference method is used to compare registrations in Madrid and Barcelona. They estimate that MC led to an increase in AFV registrations after the introduction of the LEZ of between 3.5% and 3.9% within the municipality and between 2.2% and 2.3% in the Madrid Regional Autonomous Community.

Our study seeks to contribute to this literature by implementing a synthetic control method to analyse the impact of MC on new AFV registrations in Madrid and its Metropolitan area (MMA). Synthetic controls have been widely used in the last decade to analyse the impact of various kinds of intervention on both national and local scales (Abadie, 2021). With respect to transport policies, synthetic controls have been used to estimate the impact of several policy interventions. Zink et al. (2020) use this method to study the impact of subsidies in Germany on the purchase of electric vehicles and on charging infrastructure. They conclude that their impact is rather small when considering the market size. Welde and Tveter (2022) use synthetic controls to analyse the impact of new road investments on commuting, population, new firms and employment. Kunimi and Seya (2021) suggest using this method to analyse the impact of transport infrastructure interventions on land prices. Runst and Ho (2022) use synthetic controls to determine the impact of an increase of about €66/t CO_2 on the German eco tax on transport emission, and estimate that it led to a decline of about 0.2-0.35 t per person per year. This method has also been used to determine the effect of transport improvements on commuting (Tveter, 2018), of free-fare public transport policy on subway ridership (Dai et al., 2021) and of the penalty point system on road fatalities in Spain (Martinez-Gabaldon et al., 2020). Despite these examples, this study is the first attempt at using synthetic controls to analyse the impact of an LEZ on AFV registration.

3. Methodology

a. Theoretical Framework

The present study relies on the synthetic control method to determine the impact of the introduction of Madrid Central on the purchasing of alternative fuelled vehicles (Abadie et al., 2012; Abadie and Gardeazabal, 2003). This method consists in creating a synthetic version of the treated unit as a function of a group of similar untreated and unaffected units, called “donor pool”, using data prior to the intervention. Once the synthetic control of the treatment unit is identified, the effect τ of the measure in a post-intervention period t is given by:

$$\tau_{jt} = Y_{jt}^{I} - Y_{jt}^{N} \qquad (1)$$

where, Y_{jt}^{N} represents the potential response without intervention on unit j = 1,2,…,J+1 in period t and Y_{jt}^{I} the potential response under the intervention. Index j identifies the J+1 units observed and for simplicity j=1 is considered to be the unit affected by the intervention.

Therefore, the main aim of the synthetic control estimation is to identify Y_{1t}^{N}, that is the synthetic version of the affected unit and compare it to the post treatment observed values of the same unit (Y_{1t}^{I}).

In its original specification (Abadie et al., 2012; Abadie and Gardeazabal, 2003), Y_{jt}^{N} is calculated as a weighted average of the units in the donor pool. The weights in this specification are calculated in order to minimise the mean squared prediction error (MSPE) on a set of predictors. These predictors may include also pre-intervention values of the variable of Y_{jt}. The weights are restricted to be a convex combination of the donor pool, that is they are non-negative and sum to one.

However, Abadie (2021) notes that this approach, which focuses on the effect on one or few treated units, implies that the effect of the intervention might be hard to distinguish from other shocks in the outcome variable in presence of high unit-specific volatility. Hence, it is recommended to reduce this volatility by averaging and in cases where a substantial volatility is still present using filtering techniques on the data before applying the synthetic control method.

Since both NO_2 concentrations and AFVs purchasing decision present over time substantial volatility and seasonal effects, the procedure introduced by Amjad et al. (2018) is employed, as suggested in Abadie (2021) to de-noise the data. The idea behind their approach, instead of using weights, is to approximate the matrix of observational data on the pollutants using a factorisation technique called the singular value thresholding (Chatterjee, 2015). This allows to identify a low rank approximation of the matrix without the noise component. Then, to derive the synthetic version of the treated unit, the linear relationship between the treated unit and the donor pool is then identified on the pre-intervention portion of the de-noised data and extended to model the post-intervention results. This releases the restriction in the original model of weights being a convex combination of the donor pool observation to be a linear combination instead. However, as in the original specification, it requires the mean vector of the outcome variable over the pre-intervention period to lie in the span of the mean vectors of the control units in the donor pool to allow the existence of a set of linear weights to build the synthetic control. This means the treated unit should not be extreme in values compared to the control units, although this can be achieved also through data transformation.

This methodology allows involving only pre-treatment values in order to determine the synthetic control. Again, Amjad et al (2018) provide an extensive and formal explanation of the procedure. For a more formal and complete definition of the model, as well as a comprehensive state-of-the-art guide on his properties and characteristics, can be found in Abadie (2021).

To ensure the validity and robustness of the model results three sensitivity analysis tests suggested by Abadie (2021) were employed. The first test involves comparing model results with alternative model specifications in each of which a different station from the donor pool is taken as treated unit in order to identify possible “placebo effects”. Since the units in the donor pool are assumed not to be affected by the policy, these placebo tests should not show a similar behaviour as the treated unit model in correspondence with the introduction of the policy. The following test statistic, root mean squared prediction error (RMSPE), can be used to measure the ratio of the post-intervention fit relative to the pre-intervention. For $0 \leq t_1 \leq t_2 \leq T$ and $j = \{1, \dots, J+1\}$:

$$R_j(t_1, t_2) = \left(\frac{1}{t_2 - t_1 + 1} \sum_{t=t_1}^{t_2} \left(Y_{jt} - \hat{Y}_{jt}^N \right)^2 \right)^{1/2} \quad (2)$$

where $\hat{Y}_{jt}^N$ is the outcome on period t produced by a synthetic control when unit j is coded as treated and using all other J. A measure of the quality of the fit of a synthetic control for unit j in the post-treatment period compared to the fit in the pre-treatment period is given as follows:

$$r_j = \frac{R_j(T_0 + 1, T)}{R_j(1, T_0)} \quad (3)$$

Where $0 \leq T_0 \leq T$ is the last pre-intervention period. Comparing then the r_j among all units, treated and untreated, the effect of the treatment is considered to be significant when the magnitude of the treated unit effect is substantially larger than the permutations distribution (Abadie, 2021). When the number of units in the donor pool is limited, the presence of an intervention effect on the treated unit may produce effects in the opposite sign in the placebo synthetic controls, since the treated unit is in the donor pool. In this case, replacing $Y_{jt} - \hat{Y}_{jt}^N$ with its positive part, $(Y_{jt} - \hat{Y}_{jt}^N)^+$, in $R_j(T_0 + 1, T)$ allows considering only effects of the same sign as those in the treated unit. This leads to one-sided inference which may result in a substantial gain of power in presence of limited number of units in the donor pool, compared to the double-sided inference of equation 3.

The second test consists in backdating the introduction of the treatment to an arbitrary previous period to check whether this leads to a change in the model results due to anticipation effects. This is equivalent to reducing the pre-treatment data considered to construct the synthetic control to a previous time period. The third test, to check the robustness of the results involving repeating the synthetic model iteratively leaving out one of the control units to assess how much this impacts the results.

b. Policy context

On October 29th, 2018, the governing board of Madrid City Council approved the introduction of Madrid Central LEZ, starting from December of the same year. Nonetheless, the measure was implemented with an initial 3-months trial period in which LEZ violations were not sanctioned.

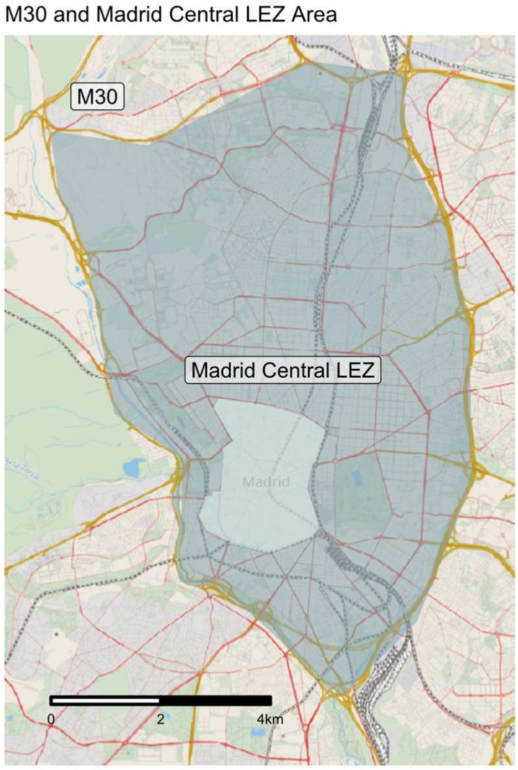


Figure 4.1 Map of Madrid inner area, highlighting M-30 ring and Madrid Central LEZ areas

The area (Figure 4.1) of 4.72 Km2 covered the inner city centre of Madrid. The main objective of the policy was to reduce the concentrations of pollutants, in particular NO2, to comply with EU standards. To do so, it required any vehicles wanting to access the LEZ to display the environmental label provided by the National traffic directorate (DGT), introduced by the National Plan for Air Quality and Protection of the Atmosphere 2013-2016 (Plan Aire, TRA 6, 2013). The label divides vehicles into 4 categories (0, ECO, C, B) informing consumers about the polluting potential of the car. The assignment to a specific category considers the fuel type and the year of production. Based on the category different restriction to access were then applied as reported in Table 4.2, along with each category admission requirements. Residents of the area were excluded from the limitation, but unlabelled vehicles had to be retired by 2025. Upon publishing the policy, the city council announced the plan to introduce from 2025 on some limitations for the whole Madrid urban area, the inner part of the M-30 highway ring, with further progressive restrictions.

Table 4.2 Labels requirements, access and parking limitations for non-resident private vehicles within the LEZ area. Different restrictions apply to heavy, service and commercial vehicles.

LABEL	ADMISSION REQUIREMENTS	ACCESS ALLOWED
0	BEVs, REEV and PHEV	No restrictions, Free parking
ECO	HEV and alternative fuelled vehicles (NGV, LPG)	No restrictions, Limited free parking
C	Gasoline vehicles from 2006 and diesel from 2014	From 7 to 22
B	Gasoline vehicles from 2000 and diesel from 2006	From 7 to 22 (only until end of 2021)
No Label	Older gasoline and diesel vehicles	Not allowed

BEV= Battery Electric Vehicle; REEV= Range Extended Electric Vehicle; PHEV= Plug-in Hybrid Electric Vehicle; HEV; Hybrid Electric Vehicle; NGV= Natural Gas Vehicle; LPG= Liquid Petroleum Gas Vehicle

Along with the LEZ, in the same December 2018, the Autonomous community of Madrid implemented the Plan MUS 2018 for sustainable urban mobility. The plan allocated 2 million euros in subsidies for the purchase of AFV and motorcycles, as well as investments in charging infrastructure. The plan subsidized the purchase of an electric vehicle with up to 5,500 € and a gas vehicle with up to 2,500€. The plan depleted its funds in few days since its opening, so it is expected to have impacted vehicles purchases only for the month of December. The Plan was then renewed in April 2019 for a second edition with a 3 million euros budget.

At national level, starting from 2019 Plan Moves, issued by the Spanish Government's Institute for the Diversification and Saving of Energy (IDAE), subsidised the purchase of AFVs with a total budget of 100 million euros. The budget was assigned based on registered population to each autonomous community, upon their acceptance to implement it. Each autonomous community was then responsible to administrate it. This implied differences in timings at which each community activated the subsidy program, while Cantabria and Extremadura did not implement it at all.

4. The impact of Madrid Central on NO2 concentrations.

The case study reported in this section seeks to analyse the impact of Madrid's LEZ on air quality within and around the perimeter of the MC area. An earlier assessment of its impact on NO2 concentrations is provided by Salas et al. (2021), but is limited to the first 6 months of MC implementation. This study contributes to the relevant literature by extending the post-intervention period under analysis to the beginning of February 2020, seeking to estimate the impact of the policy over an extended period of time. Also, the different methodology used enables to assess the performance of the policy over time and reduces the data requirement to just observational data on NO2 concentrations. This method means that the analysis can easily be applied to other cities where data availability on potential explanatory variables is limited.

The chapter comprises six sections. After this brief introduction, Section 2 provides a review of the existing literature on the assessment of LEZ effectiveness in other European capitals and a review of earlier articles on MC. Section 3 describes the research methodology applied and the data employed in the analysis. Section 4 presents the results on the effectiveness of MC in reducing NO2 concentrations and Section 5 discusses those results. Finally, Section 6 provides some concluding remarks.

a. Data collection and model specification

In this study the units of observation are represented by a sub-group of meteorological and air quality monitoring stations scattered throughout the municipality of Madrid and the whole of the regional Autonomous Community of Madrid (CAM). Data on the average monthly concentration of NO2 were collected from these stations. Those data were collected via the official websites of the municipal authorities of Madrid and the regional government of the CAM. The treatment unit is the station located at Plaza del Carmen, the only one fully within the MC perimeter (marked in red on Figure 4.2).

Under the synthetic control method theory, donor pool units should not be affected by the policy. Hence, to avoid spillover effects such as those identified by Salas et al. (2021) all the stations within the M-30 ring have been excluded. Only five stations within the municipality of Madrid have been included that can be safely assumed to be distant enough to escape potential spillover effects from the treatment, since they lie outside the main city ring (M30). These assumptions are supported by the results of Salas et al.(2021), which show no significant evidence of NO2 reductions at stations outside the M30 and farther away. The other twelve units come from relatively large urban areas of the CAM within the metropolitan area of Madrid.

Meteorological stations can be categorised as background (BG) or roadside (RS) stations based on their location with respect to streets[15]. The treatment unit at Plaza del Carmen is a background station, but the control and spillover groups also include some roadside stations. Pollutant concentrations are expected to be more traffic sensitive at roadside stations, but the synthetic control model excludes the effect of station-specific characteristics (Abadie, 2021). Given the limited number of stations available, the priority has been given to stations in the metropolitan area of Madrid rather than considering only stations of the same type, as this would have required to include stations from outer areas. The fact that only a BG station is available within the Madrid Central area also prevented us from analysing the contribution of traffic alone to NO2 concentrations. The final donor pool comprises

[15] Roadside stations are located nearby roads, motorway or highway, such that the pollution readings are mainly influenced by emissions from traffic. Background stations are located so that they are not influenced significantly by any single source.

17 stations (Figure 4.2): 5 within the municipality of Madrid and 9 from the rest of the CAM. Table 4.3 shows all the stations considered, with control stations numbered according to their positions in Figure 4.2.

To check for positive or negative spillovers in the area surrounding MC, the Plaza del Carmen station has been iteratively substituted as the treatment unit by other nearby stations. The synthetic control method has then been repeated to check for any impact of the policy in those areas. This has involved four stations (marked in yellow on Figure 4.2): Plaza de España (RS), Escuelas Aguirre (RS), Retiro (BG) and Mendez Alvaro (BG).

Table 4.3 Summary of stations involved in the analysis

Num	Station name	Category	Type	Location
	Escuelas Aguirre	Spillovers	RS	Madrid
	Mendez Alvaro	Spillovers	BG	Madrid
	Parque del Retiro	Spillovers	BG	Madrid
	Pza. de España	Spillovers	RS	Madrid
	Pza. del Carmen	Treated	BG	Madrid
1	Farolillo	Control	BG	Madrid
2	Juan Carlos I	Control	BG	Madrid
3	Moratalaz	Control	RS	Madrid
4	Pza. Elíptica	Control	RS	Madrid
5	Villaverde Alto	Control	BG	Madrid
6	Alcalá de Henares	Control	RS	CAM
7	Alcobedas	Control	RS	CAM
8	Alcorcón	Control	BG	CAM
9	Arganda del Rey	Control	BG	CAM
10	Collado Villalba	Control	BG	CAM
11	Colmenar Viejo	Control	RS	CAM
12	Coslada	Control	BG	CAM
13	Fuenlanbrada	Control	BG	CAM
14	Getafe	Control	RS	CAM
15	Leganes	Control	BG	CAM
16	Mostoles	Control	BG	CAM
17	Torrejón de Ardoz	Control	BG	CAM

Data has been collected for the period from January 2016 to February 2020, which gave us about 3 years of pre-treatment periods from January 2016 to November 2018. This is in line with the pre-intervention period used in Salas et al. (2021) and the number of periods is similar to those in previous studies involving the application of the synthetic control method (Abadie, 2021).

For the post-intervention period, although data is available for the period from March 2020 onwards, this has not been used to avoid incorporating the impact of the Covid-19 pandemic outbreak. The model is generally robust to events that affect all stations at once (such as the pandemic or seasonal effects), but the size of this structural break would make it impossible to interpret the results due to potentially uneven distributional impacts across the different areas in the CAM.

The analysis for the robust synthetic control was conducted using Python, with the scripts developed and made available by Amjad et al. (2018)[16].

