The transition towards a Circular economy in Brussels from an Exnovation perspective

Extent of delinearization and potential impacts of the current path – the car-sharing example

Document type	Research deliverable
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Date of delivery	30/05/2021
Version	1.2 – Working document
Dissemination level	Internal
Keywords (Maximum six)	Exnovation, linear/ownership economy, circular/sharing economy, car sharing, sustainability impacts

Summary

The present report, together with D2.3 and D4.3, presents the second in-depth case analysis of exnovation in the Brussels Capital Region, which refers to the exnovation of the linear economy (LE) as implied in the transition towards a circular economy (CE), from a sustainability assessment perspective. Our main objective with this case study is to assess and to highlight the extent of this process and related potential sustainability impacts. In order to do so, we seek two address two main questions. First, what are the *current trends* in terms of diffusion of the CE and exnovation of the LE? We use car sharing (CS) as an example of a CE offering which promise is to replace the use of privately owned vehicles and we seek to generalize our findings to other CE offerings, whenever possible. While circular offerings seem to emerge since a few years in certain sectors, including CS, we found no evidence that the linear regime (e.g. the ownership-based automotive regime) is being destabilized. The destabilization of the regime seems yet to be a condition for the sustainability benefits of circular innovations such as CS to be realized. This is what came up when we sought to address the second research question: What are the potential *sustainability impacts* of circular innovations? The net environmental impact of a circular offering depends on its combined effects on i) life cycle/per unit impacts and ii) produced and consumed quantities. CS is likely to be more environmentally efficient at a product/service level than its linear counterpart (the use of privately-owned car), however it is likely to increase produced and consumed quantities overall. In fact, while it is expected that CS reduces the fleet size, the number of produced vehicles and car use, those effects are uncertain, because of circular economy rebounds (CER) or Environmental rebound effects (ERE) of circular offerings. CER are composed of classical rebound effects (i.e. re-spending rebound effects that arise when households use the generated savings for other, carbon-intensive consumption activities) and of effects that seem to be specific to CE offering: this is the case of effects generated because of the imperfect substitution between the innovation and what it is meant to replace, but also of induction effects that arise because the innovation improves the access to the good/service. Conclusion/policy implications: In this context, there seems to be a need for (exnovation) policies targeting the linear economy, in addition to (or rather than) policies supporting circular innovations, so that an effective replacement occurs, and produced and consumed quantities do not increase.

Highlights

- Currently, there is a strong growth of car sharing (CS) and of some other circular offerings. Yet, there is no evidence that a destabilization of the (ownership-based) automotive regime is happening. There is no evidence either of such destabilization for the LE in general.
- CE offerings, including CS, are likely to be more environmentally efficient than their linear counterparts are. However, a number of side- and rebound effects (also coined as circular economy rebound) are likely to mitigate nay to offset impact reduction, through an increase in overall demand: circular economy demand would displace linear economy demand only partly, and would thus increase overall consumption.
- For the particular case of CS, those effects come from the imperfect substitution rebound effect (no replacement on a 1:1 basis) and from the induction effect (induction of additional demand or market expansion). On the manufacturing side, shared cars are likely to be replaced more quickly than private cars because of their intensive use and CS is likely to expand the market because of previously carless drivers (this mitigating the cannibalization effect, which extent is itself discussed). On the use side, for previously carless drivers, car sharing replaces public and soft transport rather than private vehicles, and car-use is likely to increase, this mitigating the expected benefits arising from previous car owners. This risk is even more important in the BCR, given the low car ownership rate of Brussels inhabitants.
- (Exnovation) policies targeting the use of privately owned vehicles/the linear economy are likely to mitigate those effects arising from the diffusion of car sharing/circular initiatives. Subsidies for car sharing/circular initiatives (as a policy supporting an innovation) should be distributed parsimoniously, since those are likely to increase car use/overall demand.

The transition to a circular economy in Brussels from a sustainability assessment perspective

Dr. Solène Sureau and Prof. Wouter Achten (SONYA – ex-Geste - IGEAT/ULB)

Table of content

Tables

Figures

Boxes

1. Introduction

1.1 The exnovation of linear economy as implied by the circular economy transition

1.1.1 What is circular economy?

Resource-use and waste generation as main issues at stake

Brussels is a major importer of resources and a major exporter of waste due to its fully urbanized environment. According to a study of its urban metabolism (i.e. a photograph of circulating material flows) published by Bruxelles Environnement in 2015 (BE 2016), 9 millions of tons of materials are imported annually, and 7 million tons are exported.

In terms of resource use, the study shows that "due to its tertiary nature, the BCR is based on an economy that is essentially linear and **dependent on the outside** in terms of incoming flows (massive supply of materials, goods, energy resources and water)", in a context of scarcity of resources (BE 2016, 12). In addition, this resource-consuming and waste-generator metabolism generates **environmental impacts**, in Brussels and elsewhere, due to the treatment of waste and to the extraction, processing and use of resources.

According to the Intergovernmental Panel on Climate Change, "the phases of extraction and processing of materials, fuel and food products (or indirect emissions) contribute to 50 to 65% of total greenhouse gas emissions, and to more than 90% global biodiversity loss and global water stress" (Belin and Hananel 2019, 14). Concerning climate impacts, 83% of the BCR GHG emissions are actually emitted elsewhere (i.e. are indirect emissions) (Ibid).

Circular economy as a way to address those issues

To reduce those environmental impacts and to address the dependency issue, **Circular economy** (CE) is put forward by governments, including in Brussels. CE is « an economic system of exchange and production which, at all stages of the life cycle of products (goods and services), aims to increase the efficiency of resource use and to reduce the impact on the environment, while developing the well-being of individuals. It is in opposition to the linear economy characterized by the phases 'extracting-manufacturing-consuming-discarding' » (BE 2016, 13). Concretely, a circular business model incorporates "*elements that slow, narrow, and close resource loops, so that the resource input into the organisation and its value network is decreased and waste and emission leakage out of the system is minimised*" (Geissdoerfer et al. 2018, 713).

CE is an umbrella concept for a diversity of models. A recent classification identify three main models (and 14 sub-models) following the life cycle stages of products and services (DG for Research and Innovation (EC) 2020, 11–15) (cf. Figure 1):

- **"Activities contributing to Circular Design and Production** aim at increasing resource efficiency through (i) design innovation, (ii) process innovation and reengineering and/or (iii) material innovation and substitution. While such interventions take place early in the product lifecycle, their positive environmental impacts mostly materialise in the use and after-use phases and through reduced use of virgin materials.
- **Activities contributing to Circular Use** aim at increasing resource efficiency through (i) product and asset lifecycle extension based on reuse, repair, repurposing, refurbishment or remanufacturing strategies and/or (ii) product and asset use-optimizing leasing and sharing models. Such interventions typically take place during or at the end of the use phase of products and assets.
- **Activities contributing to Circular Value Recovery** aim at increasing resource efficiency through the recovery of wastes in preparation for reuse and recycling or other CE strategies. Such interventions typically take place during the after-use phase of products and assets".

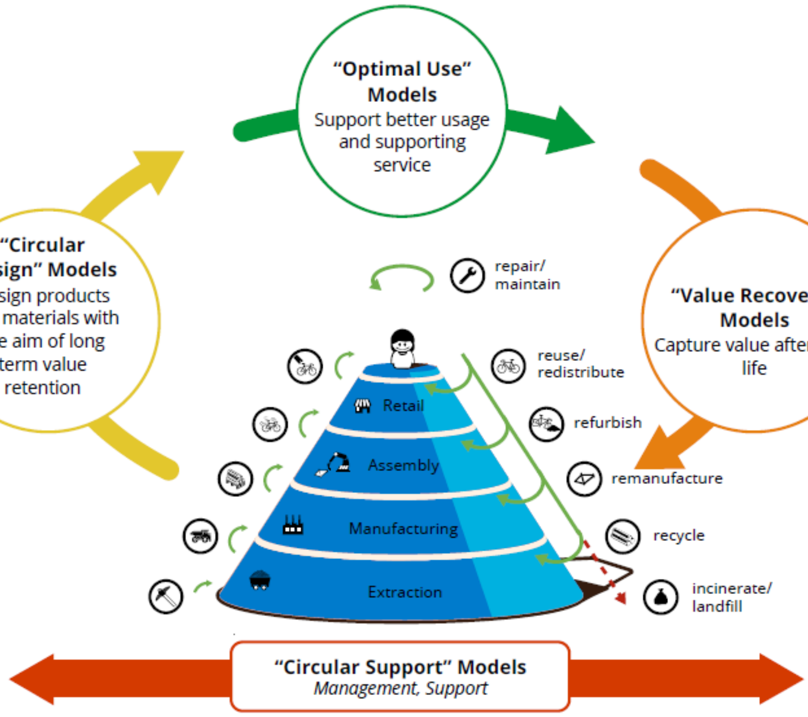

Figure 1: Business models summarized in the Value Hill (Achterberg, Hinfelaar, and Bocken 2016)

1.1.2 The Brussels strategy towards circular economy transition

The Programme regional d'économie circulaire (PREC)

For the Brussels government, the objective is "to encourage the transformation of the linear economy in circular economy, by developing a strategic and operational vision of the environment as a resource that create local jobs" (2025 stratégy, adopted the 16 June 2015, cited by (BE 2016).

In Brussels, the Programme Régional d'Economie Circulaire (PREC) support the development of CE. This regional program contains numerous measures targeting both the reduction of environmental impacts and the generation of economic opportunities and jobs through an embedding of the economy in Brussels, to "produce locally when possible, reduce travel, optimize land use and create added value" (BE 2016). The PREC contains measures for the sectors of building, resources and waste, logistics and retail trade. Other sectors such as food and mobility have dedicated plans (Good Food, Good Move), including measures based on CE principles (e.g. measures to reduce food waste, or support to Mobility as a service) (Bruxelles Mobilité 2018; BE 2016).

As the main programme supporting the transition towards CE in Brussels, the PREC contains mainly 'niche cultivation policies', measures supporting CE *directly* and aiming to facilitate the development of circular offerings (cf. D2.3).

Circular economy as a way to reduce environmental impacts and to create jobs in Brussels

Beyond the environmental objective, the Brussels government puts forward CE as a way to stimulate local economic activity and to create local jobs. The economic component is actually part of the three main objectives of the regional programme and seems to be dominant, next to environmental objectives:

- "To turn environmental goals into economic opportunities.
- To settle the economy in Brussels in order to produce locally when possible, to reduce travel, to optimize the use of the territory and to create added value for the people of Brussels.
- To help create jobs" (BE 2016, 3).

The impact of the PREC and of CE offerings as a question mark

A number of CE initiatives emerged in recent years through this regional support (and measures such as the 'Becircular' project calls or the 'circlemade.brussels' cluster). To date, **there is as yet little information on the effective sustainability impacts of those initiatives** supported by the region or of the policy support (Be Circular 2018, 34; Belin and Hananel 2019, 105). The mid-term assessment report of the PREC includes sheets named 'impact case studies' (*cas d'études d'impact*), which are presented as exploratory work, or "Illustration of potential scenario, with an as much scientific and referenced approach as possible", that should be improved and refined in the future (Be Circular 2018, 34). Rather than a systemic environmental and economic impact assessment, it includes some input and flow data about some of the CE practices/offerings that are supported through the PREC, and an extrapolation exercise to other Brussels actors (e.g. "what would be the energy savings if other Brussels brewery would be circular as well").

This rather limited impact assessment work is justified by the lack of available data (Be Circular 2018) and by the lack of "assessment tool of the transition", (Belin and Hananel 2019). The region plans to deepen this impact assessment work Initiatives to address the latter issue have been undertaken at two levels, referred to as "long term processes, because of the complexity environmental and social impacts" (Belin and Hananel 2019, 106):

- the Brussels-Capital Region participates in the "intra-regional platform of the Circular Economy" alongside other Belgian regions and federal authorities, within which a working group is dedicated to circular economy indicators.
- Bruxelles Environnement is developing a general framework to establish relevant indicators.

In addition, it is uncertain **whether the PREC (and supporting innovations) contribute to the decline or the transformation of the existing and dominant linear economy in Brussels**, especially given its current orientation including mainly 'niche cultivation policies' (cf. D.2.3). Research in Transitions Studies argue that beside those 'creative' policies, there is a need for 'destructive' policies, so that the destabilization of the unsustainable production and consumption modes, such as the linear economy, effectively happens and so that sustainable innovations disseminate (Kivimaa and Kern 2016; Rogge and Johnstone 2017).

1.2 Research questions to be answered in this deliverable

We seek in this deliverable to address two main research questions. First, we aim to understand what are the *current trends* in terms of diffusion of the CE and exnovation of the LE. We propose to look first at key trends and consumption behaviors regarding i) CE/LE in general and regarding ii) a specific CE case (car sharing) in order to address the following sub-questions:

- What are the consumption trends regarding the circular and linear economy?
- How do CE initiatives interact with the existing consumption and production modes? Is there a destabilization of incumbent actors going on or of the linear economy in general?

We will see in this first part (and in D2.2) that the transition to CE is mainly envisaged from the perspective of the support to innovations/CE initiatives, and that the destabilization of the linear economy is yet to be initiated. Thus, in a second stage, we look at the potential sustainability impacts of the diffusion of the CE initiatives, including the specific innovation that we chose that is car sharing, through a literature review. This will help us understand the importance of considering the other side of transitions (the exnovation) from the perspective of the sustainability impacts of transitions strategies. We want to address the following sub-questions:

- What are the various effects of the diffusion of car sharing? Is the diffusion of car sharing positive for the environment? What are other sustainability impacts?
- To which extent can we generalize those results to other CE initiatives?

Link with our 1st exnovation case

In D3.1, we have investigated another exnovation case: the LEZ and its future, including with the ICE phasing-out. As a case of exnovation process steered by regional authorities, we addressed two main questions: (i) Are the exnovation policies put forward by the region able to address regional objectives in terms of pollution and climate impacts and what are the sustainability impacts of those policies? (ii) How to assess impacts of exnovation futures for a low-emission mobility in Brussels? Which exnovation scenarios could be assessed? Which impact categories should be assessed and how?

With this second case, the exnovation issue has to be approached differently. The focus is not sectoral, but **transversal and related to the business model** of companies, how they use resources and manage waste. Also, our **starting point is the innovation (CE models)** rather than the object to be exnovated and related exnovation policy (the starting point of case 1 was the exnovation policy, i.e. the phasing out of *diesel and petrol vehicles*). This starting point for case 2 is guided by the fact that progresses of exnovation policies in the transition towards a CE are less clear at first sight, in comparison with the first case for which exnovation policies are already implemented and discussed. Consequently, for case 1, impact assessments of the exnovation policy at issue (the LEZ) could be found. However, for this case, there is no such literature for a policy targeting the exit from the linear economy. Thus, the case has to be approached first from the circular economy or the innovation perspective.