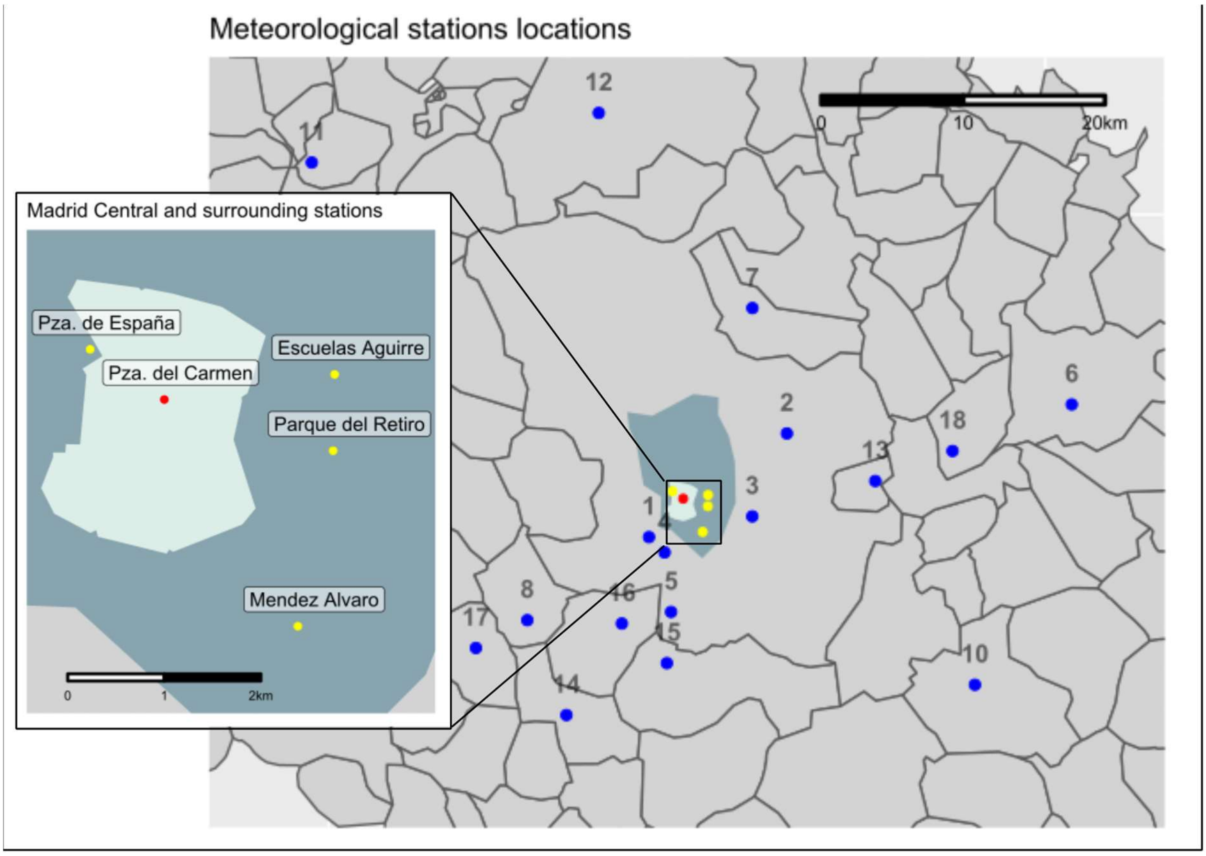


Figure 4.2 Meteorological stations considered within Madrid´s Autonomous Community, control stations in blue, surrounding in yellow and treated unit in red.

b. Robust Synthetic Control estimation

Figure 4.3 shows the observed NO2 concentrations for the Plaza del Carmen station (blue) and those obtained by the synthetic control method (red). The red line is the result of the robust synthetic control method and can be interpreted as a business-as-usual scenario ("without the policy"). The goodness of fit of the model is shown by how close it is to actual observations in the pre-intervention period, while the difference between the two lines in the post-intervention period represents the impact of the policy. To better visualise the post-intervention results, the figure only shows data from January 2018 onwards.

[16]https://github.com/jehangiramjad/tslib

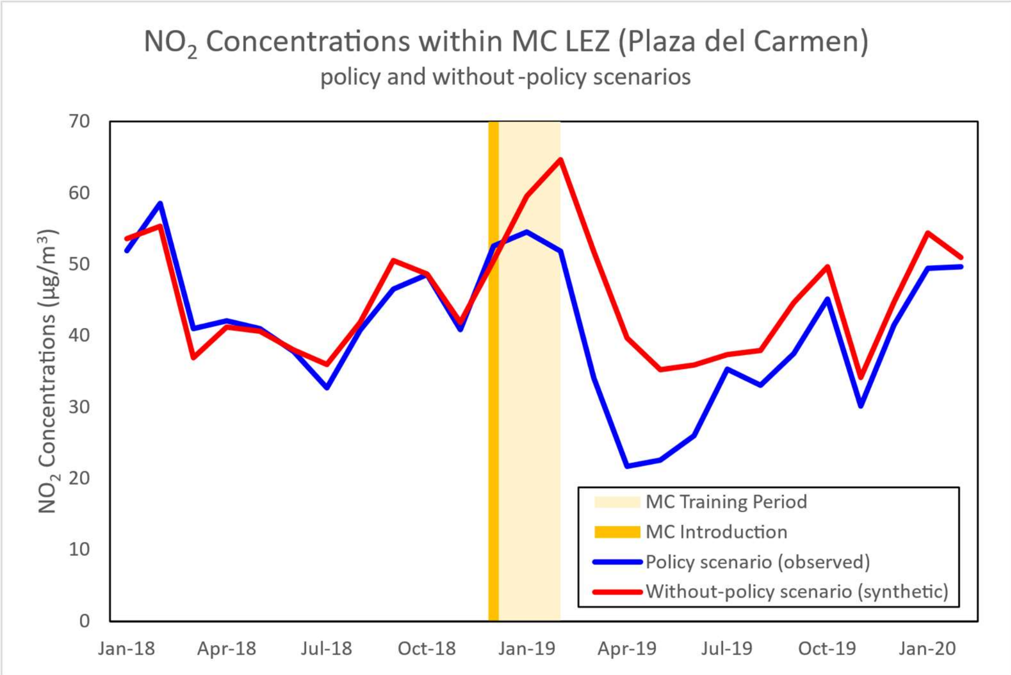


Figure 4.3 Robust synthetic control results for Plaza del Carmen station. (Only post-2018 data displayed)

Results show a significant difference between the synthetic "without policy" scenario and the observed "with policy" scenario; the difference initially increases but then disappears as the 4thquarter of 2019 is reached. This means that there was a substantial reduction in average monthly NO2 levels at the station within the LEZ area from the implementation of the policy up to July 2019. After that, the impact of the measure becomes less evident and the synthetic control returns values very similar to the treatment unit. Figure 4.4 shows the percentage gaps in the observed "policy scenario" with the "without policy" synthetic Plaza del Carmen values as a reference. The figure shows an overall average post-treatment reduction of 16%. However, as mentioned above, the reduction is not evenly distributed. In fact, the results clearly show an average reduction of 29% in NO2 concentration in the first six months of 2019, a result which is in line with findings from Salas et al. (2021), with a peak reduction of 45% in April. However, the gap drops from July 2019 onwards and although concentrations levels remain lower than in the without policy scenario, the impact appears less distinguishable in size from the gaps in the pre-treatment period.

Despite this gap, annual average NO2 concentrations within LEZ area were found to be 36.1μg/m3 in the period considered, dropping for the first time below the 40 μg/m3 limit set by the EU. The without policy scenario indicates that average NO2 concentrations within the Madrid Central area in 2019 would have been at 44.6 μg/m3, i.e. above the threshold.

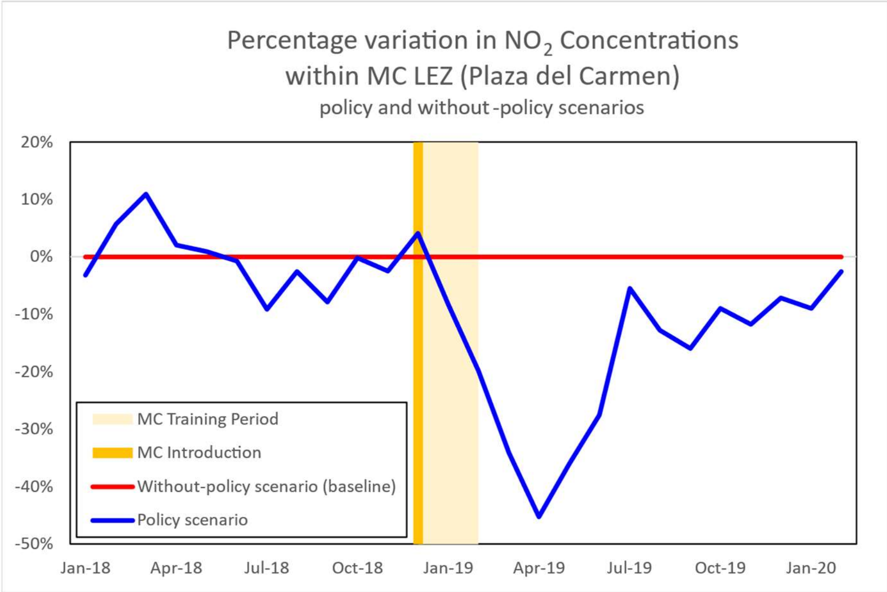


Figure 4.4 Average monthly percentage gap between observed and synthetic Plaza del Carmen. (Only post-2018 data displayed)

c. Sensitivity analysis

Sensitivity tests were conducted to validate these results. The first was the "placebo test", which involved substituting the treatment unit by other stations in the donor pool, which by assumption should not be affected by the policy. This is done to prove that the effect shown in the results is not a spurious artefact of the model specification and only appears for the actual treatment unit.

Figure 4.5 reports the results of the placebo test. The test is represented as absolute gaps in µg/m3 between the real data (the horizontal red line) and the synthetic method results for each donor pool station (in grey). The orange vertical line again represents the introduction of the Madrid Central LEZ, and Plaza del Carmen is highlighted in blue. Since the model only uses pre-intervention data to develop the synthetic "without policy" scenarios, in the pre-intervention period the fit of each model is represented by how close the placebo gap lines are to the real data line. After the introduction of MC larger gaps between these lines are expected, so only the treatment unit should show an evident impact of the policy. This is the case in Figure 4.5, where the test shows that no station other than Plaza del Carmen experienced a substantial decrease in NO2 on the introduction of the LEZ. This result is confirmed in Figure 4.6, which shows the one-sided inference statistic Rj used to measure the goodness of fit of the model, i.e. the ratio between the post- and pre- mean squared prediction errors (MSPE). As expected, this indicator is substantially larger for the treatment unit, meaning that the Plaza del Carmen station is the one that shows the greatest difference between "with policy" and "without policy" scenarios in the seven post-intervention months.

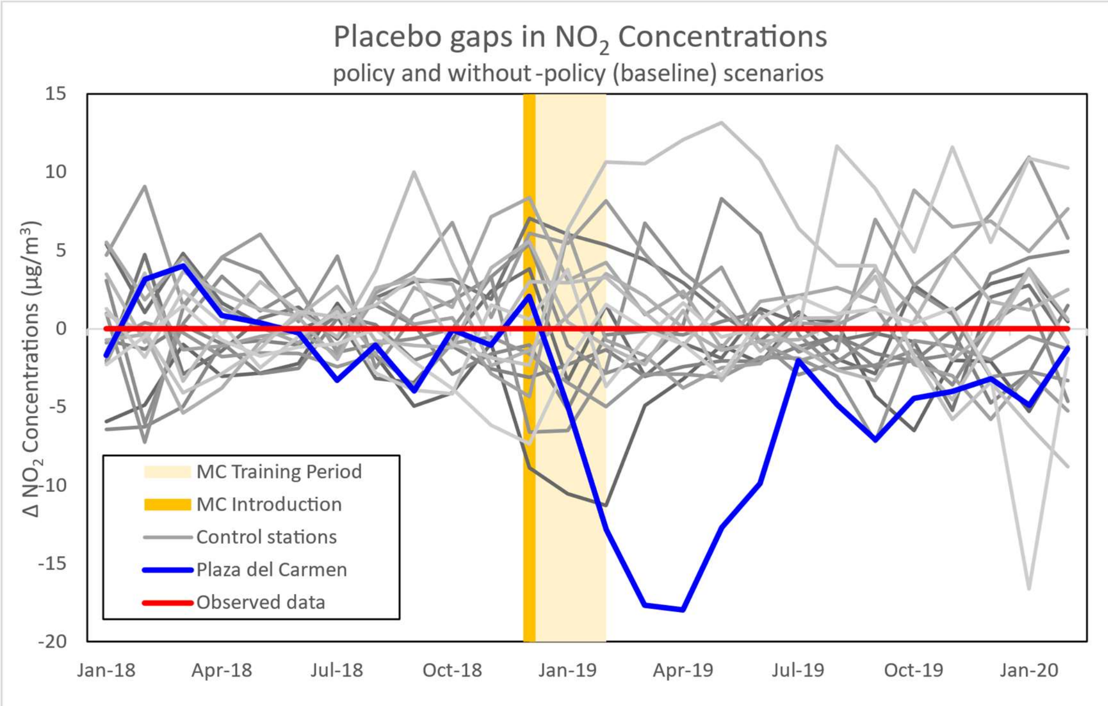


Figure 4.5 Placebo tests: absolute gaps between synthetic and observed data for each station. (Only post-2018 data displayed)

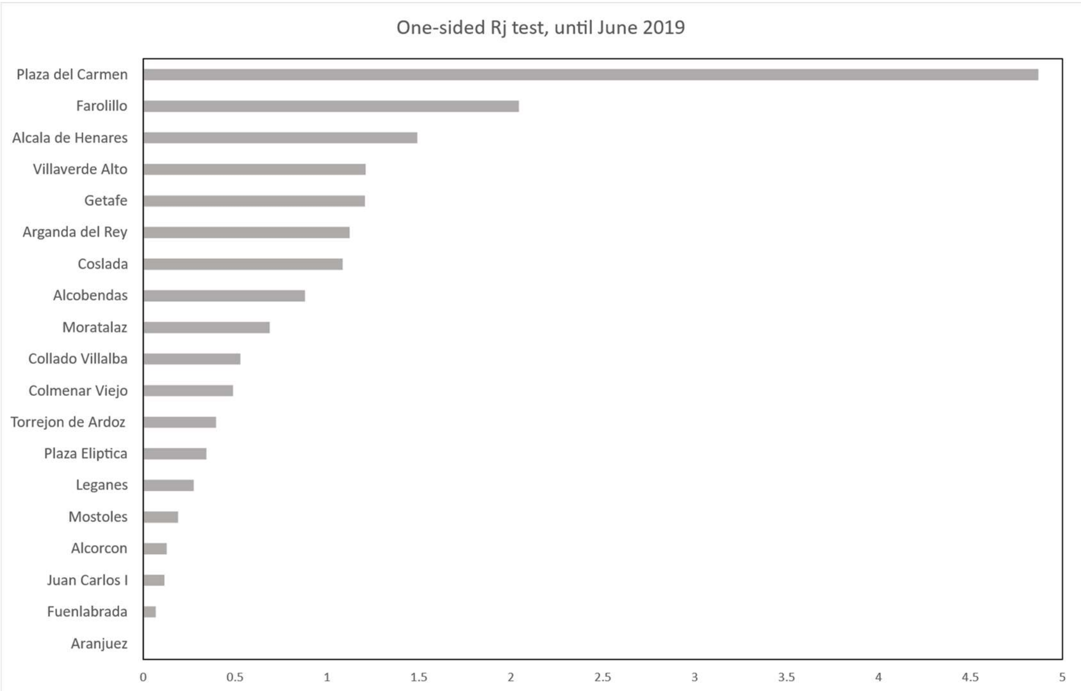


Figure 4.6 Post/Pre mean square prediction error ratio in each station

The second test involves backdating the start of the treatment to check for evidence of an anticipation effect that could influence the base model results. The methodology relies solely on pre-treatment data to construct the synthetic control, so this is equivalent to moving the pre-treatment data to a previous period. Figure 4.7 shows the results for a six-month anticipation period. Although this negatively affects the fit, the figure consistently shows that the synthetic control follows the observed data until the actual introduction of the LEZ, excluding any significant anticipation effect. It also shows a consistent reduction in emissions for the first 7 months of LEZ implementation.

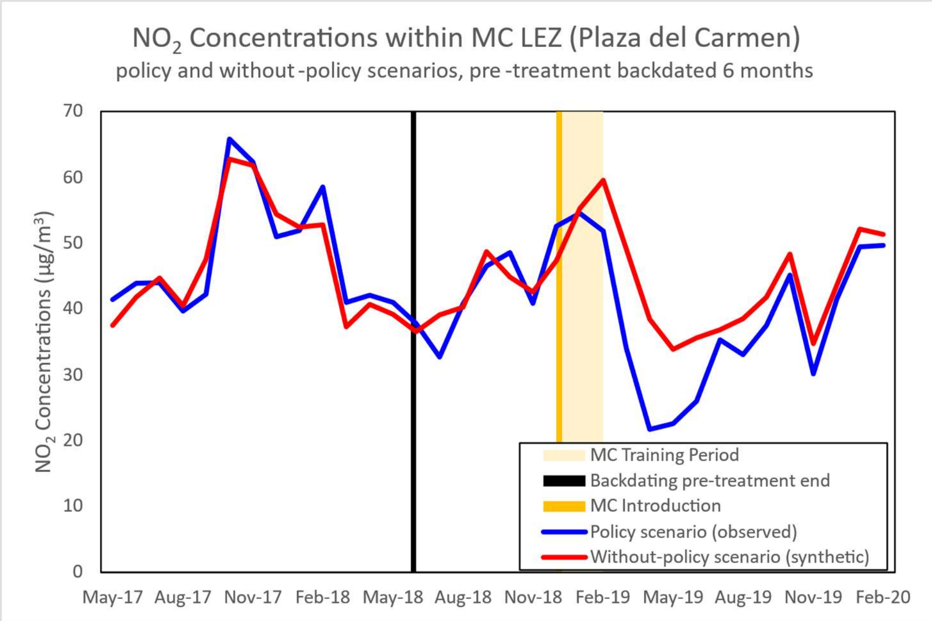


Figure 4.7 Backdating: Comparison between synthetic and observed NO_2 concentrations in Plaza del Carmen with 6 months anticipation. (Only post-May 2017 data displayed)

d. Spillover effects

To check for spillover effects, that is either positive or negative impacts on the areas surrounding MC, the robust synthetic control method has been employed four more times, taking one of the four stations closest to the LEZ (Plaza de España, Retiro, Escuelas Aguirre and Mendez Alvaro) as the treatment unit. Figure 4.8 reports the results of the check for spillover effects for the policy's impact on the four stations in the areas surrounding MC. In all four graphs the blue line represents observed data on NO2 concentrations while the red line represents the synthetic results for the "without policy" scenario. The orange vertical line represents the introduction of MC. Again, any impact of the policy in these areas would result in a gap between the observed and synthetic lines following the introduction of the policy.

Evidence of strong spillover effects seems to be rather limited in the area surrounding MC. The only exception is Retiro, which shows a reduction in NO2 concentrations similar to that at Plaza del Carmen. In this station, an average reduction in NO2 concentrations of 17% was estimated between December 2018 and September 2019. Also in this case, synthetic concentrations return to levels similar to the observed values after September 2019. Plaza de España is the closest station to the LEZ as it is right on its border. However, the synthetic curve does not clearly show any consistent spillover effect in the post-treatment period. The Escuelas Aguirre station shows no effect in the first 6 months of MC implementation, though after that it seems to show a slight reduction. The synthetic line for the Mendez Alvaro station only shows a reduction in the first two months after implementation but then returns to figures close to the observed values. Of the four stations close to the Madrid Central LEZ, only Plaza de España and Escuelas Aguirre were consistently exceeding the EU threshold before the intervention. The reduction during the first 6 months of the policy is below 3% at those stations. By the end of 2019, Escuela Aguirre exceeded the NO2 concentration threshold with an average of 51 µg/m3, while Plaza de España was just below the limit at 39.8µg/m3.

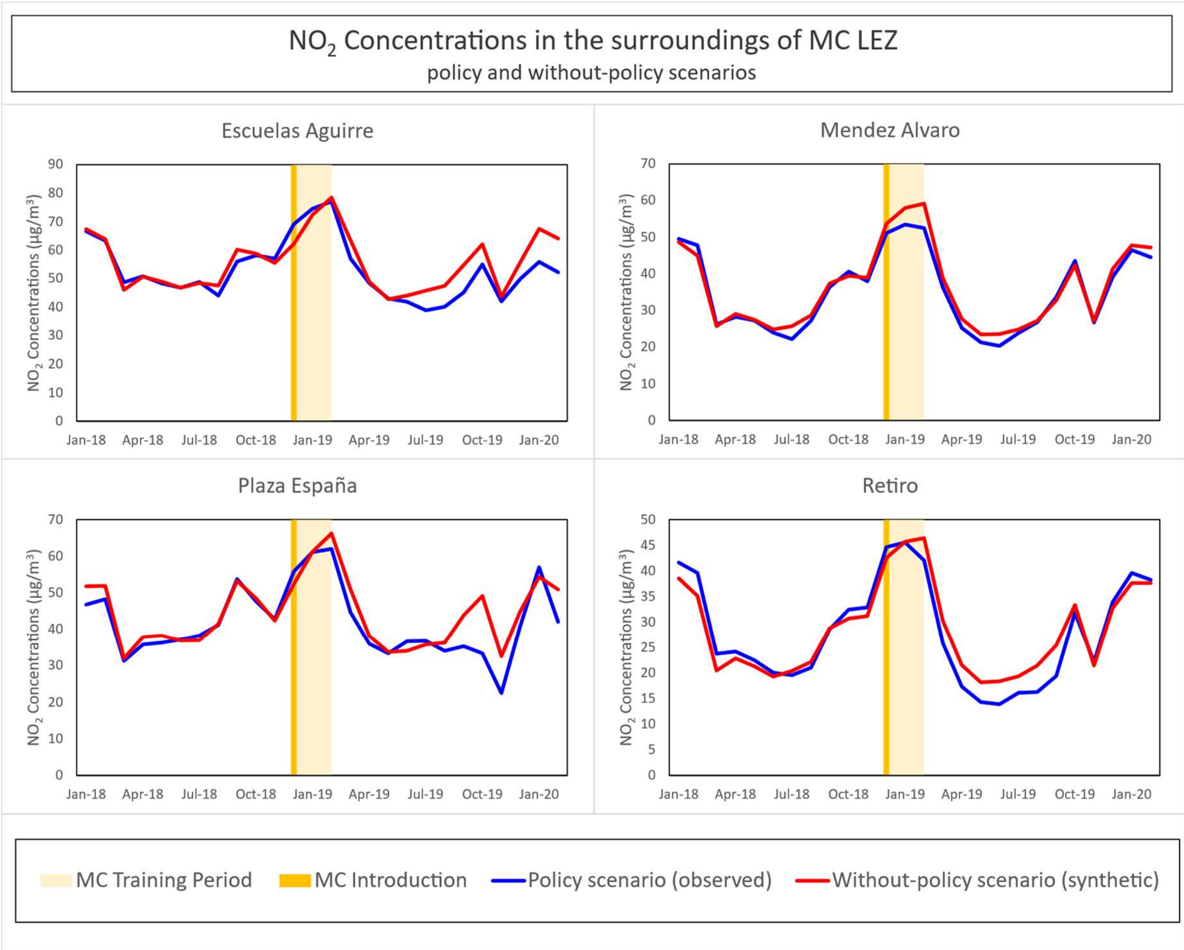


Figure 4.8 Spillover effects for stations in the proximity of MC. (Only post-2018 data displayed)

5. The impact of Madrid Central on alternative-fuelled vehicles uptake.

This section seeks to analyse the impact of Madrid's LEZ, in combination with the MUS plan, on the purchase of alternative fuelled vehicles (AFVs). The main objective of LEZ measures is concerned with their direct impact on pollutant concentrations, but they also create an incentive to renew the local vehicle fleet towards newer, more efficient vehicles if properly designed to do so (Wolff, 2014). This is important in maintaining the efficacy of the policy in the long run by accelerating substitution towards more efficient vehicles. This might also accelerate the electrification of road transport, which is one of the main objectives of the European strategy for low-emission mobility (European Commission, COM(2016) 501).

Along with the introduction of the LEZ, the Regional Autonomous Community of Madrid also implemented an incentive scheme called the MUS plan to subsidise the purchase of AFVs. The first version of this plan came into effect in December 2018, coinciding with MC, and it was re-implemented in April 2019. Moreover, starting from 2019 the Spanish government also introduced a national scheme to subsidise the purchase of AFV, called the MOVES plan, which has been repeated annually ever since with a substantially increasing budget endowment. These measures show an effort by the Spanish administration to accelerate the transition towards the electrification of road transport. LEZs are expected to be adopted in several other cities in Spain, so it is important to understand how they may contribute to increasing purchases of AFVs.

This chapter is structured as follows: Section 2 briefly reviews existing literature on LEZs and the synthetic control method; Section 3 presents the theoretical framework upon which the model relies, the data involved and the context of the Madrid LEZ policy; Section 4 describes the data trends and the model results; Section 5 discusses the main results, and Section 6 gives some concluding remarks.

a. Data collection and model specification

This analysis uses data from Spain's Directorate General for Traffic (DGT) on new private vehicle registrations between December 2016 and February 2021. There are data available from 2014 onwards, but those from before the period considered here are affected by the extremely low ownership levels of AFVs, especially electric vehicles (HEV, PHEV and BEV), with several periods when no AFVs at all were sold in most cities. This would negatively affect the determination of the synthetic control if these data were considered.

Results from March 2020 onwards are omitted due to the substantial impact of the Covid-19 pandemic on vehicle sales. Although the model bases the creation of the synthetic control on the pre-intervention period only, any interpretation of results during the pandemic would be hard to address to Madrid Central.

The original data from the DGT provide extensive details on each registration of all types of vehicles during the period analysed. Monthly totals were derived from these data for Madrid and the cities in the control group. Hence, units of observations are represented by a subset of Spanish cities.

Table 4.4 Regional plans and Moves introduction by autonomous Communities. Excluded communities are highlighted in red while approved ones in green. *Communities without cities of sufficient size to enter in the donor pool.

CCAA	Regional plans	Moves 2019 start
Andalucía	Andalucia A+ (ended 2015, not affecting)	19/06/2019
Aragón	none found	08/07/2019
Asturias	none found	30/04/2019
Canarias	EXCLUDED	EXCLUDED
Cantabria	Plan Renove Eficiente, no publicaron moves I	NOT IMPLEMENTED
Castilla La Mancha	none found	23/05/2019
Castilla y Leon	none found	31/05/2019
Cataluña	barcelona lez, Plan PIRVEC	EXCLUDED
Ceuta	EXCLUDED	EXCLUDED
Comunidad Valenciana	Plan de Impulso del Vehículo Eléctrico	30/05/2019
Extremadura	Plan regional de ayudas movilidad electrica, no moves I	NOT IMPLEMENTED
Galicia	Plan de Impulso del Vehículo Eléctrico, IN421U	17/06/2019
Illes Baleares	EXCLUDED	EXCLUDED
La Rioja*	none found	22/08/2019
Madrid	Plan Cambia 360, Plan MIUS	16/07/2019
Melilla	EXCLUDED	EXCLUDED
Murcia	none found	24/07/2019
Navarra*	none found	14/06/2019
País Vasco	Plan PAVEA	02/04/2019

Only cities among those Autonomous communities which had not implemented local initiatives to incentivise alternative vehicle purchasing in the period under scrutiny have been selected. This has been done because the effect of these policies might be confounding when creating the synthetic control, as well as might affect the interpretation of results in the post treatment period. For the same reason cities which implemented the MOVES Plan to subsidize purchase of AFVs with more than 1 month distance with respect to Madrid have been excluded. Since this has been the main national initiative that could affect AFV purchases and the interpretation of post-intervention model results. Table 4.4 reports for each autonomous community the presence of regional plans and the start date of the Moves plan. In green are highlighted those communities falling into the selection requirements.

Cities with less of 300´000 inhabitants have also been excluded. Since the synthetic control model benefits when the donor pool is reduced to units that are closer to the treated unit, this number of population has been selected as it allows to get at least 5 cities in the donor pool while avoiding including cities that are too small, with urban transport system that might present large differences with Madrid. Although being the closest city for size, Barcelona has also been excluded since it implemented a regional LEZ policy in the same period as Madrid Central, although with less restrictive access requirements. The comparison between these two cities has been conducted by Peters et al.

(2021). This resulted in a donor pool composed by 6 cities: Cordoba, Malaga, Murcia, Seville, Valladolid and Zaragoza. Figure 4.9 reports the location of Madrid and the other cities considered.

Figure 4.9 Location of Madrid and donor pool cities in continental Spain

Presence of spillover effects was analysed, i.e. whether the policy also affected the areas surrounding the municipality of Madrid. To that end, data was retrieved for all 23 municipalities considered as part of Madrid's metropolitan area as per the 1963 definition[17]. These were then divided into 2 groups based on their population size and density and their distance from Madrid. Table 4.6 shows the two groups of municipalities in Madrid's metropolitan area.

First-time registrations of vehicles categorised as standard cars (*turismo* in Spanish) purchased by natural persons were considered. The second-hand vehicle market was excluded as it does not entail new vehicles coming onto the streets and it mainly concerns traditionally fuelled vehicles rather than AFVs, most of which are rather new. Vehicles owned by legal persons were also affected, which made the data quite noisy because of medium and large companies acquiring multiple vehicles at once. The actual presence of these vehicles in one city might also be hard to track due to companies registering them at their headquarters which may not be in the city where they are actually used. Moreover, the significant presence in Madrid of over 2000 electric carsharing vehicles (Silvestri et al., 2021) would also affect the data due to their fleet adjustments and replacements.

In specifying the model, the proportion of the total number of vehicles registered per month accounted for by AFVs in each of the cities considered was selected as variable of interest. The pre-treatment period is taken as running from December 2016 to September 2018, the last month prior

[17]*Plan General de Ordenación del Área Metropolitana [General Structural Plan of the Metropolitan Area], 1963*

to the approval of the policy by Madrid's municipal authorities. This was done because once the policy was officially approved it might have had an influence on purchasing decisions even before the measures were actually introduced.

Table 4.5 Municipalities constituting the Madrid's metropolitan area and their subdivision into group A and B

	GROUP A	GROUP B
Municipalities	Leganés Alcorcón Coslada Getafe Alcobendas Torrejón de Ardoz	Pozuelo de Alarcón Las Rozas de Madrid San Sebastián de los Reyes Majadahonda Boadilla del Monte Rivas-Vaciamadrid San Fernando de Henares Tres Cantos Pinto Mejorada del Campo Villaviciosa de Odón Colmenar Viejo Villanueva del Pardillo Velilla de San Antonio Paracuellos de Jarama Villanueva de la Cañada Brunete
Total population	868222	793409
Average density (hab/km^2)	4177	940
Average distance from Madrid (km)	13	23

The analysis for the robust synthetic control with the singular value thresholding procedure is conducted using Python, based on the scripts developed and made available by Amjad et al. (2018)[18].

b. Descriptive statistics

Figure 4.10 shows the total vehicle registrations by type in Madrid in the period under analysis. Figure 4.10.A shows the total registrations for each type with dotted trend lines based on a 5-period moving average, while Figure 4.10.B shows the stacked cumulative total registrations, highlighting the share accounted for by each type in different colours. Total registrations show a recurrent seasonal effect with noticeably fewer sales in August and September each year, which is to be expected due to summer vacations. The figure also shows a slightly curving trend starting from mid-2018, resulting mainly from a downturn in sales of both petrol- and diesel-fuelled vehicles.

[18] https://github.com/jehangiramjad/tslib

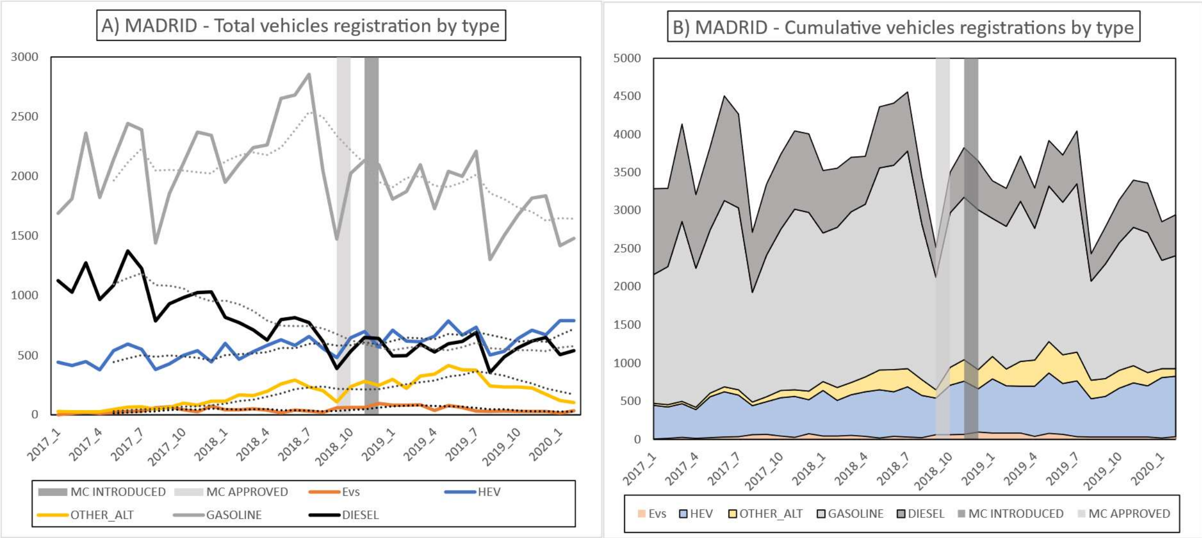


Figure 4.10 Total and cumulative vehicles registration in Madrid, by vehicle type

Although they account for only a small proportion of total sales, Hybrid Electric Vehicles (HEVs), electric vehicles (EVs: plug-in hybrid or battery electric) and vehicles with other fuels all show an increasing trend, although that trend is reversed for EVs and other alternative fuelled vehicles in the last 6-8 months. HEVs are the biggest group within AFVs. Also, HEVs started at only half the proportion of diesel vehicles at the beginning of 2017, but outnumbered the latter consistently from September 2018 onwards.

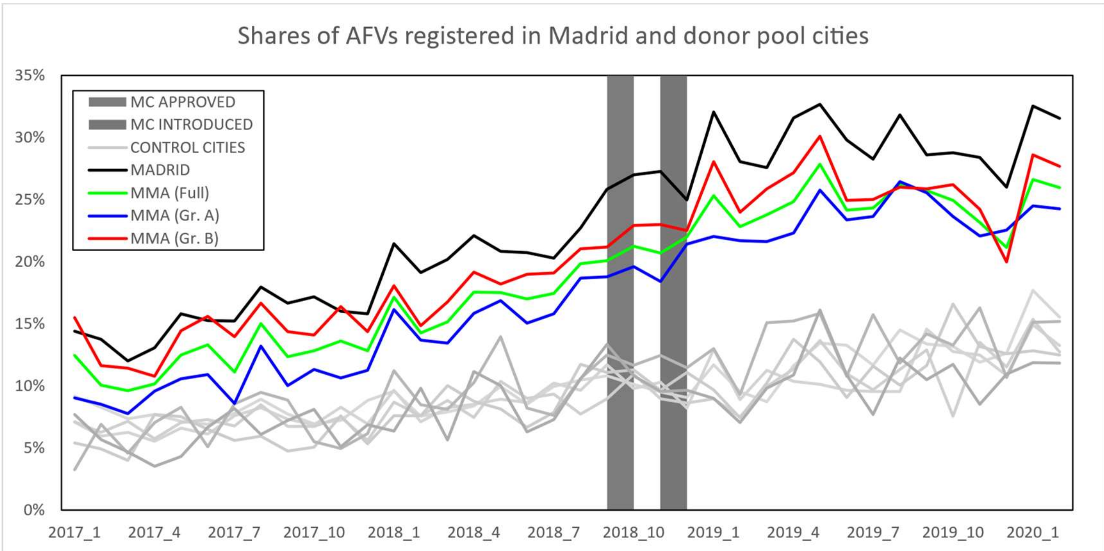


Figure 4.11 Shares of AFVs registered in Madrid and donor pool cities.

Figure 4.11 compares the proportions of AFV registrations in the city of Madrid (in black) to those in the metropolitan area (MMA) (in green for the full area, in blue and red for the two subdivisions A and B) and the cities in the donor pool (in grey). The figure shows upward trends in AFVs registrations in all cities over the period, but the proportions of AFVs in Madrid and MMA are substantially higher. This higher proportion may be partly because Madrid and its metropolitan area are bigger than the control cities, or because of specific local conditions such as a more developed local charging infrastructure and the free-parking policy for this type of vehicles. Madrid has a higher proportion of AFV registrations per month than its MMA. A comparison of the two subdivisions of the MMA reveals, interestingly, that group B (less densely populated and further from the city) actually has a higher proportion than group A. The gap between Madrid and its MMA on the one hand and the control units on the other can be removed by transforming the data to accommodate the requirements of the robust synthetic control model (Firpo and Possebom, 2018). Prior to running the model Madrid's proportions are transformed to 40% of their actual figures so that the mean value in the pre-treatment period is within the span of the mean pre-treatment values of the control units. Full MMA, Group A and Group B values are transformed to 50%, 45% and 60% of their total figures respectively. After the model is applied, a reverse transformation provides the final results.

c. Robust synthetic control estimation results: Policy vs. No Policy scenarios

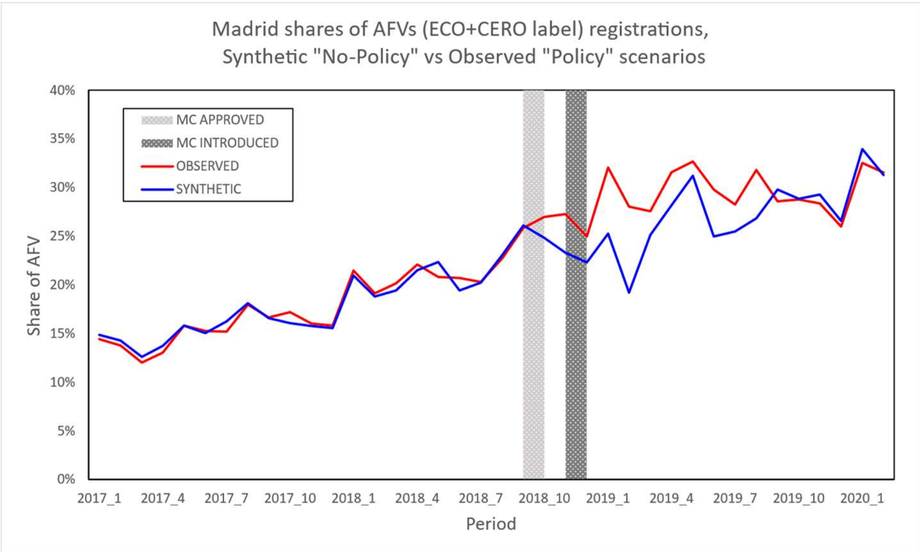


Figure 4.12 AFVs registrations in Madrid in the "observed" policy scenario vs. "synthetic" no policy scenario

Figure 4.12 shows the policy scenario, comprising the observed proportion of new AFV vehicles registered in Madrid by private customers (red) as a percentage of the total vehicles registered. This is compared with the results of the no-policy scenario from the synthetic control estimation (blue). The grey vertical bar marks the official approval of the Madrid Central LEZ in October 2018. The dark grey bar marks the official start of the policy with the initial 3-month trial period in December 2018. The closeness of the two scenario lines in the pre-treatment period represents the goodness of the fit of the model. Model results are also reported in Figure 4.13 in terms of percentage variation on total registrations of AFVs between the synthetic "no policy scenario" and the real data "policy scenario".