1.3 Material and methods

1.3.1 A focus on a specific CE model and sector

Within the diversity of CE business models, we chose to focus on a specific CE offering in a specific sector in order to be able to address the research questions, and to illustrate the issues, effects and impacts at stake. We chose to focus on **car sharing**, which is “a vehicle access scheme […] which allows and facilitates communal (shared) rather than private access to a pool of vehicles distributed in the city (for personal use) by a provider […] ” (Amatuni et al. 2020).

There are several reasons for this choice. First, we see an interest in building on the previous work conducted on the first case, which focused on mobility issues, especially in building bridges with exnovation scenarios of case 1. Secondly, the transport sector is an important contributor to regional direct greenhouse gas emissions (together with housing) and so-called mobility-as-a-service[1], which encompasses car sharing, is considered as a key solution to mobility issues (RBC 2019; Bruxelles Mobilité 2018). Thirdly, there is already a corpus of scientific publications on sustainability impacts of this CE business model (sharing), especially in the transport sector (Rademaekers et al. 2018).

Defining car sharing

In order to address our research questions, we focus on a specific CE model: sharing is one of the categories of the ‘Optimal or Circular use model’ of the CE business model typology of (DG for Research and Innovation (EC) 2020) (cf. Figure 1). The objective is to “increase[e] resource efficiency through […] product and asset use-optimizing leasing and sharing models” (Ibid, 10).

Sharing models are also called functional economy or Product-service systems (PSS). A PSS consists of “a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs” (Tukker and Tischner 2006a, 1552). There are three main PSS categories (cf. Figure 2): i. Product-oriented services ii. Use-oriented services iii. Result-oriented services. In the **product-oriented business model**, a product is sold but with services added to it. The **use-oriented business models** imply that the company providing the product remains the owner of

[1] “Mobility-as-a-Service (MaaS) “describes a shift away from personally-owned modes of transportation and towards mobility provided as a service”. […] It is an emerging type of service that, through a joint digital channel enables users to plan, book, and pay for multiple types of mobility services (“Mobility as a Service” 2021)

the good that provides the service(s). Finally, in the **result-oriented business models**, the provider sells a result which, in theory, can be reached in the way that suits the provider (Tukker 2004)" (Moreau, Zeller, and Achten 2021). Car sharing is a use-oriented PSS: the car-sharing company that provides the service remains the owner of the good.

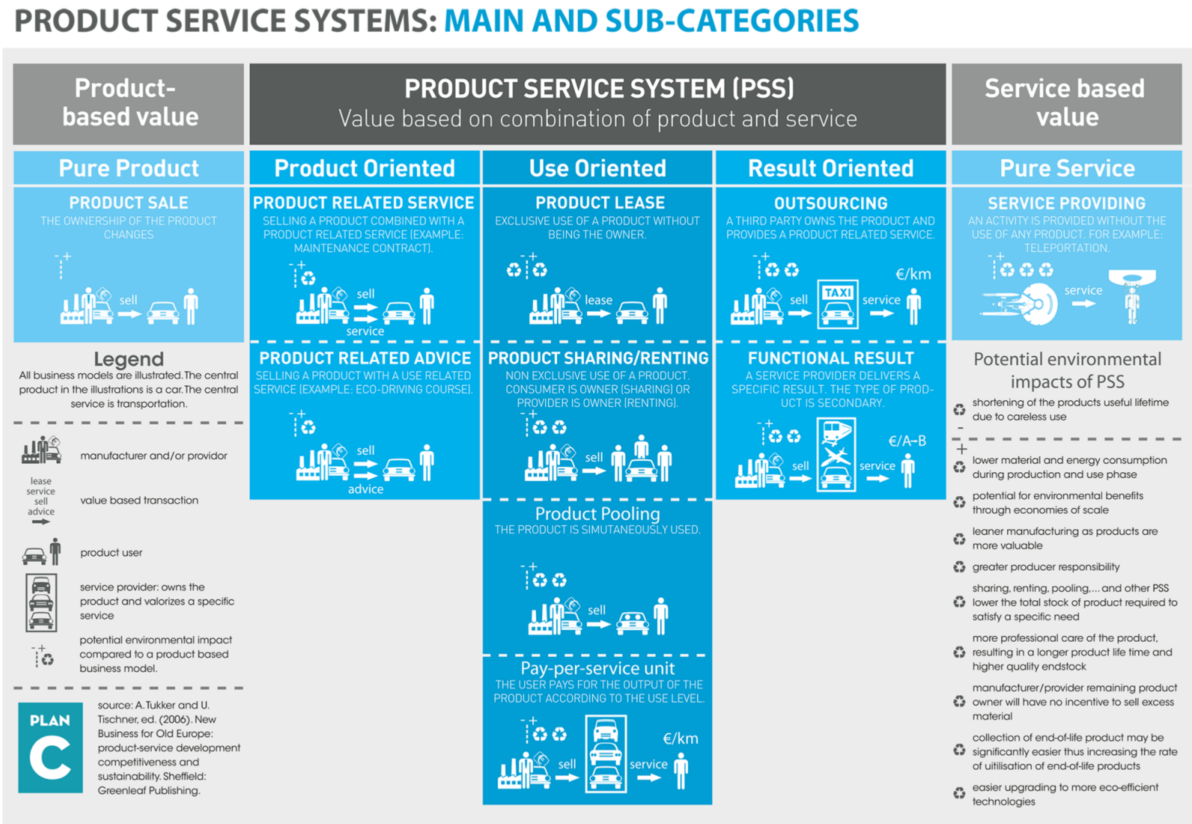

Figure 2: PSS: main and sub-categories (Tukker and Tischner 2006b), retrieved from (Roman 2020)

Among car sharing, there are different models: i) Peer to peer schemes (Degage, Getaround/ex Drivy); ii) Point to point station based systems (Cambio); iii) Free floating car sharing (Zen, Drivenow). In car sharing schemes, only the vehicle is shared, the vehicles remaining itself driven. At the opposite, in ride hailing (Uber) or ride sharing (Blablacar) schemes, both vehicles and drivers are shared (T&E 2017).

Car sharing is emerging as an alternative and sustainable travel mode supposed to replace private cars. This transport mode is expected to bring a number of environmental benefits, also because it would contribute to displace the dominant transport mode which is the ownership-based automotive regime.

1.3.3 Methodological approach

In this deliverable, we provide a comprehensive overview of the issues at stake regarding this exnovation case from the sustainability assessment perspective. Particularly, on the basis of desk research and literature review, we present and analyse the consumption patterns and relevant trends **(section 2)** as well as the sustainability issues and impacts relating to the case **(section 3).** In a concluding section, we recap and discuss the main results of this deliverable.

In the next section, we look at the trends and consumption behaviors relating to CE and the destabilization of the linear economy.

2. CE/CS consumption trends in the BCR: towards the destabilization of the linear economy?

In this section, we seek to **identify and analyze trends and consumption behaviours** with respect to the challenges of the exnovation of the linear economy as implied by the transition towards a reuse and sharing economy. This implies looking at the trends relating to the innovation (CE/car sharing) and to the object to be exnovated (linear economy/ownership-based automotive regime).

2.1. General CE/LE trends

2.1.1 The emergence and dissemination of CE

The flourishing of CE offerings in Brussels

With the support of the PREC, CE initiatives developed greatly in the last five years in the BCR. In two years (2016-2017), the program had financially supported 139 circular SMEs, so that the region "welcomes a large number of wide variety of small-scale circular activities", in comparison with the two other Belgian regions (Dufourmont et al. 2019, 22; Be Circular 2018).

The programme supports numerous sectors, with a predominance of projects relating to food and construction (Be Circular 2018), but CE offerings go beyond those two sectors and include e.g. clothing, small and IT equipment, mobility, with various business models, e.g. 3R (Repair, Reuse, Recycle) or Product services systems (Roman 2020; Belin and Hananel 2019).

It has to be noted however that in some sectors, the strong growth experienced those last years has fallen rapidly, as illustrated with the case of shared bikes and e-scooters (*BX1* 2020b). Also, CE initiatives are not always successful, as demonstrated with the Brussels leading figure of PSS Taleme (renting of clothes for children) which has gone bankrupt, or with free-floating car sharing providers which are not always profitable, or not on the whole Brussels territory (*L'Echo* 2019; *BX1* 2020, 1).

A trend that influences big players as well

CE offerings supported by the PREC are mainly local SMEs companies, but big players have started developing CE offerings as well, extending B2C and C2C circular economy market at least. In Belgium, existing big players of the linear economy start developing CE offerings in parallel to their linear offerings: this is the case of IKEA, selling second-hand furniture, Décathlon renting some of its products rather than selling it, or car manufacturers developing shared mobility offerings (Heinderyckx 2020; Bouchar 2021; Wells et al. 2020).

Food retailers in France also start developing CE offerings, with the selling of second-hand products: Leclerc started in 2018, and other main retailers followed the same path in the following years (Auchan, Carrefour, Cora, Système U) (Raffin 2020). While electrical retailers (Darty Fnac, Boulanger) entered the market a few years ago, clothes retailers just started entering the market (Gemo, Kiabi) (Chapuis 2020; Picard 2018).

The boosting role of e-commerce, resulting in a strong forecasted growth

Globally, the sales of marketplaces such as Vinted, Thredup, Facebook or Backmarket proposing second hand or refurbished products are surging: in this case, the rise of e-commerce boosts CE sales (Paquay 2020).

In fact, many CE practices developed with the support of the web, including sharing and resale activities (CREDOC 2014). Their sustainability impacts are however questioned, for their sustainability performance or for their impacts on demand (Nottet 2021; Kokabi 2020).

While second-hand offerings are not new on the market, those are currently experiencing a surge: "Currently estimated at $ 36 billion in 2021, the global second-hand market is expected to double over the next five years to $ 77 billion". The resale market could thus grow 11 times faster than the retail sector by 2025" (Thredup cited by RTBF Tendance avec AFP 2021). According to forecasts from Cross-Border Commerce Europe in the apparel sector, by 2025, the sale of second-hand items will be 1.5 times greater than that of fast fashion and will represent 13% of the average wardrobe (Paquay 2020).

A market that gains new consumers

More and more consumers buy second-hand products and their profile changes as well. In 2016, 40% of Belgian had bought second-hand products in the last 12 months; they were 68.8% in 2020 (Trends Tendances 2017; Gondola Academy and Bpost 2020). While the price was the main incentive to buy second-hand products a few years ago, ecological reasons are increasingly put forward, and the range of consumers buying second-hand products extends from vulnerable households to female, young and urban people that want to buy sustainable products (Gondola Academy and Bpost 2020).

As a first conclusion, some CE offerings seem to flourish at a regional level and beyond, but what does CE represent within the regional landscape?

Less than one tenth of Brussels economy would be circular

Beyond those exemplary CE initiatives, a large proportion of Brussels companies implement CE actions: according to a survey among them, 45.4% have implemented at least one CE action, such as reducing water, energy or resource consumption (Hub.brussels et al. 2018).

On the supply side, according to two recent studies from Fondation Roi Baudouin and the UNEP, "jobs related to the CE represent between 8.1% and 9.65% of the total number of jobs in the Brussels region" (Belin and Hananel 2019, 104). Following the estimates from Fondation Roi Baudouin, this is more than in Flanders (7.5%) or in Wallonia (6.8%), but this would be linked to the presence of headquarters of companies of the digital industry, whose jobs are considered as circular[2] (Dufourmont et al. 2019).

Around 58000 jobs would be circular in Brussels, with 38 % of those being in the digitalization, 7 % in the management of waste and resources, 6 % in repair and maintenance and 38% of jobs being created indirectly by CE (in retailing, public administrations and building sector) (Dufourmont et al. 2019).

Also, according to a recent calculation, the BCR is 7.7 % circular (when the trade of waste for treatment is considered[3]), which is more than in Flanders (6%), but less than in Wallonia (8.5%). In turn, the trade-corrected circularity gap index, which is the "portion of the unrecovered materials, in the total waste generated in that region, irrespective of where the waste treatment occurs", amounts 56.2%, the capital region performing equally to Wallonia (55.8%) but better than Flanders (62.1 %) (Towa, Zeller, and Achten 2021, 2). According to the study of the Brussels metabolism conducted in 2015, "the deposits of materials to be better recirculated in the territory are construction waste, metals, plastics and organic flows because they represent significant deposits and could recreate economic activity in the territory for part or all of the value chain (from production to use / consumption and reprocessing)" (Ecores sprl, ICEDD, and BATir (ULB) 2015).

Those figures make it possible to appreciate the importance and evolution of the circular economy, which seems to grow at least for some specific business models (e.g. second-hand, refurbishment, sharing), sectors (apparel, small equipment, electric devices, furniture) and markets (B2C, CT2). How does the regime or the linear economy react to those trends? What are the main trends in terms of resource use, waste production and treatment and resource productivity?

[2] Since jobs in the digital industry are considered as ('supporting') CE jobs since it supports the development of 'basic' CE jobs such as a jobs in renewable energies, recycling and repair sectors.

[3] This figure is the Trade-corrected circularity index that corresponds to "the portion of the recovered materials, in the total materials input, irrespective of where the recovery occurs" (Towa, Zeller, and Achten 2021, 2).

2.1.2 Are our economies becoming circular or is the linear regime getting destabilized?

When looking at macro indicators, the picture is less positive. At a global level, the circularity of the global economy would have decreased in two years, from 9.1 % to 8.6 % (CGRi 2021). And the material footprint per capita is increasing: "in 1990, some 8.1 tonnes of natural resources were used to satisfy a person's need, while in 2017, almost 12.2 tonnes of resources were extracted per person" (UNEP 2020). This increase also holds for high-income countries, which have seen their material footprint per capita increase by 2.7% (UNSD n.d.) (cf. Figure 3).

In addition, "there has been no decoupling of material footprint growth from either population growth or GDP growth, [since] the global material footprint is increasing at a faster rate than both population and economic output" (UNSD n.d.).

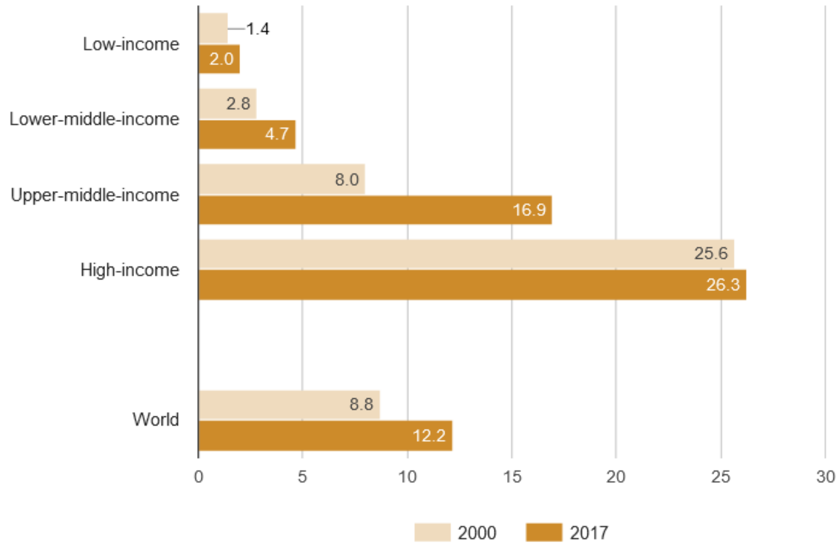

Figure 3: Material footprint per capita, 2000 and 2017 (metric tons per person) (UNSD n.d.)

In this section, we seek to identify the main trends at European, Belgian and when possible Brussels level.

Waste production and recycling

At the Belgian level, in terms of waste (production and recycling), there has been substantial improvements in the last 20 years, but those stagnate since 2015.

The volume of **municipal waste per capita** has been decreasing between 2007 and 2015. This decrease has been pushed by the trend occurring in Brussels, where the volume was almost halved since 2005. However, since 2015, the trend stagnates, municipal waste reaching 416 and 284 kilograms respectively in Belgium and in Brussels in 2019 (Federal Planning Bureau 2021b).

The **proportion of municipal recycled waste** stagnates at Belgian level since 2008, and reached 55% in 2019. In Brussels, this proportion has been substantially lower than in the two other regions but the trend has been upward until 2014, to reach and stagnate at the Walloon level since then (both regions position 20 points lower than the Flemish level, at around 40 %, against 60 % for Flanders). There is thus still scope for further improvement and "to achieve the sustainable development goal by 2030, this figure must increase" (Federal Planning Bureau 2021c).

Resource consumption

In terms of resource consumption, there is a lack of sound data to draw specific and precise conclusions. Indicators to assess resource consumption adequately are currently in development (cf. Box 1), and there is no data available at the Brussels level over time.

Box 1: How to measure resource consumption?

Definitions of indicators

To assess the evolution of resource consumption, the DMC indicator (or Domestic material consumption) has been mainly used until now. Abbreviated as DMC, it "measures the total amount of materials directly used by an economy and is defined as the annual quantity of raw materials extracted from the domestic territory, plus all physical imports minus all physical exports" (Eurostat n.d.).

This indicator might however not be the best suited and the emerging RMC indicator (or Raw material consumption) would be more relevant: the DMC does "not provide an entirely consistent picture of global material footprints because they record imports and exports in the actual weight of the traded goods when they cross country borders instead of the weight of materials extracted to produce them" (Eurostat 2020). Close to the material footprint, the RMC corresponds to the "annual quantity of raw materials extracted from domestic territory, plus all physical imports and minus all exports, both expressed in raw material equivalents" (EEA 2019, 81).

According to the Flemish CE policy research Center, the use of DMC is not adequate: *"Policy only based on the DMC indicator would have the risk of not focussing on the most important issues. Measuring resource productivity based on DMI or DMC alone does not give complete information of resource dependence and burden shifting, and as such can limit decision making. For example, growing specialization within regions will shift the burden of raw material extraction and thus the DMI and DMC indicator shifts with it. Exporting regions have increasing DMI and DMC values and importing (mostly developed) regions such as Flanders have decreasing values. Developed regions typically experience an increase in imports of semi-finished and finished products and a transition towards a service economy. This is reflected in a reduced DMI and DMC and makes these regions look more resource efficient, but they actually remain highly dependent on materials. The added value of the RMC and MF is that they reallocate the burden to the ultimate point of consumption, and as such both indicators are less affected by specialization trends (Wiedmann et al, 2015)"* (Christis and Vercalsteren 2020, 51–52).

What do figures say?

The RMC has been measured at a European level, at a Flemish level[4] and in a few other countries (EEA 2019). According to recent estimations from Eurostat, "EU imports in 2018 were 2.1 times higher when expressed in RME than imports recorded in EW-MFA. Exports were 3.1 times higher. The derived global material footprint, also referred to as raw material consumption (RMC), was 14.5 tonnes per capita in the EU in 2018 and 3.1 % higher than DMC" (Eurostat 2020).

Whether DMC and RMC follow similar trends depends on the trade profile of assessed areas. At a European level, the DMC and RMC curbs follow each other (Eurostat 2020). For Flanders, the picture is different: "the estimation of the indicators for Flanders shows a decreasing trend for the DMC-indicator between 2010-2018, while the RMC-indicator shows an increasing trend. It is assumed from the assessment that one reason for the increased gap between the DMC and RMC is the outsourcing of material intensive steps" (Christis and Vercalsteren 2020, 44). (cf. Figure 6).

Whether for the DMC or the RMC, there is no figures available at Brussels level to appreciate the evolution of resource consumption. At the Belgian level, only the DMC is available. The trend for **DMC per capita is "favourable" since 2000 at the Belgian level**, contrary to the trend at EU level, which is overall stagnating (cf. Figure 4). However, "to achieve the sustainable development goal by 2030, [the DMC per capital (of 10.7 tonnes per capita in 2019)] must [further] decrease" (Federal Planning Bureau 2021a).

[4] According to EEA, the Walloon region made the exercise as well, but we could not find those figures.

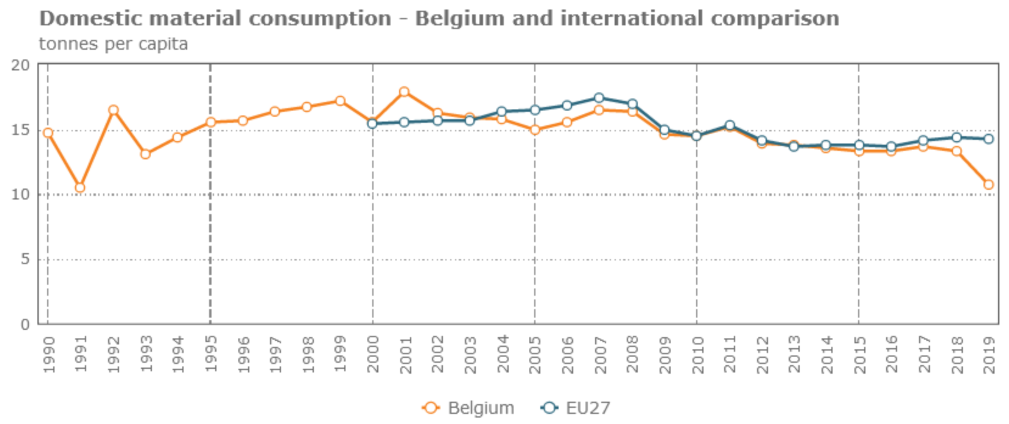

Figure 4: Domestic material consumption for Belgium and EU-27 (Federal Planning Bureau 2021a)

When looking at the DMC by material, the declining trend is mainly to be observed for fossil energy materials and non-metallic minerals (cf. Figure 5), both trends being also observed at an EU level (EEA 2019). According to the analysis from the European Environment Agency, the decline in non-metallic minerals "was mostly caused by the decline in the construction sector from 2007 onwards ». The decline in the use of fossil fuel would results from i) "a decrease in overall economic activity from 2008 onwards, resulting in lower consumption of energy; ii) a long-term trend in the EU of increasing the use of energy from renewable sources; iii) the improving overall energy efficiency of the economies" (EEA 2019, 20).

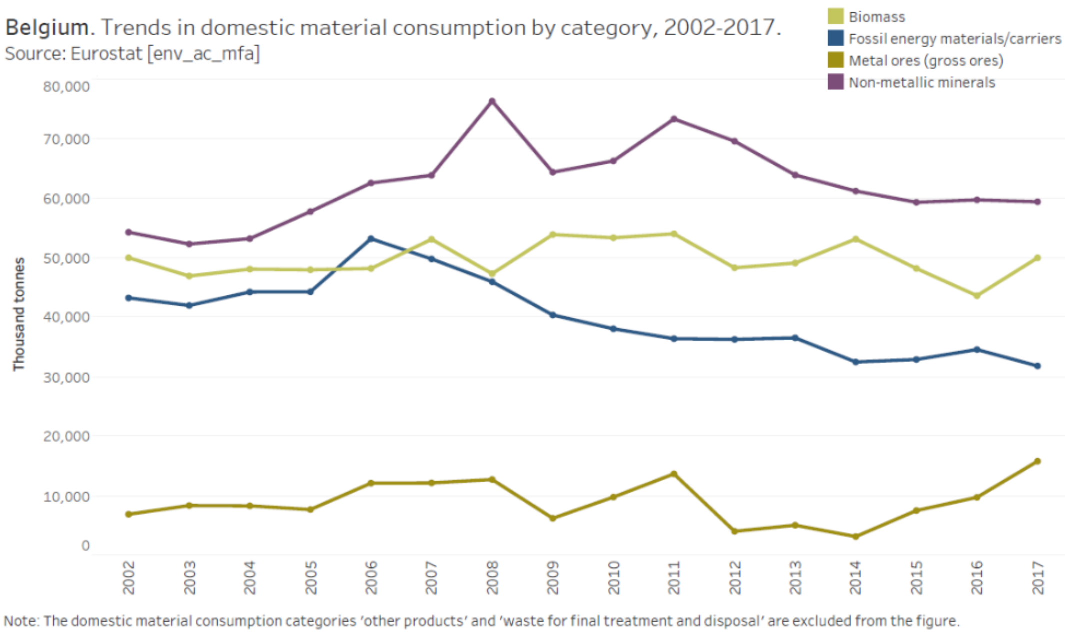

Figure 5: Trends in domestic material consumption by category, 2002-2017 (ETC/WMGE 2019)

When looking at the DMC, the picture is thus "favourable", but the decreasing trend is only partly attributable to the growth of the circular economy, given the role of the 2008 crisis. Also, it has to be kept in mind that a favourable DMC trend does not always mean a favourable RMC trend, as shown by the Flemish calculation (cf. Box 1 and Figure 6) (Christis and Vercalsteren 2020). Those results for the Flemish region cannot yet be extrapolated to the Brussels region given the major differences distinguishing both regions.

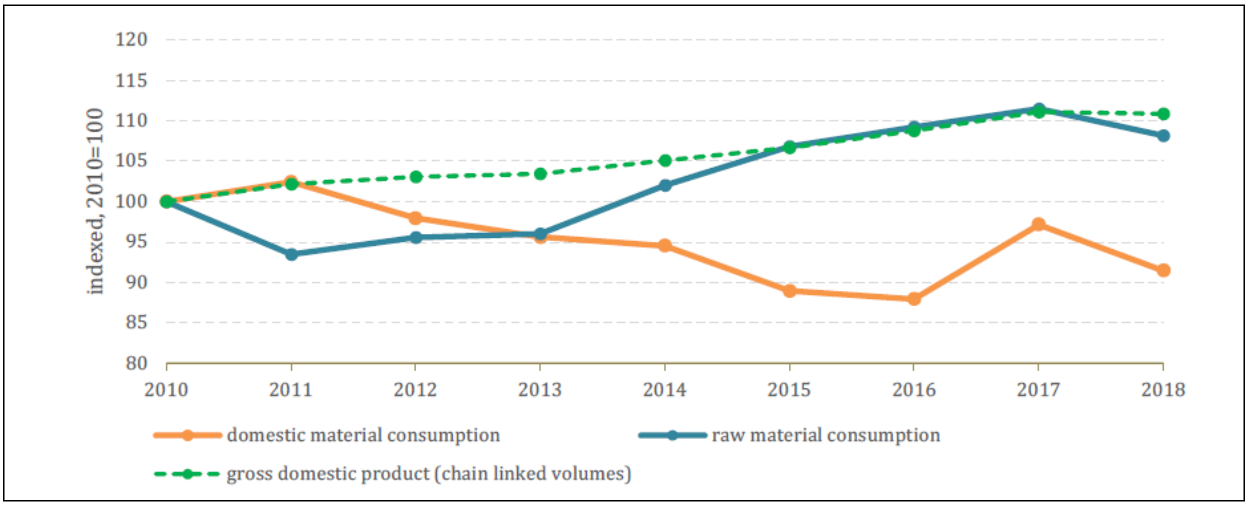

Figure 6: Domestic material consumption, raw material consumption (incl. the weighting average method) and gross domestic product (in chain linked volumes) of Flanders, indexed values (2010 = 100), 2010-2018 (Christis and Vercalsteren 2020, 44).

Resource productivity/circular use of material

At the Belgian level, for both the resource productivity (expressed as the relation between GDP and DMC) and the circular material use (showing the share of materials recovered and fed back into the economy in overall material use), trends are going upward (SPF SPSCAE 2020) (cf. Figure 7).

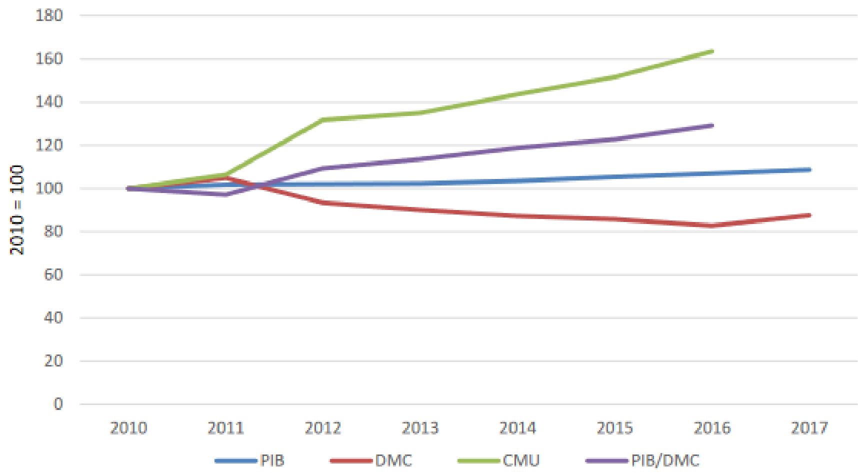

Figure 7: Resource efficiency (GDP/DMC), Domestic material consumption (DMC), Circular material use (CMU), source : Eurostat (SPF SPSCAE 2020)

At the EU level, the trend is similar for resource productivity (cf. Figure 8). However, again the EEA warns about the impact of the 2008 economic crisis and provides the following comment to Figure 8: "while this improvement is both welcome and impressive, at this stage it would not appear justified to attribute it entirely to the success of environmental policies. Other economic or technical factors may have played a role, including the changing structure of the economies, the way in which the economic crisis affected the economies, globalisation and increasing reliance on imports, and even the nature of the indicator itself" (EEA 2019, 25).