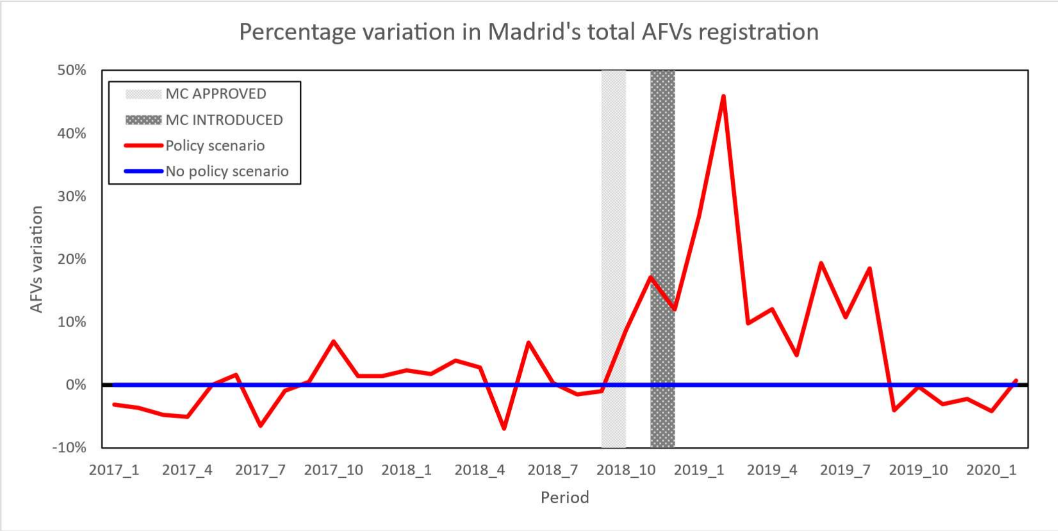


Figure 4.13 Percentage variation in AFVs registrations in the policy scenario compared to the no policy baseline

The results show a noticeable increase in the share of AFV registered in the policy scenario with respect to the no-policy scenario already from October 2018 onwards. This suggests an anticipation effect on the sales of AFV vehicles with respect to the introduction of the policy. In relative terms, registrations of AFVs were 9% higher in October and 17% higher in November than in the no-policy scenario. In a period in which the subsidies of the MUS Plan were not yet available, this suggests that the policy announcement was responsible for this effect. A substantial increase in total AFV registrations is then maintained throughout the trial period of the policy (December 2018- February 2019), with the highest increases being 27% in January and 46% in February, the last month prior to the actual enforcement of the LEZ. In both these months the budget of the MUS Plan had already been depleted (Peters et al., 2021), so again the effect is likely to be dependent rather on the Madrid Central LEZ policy. The observed figures for AFVs registered remain higher than in the no-policy scenario until the month of August 2019. Starting from September 2019, the effect seems to suddenly disappear as the gap between observed registrations of AFVs drops to levels similar to the no-policy scenario and stays there until the end of the period under analysis.

Overall, in relative terms, post-intervention registrations of AFVs are on average 10.2% higher than in the no-policy scenario. This is equivalent to a 2.4% increase of AFVs out of the total vehicles registered between October 2018 and February 2020. However, between October 2018 and August 2019 the average increase in AFVs registrations is 16.9%, but in the following months there is no substantial difference between the two scenarios. This is equivalent to a 4% average increase in AFVs registrations out of the total vehicles registered between October 2018 and August 2019. In absolute terms this means that from the announcement of Madrid Central to August 2019 there an average of 138.25 more vehicles were registered per month than in the no policy scenario. By contrast, the average from September 2019 to February 2020 is slightly lower than in the no policy scenario at -2.2%, though this is likely to fall within the margin of error of the model.

d. Spillover effects

This section analyses whether the impact of the LEZ and subsidy programme extended beyond the municipality of Madrid to the 23 municipalities that comprise its metropolitan area. To that end, we model the proportion of AFVs registered has in both the full metropolitan area and the two groups defined in Section 3c. Figure 4.14 reports the gaps between the policy and no policy scenario for Madrid (as in Figure 4.13 in black, for the Metropolitan area as a whole in green, for Group A in blue and for B in red). Overall, the metropolitan area seems to have experienced a similar increase to the city of Madrid, starting from October and peaking in February 2018. In particular, the full metropolitan area quite closely follows the pattern of the municipality of Madrid in the first 6 months as from final approval of Madrid Central. However, starting from May, municipalities in group A (which are larger and more densely populated) show a greater impact of the policy than those in group B and even than the municipality of Madrid itself. They also maintain a positive impact after July 2019 when that effect seems to die out in the other areas. However, the absolute figures for the proportions of AFVs registered in group A remain higher than those in group B for most of the period, as shown in section 5.b.

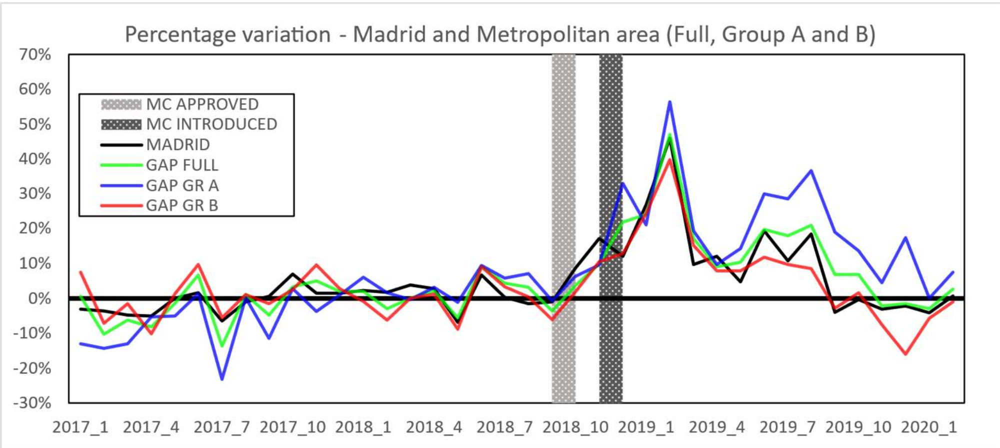


Figure 4.14 Percentage variation in AFVs registrations in the policy scenario compared to the no policy baseline for Madrid and its metropolitan area

e. Sensitivity analysis

Three post-estimation tests were used to analyse the causal inference, the presence of anticipation effects and the robustness of the model results in both the main model and the spillover effects models.

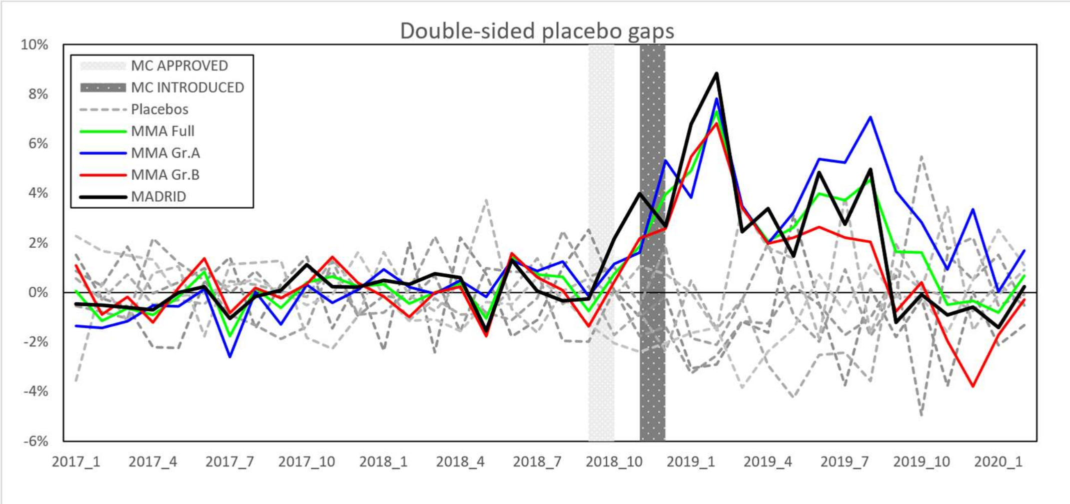
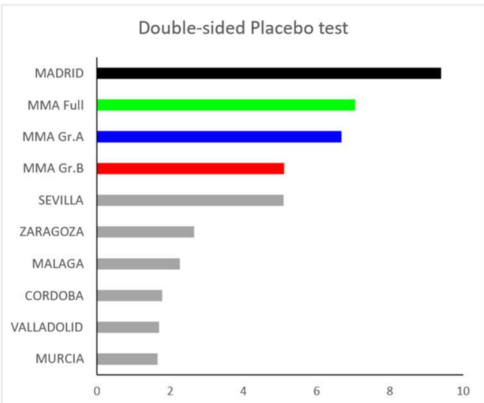


Figure 4.15 Variation in AFVs registration in Madrid compared to placebo effects in donor pool cities

Following Abadie (2021), inferences on the causal relationship between the policy introduction and the effect on AFV registrations is are carried out via so-called placebo tests. These involve repeating the model, switching the treated unit to each other unit in the donor pool. In this case, the control units are not expected to show any major effect on the beginning of the intervention. Figure 4.15 reports gaps between the policy and no-policy scenarios, represented by the 0% line, for Madrid (black line), its metropolitan area and the other cities in the donor pool (dotted lines). Again, the approval of Madrid Central, which delimits the training period, is marked by the light grey bar and the actual entry into force of the policy by the dark grey bar. As the figure shows, Madrid is the only city where the figures for AFVs registered since the intervention are substantially higher than in the no policy scenario throughout the period until August 2019: no clear and consistent impact is shown in any other city.



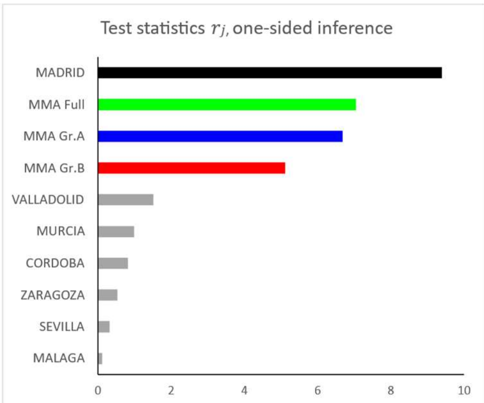


Figure 4.16 Double-sided and one-sided test statistics r_j, for Madrid and donor pool placebo tests

As in Abadie et al. (2012), the inference on causality is based on the test statistic r_j (equation 3), which assesses the quality of the fit for city j in the post intervention period compared to the pre intervention period, up to August 2019. The results of the tests for each city are reported in Figure 4.16. The bar graph on the left reports the test statistics for each city considering both positive and negative gaps in the building of the test statistic r_j. In this case, the graph shows that the impact on Madrid is about twice as large as on Seville, the largest control city in terms of RMSPE ratio size. Also spillover units end up above any control unit, but with a lower ratio. In particular MMA group B ends up being very similar to Seville control. However, when the number of units in the donor pool is relatively small, the presence of Madrid in that pool may influence the synthetic estimates for the placebo tests in the opposite direction. To overcome this limitation, Abadie (2021) suggests considering only effects in the same direction as in the treated unit, setting negative gaps to zero. This leads to one-sided inference, reported by the graph bar on the right. Compared to double-sided inference, the scale of the effect in Madrid and in the metropolitan area is substantially larger at more than 5 times the second largest effect for Madrid and more than 3 times the effect for the MMA. This graphically supports the inferential power of the model results.

Although effectively approved in October 2018, Madrid Central had been planned and announced months earlier. According to Peters et al. (2021), the policy was announced to the public in July that year. It is therefore reasonable to expect that the announcement might have led to higher registrations of AFVs prior to its definitive approval. To check for further anticipation effects the end of the training period was backdated to March 2018, 6 months before its actual official end. The fit of the model is negatively affected by a lower number of pre-treatment periods considered and by their distance in time from the actual implementation of the policy, but Figure 4.17 shows that again the gap between the policy and no policy scenarios starts in October 2018, when the policy was finally approved. Thus, no further anticipation effects appear to have occurred.

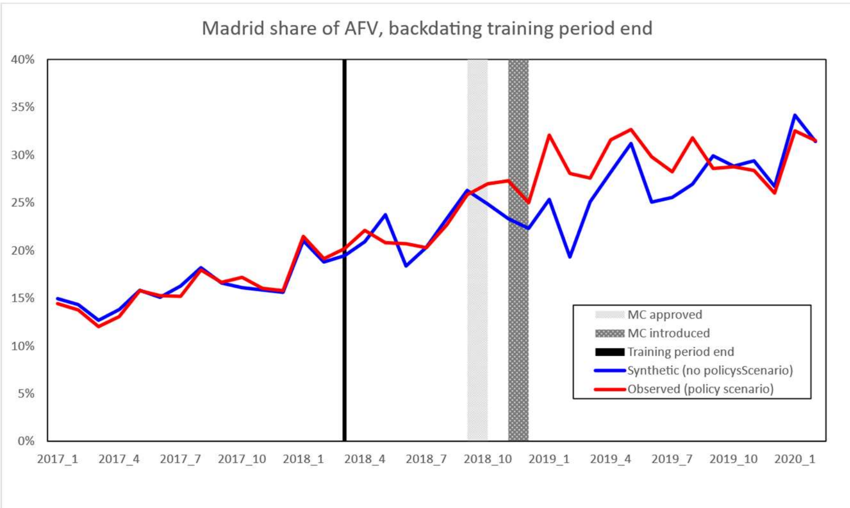


Figure 4.17 Madrid Policy vs No policy scenario, backdating end of training period

The specification used to compute the synthetic control is robust to volatility in the outcome variable, since it is removed by the de-noising process (Abadie, 2021; Amjad et al., 2018). However, to properly assess the robustness of the results Abadie (2021) suggests measuring their dependence on changes in the donor pool. To that end, Figure 4.18 reports the results of a leave-one-out reanalysis of the model, removing each country in the donor pool from the sample one-at-a-time. The figure reports the policy and no policy scenarios, along with each no policy scenario obtained when one donor pool city is left out. All these estimates closely track the share of AFVs registered in the pre-intervention period and reflect the impact of the policy similarly to the results produced using the entire pool. The result of a positive impact of the policy in the first 9 months since its approval is hence robust to the exclusion of any particular city.

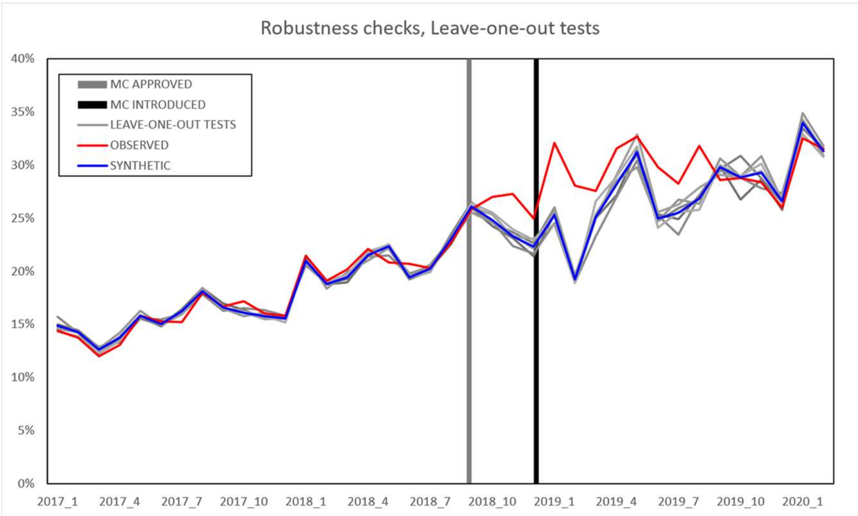


Figure 4.18 Madrid synthetic No policy scenario and leave-one-out robustness checks

6. Discussion

a. Impact on NO2 concentrations

Even before its introduction, MC attracted considerable attention from the media and was at the centre of the political debate in the following municipal elections in the summer of 2019. Ultimately, the elections brought a change in the government of Madrid, with the administration that introduced the policy losing office. The new administration tried to suspend the policy as early as July 2019, but the local courts suspended the attempt de facto, maintaining the LEZ in force. The new government announced changes to the policy starting from January 2020, with the new package named "Madrid 360". The main difference between the two policies was that C class vehicles would now be allowed to access the area if they had more than one occupant.

The findings reported here indicate that MC significantly reduced local NO2 concentrations in the first six months of implementation. Over that period there was an average reduction of 29% in NO2 concentrations between the observed results and the "without policy" scenario derived from the robust synthetic control method. This result is in line with the previous study of the policy by Salas et al. (2021), which focused only on the first six months of implementation (until May 2019).

Out of the four stations checked for spillover effects, only Retiro showed a reduction in NO2 concentrations. A major distinction needs to be drawn between these meteorological stations, as Retiro is located in the middle of the largest green area in the heart of Madrid. This means that there are hardly any local emissions of NO2 from the transport and residential sectors. Hence the reductions shown at this station suggest a transfer of the positive impact of the LEZ to NO2 concentrations outside the policy area[19]. However, the lack of any similar effect in the other three stations close to the LEZ may indicate that spillover effects in this area were covered or offset by local emissions of NO2 from the transport or residential sectors.