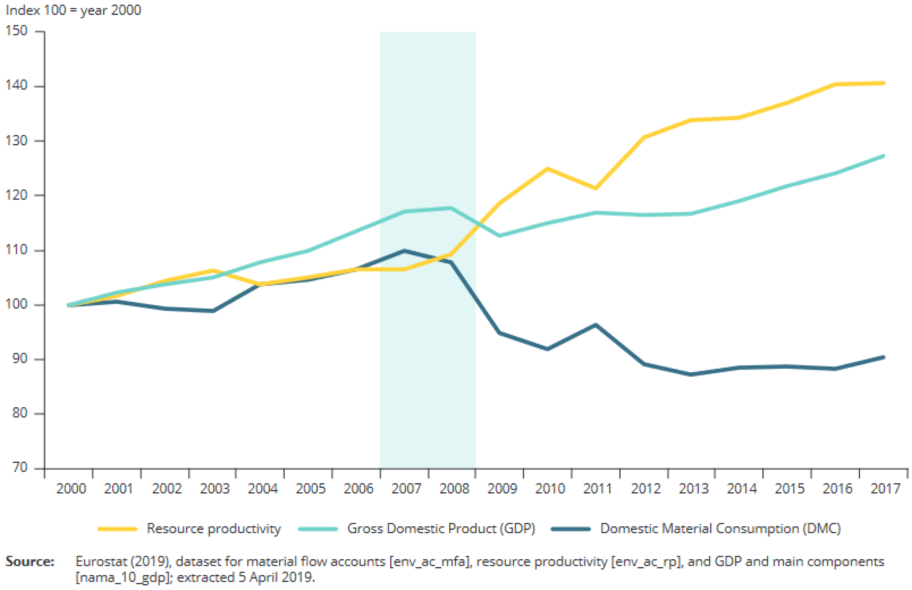

Figure 8: EU gross domestic product, domestic material consumption and resource productivity, 2000-2017 (year 2000 = 100) (EEA 2019, 25)

The circular material use (CMU) rate was calculated by material at the EU level. According to the EEA analysis, "the CMU rate in the EU is relatively low, but increased from 8.3 % to 11.7 % overall in the period 2004-2016. At 25 %, the CMU rate was highest for metals and metal ores, followed by non-metallic minerals at about 15 %" EU level (EEA 2019, 24) (cf. Figure 9).

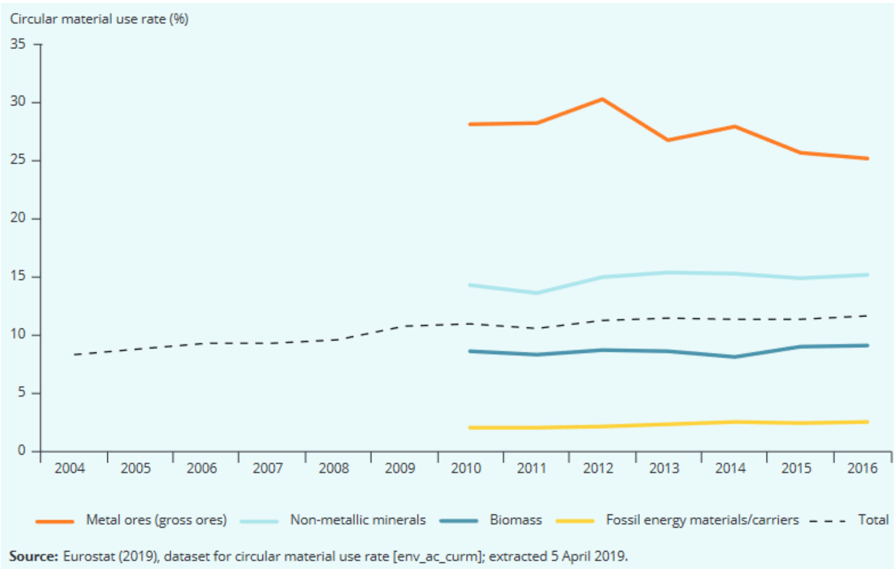

Figure 9: Circular material use rate in the EU, 2004-2016 (EEA 2019)

We can conclude that **it is uncertain whether the overall economy is turning into circular, at Brussels, Belgian and EU levels**. After significant improvements in the last decades, progress in terms of waste production and treatment stalled in the last 5 years in the BCR. In terms of material consumption, there is a lack of relevant figures at Brussels, Belgian and EU levels; existing calculations are judged not totally satisfactory. At the global level of high-income countries, the material footprint still increases. Even if some trends seem satisfactory at EU level, analysis from the EEA highlights the role of the 2008 economic crisis and other factors in those trends and does not claim victory regarding the ongoing transformation of our economies towards more circularity.

In a second subsection, we look more specifically at ongoing trends for the specific case of car sharing.

2.2 Trends relating to car sharing services in Brussels

2.2.1 The emergence of car sharing in Brussels

CE offerings develop in the mobility sector, with the rise of shared mobility or Mobility as a service (MaaS) (Nottet 2021; Lelievre 2021). This is especially the case for car sharing.

The presence of car sharing in Brussels

A recent article provides specific data on car sharing in Brussels, on the basis of a survey conducted among car-sharing operators and their members (Wiegmann, Keserü, and Macharis 2020, 2):

- "In 2017, five carsharing services were in operation in Brussels: Cambio, Ubeeqo and ZenCar provided station-based carsharing, with 670 cars in service in 218 stations and a total of 623 parking spots. The three providers had 13 688 active members who made 230 216 trips in 2017 (630,7 per day).
- DriveNow and Zipcar were the two free-floatin g providers active in Brussels in 2017: they offered 570 vehicles in a more restricted operational area which covered 45 % of the territory of the region and 70 % of the population. Combined, the FFCS operators had 12 300 members who made 334 073 trips (915 per day).

This study thus excludes peer-to-peer car sharing and their members. According to an estimation from the Vlaams Netwerk Autodelen, there would be around 104.000 car sharing members in Brussels (Beeckman 2019).

A strong growth, also forecasted

With the figures provided by Cambio, we can observe the rather steady growth of car sharing in the last 10 years in Brussels: the number of parking places dedicated to Cambio more than doubled (from 233 in 2010 to 571 in 2019) and the number of members increases by around 50% every five years (from 6222 in 2010 to 16384 in 2019) (IBSA n.d.). The predicted growth is even more impressive at a European level, with an increase of users by 600% between 2014 and 2020 (cf. Figure 10). PwC predicted in 2016 that the value of shared mobility services in Europe is estimated to grow from €5.1 billion in 2017, to € 100 billion by 2025 (T&E 2017).

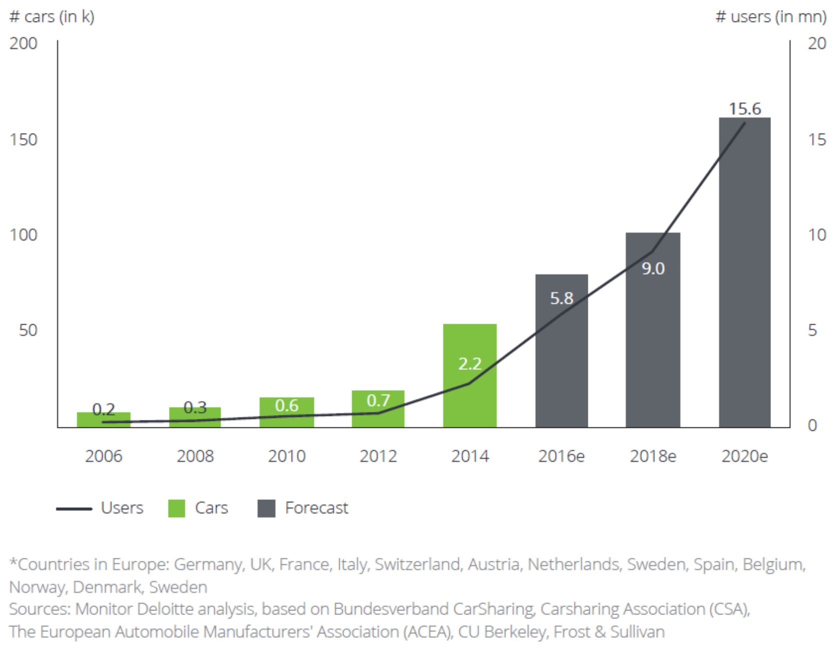

Figure 10: Car sharing market development for Europe (2006-2020) (Deloitte 2017)

Car sharing users

The car sharing innovation is not adopted equally by all types of households: "The average carsharing user is young, male and with a high level of education. This profile is even more pronounced in the case of free floating car sharing users:

- 37,7 % of station-based users and 50,8 % of free-floating users are between 26 and 39 years of age (only 33,8 % of Brussels Region residents above age 20 being in this age range).
- 27,3 % of station-based and 13,6 % of free-floating respondents are between the ages of 50 and 64 (in BCR overall, the proportion of people aged 50-64 is 21,3 %).
- Only 23,3 % of free floating users and 41,2% of station-based users are female.
- 69,4 % and 63,9 % of respectively free-floating and station-based users have university education (the share of BCR residents in 2018 between the ages of 25 and 64 who had attained higher education was 47,5 %).

Also, despite the strong growth experienced in the last years, car sharing is still a niche and sharing vehicles would represents 1-4 % of passenger-kilometers globally according to a 2017 study from McKinsey (T&E 2017). The phenomenon is also considered still marginal in Flanders, where less than 2% of driving licence holders share a car (Van Zeebroeck 2019, 31). In Brussels, car sharing seems however more important than in the rest of Belgium, with 104 000 users for around 1 million inhabitants that have the age of driving, and around 500 000 cars in the Brussels fleet (Beeckman 2019; FEBIAC 2020).

According to this review, car sharing is strongly growing, and is gaining ground especially in Brussels, but could it be at the expense of the ownership-based car use?

2.2.2 To which extent does it destabilize the automobility regime?

An uncertain impact of car sharing on car ownership

While car sharing is supposed to be an alternative to private car ownership and to reduce the fleet size, even the demand for new vehicles, the impacts on car ownership is uncertain. When looking at the evolution of the Brussels fleet size of individuals, we can observe that after a growth until 2016, the fleet size decreases since then (from 325,822 in 2016 to 316,664 in 2020 (FEBIAC 2020). However, the link between the growth of car sharing and the decrease in the fleet size cannot be established, since other factors could intervene.

When we look at the results of the survey conducted among the Brussels car sharing members (Wiegmann, Keserü, and Macharis 2020), car sharing has an effect on car ownership, though limited:

- "13,6 % of free-floating users and 33,1 % of station-based users claim that they had got rid of a vehicle since becoming a car sharing member.
- Half of them declare that they "would have considered [probably] buying a car (or an additional one) if the car sharing service was not available"
- For a minority of users, car sharing is a means of testing a car model before perhaps buying one depends very much on the operator" (Ibid, p. 4-5)

Car sales could increase due to an increase in car use

Even if car sharing has *in fine* an effect on car ownership, and reduces the vehicle stock, it is not certain that the automotive regime will be weakened. A study from the Boston Consulting Group had predicted a limited decrease in car sales due to car sharing by 2021 (Bert et al. 2016) and a similar study from PwC predicts even an increase in car sales by 2030, together with an increase in car sharing (one third of kilometres driven will be 'shared' globally), and a decrease in vehicle stock in Europe. Car sales will thus increase by one third to more than 24 million cars by 2030, because of the increase in personal mileage (+23 % in Europe) and increased use intensity, themselves reinforced by the rise in electric and self-driving cars (PwC 2018).

What is the impact of car sharing on the regime? Insights from Sustainability transitions studies

On the basis of available data for Brussels, it is difficult to conclude over a destabilization of the (ownership-based) automotive regime. Looking beyond Brussels and at Sustainability Transitions research, two recent studies investigate how car-sharing offerings impact their environment, including incumbents. Those two studies do not find evidence of a disruption or destabilization of the regime.

(Bocken et al. 2020) investigate how car-sharing initiatives have coevolved in four Swedish cities, with the use of the ecologies of business models' concept, which allows to analyse "how new business models influence existing ones through mechanisms such as competition, symbiosis and mutualism" (Ibid, p. 2). While car sharing is supported by the municipalities, the study "did not find evidence for the "breaking down" of dominant non-sharing business models". They also find that "carsharing is complementary to existing private car usage in cities, rather than a replacement" (Ibid, p.1).

(Wells et al. 2020) ask whether peer-to-peer car sharing, ride sharing and ride hailing schemes (Getaround, BlaBlaCar and Uber) "constitute a disruptive threat to the established automotive industry". They conclude that, "despite expectations that automobility-as-a-service, enabled by digital platforms, may erode the market for new cars and the existing model of individual car ownership, […] it is not necessarily disruptive to the incumbent automotive companies. Rather, network platform business models via automobility-as-a-service are argued to be one mechanism by which the primacy of the car may be retained" (Ibid, p. 1).

The studies point out several mechanisms. They argue that those schemes act to stimulate demand, it is thus "likely that more cars will be in circulation than in the absence of such systems". On one side, "it allows car owners (or prospective owners) to underwrite the cost of purchase in whole or in part (Smith, 2018)", and on the other side, "more intense use may result in cars being re-sold after a shorter period of initial ownership, and hence may support continued new car sales and the used car trade" (Ibid, p. 7).

Second, "peer-to-peer car sharing [would be] too small in scale to be disruptive to the industry" (Ibid, p. 5). This echoes with the findings of (Bocken et al. 2020) that carsharing is still rather a niche in the four Swedish cities, where car ownership is still on the rise.

Finally, car sharing is captured and controlled by the incumbents (car manufacturers, car renting companies). The automotive incumbents who use the peer-to-peer scheme as a route to market, as they used to do with the daily rental industry (Wells et al. 2020). In Sweden, the main car sharing provider is the one owned by incumbents (a car manufacturer and a renting company), who use car sharing to maintain their position (Bocken et al. 2020).

As for CE in general, there is no evidence that the ownership-based automotive regime is currently and will be destabilized by the emergence of car sharing.

In the next section, we review the sustainability impacts of this specific CE offering which is car sharing.

3. Sustainability impacts of the CE/CS: from initial promises to CE rebound

The main objective of use-oriented PSSs such as car sharing is to decrease environmental and resource impacts of manufacturing through the production volume of goods. As regards our case, the objective is to **decrease production volume of cars**. In addition, the following two consequences are expected:

- A **reduction of the fleet size** in the area (or of the stock) as well as of parking infrastructure needs and dedicated space needed on public roads.
- A **reduction of direct emissions** linked to travels in the area or to the use of the shared good (and other alternatives): car-sharing fleets are considered as less emitting than private cars and the use of cars should be reduced in the area, for the benefit of soft and public transport.

However, between initial objectives and effective results, there is sometimes a gap. In fact, every innovation (or policy supporting it) implies unintended side effects, in addition to effects supporting the primary objectives. Those effects, that can be positive or negative, could offset, at least partly, the environmental benefits expected by the diffusion of car sharing. Those are called **side, secondary, ripple, rebound effects** and include spill-over and transformational effects (Hertwich 2005). In the last years, the rebound effect (RE) concept becomes prominent, even if used by different disciplines and researchers with different meanings and contents (cf. Box 2). We distinguish two main types:

- RE linked to the re-spending effect, that is close to classical RE measured by energy economics;
- Other RE that are captured by the 'Environmental rebound effect' concept coined by (Font Vivanco et al. 2016) (from Industrial ecology) including those linked to the substitution effect.

Effects of car sharing are numerous and complex, as showed by Figure 11, which is a causal loop diagram mapping the various causalities between car sharing services and their environment.

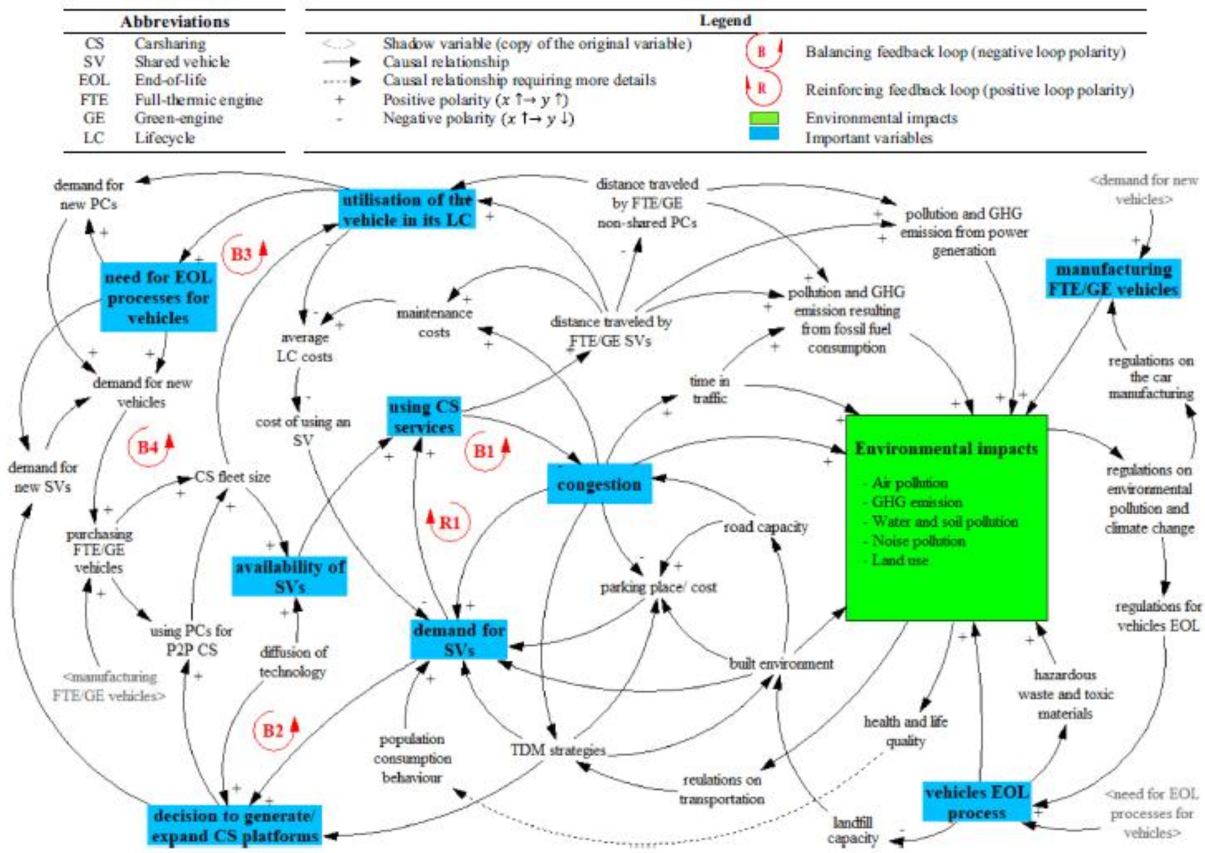

Figure 11: Causal loop diagram to illustrate the map of causalities between carsharing services and environment (Shams Esfandabadi et al. 2020)

On the basis of our review of studies assessing the sustainability impacts of car sharing, we identified and classified the main variables and mechanism that come into play. Those are summarized in Table 1. Those effects are likely **to affect both the environment and the economy** (through the demand for goods and services, economic activity and related jobs). We distinguish two main types:

- Those linked to the **technical characteristics or performances** of the shared car itself, i.e. how much environmental impacts are generated by one kilometer traveled by one person with car sharing in comparison with one kilometer travelled with a private car, whatever user behavior (supply-side variables). To those technical characteristics, we add other **organizational characteristics** of car sharing that may have socioeconomic and societal implications (3.1);
- Those linked to the effects **on mobility behaviors and demand**, i.e. effects on car ownership, on car-use and on modal shift (demand-side variables) (3.2);

Among the various side effects of car sharing, several authors investigated specific effects that are the **classical rebound effects** linked to price or income (re-spending rebound effects) (3.3).

Box 2: (Environmental) rebound effects (RE)

The concept of RE has been originally used in **energy economics** as an effect encompassing "both the behavioral and systems responses to cost reductions of energy services as a result of energy efficiency measures" (Hertwich 2005, 85). RE include both **direct and indirect effects**: in the former case, cost reductions resulting from energy savings are spent in increased consumption of the same product or service, and in the latter case in increased consumption of other products and services[5]. As a result of the effect, "the environmental benefits of eco-efficiency measures are **lower than anticipated (rebound) or even negative (backfire)"** (Hertwich 2005).

(Hertwich 2005) who comes from Industrial ecology propose **to go beyond the energy efficiency focus**, and to include effects of other (environmental) measures. (Font Vivanco et al. 2016) propose the concept of Environmental Rebound Effect (ERE) as the "environmental consequences from changes in demand in response to efficiency changes from technical improvement" (Ibid p. 61).

In this review, we use a definition of RE which is in line with the industrial ecology approach and partly with the ERE concept (our definition goes beyond the ERE definition since it include also non-technological changes, e.g. organizational changes/innovations), that is "when a household adjusts to the introduction of a sustainable consumption program, it may adopt accompanying activities with greater environmental impacts" (Hertwich, 2005) cited by (Briceno et al. 2005). It may include effects linked to price or income (re-spending effect), but also others, such as substitution effects (cf. Figure 12).

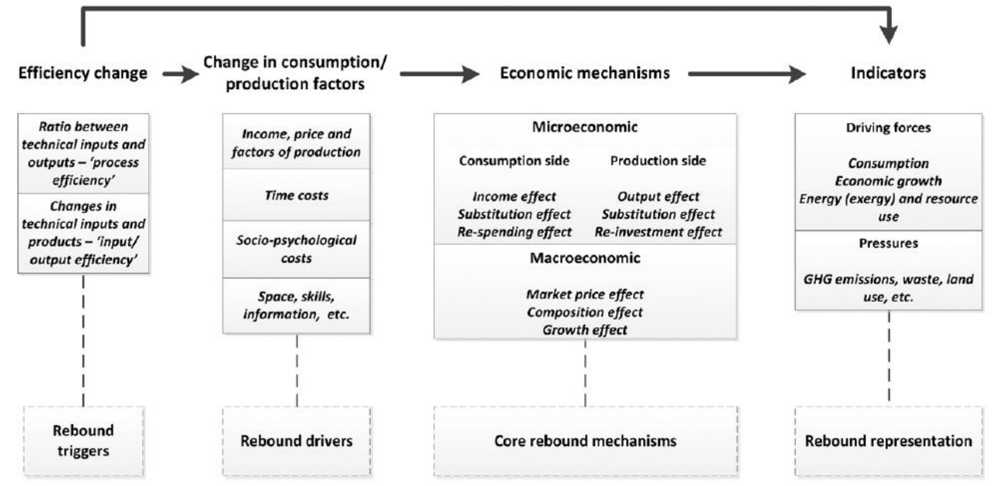

Figure 12: General framework for the study of ERE (Font Vivanco et al. 2016, 66)

[5] E.g. a household reduce less than expected its emissions resulting from the retrofit of its house because it uses the generated savings for other carbon-intensive activities (e.g. more heating (direct), or more travels (indirect)).

Table 1: Overview of the identified variables affecting sustainability impacts of car sharing

Variables	Mechanisms	Affected impact categories
(3.1.1) Variables influencing environmental impacts on the supply side, on the basis of (Rademaekers et al. 2018; Chen and Kockelman 2016; Chapman, Eyckmans, and Van Acker 2020)		
Intensity level of use of cars/ Functional lifetime of vehicles	(+) Increase in mileage due to higher use intensity (-) Automobile lifetime shift effect since shared cars could have a lower lifetime, leading to an unintended preservation of the manufacturing rates (Amatuni et al. 2020)	-Environmental impacts related to the manufacturing of vehicles and to land-use -Economic activity of car manufacturers and services and corresponding jobs
Vehicle age/ fuel efficiency	(+) Shared cars tend to be more recent and thus fuel efficient than private cars because of their faster replacement rate (as a result of their higher utilization rates). They also tend to be smaller and to have electric engines. (-) Less-fuel efficient shared cars are then sold into the second-hand market.	-Environmental impacts related to the use of vehicles (e.g. GHG and air pollutant emissions from fuel production and combustion)
(3.2) Variables influencing environmental impacts on the demand side, on the basis of (Rademaekers et al. 2018; Chen and Kockelman 2016; Chapman, Eyckmans, and Van Acker 2020)		
Evolution of vehicle ownership/ of fleet size	(+) Decrease in vehicle ownership for car owners or *cannibalization effect* (Ke, Chai, and Cheng 2019) (-) Increase in the total number of vehicles since customers who originally do not own cars may *expand the market* through their membership to car sharing (Ke, Chai, and Cheng 2019, 12471)	- Environmental impacts linked to the manufacture of vehicles (resource and material use, GHG and pollutant emissions) - Economic activity of car manufacturers and services and corresponding jobs; - Parking infrastructure demand/use of space (because of impacts on the fleet size);
Influence on other modes of transport/ modal shift effect	(+) Increase in use of soft and public modes by car owners (-) Decrease in travelled km in soft or public modes by car-less people (*modal shift effect)*	- Environmental impacts related to the use of transport modes and to their life cycle more generally - Impacts on traffic, congestion and safety on road
Evolution of car use/ Vehicle kilometers travelled	(+) Decrease by car owners (-) Increase by car-less drivers *(car-use effect)*	-Environmental impacts related to the use of vehicles (e.g. GHG and air pollutant emissions from fuel production and combustion) -Social: Traffic and congestion, accidents & Increase or upkeep of access to vehicles, including for formerly carless households, resulting in increased access to goods and services, including that fulfil primary needs
(3.3) Other effects		
Indirect rebound effects	Increase in the consumption of other (polluting) goods given increased available budget freed by lower car sharing costs	Various environmental impacts

3.1 Impacts from the characteristics of car sharing

3.1.1 Impacts from technical characteristics of vehicles or supply-side variables

Main claims

Sharing economy initiatives are developed in order to increase the use of underutilised goods/physical assets. Private vehicles are one of those underutilised goods; they typically stand idle for around 95% of the time, and occupy a large share of urban public space (Shaheen, Cohen, and Farrar 2019). Contrary to traditional car leasing or renting, vehicles can be used potentially by several users in a single day. It thus facilitates temporary access to vehicles for its users, without owning those vehicles.

Through this mechanism, shared cars drive more than private cars, car sharing would thus **increase the use intensity of vehicles** so that the environmental impacts linked to the manufacturing of vehicles are distributed on a larger number of kilometers.

Whereas the use intensity of shared vehicles decreases production-related impacts, the **age of shared vehicles** decreases use-related impacts: the age of shared vehicles is generally lower than the age of private cars and thus more fuel efficient, this rendering the use of car sharing less impacting than the use of private vehicles. Also, shared cars are usually smaller (and thus less energy consuming) and often have electric engines (and thus less emitting during the use phase).

Those variables and other side-effects on the supply side as identified or assessed by reviewed studies are summarized in lines 3.1.1 of Table 1 (together with other variables).

How does car sharing perform compared with other transport modes? Result from a LCA study

A study conducted for the EC DG Environment (Rademaekers et al. 2018) compares the impacts of one person-km according to different collaborative economy transport models, including car sharing[6], and with traditional car transport and the traditional transport mix at EU level (which is currently dominated by passenger cars (67% of persons-km)). The infrastructure (production, maintenance and end of life of vehicles and roads) and the energy use and direct emissions during operation are considered in the assessment.

According to the assessment, differences between shared and traditional cars locate at the levels of:

- **The intensity level of use of cars/functional lifetime**: in carsharing systems, cars are shared, not simultaneously, but potentially by several users in a single day[7]. This should lead to fewer cars being needed to be produced. This implies that:
    - **the service life** (in km) is expected to be higher than average cars: the distance driven is estimated to be at least 50% higher, i.e. corresponding to 225000 km, as opposed to 150000 km for traditional cars)). Due to the more intensive use of the cars, a lower use of road infrastructure per km driven is assumed (17 times lower).
    - **the average occupancy** rate of the shared vehicle is however considered to be equal to the rate of traditional cars (1.6 persons per car) since vehicles are not shared simultaneously.
- **The age of cars/fuel efficiency of vehicles:** in the assessment, shared cars are EURO 6 cars.

The assessment finds indeed that “the current environmental impact of travelling with collaborative economy transport is generally smaller than or equal to travelling with the traditional transport mix[8]”, but smaller when comparing to traditional car transport (cf. Figure 13).