Interestingly, these results show that the policy ceased to be effective as from July 2019. There are two possible explanations for this: the first is that there may have been a positive spillover effect, i.e. a "contagion" of the MC treatment to adjacent areas (Cao and Dowd, 2019). However, given that only limited evidence of spillover effects in the proximity of the policy area has been found, it would be hard to explain such a “contagion” effect in the control units much farther away from the LEZ. The second, more plausible explanation is that there was a relaxation in enforcement of driver compliance with the restrictions following the change in the municipal government in July 2019 and the uncertainty that this generated about the continuity of one of the outgoing municipal government's flagship programmes. Indeed, this uncertainty could have generated a surge in noncompliance with the LEZ by people who believed that the policy was suspended or would not be enforced by the new administration. In support of this thesis, Figure 4.19 reports the absolute monthly number of fines for infringement of MC regulations during the period under scrutiny, compared to the gaps in NO2 concentrations between scenarios. The number of fines climbs sharply from June 2019 onwards and maintains average levels 10 times higher than in the first 3 months of policy enforcement. The number of fines remained high, albeit at lower levels, even in the first few months of 2020 when the LEZ restrictions were partially relaxed and access was granted to more vehicles. This result shows evidence that a treatment may cease to be effective before it is discontinued if its credibility is eroded or the end of the treatment is expected. This is therefore similar to the so-called "peace dividend" effect found in some studies that analyse the effect of armed conflict on GDP and show that in some cases GDP grows faster even before the end of the war "treatment" (Gardeazabal and Vega-Bayo, 2017).

Another interesting insight concerning the impact of the policy is that it appears to have brought about a significant reduction in concentrations of NO2 also in the first two months of 2019, particularly in February, in what was considered as a “training period”, when fines were not yet enforced.

[19]Note also that this result seems also to rule out any negative *spillovers* which might have occurred if polluting vehicles were transferred from the LEZ to the surrounding areas. This finding is also, at least partially, in line with those of Salas et al. (2021).

On a methodological note, the robust synthetic control approach enables us to analyse the impact of the policy based solely on pre-intervention concentrations of NO2, i.e. it requires far fewer data than regression approaches. This methodology has never before been applied to the study of urban concentrations of pollutants, but it appears to be suitable for the task as enables the effect of random noise at station level from external confounders, such as increased vehicle presence due to specific events, to be excluded. The methodology is also robust to station- and time-specific random effects, which it cancels out (Abadie, 2021). Its low data requirements make this approach appealing in cases where there is a lack of data on potential explanatory variables (e.g. meteorological data, traffic data, local events).

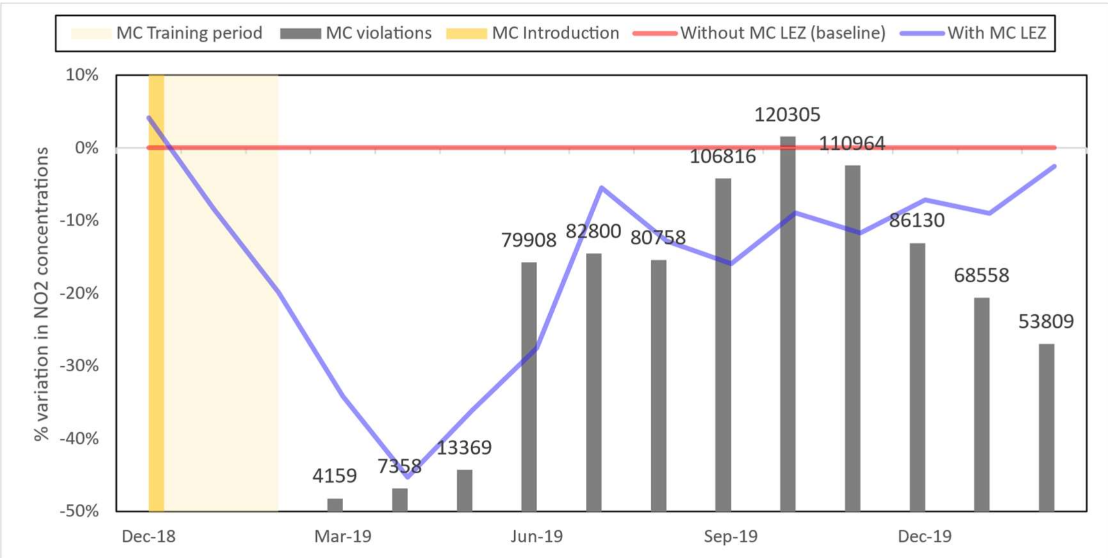


Figure 4.19 Cumulative monthly fines for infraction of Madrid Central LEZ, in contrast to evolution of NO_2 concentrations within MC area

b. Impact on AFV sales

Based on the results of the case study on AFV sales, the introduction of the MC LEZ in combination with the MUS subsidy plan produced a substantial increase in AFV registrations from its announcement until August 2019. The presence of an anticipation effect, with registrations increasing as from the official approval of the LEZ, before any subsidy was available, suggests the LEZ is at least partly responsible for this effect.

The first MUS plan was reported to have used up its entire budget allocation in just few days leaving only the LEZ active between January and March, the months when the biggest increase in AFV registrations is estimated to have occurred. This suggests the LEZ policy was the main driver of the effects on AFVs thanks to its benefits of free entry and free parking for plug-in hybrid and electric vehicles.

Madrid's AFV registrations remain higher than those of the no-policy scenario even after the announcement and activation of the MOVES plan in Spain up to August 2019. Starting from

September, however, the effect of the policy abruptly ceases and the two scenarios show similar registration figures throughout the rest of the period under analysis. This result is similar to that found for nitrogen dioxide concentrations within the LEZ area. The cessation of the effectiveness of MC may be connected to the change in local administration at the end of June 2019. It may be that the uncertainty spread over whether the LEZ would still be enforced also affected purchasing intentions for AFVs, cancelling out the incentive for the uptake of such vehicles. It may also be that the introduction of the LEZ and the subsidy scheme generated a "harvesting effect", incentivising those who already planned to purchase an AFV in the near future to bring forward their decision, which then resulted in a compensatory reduction in the second half of 2019.

The study also highlights strong spillover effects extending to the metropolitan area of Madrid. The effect on the MMA is similar in size to the effect on Madrid itself and is even bigger when only the largest, closest municipalities in the area are considered. The same ceasing of effectiveness is found also in the metropolitan area, but a comparison of the two subgroups shows that group A (which includes the largest and closest municipalities) maintains a positive effect until the end of the period under analysis. By contrast, group B shows a counter effect with AFV registrations dropping to figures even lower than in the no policy scenario.

Another interesting insight is the role of the policy approval which seems to have prompted the increase in AFVs registrations, and of the training period, where the highest levels of AFVs registrations are found. The backdating test shows that the policy announcement earlier in 2018 had no influence on AFV registrations: the anticipation effect came into play only when official approval was given. This suggests that people are actually inclined to change their investment decision only when they perceive the policy introduction to be credible and imminent.

On a methodological note, the robust synthetic control method enables us to make a significant contribution to the discourse on the effectiveness of the policy. As a matter of fact, the model results facilitate comparison between the policy and no policy scenarios and enable us to identify the cessation of effectiveness of the policy as from September 2019. This effect has been overlooked in previous studies using the difference-in-difference methodology (Peters et al., 2021), where post intervention periods are treated alike. Nonetheless, these results were achieved using an extremely limited amount of data as the model relies solely on AFV registration data. This makes this approach appealing when there is a lack of potential explanatory variables.

7. Conclusions

Local air pollution due to excessive use of combustion-engine vehicles is a problem currently faced by many cities. LEZs are seen as a good tool for improving air quality and health and reducing GHG emissions in urban areas. Nonetheless, LEZs provide an incentive to adopt AFVs, if designed to give privileges to such types of vehicles. In 2018, the city council of Madrid announced the introduction of a LEZ, called Madrid Central, in part of the historical city centre to reduce pollutants exceeding EU standards, in particular NO2. The policy in most part does not affect AFV compared to gasoline and diesel ones resulting in a potential incentive towards their purchasing.

In this study, a novel application of the so-called synthetic control method has been provided (Abadie et al., 2012; Abadie and Gardeazabal, 2003), in the version proposed by Amjad et al. (2018), to estimate the impact of such urban mobility policies in reducing concentrations of NO2 and its potential side-effects as incentive to purchasing AFV. This methodology creates an alternative “without policy” scenario, where a synthetic version of the unit of interest is derived from a combination of other meteorological stations (control units). The effect of the policy is then identified as the difference between the synthetic and observed outcomes. The advantages of this methodology include the fact that it provides a clear picture of the trend in the effectiveness of the policy over time, is highly transparent in terms of the fit of the model to the data and has low data requirements.

Our results show that the policy induced a substantial reduction in average NO2 concentrations within the LEZ during the first six months of 2019, immediately following its implementation. NO2 concentrations fell on average by around 29%. Some of the surrounding stations also showed positive spillovers, although the effect appears limited. However, from July onwards the effectiveness of the policy decreased substantially, with the observed data being close to the synthetic results. This may be due to a change in the enforcement of the measure which ultimately resulted in an increasing number of vehicles breaking the restrictions set by the LEZ.

With respect to AFV purchases, the LEZ in combination with a subsidy scheme implemented in the same period, brought a substantial increase in AFVs registrations, both in Madrid and its metropolitan area. An anticipation effect has been identified with registrations increasing from the official approval, 2 months earlier to the actual start of the LEZ. Again, this effect abruptly ceases starting from September 2019, while the policy was still in place.

The study highlights how weak enforcement and/or loss of credibility of a regulatory measure can substantially affect its effectiveness and the potential for its future development and applications. In fact, although MC remained unchanged in the second half of 2019, it was substantially less effective in reducing NO2 concentrations due to noncompliance with the restrictions. It should be borne in mind that LEZs are policies that seek to change citizens' behaviour, and calls for accurate communication of measures, clear objectives and sanctions. As this study has shown, electoral disputes and the confusion that they generate among citizens can undermine the effectiveness of measures by eroding their credibility.

Chapter 5

Conclusions and further research

1. Conclusions

The aim of this thesis is to analyse behavioural implications of low carbon mobility transition measures in order to identify potential barriers to and enablers of the successful implementation of mobility policies. To that end, three different types of measure are analysed: the introduction of a new mobility-as-a-service alternative; travel demand management strategies to shift away from private vehicle use; and restrictions on the most polluting vehicles. The three studies cover a wide range of potential strategies that are being implemented to bring about low carbon mobility. The analysis contributes by highlighting several barriers that have previously been overlooked in the existing literature

In Chapter 2, in-depth interviews with carsharing users and stakeholders highlight several barriers to effectively contributing to the transition towards low carbon mobility:

- **The service appears to have limited complementarity with public transport.** The carsharing users interviewed did not increase their public transport use after joining the service. As a matter of fact the service is seen as particularly convenient and affordable: especially when trips are shared with other people it can work out even cheaper than public transport.
- **None of the interviewees who owned a private vehicle stated that carsharing had replaced its use.** In most cases it replaced public transport rides instead. Private vehicles always available for use provide a sense of security and reliability which is hard to replace by carsharing, where availability is not always guaranteed.
- **The service increased users' demand for mobility**, since several carsharing users stated the service motivated them to travel to destinations otherwise hard to reach by public transport. Free parking for battery electric carsharing vehicles in the city centre allows for seamless reaching of areas that are otherwise restricted to conventional private vehicles.

On a positive note, the analysis also identifies aspects in which carsharing contributes to low carbon mobility transition, in particular:

- **Free-floating carsharing provides the first experience in driving a battery electric vehicle for most users,** thus enhancing their familiarity with this type of vehicle. Most users described their experience with the vehicle as positive.
- **The presence of the shared vehicles can reduce the need to own a private vehicle**. Evidence was found that carsharing motivates its users to postpone the decision on purchasing a private vehicle or a second vehicle in households that already own one.

From these results several policy recommendations are derived to improve the role of carsharing in the transition towards low carbon mobility, in particular:

- Integration and complementarity of carsharing with public transport must be supported by specific policies. Examples include developing hubs by increasing the presence of carsharing and similar alternatives at metro and bus stops and developing a common payment infrastructure for mobility-as-a-service alternatives (including public transport)
- The convenience for seamless connections and the personal nature of carsharing must be reflected in a price premium to ensure the service does not become more affordable than public transport.

In Chapter 3, an analysis of commuting to work and grocery shopping trips identifies several social and behavioural determinants of travel mode choice. By including the impact of externality perception and sustainable mobility policy support, the analysis enables us to identify results which may act as barriers to policies to foster a shift away from private vehicle dependence:

- **Greater sensitivity to transport externalities is connected to a greater tendency to commute by private vehicle**. Different causes are discussed as potential explanations of this unexpected result. One is that private vehicle users fail to recognise that they are contributing to the very externalities they perceive. This result may also highlight the presence of habit behaviour, with people choosing private vehicles regardless of their sensitivity to transport externalities. Ultimately, these private vehicle users may just have no efficient alternative way of commuting.
- **Significant differences were found across the countries analysed with respect to mode choice for grocery shopping.** This may depend on different cultural backgrounds or geographical conditions and means that policies which are effective in one country may not be so in another.

Nonetheless, the analysis helped to identify several journey and socio-demographic aspects which can affect the transition towards low-carbon mobility:

- **Private vehicle dependence is lower with more frequent trips for grocery shopping.** People who buy groceries 4 or more times per week are more likely to walk or cycle to the store. This indicates that making trips to grocery stores shorter and easier may help to reduce private vehicle use.
- **Full-time work and larger households are associated with greater private vehicle use** in commuting and grocery shopping respectively. This highlights categories which might need support in order to shift away from private vehicle dependence.

These results suggest several policies that may be effective in reducing private vehicle use and increasing public transport and active travel:

- Awareness-raising initiatives concerning the contribution of private vehicle use to transport externalities may help reduce private vehicle use by people sensitive to transport externalities.

- Habit-breaking strategies such as “ride to work” initiatives may provide alternative travel experiences for those used to commuting by car.
- Travel-demand management policies should be country specific and based on a thorough understanding of local travel behaviour, in particular for grocery shopping trips.
- Mixed neighbourhoods, residential-commercial vehicles and e-grocery may help reduce private vehicle use for grocery shopping.

Chapter 4 looks at the impact of Madrid’s low emission zone on local concentrations of NO2 and sales of alternative-fuelled vehicles and identifies several barriers to be addressed in future policies, in particular:

- **The effectiveness of the policy in terms of NO2 reduction appears to have faded away a few months after the introduction of the low emission zone**. The chapter argues that this may due to uncertainty regarding policy enforcement brought on by the change in local administration and by a lack of clarity in communication regarding the status of restrictions.
- **The impact of the policy on the surrounding areas, so-called spillover effects, is limited**. This indicates that the policy is not effective in reducing concentrations much beyond the targeted area. It may also be that reductions in NO2 concentrations in surrounding areas are offset by an increase in traffic due to transfer from the low emission zone area.
- **Sales of alternative-fuelled vehicles increased for a few months but then returned to baseline levels**. This indicates that the policy may not provide a long-term incentive to purchase alternative-fuelled vehicles. It may also indicate a harvesting effect, with people anticipating their decision on purchasing an alternative-fuelled vehicle.

On a positive note, the analysis shows that, in the short term, the policy proved very effective in reducing NO2 concentrations and increasing alternative vehicle sales.

Nonetheless, the analysis provides some significant policy recommendations which are fundamental for the future application of low emission zones, in particular:

- Policy stability and enforcement should be guaranteed in order to ensure effectiveness in reducing pollutant concentrations.
- The policy should be supported by clear, up-to-date information on its restrictions and on the fines for noncompliance.
- The low emission zone should cover the total area where reductions in pollutant concentrations are needed rather than relying on the effect of the policy to emigrate much further, as spillover effects proved to be limited.

2. Future research

The outcomes of this thesis open up several opportunities for further extension and investigation in future research. On a general note, the main objective of the thesis relies on identifying potential barriers and enablers of the transition towards low carbon mobility. Hence, the specific effectiveness of the policy recommendations provided should be further addressed via specific studies.

With respect to the introduction of carsharing, future research may seek to support the findings with quantitative data based on larger samples. One limitation is that the impact of this alternative at national or urban level is hardly noticeable in transport indicators. Moreover, publicly available data are scarce and most quantitative data regarding these services are owned by the operating companies, which are often reluctant to share them. However, the recent widespread extension of free floating carsharing and other shared mobility options in cities such as Madrid may enable surveys to be conducted to map the extent of these services and further test the results reported here on complementarity with public transport. With the introduction of the LEZ, future research could be directed at determining whether the policy has a positive effect on carsharing use around the city centre. People whose cars are restricted could use FF or SB carsharing instead, with no need to buy a new private vehicle to enter the LEZ.

Regarding travel demand management strategies, this study reports the first attempt at incorporating the perception of externalities into the analysis of mode choice. The most striking result of this analysis is the evidence found with respect to private vehicle use being positively related to high sensitivity to transport externalities. This result needs to be further addressed via specific research with a view to identifying its main causes. This may provide insights on whether the result is indeed an expression of habit behaviour, lack of awareness or lack of alternatives, each of which may be grounds for different policy strategies.

Finally, the analysis of Madrid's low emission zone provides several opportunities to be addressed by future studies. From an impact assessment perspective, a similar approach can be used to identify whether the policy influences a shift from private to public transport in the first month since its implementation. From a methodological perspective, this study is the first application of the synthetic control method to analyse local pollutant concentrations and alternative vehicle sales. The potential of this method in transport and in environmental research should be investigated given the opportunity that it provides when there is a lack of relevant auxiliary covariate information. Guidelines on the requirements of the study set should be developed to ease future specific applications in these domains.

References

Abadie, A., 2021. Using Synthetic Controls: Feasibility, Data Requirements, and Methodological Aspects. Journal of Economic Literature 59, 391–425. https://doi.org/10.1257/jel.20191450

Abadie, A., Diamond, A., Hainmueller, J., 2012. Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program. Journal of the American Statistical Association. https://doi.org/10.1198/jasa.2009.ap08746

Abadie, A., Gardeazabal, J., 2003. The Economic Costs of Conflict: A Case Study of the Basque Country. American Economic Review 93, 113–132. https://doi.org/10.1257/000282803321455188

Achen, M., 2005. Shopping Facilities and Mobility Behaviour in East Germany: The Significance of Distance in the Choice of Store for Grocery Shopping. EUROPEAN JOURNAL OF TRANSPORT AND INFRASTRUCTURE RESEARCH 5.