[6] And other business models of the so-called collaborative economy: ride-sharing and ride-hailing.
[7] (Ke, Chai, and Cheng 2019) refer to this as the pooling effect.
[8] Only for resource depletion, the impact of car sharing is larger than the impact of traditional car transport.

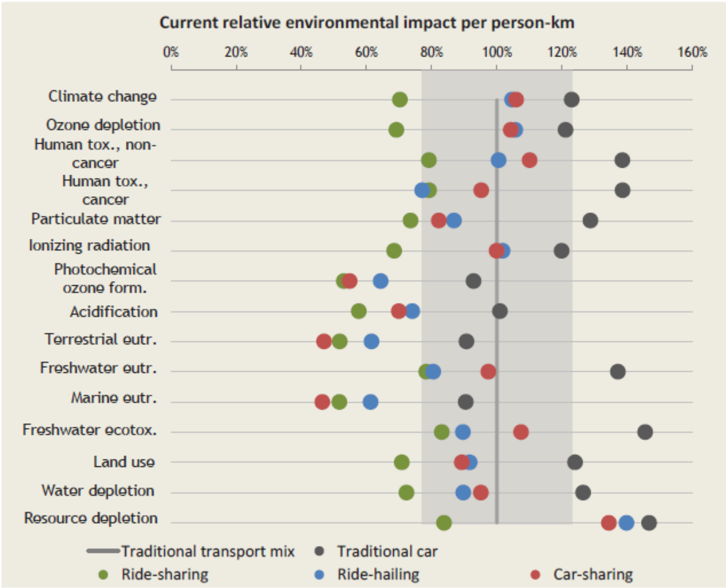

Figure 13: Comparative environmental profile of collaborative economy transport models (Rademaekers et al. 2018). The grey zone represents the uncertainty/insignificance interval

Impacts for which there is a large difference with traditional cars logically include (cf. Figure 14):

- Human toxicity, freshwater euthophication and ecotoxicity, resulting from car production for a large part (whose impacts are distributed within a higher number of kilometers);
- Particulate matter, terrestrial and marine eutrophication (resulting from the emission of nitrogen oxide for the two latter's), which are generated during the use phase in a smaller extent by the recent car sharing fleet (Rademaekers et al. 2018).

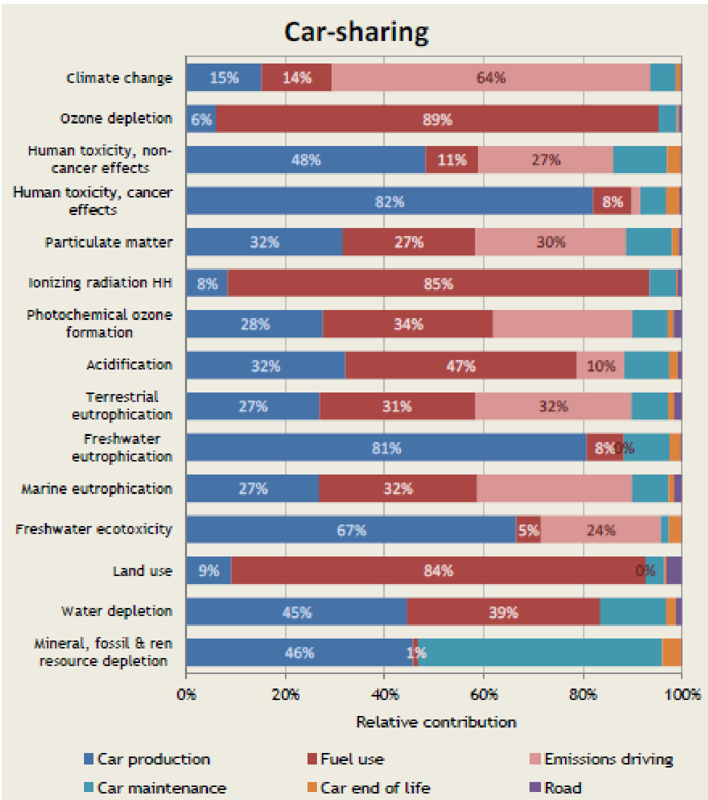

Figure 14: Contribution of the different factors to the environmental impact of car-sharing

Other side effects

Other similar assessments (that focus generally only on climate impacts) also concur with the finding that car sharing decreases environmental impacts of individual mobility. However, **assumptions generally differ on vehicle lifetime or fuel efficiency**, that render the comparison difficult (Neef, Dettmer, and Schebek 2019) (cf. Table 8 in Annex). Regarding use intensity/lifetime, (Nurhadi et al. 2017, 345) find for example that car sharing "reduces emissions by 20-40% (g CO2e/km/person) compared with Regular Purchase cars", using a vehicle lifetime only 15 % higher for shared cars (against +50% in the study of (Rademaekers et al. 2018)).

But for this latter variable, not only the extent, but also the direction of the effect is discussed: (Amatuni et al. 2020) introduces the "**automobile lifetime shift effect**, i.e. an unintended preservation of the manufacturing rates after changes in resource access patterns (sharing) caused by changing intensities of usage", which is referred to as an "effect which has been rarely addressed in previous studies". Whereas the mileage/functional lifetime of shared cars is longer, the lifetime might be shorter given the more intensive use, "with faster wear and tear and replacement", this leading to a higher than expected need of vehicles to be produced. In their study, they distinguish the lifetime (in years) and the mileage (in km) and use scenarios that vary according to those two variables, given the lack of existing related data. They conclude that, "even though the total reduction is not significantly sensitive to the proposed Lifetime mileage scenarios, introducing this parameter into the assessment by itself restricts the positive manufacturing impacts claimed by the previous studies" (Amatuni et al. 2020, 7).

For **fuel efficiency**, examples of different assumptions or findings are also found in Table 8 in Annex. At the same time, as highlighted by (Amatuni et al. 2020), "shared vehicles are usually sold into the second-hand market and continue their lives as regular personal cars". Even if shared cars might perform better than private cars on this particular aspect, overall, the overall fuel efficiency of the total fleet is not improved, since the less fuel-efficient vehicles continue functioning on the traditional market.

3.1.2 (Socioeconomic) impacts from organizational characteristics of car sharing

In addition to those technical characteristics, car sharing differs from traditional car ownership on organizational aspects. In Table 2, we list those characteristics as identified or assessed in the literature (Van Zeebroeck 2019; Rademaekers et al. 2018; Wittstock and Teuteberg 2019). Some of those have been identified through the external arena workshop of case 1 (the future of the LEZ), in which participants identified effects linked to the realization of a scenario where private individual vehicles are exnovated (Sureau, Fossati, and Dootalieva 2021). Characteristics locate at the level of (car sharing) companies and of households. Cited studies identify those characteristics but do not provide a detailed analysis or quantification of those, with in-depth case studies.

Table 2: List of other social and socioeconomic impacts as identified and/or assessed by literature

Effects	Results	References and geography
Companies		
Profitability/competitiveness	Reduction of inefficiencies, reduction of dependence on subsidies, customisation But risk of failure: High investment industry, high level of fixed capital, low level of individual brand recognition, change of internal processes	(Wittstock and Teuteberg 2019)
Political control of the applied technologies	Lack of control over power technology development, data security, legal control function	(Wittstock and Teuteberg 2019)
Risk of monopolization	High investment industry, high level of fixed capital, monopolization risks, fraudulent competition	(Wittstock and Teuteberg 2019)

Jobs quantity	"[...] car-sharing activities hardly produce any employment, apart from some jobs at headquarters of the platforms". Decrease in the number of jobs in the automotive industry and increase in the number of jobs in enterprises of the shared mobility	(Sureau, Fossati, and Dootalieva 2021; Rademaekers et al. 2018)
Jobs quality	Increase in unstable jobs in the platform economy (e.g. juicers) and risk that working conditions are leveled down because of the platform economy	(Sureau, Fossati, and Dootalieva 2021; Rademaekers et al. 2018).
Households		
Accessibility of transport services	Increased access to transport services, through the provision of (shared) cars for carless households, but risk that some people are excluded (because car sharing companies are private companies, because of the use of digitalization)	(Van Zeebroeck 2019), (Sureau, Fossati, and Dootalieva 2021).
Social inclusion	Peer to peer schemes reinforce social relations and contacts, but effectively limited to educated people	(Van Zeebroeck 2019)
Savings in transport expenses, and increase in disposable income. Note: rebound effects risks (2.3)	Savings compared to owning a car (given the many costs of driving such as depreciation, insurance, parking, tax, fuel and maintenance which are inclusive in the price of a car-sharing rental). Savings in the range of EUR 300-1,500, depending on the average distance travelled (Bundesverband CarSharing, 2017)	(Rademaekers et al. 2018)

3.2 Impacts from consumption behaviours or demand-side variables

Beyond those variables acting on the supply side of shared cars, there are also variables acting on the demand side, at the level of user's behaviors, as listed by the review of (Chen and Kockelman 2016): *"First, **vehicle "ownership"** (in terms of vehicles per person) generally falls with car sharing membership, offering environmental benefits from vehicle production and parking infrastructure savings. Second, car sharing has impacts on vehicle-kilometers **and vehicle utilization rates** (and thereby fleet replacement rates), which tends to reduce fuel consumption (as well as, arguably, road infrastructure needs, though this potential savings is generally not assessed). Lastly, car sharing **shifts many trips** previously carried out by private automobile to transit and non-motorized modes (as well as some trips previously carried out by non-auto modes to shared cars)."* (Chen and Kockelman 2016, 277).

3.2.1 Effects on car ownership and vehicle quantity

Main claim

Also called **cannibalization effect** (Ke, Chai, and Cheng 2019), the reduction in car ownership happens when car sharing members sell or scrap one or more of their car(s) or give up buying a new one, resulting in lower demand and manufacture of cars. This should result in a i) smaller fleet size circulating in the area where car sharing is implemented and in ii) the decrease in the number of produced vehicles, both parameters involving sustainability impacts.

Related impacts

The cannibalization and market expansion effects both act on the i) fleet size and on the ii) number of produced vehicles.

Environmental impacts

If the number of produced vehicles decreases, main environmental impacts linked to the production or manufacturing life cycle phase will decrease accordingly: Human toxicity, freshwater euthophication and ecotoxicity (cf. Figure 14).

Socioeconomic impacts

Also, depending on the extent of the ownership effect, economic activity of the car industry will be affected, with potential job losses. According to a study by the Boston Consulting Group (2017) that calculated "the number of private car purchases that will be displaced by car-sharing in 2021[9], and the number of cars that will be needed for the car-sharing fleet (assuming that car-sharing vehicles will be replaced every months)", […] car-sharing fleet sales will correspond to about one third of forgone private car sales. According to this study, in Europe there would be 96,000 fleet sales and 278,000 forgone private sales, i.e. a net loss of 182,000 car sales. This corresponds to EUR 2.1 billion in net lost revenues" (Rademaekers et al. 2018, 258).

On the other side, the economic activity of car sharing companies should be affected positively, and a shift from jobs in the industry (vehicle manufacturing) to jobs in services (maintenance and provision of shared cars) is likely to happen.

Territorial impacts

Whereas the impacts on the number of produced vehicles are uncertain, it is more certain that the reduced ownership will reduce the fleet size, this resulting in lower parking infrastructure demand and use of space in cities.

Extent of the cannibalization effect

While all studies find that car sharing reduces car ownership overall, there is a great variation between estimates: depending on studies, one shared car would replace 3 to 8 private vehicles. Another finding is that the impacts on car ownership is greater for roundtrip car sharing than for free-floating:

- Free-floating car sharing reduces ownership by [4.7-23]%
- Roundtrip Car sharing reduces car ownership by [23.6-67]%.

According to a recent study of car sharing in Flanders (including Brussels) (Carmen et al. 2019; Chapman, Eyckmans, and Van Acker 2020), existing studies might overestimate the impacts of car sharing on car ownership (and this would have implications for the estimation of impacts on car use, see Table 3). In fact, it is difficult "to distinguish between users who have fewer cars because of car-sharing and those who join car-sharing because they own fewer cars" (case of reverse causality) (Chapman, Eyckmans, and Van Acker 2020, 8). Yet, "by ignoring this, results will be positively biased, showing a greater effect of car-sharing than is the case in reality" (Carmen et al. 2019, 13). To overcome this methodological challenge, the study uses "self-assessed counterfactual sensitive to the strength of causality" and find that due to car-sharing, between 12.6 and 69.3% of car-sharing users reduce their car-ownership, depending on the level of confidence in the self-assessed counterfactual[10] (Chapman, Eyckmans, and Van Acker 2020, 8).

Other side effects

At the opposite of the cannibalization effect, (Ke, Chai, and Cheng 2019) identified the **market expansion effect**: users who originally do not own cars may expand the market through their membership to car sharing, this resulting in an increase in the total number of vehicles. Given those two opposite trends, they find that "*introduction of car sharing does not always reduce the total number of vehicles. Specifically, the optimal production volume becomes less in the car-sharing market if and only if the transportation need and producing cost are below some thresholds, and the market size is larger than a threshold. Otherwise the manufacturer has an incentive to produce more vehicles for a larger profit. The intuition is that the higher transportation need implies a weaker pooling effect which makes the market expansion effect dominate the cannibalization effect and therefore increases the vehicle quantity. When the market size is small, to attain the same service level, the manufacturer must provide more shared cars to each user, which increases the equilibrium production volume. In addition, a higher producing cost drives the retail price and sharing fee up, which decreases the total*

[9] In the case there would be 14 million car-sharing users by 2021.

[10] Users where asked to rate on a Likert scale whether they would have changed their ownership if they would not have used car sharing.

market demand. Just as the same way as how the market size influences the vehicle quantity, the increased producing cost makes the total number of vehicles become larger" (Ke, Chai, and Cheng 2019, 12462).

As discussed above the effects of car sharing on car ownership are uncertain. As argued by (Carmen et al. 2019, 15), "private cars are likely to be replaced less often than shared cars because of their lower use intensity. An elementary calculation can thus show that, unless car-sharing reduces car-use or increases car longevity (i.e. the total distance travelled in the car during its lifetime), then the number of cars produced will not be affected at the aggregate". According to those authors, environmental benefits of car sharing depends **on the extent to which it affects mobility behaviors**, an aspect which is often neglected by existing car sharing studies (Carmen et al. 2019, 13).