Aditjandra, P.T., Mulley, C., Nelson, J.D., 2013. The influence of neighbourhood design on travel behaviour: Empirical evidence from North East England. Transp. Policy 26, 54–65. https://doi.org/10.1016/j.tranpol.2012.05.011

Ahlfeldt, G.M., Pietrostefani, E., 2019. The economic effects of density: A synthesis. Journal of Urban Economics 111, 93–107. https://doi.org/10.1016/j.jue.2019.04.006

Ajanovic, A., 2015. The future of electric vehicles: prospects and impediments. Wiley Interdisciplinary Reviews: Energy and Environment 4, 521–536. https://doi.org/10.1002/wene.160

Ajzen, I., 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes, Theories of Cognitive Self-Regulation 50, 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Ambrosino, G., Nelson, J.D., Boero, M., Pettinelli, I., 2016. Enabling intermodal urban transport through complementary services: From Flexible Mobility Services to the Shared Use Mobility Agency: Workshop 4. Developing inter-modal transport systems. Research in Transportation Economics 59, 179–184. https://doi.org/10.1016/j.retrec.2016.07.015

Amjad, M., Shah, D., Shen, D., 2018. Robust Synthetic Control. J. Mach. Learn. Res.

Anable, J., Gatersleben, B., 2005. All work and no play? The role of instrumental and affective factors in work and leisure journeys by different travel modes. Transportation Research Part A: Policy and Practice, Positive Utility of Travel 39, 163–181. https://doi.org/10.1016/j.tra.2004.09.008

Bachman, W., Katzev, R., 1982. The effects of non-contingent free bus tickets and personal commitment on urban bus ridership. Transportation Research Part A: General 16, 103–108. https://doi.org/10.1016/0191-2607(82)90002-4

Ballinger, A., Chowdhury, T., Crombie, H., Owen, L., 2017. Modelling the cost-effectiveness of interventions to reduce traffic-related air-pollution. The Lancet, Public Health Science 2017 390, S7. https://doi.org/10.1016/S0140-6736(17)32942-2

Bamberg, S., Ajzen, I., Schmidt, P., 2003. Choice of Travel Mode in the Theory of Planned Behavior: The Roles of Past Behavior, Habit, and Reasoned Action. Basic and Applied Social Psychology 25, 175–187. https://doi.org/10.1207/S15324834BASP2503_01

Bamberg, S., Schmidt, P., 2003. Incentives, Morality, Or Habit? Predicting Students' Car Use for University Routes With the Models of Ajzen, Schwartz, and Triandis. ResearchGate.

Banister, D., Anderton, K., Bonilla, D., Givoni, M., Schwanen, T., 2011. Transportation and the Environment, in: Gadgil, A., Liverman, D.M. (Eds.), Annual Review of Environment and Resources, Vol 36. Annual Reviews, Palo Alto, pp. 247–270.

Bernardo, V., Fageda, X., Flores-Fillol, R., 2018. How Can Urban Congestion Be Mitigated? Low Emission Zones vs. Congestion Tolls (SSRN Scholarly Paper No. ID 3289613). Social Science Research Network, Rochester, NY.

Bjørgen, A., Bjerkan, K.Y., Hjelkrem, O.A., 2021. E-groceries: Sustainable last mile distribution in city planning. Research in Transportation Economics 87, undefined-undefined. https://doi.org/10.1016/j.retrec.2019.100805

Bolck, A., Croon, M., Hagenaars, J., 2004. Estimating Latent Structure Models with Categorical Variables: One-Step Versus Three-Step Estimators. Political Analysis 12, 3–27. https://doi.org/10.1093/pan/mph001

Brand, C., Anable, J., Tran, M., 2013. Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. Transp. Res. Pt. A-Policy Pract. 49, 132–148. https://doi.org/10.1016/j.tra.2013.01.010

Browne, M., Allen, J., Anderson, S., 2005. Low emission zones: the likely effects on the freight transport sector. International Journal of Logistics Research and Applications 8, 269–281. https://doi.org/10.1080/13675560500405899

Cass, N., Faulconbridge, J., 2016. Commuting practices: New insights into modal shift from theories of social practice. Transport Policy 45, 1–14. https://doi.org/10.1016/j.tranpol.2015.08.002

Ceccato, R., Diana, M., 2018. Substitution and complementarity patterns between traditional transport means and car sharing: a person and trip level analysis. Transportation. https://doi.org/10.1007/s11116-018-9901-8

Cesaroni, G., Boogaard, H., Jonkers, S., Porta, D., Badaloni, C., Cattani, G., Forastiere, F., Hoek, G., 2012. Health benefits of traffic-related air pollution reduction in different socioeconomic groups: the effect of low-emission zoning in Rome. Occupational and Environmental Medicine 69, 133–139. https://doi.org/10.1136/oem.2010.063750

Chatterjee, S., 2015. Matrix estimation by Universal Singular Value Thresholding. Ann. Statist. 43. https://doi.org/10.1214/14-AOS1272

Dai, J., Liu, Z., Li, R., 2021. Improving the subway attraction for the post-COVID-19 era: The role of fare-free public transport policy. Transp. Policy 103, 21–30. https://doi.org/10.1016/j.tranpol.2021.01.007

Dargay, J.M., Vythoulkas, P.C., 1999. Estimation of a Dynamic Car Ownership Model: A Pseudo-Panel Approach. Journal of Transport Economics and Policy 33, 287–301.

De Borger, B., Fosgerau, M., 2008. The trade-off between money and travel time: A test of the theory of reference-dependent preferences. J. Urban Econ. 64, 101–115. https://doi.org/10.1016/j.jue.2007.09.001

De Borger, B., Proost, S., 2013. Traffic externalities in cities: The economics of speed bumps, low emission zones and city bypasses. Journal of Urban Economics 76, 53–70. https://doi.org/10.1016/j.jue.2013.02.004

del Mar Solà, M., de Ayala, A., Galarraga, I., 2021. The Effect of Providing Monetary Information on Energy Savings for Household Appliances: A Field Trial in Spain. J Consum Policy 44, 279–310. https://doi.org/10.1007/s10603-021-09483-3

DeSalvo, J.S., Huq, M., 1996. Income, Residential Location, and Mode Choice. Journal of Urban Economics 40, 84–99. https://doi.org/10.1006/juec.1996.0024

Dieleman, F.M., Dijst, M., Burghouwt, G., 2002. Urban Form and Travel Behaviour: Micro-level Household Attributes and Residential Context. Urban Studies 39, 507–527. https://doi.org/10.1080/00420980220112801

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, 2008. , 152.

Directorate-General for Mobility and Transport (European Commission), 2021. EU transport in figures: statistical pocketbook 2021. Publications Office of the European Union, LU.

Duranton, G., Turner, M.A., 2009. The Fundamental Law of Road Congestion: Evidence from US cities (Working Paper No. 15376), Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w15376

Ellison, R.B., Greaves, S.P., Hensher, D.A., 2013. Five years of London's low emission zone: Effects on vehicle fleet composition and air quality. Transport. Res. Part D-Transport. Environ. 23, 25–33. https://doi.org/10.1016/j.trd.2013.03.010

Eriksson, L., Garvill, J., Nordlund, A.M., 2006. Acceptability of travel demand management measures: The importance of problem awareness, personal norm, freedom, and fairness. J. Environ. Psychol. 26, 15–26. https://doi.org/10.1016/j.jenvp.2006.05.003

European Commission, 2016. A European Strategy for Low-Emission Mobility.

Ferreira, F., Gomes, P., Tente, H., Carvalho, A.C., Pereira, P., Monjardino, J., 2015. Air quality improvements following implementation of Lisbon's Low Emission Zone. Atmospheric Environment 122, 373–381. https://doi.org/10.1016/j.atmosenv.2015.09.064

Figliozzi, M.A., 2011. The impacts of congestion on time-definitive urban freight distribution networks CO2 emission levels: Results from a case study in Portland, Oregon. Transp. Res. Pt. C-Emerg. Technol. 19, 766–778. https://doi.org/10.1016/j.trc.2010.11.002

Firpo, S., Possebom, V., 2018. Synthetic Control Method: Inference, Sensitivity Analysis and Confidence Sets. Journal of Causal Inference 6.

Gardeazabal, J., Vega-Bayo, A., 2017. An Empirical Comparison Between the Synthetic Control Method and HSIAO et al.'s Panel Data Approach to Program Evaluation. https://doi.org/10.1002/JAE.2557

Garling, T., Schuitema, G., 2007. Travel demand management targeting reduced private car use: Effectiveness, public acceptability and political feasibility. J. Soc. Issues 63, 139–153. https://doi.org/10.1111/j.1540-4560.2007.00500.x

Gehrsitz, M., 2017. The effect of low emission zones on air pollution and infant health. Journal of Environmental Economics and Management 83, 121–144. https://doi.org/10.1016/j.jeem.2017.02.003

Golob, T.F., Hensher, D.A., 1998. Greenhouse gas emissions and australian commuters' attitudes and behavior concerning abatement policies and personal involvement. Transportation Research Part D: Transport and Environment 3, 1–18. https://doi.org/10.1016/S1361-9209(97)00006-0

Gu, J., Deffner, V., Kuechenhoff, H., Pickford, R., Breitner, S., Schneider, A., Kowalski, M., Peters, A., Lutz, M., Kerschbaumer, A., Slama, R., Morelli, X., Wichmann, H.-E., Cyrys, J., 2022. Low emission zones reduced PM10 but not NO2 concentrations in Berlin and Munich, Germany. J. Environ. Manage. 302, 114048. https://doi.org/10.1016/j.jenvman.2021.114048

Hackbarth, A., Madlener, R., 2013. Consumer preferences for alternative fuel vehicles: A discrete choice analysis. Transportation Research Part D: Transport and Environment 25, 5–17. https://doi.org/10.1016/j.trd.2013.07.002

Handy, S.L., Clifton, K.J., 2001. Local shopping as a strategy for reducing automobile travel. Transportation 28, 317–346. https://doi.org/10.1023/A:1011850618753

Harrington, W., Krupnick, A.J., Alberini, A., 2001. Overcoming public aversion to congestion pricing. Transportation Research Part A: Policy and Practice 35, 87–105. https://doi.org/10.1016/S0965-8564(99)00048-8

Heldt, B., Matteis, T., von Schmidt, A., Heinrichs, M., 2021. Cool but dirty food? – Estimating the impact of grocery home delivery on transport and CO2 emissions including cooling. Research in Transportation Economics, E-groceries, digitalization and sustainability 87, 100763. https://doi.org/10.1016/j.retrec.2019.100763

Hidrue, M.K., Parsons, G.R., Kempton, W., Gardner, M.P., 2011. Willingness to pay for electric vehicles and their attributes. Resource and Energy Economics 33, 686–705. https://doi.org/10.1016/j.reseneeco.2011.02.002

Hilton, D., Charalambides, L., Demarque, C., Waroquier, L., Raux, C., 2014. A tax can nudge: The impact of an environmentally motivated bonus/malus fiscal system on transport preferences. Journal of Economic Psychology 42, 17–27. https://doi.org/10.1016/j.joep.2014.02.007

Holman, C., Harrison, R., Querol, X., 2015. Review of the efficacy of low emission zones to improve urban air quality in European cities. Atmospheric Environment 111, 161–169. https://doi.org/10.1016/j.atmosenv.2015.04.009

Huber, R.A., Wicki, M., 2021. What explains citizen support for transport policy? the roles of policy design, trust in government and proximity among Swiss citizens. Energy Research & Social Science 75, 101973. https://doi.org/10.1016/j.erss.2021.101973

Idris, A.O., Nurul Habib, K.M., Shalaby, A., 2015. An investigation on the performances of mode shift models in transit ridership forecasting. Transportation Research Part A: Policy and Practice 78, 551–565. https://doi.org/10.1016/j.tra.2015.06.012

Izquierdo, R., García dos Santos, S., Borge, R., Paz, D. de la, Sarigiannis, D., Gotti, A., Boldo, E., 2019. Health impact assessment by the implementation of Madrid City air-quality plan in 2020. Environmental Research 109021. https://doi.org/10.1016/j.envres.2019.109021

Jensen, A.F., Cherchi, E., Ortúzar, J. de D., 2014. A long panel survey to elicit variation in preferences and attitudes in the choice of electric vehicles. Transportation 41, 973–993. https://doi.org/10.1007/s11116-014-9517-6

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-Gonzalez, M.J., Narayan, J., 2017. Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. Urban Plan. 2, 13–25. https://doi.org/10.17645/up.v2i2.931

Jung, J., Koo, Y., 2018. Analyzing the Effects of Car Sharing Services on the Reduction of Greenhouse Gas (GHG) Emissions. Sustainability 10, 539. https://doi.org/10.3390/su10020539

Kamargianni, M., Dubey, S., Polydoropoulou, A., Bhat, C., 2015. Investigating the subjective and objective factors influencing teenagers' school travel mode choice - An integrated choice and latent variable model. Transp. Res. Pt. A-Policy Pract. 78, 473–488. https://doi.org/10.1016/j.tra.2015.06.011

Kelly, F.J., Kelly, J., 2009. London air quality: a real world experiment in progress. Biomarkers 14, 5–11. https://doi.org/10.1080/13547500902965252

Keyes, A.K.M., Crawford-Brown, D., 2018. The changing influences on commuting mode choice in urban England under Peak Car: A discrete choice modelling approach. Transportation Research Part F: Traffic Psychology and Behaviour 58, 167–176. https://doi.org/10.1016/j.trf.2018.06.010

Kroesen, M., Handy, S., Chorus, C., 2017. Do attitudes cause behavior or vice versa? An alternative conceptualization of the attitude-behavior relationship in travel behavior modeling. Transportation Research Part A: Policy and Practice 101, 190–202. https://doi.org/10.1016/j.tra.2017.05.013

Kunimi, T., Seya, H., 2021. Identification of the geographical extent of an area benefiting from a transportation project: A generalized synthetic control. J. Transp. Land Use 14, 25–45. https://doi.org/10.5198/jtlu.2021.1784

Lanzini, P., Khan, S.A., 2017. Shedding light on the psychological and behavioral determinants of travel mode choice: A meta-analysis. Transportation Research Part F: Traffic Psychology and Behaviour 48, 13–27. https://doi.org/10.1016/j.trf.2017.04.020

Lazarsfeld, P.F., 1950. The Interpretation and Mathematical Foundation of Latent Structure Analysis. Measurement and Prediction 413–472.

Lazarsfeld, P.F., Henry, N.W., 1968. Latent structure analysis. Houghton, Mifflin, New York.

Le Vine, S., Polak, J., 2017. The impact of free-floating carsharing on car ownership: Early-stage findings from London. Transport Policy. https://doi.org/10.1016/j.tranpol.2017.02.004

Lebrusan, I., Toutouh, J., 2020a. Assessing the Environmental Impact of Car Restrictions Policies: Madrid Central Case, in: Nesmachnow, S., Hernández Callejo, L. (Eds.), Smart Cities, Communications in Computer and Information Science. Springer International Publishing, Cham, pp. 9–24. https://doi.org/10.1007/978-3-030-38889-8_2

Lebrusan, I., Toutouh, J., 2020b. Car restriction policies for better urban health: a low emission zone in Madrid, Spain. Air Qual. Atmos. Health. https://doi.org/10.1007/s11869-020-00938-z

Limtanakool, N., Dijst, M., Schwanen, T., 2006. The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium- and longer-distance trips. Journal of Transport Geography 14, 327–341. https://doi.org/10.1016/j.jtrangeo.2005.06.004

Litman, T., 2000. Evaluating Carsharing Benefits. Transportation Research Record: Journal of the Transportation Research Board 1702, 31–35. https://doi.org/10.3141/1702-04

Loose, W., 2010. The State of Carsharing in Europe (Research project report). Bundesverband CarSharing e. V.

Malhotra, N.K., Birks, D.F., 2007. Marketing Research: An Applied Approach. Prentice Hall/Financial Times.

Malina, C., Scheffler, F., 2015a. The impact of Low Emission Zones on particulate matter concentration and public health. Transportation Research Part A: Policy and Practice 77, 372–385. https://doi.org/10.1016/j.tra.2015.04.029

Malina, C., Scheffler, F., 2015b. The impact of Low Emission Zones on particulate matter concentration and public health: A Rejoinder. Transportation Research Part A: Policy and Practice 82, 257–258. https://doi.org/10.1016/j.tra.2015.10.001

Marquet, O., Miralles-Guasch, C., 2014. Walking short distances. The socioeconomic drivers for the use of proximity in everyday mobility in Barcelona. Transp. Res. Pt. A-Policy Pract. 70, 210–222. https://doi.org/10.1016/j.tra.2014.10.007

Martin, E., Shaheen, S., 2011. The Impact of Carsharing on Household Vehicle Ownership 1, 22–27.

Martin, E., Shaheen, S., Martin, E., Shaheen, S., 2011. The Impact of Carsharing on Public Transit and Non-Motorized Travel: An Exploration of North American Carsharing Survey Data. Energies 4, 2094–2114. https://doi.org/10.3390/en4112094

Martinez-Gabaldon, E., Mendez Martinez, I., Eduardo Martinez-Perez, J., 2020. Estimating the impact of the Penalty Point System on road fatalities in Spain. Transp. Policy 86, 1–8. https://doi.org/10.1016/j.tranpol.2019.11.003

McFadden, D., 1974. The measurement of urban travel demand. Journal of Public Economics 3, 303–328. https://doi.org/10.1016/0047-2727(74)90003-6

McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. P. Zarembka (ed.), Frontiers in Econometrics. New York: Academic Press.

Millard-Ball, A., 2005. Car-sharing: Where and how it Succeeds. Transportation Research Board.