3.2.2 Effects on mobility behaviors

Car sharing can affect mobility behaviors through two manners: by affecting the modal shift, and by affecting car use. According to reviewed studies, the way that car sharing affects mobility behaviors varies according to car sharing users, and namely on **whether they are owner of one or more car(s)** before their membership and on **whether car sharing affects their car ownership**. As illustrated inTable 3, for users who reduce their car ownership with car sharing and have thus a lower access to cars (i.e. car owners who get rid of one of their cars or carless drivers who would have bought a car had they not been members of car-sharing), car sharing travels replace the travels with their former private car or with the car they would have bought (3rd column). It is also likely the use of public or soft transport is higher than without car sharing membership, this resulting in a decrease in car use overall (4th column). At the opposite, drivers who previously did not own a car and who used to travel with public or soft transport modes are likely to use car sharing instead for some or all of their travels (3rd column). It is also possible that those drivers travel more because of the easier access they have to a car with car sharing (4th column). This effect of increased car-use regards also car owners who use car sharing as an additional transport mode and who do not abandon their car or one of their car(s) (those users being together users with higher access to cars).

Thus looking at the impacts of car sharing on mobility behaviors means looking at i) what it replaces (as transport mode) and at ii) whether it increases mobility demand (whether the innovation increase the demand, or is a mere replacement). Whether car sharing generates environmental benefits depends on the share of those two types of drivers among car sharing users, and also on the extent of the described effects.

Table 3: Differentiated effects of car sharing on mobility behaviors according to user types, adapted from (Chapman, Eyckmans, and Van Acker 2020, 8) and (Carmen et al. 2019, 88)

Car sharing users	**Impact on vehicle ownership**	**Impact on mobility behaviors**	
		What does it replace? Modal shift effect	**Influence on car use**
Car owners that have one less car because of car sharing (and carless drivers who did not buy a car because of car sharing) or lower access users	Car-sharing causes users to have less cars	Car sharing replace(s) private cars. Public and soft transport likely replace private cars as well.	Decrease in car ownership results in an increase in car-use (direct effect) due to higher access and to a decrease in car-use (indirect effect) due to a lower access
Carless drivers that would not have bought a car without car-sharing (and car owners who do not change their car-ownership because of car sharing) or higher access users	No effect on vehicle ownership	Car sharing replaces public or soft transport modes and/or adds travels. Likely decrease in public or soft transport use	Increase in car-use (direct effect only) due to higher access

Related impacts

Through the modal shift and the car-use effects, it is mainly the *environmental impacts* related to the use of transport modes, including motorized vehicles (e.g. GHG and air pollutant emissions from fuel production and combustion) which are targeted.

Regarding *economic aspects*, a modal shift from private car use to the use of other soft, public and shared transport could impact the economic activity, profitability and jobs of the sector. Companies of the life cycle of soft, public and shared transport would be affected positively, while companies of the life cycle of private vehicles would be affected negatively. A reduction in car-use would affect companies supplying fuel and energy for cars particularly.

Regarding *social aspects*, a decreased use of vehicles could reduce traffic and congestion. On the other side, an increased access to vehicles, including for carless households could result in an increased access to goods and services, including those fulfilling primary needs.

Modal shift effect

Several studies have sought to consider the car-use effect to assess the impacts of car sharing, but less have sought to consider the modal shift effect (Amatuni et al. 2020).

The effect illustrated with a study on shared e-scooters

Beyond the car sharing example, the importance of the previous transport mode for the sustainability impacts of an innovation such as car sharing can be illustrated with the results of a case study assessing the environmental impacts of shared e-scooters (Moreau et al. 2020). To do so, it compares the sustainability performance of the shared e-scooter with the performance of the mode of transportation that it displaces, i.e. in this case a mix of modes of transportation, including public transport, car, walking and bicycle (Table 4). Authors find out that the use of the e-scooter generate more environmental impacts (GWP, fine particulate matter formation, and mineral resource scarcity) than the modes of transportation it displaces, except for fossil resource scarcity (Figure 15).

Table 4: Mode of transportation displaced by the use of dockless e-scooters (Moreau et al. 2020)

Mode of Transportation Displaced	Dockless Users n = 757
Public transportation	29.2%
Car	26.7%
Walking	26.1%
Bicycle	14.2%
Electric bicycle	1.5%
Additional trips	1.8%
Other	0.1%
Motorcycle	0.4%

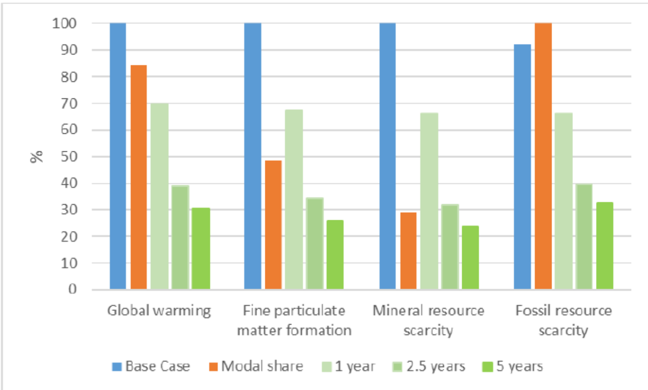

Figure 15: Comparison of impacts from the displaced modal share with the e-scooter (base case). including different lifetime scenarios. Unit: % of the most impactful

According to the study, "the high results for the shared e-scooter, in terms of GWP, are mainly caused by the short lifespan of the shared e-scooter" (Moreau et al. 2020, 1). However, this study shows that sustainability impacts of an innovation depends on its sustainability performance compared to other transport modes (e.g. private cars), but also for a large part on which transport modes it replaces, or the transport mode that was previously used by travelers.

Thus, in order to decrease the environmental impacts generated by the e-scooter use, one could act on the lifespan (to increase lifespan), but also on the targeted users, so that e-scooters replace mainly car drivers, rather than walkers, cyclists or users of public transport, i.e. so that the exnovation shift generate environmental benefits by targeting the right users. Acting on targeted users could be done by dissuading walkers and cyclist not to operate a modal shift or by inciting car drivers not to use their cars/not to own cars.

The modal shift effect assessed: what do studies say about what car sharing replaces?

As summarized in Table 9 in Annex, existing studies find **diverging results** regarding the modal shift effect of car sharing. Two studies about car sharing in Belgium and in the Netherlands highlight the positive effects on modal shift, car sharing increasing the use of soft and public transport (Meijkamp (1998) and Ryden and Morin (2005) cited by (Rademaekers et al. 2018). However, more recent studies moderate those findings: in Germany, for car owners, no significant changes in the modal split is observed, and for carless drivers, biking decreased (Gsell et al. (2015) cited by (Rademaekers et al. 2018). A study conducted in Paris distinguishes the effect of roundtrip carsharing (overall positive for public and soft transport) and of free-floating car sharing (overall negative, for public transport and bike use (6T-Bureau De Recherche (2014), cited by (Shaheen, Cohen, and Farrar 2019).

In Belgium, two recent surveys conducted towards car sharing members in Flanders and Brussels (both from private operators and Peer to peer schemes) and car sharing members in Brussels (private operators only) (Wiegmann, Keserü, and Macharis 2020) suggest **rather negative or neutral modal shift**. The Flemish survey reports that “70% of car-sharing users joined car-sharing because it is faster than public transport, suggesting that for some members, car-sharing could substitute for public transport” (Carmen et al. 2019, 1). The Brussels survey reports that “the majority (61,9 % free-floating and 71,5 % station-based) of carsharing users state that their frequency of public transport use remained unchanged since becoming a member. Among the users who experienced a change, free-floating users report a tendency to use public transport less often than before, whereas station-based users report a weak tendency to use it more often” (Wiegmann, Keserü, and Macharis 2020, 7).

Car-use effect

The effect on car-use is calculated by estimating the change in kilometers travelled by users since their car sharing membership, which is composed of two opposing trends. First, a decrease in car-use by some users ((former) car owners): this effect is one primary objective of car sharing. It can be explained by the fact that, “as the user pays for access rather than ownership, they are incentivized to decrease the number of uses (Junnila, Ottelin, and Leinikka 2018). Secondly, an increase in car-use by some other users (carless drivers), this effect being considered as a side effect, i.e. an effect that is secondary to the one intended that is unintended.

The car-use effect assessed: what do studies say about what car sharing replaces?

Existing studies find that on average, car sharing reduce car-use, meaning that the reduction in car use by (former) car owners is larger than the increase in car-use by carless drivers (Chapman, Eyckmans, and Van Acker 2020, 3). However, as for the ownership effect, decreases in car-use vary greatly, from 11% (calculated in Paris) to 72 % (calculated in Switzerland) (cf. Table 9 in Annex).

The extent of each effect depends on the number of users by type and on the difference in kilometers travelled by the two types of users. A study conducted in the US found that even if “the number of car-sharing users that increased their kilometers travelled by car was greater than those that reduced their in car kilometer”, […] at the aggregate, car sharing resulted in fewer km driven by car (and less emissions) due to the size of the effect: the decrease in km travelled by car per person because of car-sharing was much larger than the increase in km travelled for the other group without a car” (Martin and Shaheen (2011) cited by (Carmen et al. 2019, 15).

Some authors argue that some of the studies might overestimate the positive car-use effect, since those “are based on directly asking users how their behavior has changed, rather than using methods more appropriate for quantitative impact evaluation, that is, quasi-experimental methods” (Chapman, Eyckmans, and Van Acker 2020, 1–2). Addressing this methodological issue, the study conducted on car sharing in Flanders (including Brussels) finds a reduction of car-use by 54 km per user per week (assuming that car-sharing has a large effect on car-ownership), to an increase by 24 km (assuming that car-sharing does not have a large effect on car ownership). More precisely, the study finds that for (former) car owners, a decrease in car use between 54.3 and 93.8 km is observed, while for carless drivers or those who do not change car ownership, an increase in car use between 31.5 and 35.6 km is observed. The study concludes that "there is a danger that car-sharing adds to environmental pressures if it is used as an additional form of mobility, rather than as a replacement for private car ownership" (Carmen et al. 2019, 1).

Policy implications

> *"On the evidence of this report, car-sharing could help to reduce the environmental impacts associated with mobility, but only under certain conditions. There is a danger that car-sharing adds to environmental pressures if it is used as an additional form of mobility, rather than as a replacement for private car ownership. Thus, in order to maximise the environmental benefits of car-sharing, and to minimise the risk of increasing environmental burdens, car-sharing should only be encouraged at the expense of car ownership".* (Carmen et al. 2019, 1)

Concretely, if car sharing is promoted to reduce car ownership (so that the fleet size is reduced as well as car use indirectly), one should be aware first that a decrease in car ownership is not automatic, and that through the market expansion effect (that makes the fleet increases with the membership of carless drivers) the effect on the fleet size is uncertain. Secondly, one should be aware that it generates other (unintended) impacts, such as an increase in car use by some users, and a decrease in public and soft transport.

Thus, the policy supporting innovation/niche cultivation policy should not be implemented alone, but together with policies discouraging i) car ownership and ii) car use.

Also, the same authors argue that the cost of car sharing to consumers should not be reduced, otherwise modal shift and car-use side effects will be increased:

> "*There is little evidence that reducing the cost of car-sharing for users will have environmental benefits. Evidence from those who already use carsharing show that 91% do so because it is cheaper than owning and using a private car […]. Moreover, of those who are not-sharing, cost was the least important barrier […]. Reducing the cost of car-sharing to consumers will lead to a greater risk of increasing car-use, at the expense of public transport and cycling. Thus, policy should avoid subsidies, both for firms and consumers, whether in the form of direct cash transfers, refunds, or beneficial tax treatment. »* (Carmen et al. 2019, 1)

What do studies find in terms of car sharing sustainability impacts

Considering the car-use effect

The study of (Chen and Kockelman 2016) which is a meta-analysis and which is based on previous assessments (by combining and averaging existing results) (Amatuni et al. 2020, 6) finds that with car sharing membership in the US, energy use and GHG emissions can be reduced by 33 to 70 %, and by 51 % in the most likely scenario. The assessment considers "cradle-to-grave impacts of carsharing on vehicle ownership levels, travel distances, fleet fuel economy (partly due to faster turnover), parking demand (and associated infrastructure), and alternative modes" and concludes that the most important contributor to carsharing's lowered impacts is avoided travel and travel shifted to non-auto modes" (Chen and Kockelman 2016, 281).

The study of (Carmen et al. 2019, 102) on the impacts of car sharing in Flanders that use quasi-experimental methods to better consider the car-use effect finds more nuanced results. In the best case scenario, car sharing leads to environmental benefits in 97.5% of simulations (average reduction of 1064kg of CO_2eq. emissions from cars per week), while in the middle scenario, it leads to environmental benefits in only 30.7% of simulations (average increase of 238kg of CO_2eq. emissions).

"These results show that the environmental impacts of car-sharing are very sensitive to the effect of car-sharing on car-ownership. The impacts of those whose car-ownership is not affected by car-sharing [carless drivers and car owner who do not reduce their number of car] are large and may offset those who have fewer cars because of car-sharing [carless drivers who would have bought a car in the absence of car sharing and car owner who would have an additional car in the absence of car sharing]." (Carmen et al. 2019, 97).

Considering the modal shift effect

(Amatuni et al. 2020) nuance as well the environmental benefits of car sharing by including the distance-based modal shift effect (as well as the lifetime effect, cf. 3.1.1) in a study of Nijland and van Meerkerk (2017) about the impacts of car sharing in the Netherlands: "a total annual decrease in 150-219 kg of CO2-eq is estimated (depending on scenarios based on the lifetime and mileage of carsharing vehicles), 186 kg of CO2-eq for the unchanged (middle) scenario. This translates into a 7-10% reduction of the total annual mobility-related emissions because of CS participation." It concludes that "while the reduction in private driving is the strongest single contributor to the change in total emissions (_823 kg CO2-eq), emissions caused by an increase in CS driving and other modes moderate the total change significantly" (cf. Table 5 and Figure 16).