Miralles-Guasch, C., Martínez Melo, M., Marquet Sarda, O., 2014. On user perception of private transport in Barcelona Metropolitan area: an experience in an academic suburban space. Journal of Transport Geography 36, 24–31. https://doi.org/10.1016/j.jtrangeo.2014.02.009

Mishra, G.S., Clewlow, R.R., Mokhtarian, P.L., Widaman, K.F., 2015. The effect of carsharing on vehicle holdings and travel behavior: A propensity score and causal mediation analysis of the San Francisco Bay Area. Research in Transportation Economics, Sustainable Transportation 52, 46–55. https://doi.org/10.1016/j.retrec.2015.10.010

Morfeld, P., Groneberg, D.A., Spallek, M., 2015a. Letter to the Editor: On the effectiveness of low emission zones. Atmospheric Environment 122, 569–570. https://doi.org/10.1016/j.atmosenv.2015.10.029

Morfeld, P., Groneberg, D.A., Spallek, M., 2015b. The impact of Low Emission Zones on particulate matter concentration and public health: A Comment. Transportation Research Part A: Policy and Practice 82, 255–256. https://doi.org/10.1016/j.tra.2015.10.002

Möser, G., Bamberg, S., 2008. The effectiveness of soft transport policy measures: A critical assessment and meta-analysis of empirical evidence. Journal of Environmental Psychology 28, 10–26. https://doi.org/10.1016/j.jenvp.2007.09.001

Mudway, I.S., Dundas, I., Wood, H.E., Marlin, N., Jamaludin, J.B., Bremner, S.A., Cross, L., Grieve, A., Nanzer, A., Barratt, B.M., Beevers, S., Dajnak, D., Fuller, G.W., Font, A., Colligan, G., Sheikh, A., Walton, R., Grigg, J., Kelly, F.J., Lee, T.H., Griffiths, C.J., 2019. Impact of London's low emission zone on air quality and children's respiratory health: a sequential annual cross-sectional study. The Lancet Public Health 4, e28–e40. https://doi.org/10.1016/S2468-2667(18)30202-0

Namazu, M., Dowlatabadi, H., 2018. Vehicle ownership reduction: A comparison of one-way and two-way carsharing systems. Transport Policy 64, 38–50. https://doi.org/10.1016/j.tranpol.2017.11.001

Nijland, H., van Meerkerk, J., 2017. Mobility and environmental impacts of car sharing in the Netherlands. Environmental Innovation and Societal Transitions, Sustainability Perspectives on the Sharing Economy 23, 84–91. https://doi.org/10.1016/j.eist.2017.02.001

Nolan, A., 2003. The determinants of urban households' transport decisions: a microeconometric study using irish data. International Journal of Transport Economics / Rivista internazionale di economia dei trasporti 30, 103–132.

Nordlund, A.M., Garvill, J., 2003. Effects of values, problem awareness, and personal norm on willingness to reduce personal car use. J. Environ. Psychol. 23, 339–347. https://doi.org/10.1016/S0272-4944(03)00037-9

Ortúzar, J. de D., Willumsen, L.G., 2011. Modelling Transport. Wiley.

Panteliadis, P., Strak, M., Hoek, G., Weijers, E., van der Zee, S., Dijkema, M., 2014. Implementation of a low emission zone and evaluation of effects on air quality by long-term monitoring. Atmospheric Environment 86, 113–119. https://doi.org/10.1016/j.atmosenv.2013.12.035

Peters, J.F., Burguillo, M., Arranz, J.M., 2021. Low emission zones: Effects on alternative-fuel vehicle uptake and fleet CO2 emissions. Transport. Res. Part D-Transport. Environ. 95, 102882. https://doi.org/10.1016/j.trd.2021.102882

Plan Aire, TRA 6, 2013. Plan nacional de calidad del aire y protección de la atmósfera 2013-2016. Dirección General de Calidad y Evaluación Ambiental y Medio Natural.

Prieto, M., Baltas, G., Stan, V., 2017. Car sharing adoption intention in urban areas: What are the key sociodemographic drivers? Transp. Res. Pt. A-Policy Pract. 101, 218–227. https://doi.org/10.1016/j.tra.2017.05.012

Rapaport, E., 2002. The Stockholm environmental zone, a method to curb air pollution from bus and truck traffic. Transportation Research Part D: Transport and Environment 7, 213–224. https://doi.org/10.1016/S1361-9209(01)00020-7

Rhead, R., Elliot, M., Upham, P., 2018. Using latent class analysis to produce a typology of environmental concern in the UK. Social Science Research 74, 210–222. https://doi.org/10.1016/j.ssresearch.2018.06.001

Rienstra, S.A., Rietveld, P., Verhoef, E.T., 1999. The social support for policy measures in passenger transport.: A statistical analysis for the Netherlands. Transportation Research Part D: Transport and Environment 4, 181–200. https://doi.org/10.1016/S1361-9209(99)00005-X

Rotaris, L., Danielis, R., 2018. The role for carsharing in medium to small-sized towns and in less-densely populated rural areas. Transportation Research Part A: Policy and Practice, Smart urban mobility 115, 49–62. https://doi.org/10.1016/j.tra.2017.07.006

Rotaris, L., Danielis, R., Maltese, I., 2019. Carsharing use by college students: The case of Milan and Rome. Transportation Research Part A: Policy and Practice 120, 239–251. https://doi.org/10.1016/j.tra.2018.12.017

Rousseau, S., Franck, M., De Jaeger, S., 2020. The Impact of Spatial Patterns in Road Traffic Externalities on Willingness-to-Pay Estimates. Environ Resource Econ 75, 271–295. https://doi.org/10.1007/s10640-019-00348-5

Runst, P., Ho, D., 2022. The German eco tax and its impact on CO2 emissions. Energy Policy 160, 112655. https://doi.org/10.1016/j.enpol.2021.112655

Salas, R., Pérez Villadóniga, M.J., Prieto-Rodriguez, J., Russo, A., 2019. Restricting Traffic into the City Centre: Has Madrid Central Been Effective to Reduce NO_2 Levels? (SSRN Scholarly Paper No. ID 3495440). Social Science Research Network, Rochester, NY.

Salas, R., Perez-Villadoniga, M.J., Prieto-Rodriguez, J., Russo, A., 2021. Were traffic restrictions in Madrid effective at reducing NO2 levels? Transportation Research Part D: Transport and Environment 91, 102689. https://doi.org/10.1016/j.trd.2020.102689

Salonen, M., Broberg, A., Kyttä, M., Toivonen, T., 2014. Do suburban residents prefer the fastest or low-carbon travel modes? Combining public participation GIS and multimodal travel time analysis for daily mobility research. Applied Geography 53, 438–448. https://doi.org/10.1016/j.apgeog.2014.06.028

Santos, F.M., Gómez-Losada, Á., Pires, J.C.M., 2019. Impact of the implementation of Lisbon low emission zone on air quality. Journal of Hazardous Materials 365, 632–641. https://doi.org/10.1016/j.jhazmat.2018.11.061

Santos, G., Maoh, H., Potoglou, D., von Brunn, T., 2013. Factors influencing modal split of commuting journeys in medium-size European cities. J. Transp. Geogr. 30, 127–137. https://doi.org/10.1016/j.jtrangeo.2013.04.005

Schaefers, T., 2013. Exploring carsharing usage motives: A hierarchical means-end chain analysis. Transportation Research Part A: Policy and Practice 47, 69–77. https://doi.org/10.1016/j.tra.2012.10.024

Schwanen, T., Dijst, M., Dieleman, F.M., 2002. A microlevel analysis of residential context and travel time. Environ. Plan. A 34, 1487–1507. https://doi.org/10.1068/a34159

Shaheen, S., Chan, N., 2016. Mobility and the Sharing Economy: Potential to Facilitate the First- and Last-Mile Public Transit Connections. Built Environment 42, 573–588. https://doi.org/10.2148/benv.42.4.573

Shaheen, S.A., Cohen, A.P., 2013. Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. International Journal of Sustainable Transportation 7, 5–34. https://doi.org/10.1080/15568318.2012.660103

Silvestri, A., Foudi, S., Galarraga, I., Ansuategi, A., 2021. The contribution of carsharing to low carbon mobility: Complementarity and substitution with other modes. Research in Transportation Economics, Policies prompting sustainable transport in urban areas 85, 100968. https://doi.org/10.1016/j.retrec.2020.100968

Singleton, P.A., Wang, L., 2014. Safety and Security in Discretionary Travel Decision Making Focus on Active Travel Mode and Destination Choice. Transp. Res. Record 47–58. https://doi.org/10.3141/2430-06

Smith, G., Sochor, J., Karlsson, I.C.M., 2018. Mobility as a Service: Development scenarios and implications for public transport. Research in Transportation Economics 69, 592–599. https://doi.org/10.1016/j.retrec.2018.04.001

Sovacool, B.K., Kim, J., Yang, M., 2021. The hidden costs of energy and mobility: A global meta-analysis and research synthesis of electricity and transport externalities. Energy Research & Social Science 72, 101885. https://doi.org/10.1016/j.erss.2020.101885

Spears, S., Houston, D., Boarnet, M.G., 2013. Illuminating the unseen in transit use: A framework for examining the effect of attitudes and perceptions on travel behavior. Transportation Research Part A: Policy and Practice 58, 40–53. https://doi.org/10.1016/j.tra.2013.10.011

Steinsland, C., Fridstrøm, L., Madslien, A., Minken, H., 2018. The climate, economic and equity effects of fuel tax, road toll and commuter tax credit. Transport Policy 72, 225–241. https://doi.org/10.1016/j.tranpol.2018.04.019

Symon, G., Cassell, C., 2012. Qualitative Organizational Research: Core Methods and Current Challenges. SAGE.

Thøgersen, J., Vatn, A., Aasen, M., Dunlap, R.E., Fisher, D.R., Hellevik, O., Stern, P., 2021. Why do people continue driving conventional cars despite climate change? Social-psychological and institutional insights from a survey of Norwegian commuters. Energy Research & Social Science 79, 102168. https://doi.org/10.1016/j.erss.2021.102168

Toutouh, J., Lebrusán, I., Nesmachnow, S., 2020. Computational Intelligence for Evaluating the Air Quality in the Center of Madrid, Spain, in: Dorronsoro, B., Ruiz, P., de la Torre, J.C., Urda, D., Talbi, E.-G. (Eds.), Optimization and Learning, Communications in Computer and Information Science. Springer International Publishing, Cham, pp. 115–127. https://doi.org/10.1007/978-3-030-41913-4_10

Train, K.E., 2009. Discrete Choice Methods with Simulation, 2 edition. ed. Cambridge University Press, Cambridge ; New York.

Tveter, E., 2018. Using impacts on commuting as an initial test of wider economic benefits of transport improvements: Evidence from the Eiksund Connection. Case Stud. Transp. Policy 6, 803–814. https://doi.org/10.1016/j.cstp.2018.10.002

Tyndall, J., 2019. Free-floating carsharing and extemporaneous public transit substitution. Research in Transportation Economics. https://doi.org/10.1016/j.retrec.2019.01.005

Ubbels, B., Rietveld, P., Peeters, P., 2002. Environmental effects of a kilometre charge in road transport: an investigation for the Netherlands. Transportation Research Part D: Transport and Environment 7, 255–264. https://doi.org/10.1016/S1361-9209(01)00023-2

United Nations, 2018. World Urbanization Prospects: The 2018 Revision, WUP 2018.

Van Exel, N.J.A., Rietveld, P., 2009. Could you also have made this trip by another mode? An investigation of perceived travel possibilities of car and train travellers on the main travel corridors to the city of Amsterdam, The Netherlands. Transportation Research Part A: Policy and Practice 43, 374–385. https://doi.org/10.1016/j.tra.2008.11.004

Vance, C., Lovanna, R., 2007. Gender and the automobile - Analysis of nonwork service trips. Transp. Res. Record 54–61. https://doi.org/10.3141/2013-08

Vermesch, P., Boisjoly, G., Lachapelle, U., 2021. Commuting mode share and workplace-based public transport services: An equity perspective. Case Stud. Transp. Policy 9, 590–599. https://doi.org/10.1016/j.cstp.2021.02.013

Welde, M., Tveter, E., 2022. The wider local impacts of new roads: A case study of 10 projects. Transp. Policy 115, 164–180. https://doi.org/10.1016/j.tranpol.2021.11.012

Willis, D.P., Manaugh, K., El-Geneidy, A., 2013. Cycling Under the Influence: Summarizing the Influence of Attitudes, Habits, Social Environments, and Perceptions on Cycling for Transportation. Presented at the Transportation Research Board 92nd Annual MeetingTransportation Research Board.

Wolff, H., 2014. Keep Your Clunker in the Suburb: Low-emission Zones and Adoption of Green Vehicles. The Economic Journal 124, F481–F512. https://doi.org/10.1111/ecoj.12091

Zink, R., Valdes, J., Wuth, J., 2020. Prioritizing the Chicken or Egg? Electric Vehicle Purchase and Charging Infrastructure Subsidies in Germany. Politics Gov. 8, 185–198. https://doi.org/10.17645/pag.v8i3.3025

Appendices

Appendix 1.I - Interviews Guidelines

A. Households

a. <u>Introduction</u>

- Aim of this section: Warm-up for the conversation, obtain basic information on the interviewee, on the specific shared mobility scheme and on the use the user makes of it.

Outcome: □ Introduce the interviewee to the ENABLE.EU project (not with excessive detail, to avoid influencing interviewee answers)

□ Collect basic information on the interviewee (Age, education, work, leisure, routine, household size, travel needs)

□ Describe a normal day from beginning to end where they use this mode.

□ How does the mode work?

□ How often do they use the mode?

□ How long have they been using the mode?

□ How did they learn about the mode?

□ What are the destinations and the occasions to use it?

□ For how many kilometres do they normally use the mode?

b. <u>Factors and Lifestyle</u>

- Aim of this section: Obtain insights into which factors possibly influence propensity to subscribe to a shared mobility scheme.
- Outcome: □ What habits s-/he had before using this mode?

□ Why did they start using carsharing?

□ In which aspects do they see carsharing fits with their travel needs?

□ What were the motivations to switch to using this mode?

Possible motivations:

- Economic reasons
- Environmental attitude
- Propensity for new technologies
- Personal emotions (e.g., satisfaction from being a user, doing something good)
- Other

Extra: high presence of vehicles, low price, etc.

□ What do you think would convince more people to join the group?

c. <u>Relation with other modes</u>

- Aim of this section: Obtain insights into how the scheme relates to other modes, in particular public transport. Are they complementary or rivals?
- Outcome: □ What are the complementary modes they use to meet their transport needs?

□ How do these other modes compare to carsharing?

□ How did their use of public transport change after joining the carsharing scheme? (Did it reduce or increase?)

d. <u>Personal vehicle</u>

- Aim of this section: Obtain insights into car-use history and future willingness to buy a car for carsharing users.
- Outcome: □ Do they own a car? Did they ever own a car?

□ Which factors affected their decision of not having, or not using, a personal car?

□ Do they plan to own a car in the future? Which factors would affect this decision?

□ If they plan to buy a car in the future, what could make them rethink this decision?

e. <u>Evaluation and Electric carsharing focus</u>

- Aim of this section: Understand possibilities for improvement or implementation of an electric carsharing scheme.
- Outcome

i. Electric carsharing users

- Outcome: □ How could be the service improved?

□ Do they prefer the service to be provided by electric vehicles?

□ What are the advantages of using electric carsharing?

- compared to conventional carsharing?
- compared to other transport modes?

□ What are the barriers/limits and disadvantages of electric carsharing?

□ Would they be willing to pay more, less or the same if the service was provided with conventional cars?

ii. Other users

- Outcome: □ How could be their service improved?

□ What are the advantages and disadvantages of using carsharing?

□ Would they be willing to use the service if it were provided by electric vehicles?

□ What would be the advantages of having an electric carsharing service compared to a conventional service?

□ Would there be barriers/limits and inconveniences to it?

□ Would they prefer it?

□ Would they be willing to pay more, less or the same as conventional carsharing?

B. Stakeholders

a. Common introduction

- Aim of this section: Warm-up the conversation, obtain basic information on the interviewee.
- Outcome: □ Introduce the interviewee to the ENABLE.EU project.

□ Collect basic information on the interviewee (Time at the company/administration, role as stakeholder).

□ What is the current development of the electric carsharing system?

b. Facilitation of Electric Carsharing

- Aim of this section: Understand what factors and measures can facilitate the development and implementation of an electric carsharing scheme.
- Outcome: □ What are (or would be) the motivations to implement and foster an electric carsharing system?

□ What are the main measures to develop in order to facilitate the implementation of an electric carsharing system? Or to improve it?

□ Do they think it is worth it to have this mode? Why or why not?

□ What are the features that can determine the success or failure of this system?

□ What is the contribution that this system provides (or could provide) in urban areas?

c. Relation with other urban modes

- Aim of this section: Obtain insights into how electric carsharing relates to alternative transport modes
- Outcome: □ How does this mode relate to private car ownership? What does (or would) it imply?

□ How does this system relate to public transport? Did it increase or reduce public transport use?

□ How did (or would) urban transport change with the implementation of this system?

d. Stakeholders' specific questions

- Aim of this section: Obtain further insights into the topic through the point of view of the specific actor.

i. Policymakers

- Outcome:

□ Apart from the electric carsharing system, which measures have been developed to reduce the carbon intensity of urban mobility? Which measures are planned to be developed?

□ What are the costs and the benefits of an electric carsharing scheme?

□ On which basis were decisions made on this topic? (Convenience, environmental concern, financial balance)

□ What would be the direct and indirect benefits (e.g., health, congestion, etc.) of having a low-carbon city/region/country (depending on the PM area of influence)?

□ In their view, what are the positions of pressure groups and service providers? What are the synergies and the contrasts with them?

□ What is their vision on the future of electric carsharing? (will it increase, reduce?)

□ What is their vision on the future of low-carbon mobility in general?

ii. Pressure groups

- Outcome: □ What are the groups you usually target?

□ What are the results they aim to achieve and the strategy to pursue them?

□ What is lacking in the current situation of electric carsharing scheme?

□ In their view, what are the positions of policymakers and service providers? What are the synergies and the contrasts with them?

□ What is their vision on the future of electric carsharing? And regarding low-carbon mobility in general?

iii. Industry stakeholders

- Outcome:

□ Is the mode working completely on a commercial basis, or it is partially financed from other sources? (public support, private sponsorship, etc.)

□ Are there specific categories of people particularly targeted by the company offer? How? Why?

□ Does the company have any measure planned to provide a “Low Carbon” service? If not, why? (only for non-electric carsharing providers)

□ Does your service compete with another? Who? Does it occupy a niche in the sector?

□ In their view, what are the positions of policymakers and pressure groups? What are the synergies and the contrasts with them?

□ What is their vision on the future of electric carsharing?

Appendix 1.II – Carsharing users Template Coding

1. TRAVEL ROUTINE AND CARSHARING USE

1.1. Carsharing

1.1.1. Frequency of use
1.1.2. Usual distance/time
1.1.3. Means of use

1.2. Traditional travel modes

1.2.1. Foot
1.2.2. Bicycle
1.2.3. Public transport
1.2.4. Private car
1.2.5. Others

1.3. The routine

1.3.1. Leisure activities
1.3.2. Work time

2. FACILITATION OF CARSHARING

2.1. Personal experience

2.1.1. When started
2.1.2. Previous modes
2.1.3. Motivation to start
2.1.4. How was the mode discovered?

2.2. Opinion

2.2.1. Attributes motivating its use
2.2.1.1. Ranking
2.2.2. Barriers to its use
2.2.3. Other possible motivations people might have

3. RELATION WITH OTHER MODES

3.1. Public Transport (PT)

3.1.1. Current frequency of PT use
3.1.2.PT Use
3.1.2.1. Bus use
3.1.2.2. Metro use
3.1.2.3. Other modes use
3.1.3. PT Opinion
3.1.3.1. Bus opinion
3.1.3.2. Metro opinion
3.1.3.3. Other modes opinion

3.2. Private Vehicle (PV)

3.2.1. PV Ownership (Yes/No)
3.2.1.1. Motivation
3.2.1.2. Number of vehicles
3.2.2. Current frequency of PV use
3.2.3. PV Use
3.2.4. PV Opinion

3.3. Relation with Carsharing

3.3.1. Comparative advantages

3.3.1.1. Advantages Public Transport

3.3.1.2. Advantages Carsharing

3.3.1.3. Advantages Private Vehicle

3.3.2. Comparative advantages

3.3.2.1. Disadvantages Public Transport

3.3.2.2. Disadvantages Carsharing

3.3.2.3. Disadvantages Private Vehicle

3.3.3. Influence of carsharing on other modes use

3.3.3.1. Change in use of Public transport

3.3.3.2. Change in use of private vehicle

3.3.3.3. Change in PV purchasing intention

3.3.3.4. New demand for mobility

4. CONSIDERATIONS ON ELECTRIC CARSHARING

4.1. Type of carsharing vehicle used (Electric or Conventional)

4.1.1. Knowledge of different models of carsharing end vehicles' type

4.2. Experience with BEV electric vehicle

4.2.1. Previous experience with electric

4.2.2. Opinion on electric technology

4.3. Value of being electric

4.3.1. Willingness to pay for electric carsharing

4.3.2. Pros and Cons of the Electric vehicles

4.3.3. Influence on the intention to buy

Appendix 2.I - ENABLE.EU Mobility Household Survey (partial)

Section M - MOBILITY

Introduction: In the following 4 questions you will be asked about your usual way of moving from a place to another in your everyday routine. You will be presented a list of destination categories, for each of these, please think of the singular most habitual destination that can be referred to this category and answer according to this.

M1. How many days in a week[20] do you typically travel (incl. walking) to the following locations?

ONE answer per row

		Number of days in a week							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A	Workplace/university	0	1	2	3	4	5	6	7
B	Children's school	0	1	2	3	4	5	6	7
C	Location of children's activities	0	1	2	3	4	5	6	7
D	Grocery/shopping	0	1	2	3	4	5	6	7
E	Leisure activities (gym, sport, tours,...)	0	1	2	3	4	5	6	7

*Ask only for **M1A-to-E ≠ "0"***

Trip to *[Destinations A to E]*:

M3A. Where do you normally[21] leave from, when you travel to the *[Destinations A to E]*?

1. Home
2. Workplace/University
3. Children's school
4. Location of children's activities
5. Grocery/Shopping
6. Leisure activities (gym, sport, tours...)

*Ask only for **M1A-to-E ≠ "0"***

M3B. Which of the following travel modes you usually use to perform the trip to the *[Destinations A to E]* and how much time it takes?

Tick all that apply and mark the respective time, e.g. 5 min walking and 12 minutes bus to reach my [Destinations A to E]

	Time (hh:mm)
1. Traditional car (diesel/ gasoline)	__:__
2. Alternative fueled car (Methane/ LPG)	__:__
3. Electric/ Hybrid car	__:__
4. Motorcycle/ Scooter	__:__
5. Carpooling[22]	__:__

[20] Note for the interviewer: Typical day/week are to be referred to the most common day/week in a year, one can think of, according to her/his current situation.

[21] Please, refer to your most habitual departure location

[22] Carpooling defined as moving with a private vehicle but as passenger instead of driver.

6. Bus	__:__
7. Train	__:__
8. Metro/Tram	__:__
9. Bicycle	__:__
10. Walking	__:__
11. Other, please specify: ………………………………………….	__:__
99. Not applicable	

M4. How many kilometers does the trip to the following destinations take?

ONE answer per row

		Distance in km	(Don't know / No answer)
A	Workplace/University	_____ km	99
B	Children's school	_____ km	99
C	Location of children's activities	_____ km	99
D	Grocery/Shopping	_____ km	99
E	Leisure activities (gym, sport, tours...)	_____ km	99

M5. What importance do the following factors have in your decision between different methods of travel?

ONE answer per row

		1 Not at all Important	2	3	4	5 Very Important	Don't Know
A	Cost	1	2	3	4	5	99
B	Travel time	1	2	3	4	5	99
C	Comfort	1	2	3	4	5	99
D	Flexibility	1	2	3	4	5	99
E	Safety	1	2	3	4	5	99
F	Privacy	1	2	3	4	5	99
G	Air quality impact	1	2	3	4	5	99

H	CO_2 emissions impact	1	2	3	4	5	99
I	Reliability	1	2	3	4	5	99
J	Availability of method	1	2	3	4	5	99
K	Reputation	1	2	3	4	5	99
L	Other, please specify: ……………………..	1	2	3	4	5	99

M8. What is your level of support for the following government actions that would influence your transportation system?

ONE answer per row

		1 Strongly Opposed	2	3	4	5 Strongly Supportive	Don't Know
A	Improving traffic flow by building new roads, and expanding existing roads.	1	2	3	4	5	99
B	Discouraging automobile use with road tolls, gas taxes, and vehicle surcharges.	1	2	3	4	5	99
C	Making neighbourhoods more attractive to walkers and cyclists using bike lanes, and speed controls.	1	2	3	4	5	99
D	Reducing vehicle emissions with regular testing, and manufacturer emissions standards	1	2	3	4	5	99
E	Making public car-sharing and public transport faster by giving them dedicated traffic lanes, and priority at intersections	1	2	3	4	5	99
F	Making public transport more attractive by reducing fares, increasing frequency, and expanding route coverage	1	2	3	4	5	99
G	Reducing transportation distances by promoting mixed commercial and residential, an high density development	1	2	3	4	5	99
H	Reducing transportation needs by encouraging compressed workweeks and working from home	1	2	3	4	5	99

M9. Thinking about your daily experiences, how serious do you consider the following problems related to transportation to be?

ONE answer per row

		1 Not at all Important	2	3	4	5 Very Important	Don't Know
A	Traffic congestion you experience while driving	1	2	3	4	5	99
B	Traffic noise you perceive at home or doing your activities	1	2	3	4	5	99
C	Excessive presence of vehicles occupying urban spaces	1	2	3	4	5	99
D	Vehicle emissions, which impact local air quality	1	2	3	4	5	99

E	Accidents caused by aggressive or absent minded drivers	1	2	3	4	5	99
F	Vehicle emissions, which contribute to global warming	1	2	3	4	5	99
G	Unsafe communities due to speeding traffic	1	2	3	4	5	99

M10. How much are you satisfied with the following facilities where you live and conduce your activities?

ONE answer per row

	1 Very Low	2	3	4	5 Very High	Not applicable	Don't Know
Parking space	1	2	3	4	5	6	99
Public transport timetables	1	2	3	4	5	6	99
Public transport coverage	1	2	3	4	5	6	99
Bike lanes	1	2	3	4	5	6	99
Pedestrian lanes	1	2	3	4	5	6	99
Public shared-bikes	1	2	3	4	5	6	99
Public shared-cars	1	2	3	4	5	6	99

Section S - SOCIAL AND ECONOMIC CHARACTERISTICS

S2. What is the highest level of studies, you have completed?

Only ONE answer.

1	No formal education or below primary
2	Primary education
3	Secondary and post-secondary non-tertiary education
4	Tertiary education first stage, i.e. bachelor or master
5	Tertiary education second stage (PhD)
9	(Don't know)

S4. What year were you born?

1. …………

99. (Don't know / refuse to answer)

S5. What is your gender?

Only ONE answer.

1. Male
2. Female

S6. Which phrase describes best the area where you live?

Only ONE answer.

1. A big city (more than 0,5 mln people)
2. The suburbs or outskirts of a big city
3. A town or a small city
4. A country village
5. A farm or home in the countryside
6. (Don't know)

S8. Which of the descriptions bellow comes closest to how you feel about your household's income nowadays?

Only ONE answer.

1. Living comfortably on present income
2. Coping on present income
3. Finding it difficult on present income
4. Finding it very difficult on present income

99. (Don't know)

H4. How many of the following vehicles your household owns?

One answer per row

		Don't have	**Number of vehicles**			**(Don't know)**
			1	**2**	**3+**	
A	Petrol car	1	2	3	4	99
B	Diesel car	1	2	3	4	99
C	Alternative fuelled car (methane, LPG)	1	2	3	4	99
D	Electric car	1	2	3	4	99
E	Hybrid car	1	2	3	4	99
F	Motorcycle (or Scooters)	1	2	3	4	99
G	Electric Motorcycle (or Scooter)	1	2	3	4	99
H	Van, truck, caravan	1	2	3	4	99
I	Bicycle	1	2	3	4	99
J	Electric bicycle	1	2	3	4	99

Appendix 2.II - Trip characteristics and vehicle ownership

Table A1 A) Shares of vehicle ownership by vehicle type in each country; B) Average distances of trips by destination; C) Average travel time by destination.

A) Vehicles ownership	Hungary	Italy	Norway	Poland	Spain	Total
No motorized vehicles	35.42%	12.29%	17.77%	27.00%	28.95%	23.77%
Conventional Vehicle	64.09%	86.24%	76.41%	64.60%	69.34%	72.49%
Alternative Vehicle	1.96%	9.37%	14.50%	13.50%	3.68%	9.07%
Bicycle	58.12%	41.85%	79.77%	66.80%	36.18%	58.47%
B) Average Distance (Km)						
Workplace	13.52	12.87	11.27	13.17	7.21	11.29
SE Workplace	0.56	0.83	0.48	0.56	0.54	0.26
Grocery Shopping	4.66	4.69	2.95	3.16	2.11	3.28
SE Grocery Shopping	0.21	0.29	0.15	0.21	0.15	0.19
Leisure Activities	12.04	0.54	6.15	6.86	4.41	3.75
SE Leisure Activities	0.70	0.05	0.52	0.84	0.60	0.18
Children School	5.47	3.74	3.33	4.98	2.34	3.57
SE Children School	0.54	0.48	0.43	0.64	0.28	0.09
Children Activities	7.92	3.90	6.29	6.37	2.03	6.39
SE Children Activities	1.22	0.74	0.59	0.94	0.04	0.31
C) Average Travel Time (mm:ss)						
Workplace	27:55	24:44	25:01	24:58	21:15	24:57
SE Workplace	00:39	00:45	00:36	00:33	00:38	00:17
Grocery Shopping	17:58	16:53	13:33	13:40	08:39	14:15
SE Grocery Shopping	00:24	00:30	00:26	00:19	00:15	00:11
Leisure Activities	26:07	21:13	18:09	17:50	11:52	18:09
SE Leisure Activities	00:50	00:42	00:33	00:43	00:30	00:18
Children School	19:41	14:11	12:59	15:36	08:48	14:29
SE Children School	00:56	00:50	00:55	00:50	00:30	00:24
Children Activities	20:24	15:34	15:35	18:00	10:13	15:56
SE Children Activities	01:14	01:07	00:52	01:06	00:48	00:29

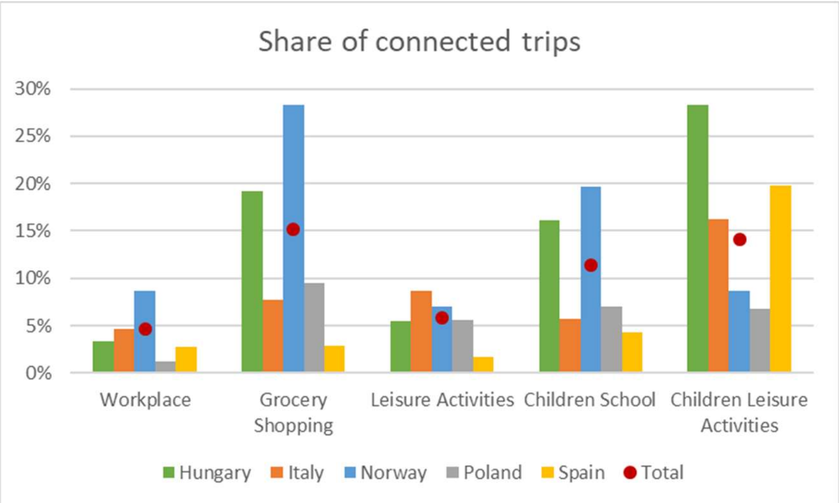


Figure A.0.1 Shares of trips connected to a previous destination (not starting from home)

Appendix 2.III – Latent classes distribution

Tables below present the result of LCA models for the sustainable policy support (Appendix A.1) and the sensitivity to transport externalities (appendix A.2).

A. Support to transport policy for low carbon mobility transition

Class 1: Moderate supporters of intervention

CLASS 1	Improving roads	Taxing car use	Work and bike lanes	Emission standards	Dedicated PT lanes	Reduce PT fares	Mixed neighborhoods	Work from home
Strongly opposed	1%	20%	0%	0%	2%	0%	1%	1%
Mildly opposed	5%	19%	3%	2%	8%	1%	6%	6%
Neutral	17%	23%	16%	15%	35%	13%	31%	31%
Midly supportive	50%	29%	54%	55%	44%	48%	52%	49%
Strongly supportive	27%	8%	26%	27%	11%	38%	9%	13%

Figure A.0.2 Predicted probability of being supportive of the specified low carbon mobility policies for Class 1

Class 2: Strong supporters of intervention

CLASS 2	Improving roads	Taxing car use	Work and bike lanes	Emission standards	Dedicated PT lanes	Reduce PT fares	Mixed neighborhoods	Work from home
Strongly opposed	6%	44%	4%	3%	11%	3%	10%	12%
Mildly opposed	5%	9%	3%	2%	6%	1%	5%	5%
Neutral	9%	14%	8%	8%	23%	4%	24%	23%
Midly supportive	12%	9%	12%	12%	12%	8%	12%	13%
Strongly supportive	68%	25%	72%	76%	48%	84%	49%	48%

Figure A.0.3 Predicted probability of being supportive of the specified low carbon mobility policies for Class 2

Class 3: Indifferent to intervention

CLASS 3	Improving roads	Taxing car use	Work and bike lanes	Emission standards	Dedicated PT lanes	Reduce PT fares	Mixed neighborhoods	Work from home
Strongly opposed	1%	24%	2%	2%	7%	2%	3%	4%
Mildly opposed	6%	15%	11%	8%	12%	7%	11%	11%
Neutral	56%	55%	66%	68%	70%	63%	78%	77%
Midly supportive	18%	5%	16%	17%	11%	17%	7%	6%
Strongly supportive	19%	1%	4%	5%	1%	10%	0%	2%

Figure A.0.4 Predicted probability of being supportive of the specified low carbon mobility policies for Class 3

B. Perception of transport-related externalities

Class 1: Somewhat sensitive to transport externalities

CLASS 1	Congestion	Noise	Space occupation	Air quality	Accidents	Global warming	Security
Not at all important	6%	5%	1%	1%	1%	1%	1%
	10%	16%	7%	6%	8%	6%	10%
	39%	45%	42%	43%	40%	46%	46%
	34%	29%	42%	43%	38%	40%	37%
Very important	10%	4%	8%	7%	13%	8%	6%

Figure B.1 Predicted probability of being sensitive to the specified transport externalities for Class 1

Class 2: Highly sensitive to transport externalities

CLASS 2	Congestion	Noise	Space occupation	Air quality	Accidents	Global warming	Security
Not at all important	6%	4%	1%	0%	0%	0%	1%
	2%	2%	1%	1%	0%	1%	1%
	9%	10%	5%	4%	4%	5%	6%
	16%	22%	20%	18%	16%	18%	21%
Very important	67%	61%	74%	78%	79%	75%	71%

Figure B.2 Predicted probability of being sensitive to the specified transport externalities for Class 2

Class 3: Insensitive to transport externalities

CLASS 3	Congestion	Noise	Space occupation	Air quality	Accidents	Global warming	Security
Not at all important	56%	68%	49%	45%	42%	29%	45%
	21%	24%	28%	32%	26%	25%	31%
	13%	6%	16%	17%	18%	27%	15%
	5%	2%	6%	5%	8%	11%	6%
Very important	4%	1%	2%	2%	5%	8%	3%

Figure B.3 Predicted probability of being sensitive to the specified transport externalities for Class 3

Appendix 2.IV – Country specific marginal effects

A. Country specific marginal effects for policy support and perception of externalities in Workplace trip

Policy support	
Indifferent	PT users
Hungary	-6.4%
Italy	-2.1%
Norway	-5.7%
Poland	-5.1%
Spain	-5.7%

Externalities perception			
Highly sensitive	PV users	PT users	
Hungary	5.3%	-4.9%	
Italy	2.8%	-1.8%	
Norway	4.4%	-4.0%	
Poland	4.8%	-4.2%	
Spain	4.7%	-4.1%	
Insensitive	PV users	PT users	AM users
Hungary	9.4%	-7.2%	-2.2%
Italy	5.2%	-2.8%	-2.4%
Norway	8.2%	-5.6%	-2.6%
Poland	8.5%	-6.3%	-2.2%
Spain	8.6%	-5.7%	-2.8%

Note: In red non-significant results, missing alternatives/classes were not connected to significant results.

B. Country specific marginal effects for policy support and perception of externalities in Grocery/shopping trip

Policy support			
Strong supporters	PV users	PT users	AM users
Hungary	-2.4%	-3.8%	6.2%
Italy	-2.2%	-0.8%	3.0%
Norway	-3.5%	-1.7%	5.2%
Poland	-4.9%	-1.0%	5.9%
Spain	-5.2%	-0.9%	6.1%

Externalities perception		
Insensitive	PV users	PT users
Hungary	3.3%	-4.7%
Italy	2.1%	-2.4%
Norway	3.7%	-4.4%
Poland	4.8%	-5.3%
Spain	5.1%	-5.5%

Note: In red non-significant results, missing alternatives/classes were not connected to significant results.

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Thesis developed within the Basque Centre for Climate Change – Klima Aldaketa Ikergai.

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Universidad del País Vasco Euskal Herriko Unibertsitatea

bc³ BASQUE CENTRE FOR CLIMATE CHANGE Klima Aldaketa Ikergai Sustainability, that's it!