Table 5: Estimation of the total 'before' and 'after' annual distances travelled by car-sharing members (Amatuni et al. 2020)

	Before CS (km)	After CS (km)	Emissions (g CO_2-eq per-PKT)
CS	*0*	*1850*	210–247
Car	*9220*	*5610*	228
Train	1431	3069	101
Bus	140	299	187
Bicycle	105	225	20
Carpooling	35	75	144
Other	70	150	75
Total	11000	11278	

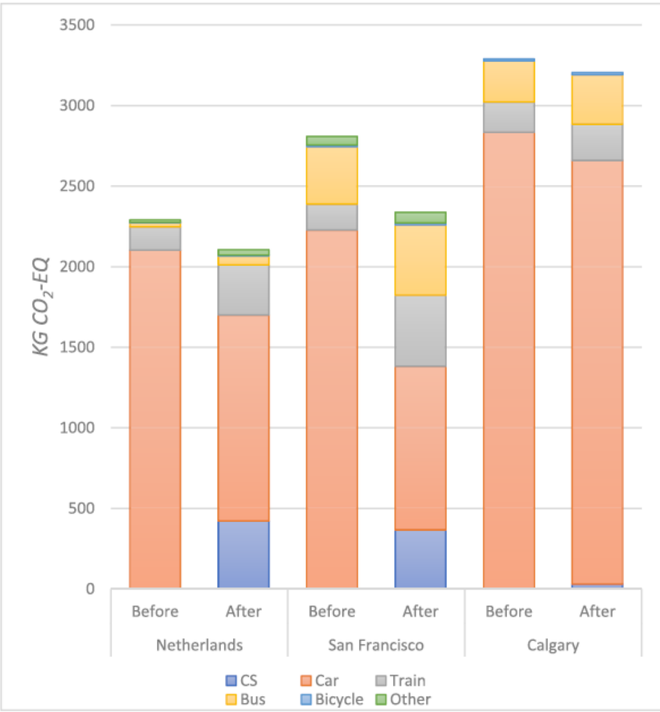

Figure 16: Effects of CS on total mobility-related GHG emissions (before-and-after analysis) (Amatuni et al. 2020)

3.3 Impacts from re-spending rebound effects

In addition to those effects from technical characteristics and mobility behaviors (that can be positive or negative), reviewed studies highlight the presence of rebound effects that could partly offset the benefits generated by car sharing.

Authors generally differentiate between direct and indirect rebound effects. In the case of car sharing, **only indirect RE** are identified, i.e. effects from savings due to car sharing on the consumption of other products and services. Indeed, savings due to car sharing would result generally in decreased car-use (because of the less easy access to cars) rather than in increased car use (that would result from lower cost of car sharing per driven kilometre) (cf. Table 10 in Annex).

Overall, studies seeking to assess RE from car sharing find variable rebound effects. Additionally, they agree on the risk that reduced car ownership through car sharing membership leads to increased air travels (Briceno et al. 2005; Junnila et al. 2018; Ottelin et al. 2017).

This is the main finding of (Briceno et al. 2005) who propose a methodology that uses "LCA and Input-output analysis (IOA) in combination with consumer expenditure information […] to evaluate sustainable consumption programs at a broad level », such as car-sharing (Ibid, p. 13). With the use of scenarios, the study finds that "the way the rebound expenditure is spent makes a large difference to the overall environmental impacts. If the households marginal expenditure is spread uniformly across non-transport items the overall environmental impacts of different transportation choices only has small changes. However, if the marginal expenditure is spent on air travel, then the rebound emissions can negate any environmental savings of a transport choices » (Ibid, p. 1).

(Ottelin et al. 2017) compare the carbon footprints of car owners and car-free households with otherwise similar characteristics and discover that "while the average rebound for reduced driving is low, the average rebound for giving up car ownership and driving entirely is quite high. This means that reduced driving reduces emissions effectively but the effect of giving up car ownership is not always as effective, and in some cases even leads to backfire", mainly because of holiday travels (Ibid, p. 12). Resulting policy implications of the study are the following:

- "Policy measures should be directed even more strongly towards car use instead of car ownership, and towards highly energy-efficient cars or cars using alternative low-carbon power technologies" (Ibid, p. 12).
- To reduce driving, distance to be driven or travelled should be reduced through urban planning, and "daily service providers, such as schools and local grocery stores, should be located near to residents, and walking and cycling supported by planning" (Ibid, p. 13).
- "Policies aiming at reduced driving must be coupled with policies aiming at reduced flying" (ibid, p. 14).

(Junnila et al. 2018) compare the carbon and material footprints of two kinds of households according to their level of ownership, defined by their ownership of a dwelling, heating system (district heating considered as shared heating), and car. They found that the "reduced ownership does not automatically reduce the environmental impact of the production–consumption system in the context of households, partly because of rebound effects, with households spending the money saved from reduced ownership on carbon-intensive services", such as vacation travel.

(Font Vivanco et al. 2015) put the RE of car sharing schemes in perspective with those of seven innovations in the transport sector. According to the study, car sharing schemes generate backfire (135 % of RE), which are particularly high RE in comparison with previous studies. Regarding other innovations, "while the studied transport innovations generally present better environmental profiles than their alternatives, […] the applied micro-to-macro model showed that environmental pressures would actually have increased in most cases due to the introduction and diffusion of the innovations, mostly because of the ERE. Only those innovations in which the change in **transport costs is negligible or positive (bound income)** show decreases in environmental pressures. In these cases, the ERE does not outweigh the technology improvements or even enhances them. Based on these results, it can be concluded that claims of environmental superiority of the seven alleged eco-innovations studied are only supported in their actual economic functioning in three cases: catalytic converters, direct fuel injection systems and Park and Ride facilities" (p 83).

3.4 From car sharing to CE sustainability impacts

3.4.1 CE rebound or how the CE makes the pie grow

As a conclusion to this section, in addition to effects supporting the primary objectives of car sharing, there are many side- and rebound effects that could offset the expected environmental benefits. We have used car sharing as an example of a CE offering in the specific transport sector. Is the presence of those effects specific to car sharing or can it be generalized to other CE business models and sectors?

(Zink and Geyer 2017) found that CE generates specific side effects, coined as **Circular economy rebound (CER)** and paralleling the energy efficiency rebound. Similarly, some researchers in Industrial ecology started investigating so-called **Environmental Rebound Effects (ERE) of circular offerings** (Makov and Font Vivanco 2018) which share most of the CER characteristics (Warmington-Lundström and Laurenti 2020). Focusing on reuse, remanufacturing and recycling offerings, both streams argue that the expected benefits of CE may be counteracted by specific side effects (called CER or ERE). The effects mentioned by those researchers echo with the side effects identified and assessed by the research on sustainability impacts of car sharing, and we argue that those could be named CER as well.

Two mechanisms would play a role for CER: "re-spending effects from price reductions and/or by failing to effectively compete with primary production (imperfect substitution)", this preventing that a displacement of linear products by circular products occurs on a 1:1 basis (Zink and Geyer, 2017) cited by (Makov and Font Vivanco 2018, 2). The first effect corresponds to direct and indirect rebound effects contemplated by energy economics researchers (cf. 3.3) (1st and 2nd lines of Table 6), while the **imperfect substitution effect or the insufficient substituability** is part of the ERE conceptual framework (Font Vivanco et al. 2016) (cf. last line of Table 6). It is unclear whether it is specific to CE innovations.

Table 6: Comparison of rebound mechanisms contemplated in industrial ecology (ERE and CER) and energy economics perspective, adapted from (Warmington-Lundström and Laurenti 2020, 2)

Definition/ scope	Energy economics (e.g. Jenkins et al., 2011)	ERE (Font Vivanco et al., 2016)	CER (Zink and Geyer, 2017)
Improvements in efficiency increases the use of the same product or service.	Direct rebound	Not contemplated	Price effects
Net gains and savings increase the demand for other goods and services.	Indirect rebound/ secondary effects	Re-spending effect	Price effects
Increase in energy efficiency on overall demand after markets adjust and re-equilibrate.	Macroeconomic effects	Not contemplated	Broader circular economy rebound
Ability to substitute primary production	Not contemplated	Imperfect substitution effect	Insufficient substitutability

Those effects would regard certain CE activities. As shown in Figure 17, "the net environmental impact of CE activities depends on their **combined effects on production impacts and production quantities**. Activities in Q2 will always increase net environmental impact, whereas activities in Q4 will always decrease net environmental impact. Activities in Q3 may not decrease primary production activities enough in order to reduce overall environmental impact and thus suffer from [a] shortfall. Activities in Q1 also have the potential to reduce overall environmental impact, but experience CE rebound" […], meaning that "increases in production or consumption efficiency are offset by increased levels of production and consumption" (Zink and Geyer 2017, 596).

Many recycling and refurbishment activities would have lower production impacts than the related primary production but are likely to increase total production and consumption (Q1), whereas realistic examples for Q4 would be « difficult to find » (Zink and Geyer 2017, 597).

		Change in production impacts	
		$e_r < e_p$	$e_r > e_p$
Change in production quantities	$\Delta Prod > 0$	**Q1: Circular Economy Rebound** Video on demand, recycling, service-based floor covering, recoverable rocketry, refurbished phones	**Q2: Higher net impact**
	$\Delta Prod \leq 0$	**Q4: Lower net impact** Smartphone parking meter Product lifetime extension (*ceteris paribus*)	**Q3: Potential shortfall** Reusable bottle Reusable grocery bag

Figure 17: Framework of potential environmental outcomes of CE activities based on changes production quantities and differences in production impacts (Zink and Geyer 2017)

Note: *er* and *ep* being the environmental impact of producing one unit of secondary and primary material, respectively, Prod=production quantities.

The imperfect substitution effect can be illustrated with **examples identified by researchers** and listed in Table 7. According to our review, only the substitution effect linked to the reuse of smartphone has been quantified: the overall ERE (including price and imperfect substitution effects) would range from 35 % to backfire effects (Makov and Font Vivanco 2018). A recent study investigated the CER of boat sharing, looking for the imperfect substitution effect and at whether boat sharing displaces boats to be manufactured, and at activities substituted by the sharing options. We add to this list the side effects of car sharing identified and assessed by sustainability assessment researchers, including:

- <u>At the manufacturing level</u>: the extent of the cannibalization effect is discussed (not all car sharing users get rid of a private car and shared cars could be replaced more quickly than private cars, since those are used more intensively) and it would be mitigated by the market expansion effect, through previously carless drivers that start using cars.
- <u>At the use level:</u> to which extent does car sharing replace the use of private car or of public and soft transport (the modal shift effect) and to which extent does the increase in car use by some users mitigate the decrease in car use by some other users (the car-use effect). This effect originates in the fact that car sharing improves access to cars: users that would use shared cars as a replacement of public and soft transport (whether previous car owners or not) or that would travel more than before, this resulting in an increase in car use.

Table 7: Examples of CER/ERE for CE activities stemming from the imperfect substitution effect

CE business model	Mechanism	Reference
Second-hand/ reused products sales	Partial displacement is possible in reuse cases, and in some instances, secondhand markets may actually increase demand for new goods. Whether used products will displace new products depends on consumers' value perceptions of secondhand goods.	Thomas (2003) cited by (Zink and Geyer 2017)
	While sales of used products should cannibalize sales of new ones, such displacement would be likely limited: reuse may stimulate new production, for example by allowing consumers to sell their older products and use the earnings toward the purchase of new units. Thus the production of new units is only partly displaced by CE products and the overall production increases.	Various, cited by (Makov and Font Vivanco 2018, 2).
Reuse and recycling	A lack of displacement/substitution can be the result of the inferior quality of secondary goods (e.g. recycled plastics and paper)	(Geyer and Doctori Blass, 2010 cited by Siderius and Poldner 2021)

	When a new market is opened up due to the vastly different price at which the new good is being sold (e.g. refurbished smartphone).	(Makov and Font Vivanco 2018) cited by Siderius and Poldner 2021)
	Displacement of new smartphones by refurbished ones is likely to be low given that refurbished phones are typically sold in developing countries where the alternative is no phone at all.	(Geyer and Doctori Blass, 2010; Zink et al., 2014; Cooper and Gutowski, 2017) cited by (Makov and Font Vivanco 2018)
Recycling	Increased recycling may fail to displace virgin material of the same kind if there is no market willing or able to absorb the increased material; the material may instead displace recycled material from other sources, resulting in increased landfilling and/or incineration.	Ekvall and Finnveden (2001) cited by (Zink and Geyer 2017)
	Recycled material can also displace completely different types of material, or no material at all.	Ekvall and Weidema (2004) cited by (Zink and Geyer 2017)
Virtualization/digitalization	Video-on-demand (=virtualization of media delivery) often has lower per-use impacts than physical video delivery, but has also increased consumption of video content	(Walgrove 2015) cited by (Zink and Geyer 2017)
Sharing	The lease of a boat via a sharing economy platform does not necessarily equate to one less boat being manufactured. Investigation of the types of consumption activities substituted by the sharing option.	(Warmington-Lundström and Laurenti 2020)
	Market expansion effect of car sharing, mitigating reduced car production volumes from the cannibalization effect. Increase in car use and decrease in public and soft transport for some car sharing users, mitigating the related expected benefits.	(Ke et al. 2019; Amatuni et al. 2020; Chapman et al. 2020)

3.4.2 What can be done to counter CER?

Such effects could have social and socioeconomic benefits (when the increased supply satisfies a specific demand, e.g. from vulnerable households or low-income countries, or the increased economic activity from rebound effects compensate for the decreased economic activity from e.g. the decreased demand for new vehicles) and suit economic interests (because the economic growth paradigm is not questioned). However, those effect are also likely to increase overall environmental burdens, and to negate the expected benefits of the CE (Zink and Geyer 2017; Makov and Font Vivanco 2018).

In order to avoid the CER, (Zink and Geyer 2017) provide three conditions to minimize CER:

- "Firstly, products and/or materials from secondary production need to be presented as **true alternatives for primary production**, with comparable quality, price and marketing efforts. If a product from secondary production cannot seriously compete with its primary alternative, meaningful substitution – as well as the accompanying environmental benefits - will likely not occur.
- Secondly, circular substitutes should, at least, **have no effect on the total demand**, or decrease total demand for the given good on the macro scale. Therefore, markets with a somewhat satiable demand or low-price sensitivity would be less vulnerable to rebound effects (e.g. home appliances would be more satiable than clothing or electronics).
- Thirdly, even in the case that the first two conditions are met, it needs to be made sure that introducing a new product from secondary production to the **market indeed diverts buyers away from primary production**. This is especially difficult since the usual methods to draw consumers (searching niche markets or lowering prices) should not be used to ensure the environmental benefits by avoiding CER" (Siderius and Poldner 2021, 4).

Thus, the focus should not be on simply improving efficiency at an individual level, but also on causing displacement of what the CE offering should substitute. (Makov and Font Vivanco 2018, 8–9) advise to implement taxes that internalize environmental externalities into the prices. Coming back to the car sharing example, (Carmen et al. 2019, 1) advise that "car-sharing should only be encouraged at the expense of car ownership", in order to minimise the risk of increasing environmental burdens. In addition, reducing the cost of car sharing, including through subsidies should be avoided, so that the risk of increasing car-use, at the expense of public transport and cycling is minimized.

Briefly, those authors advise policies constraining the demand for linear offerings rather than policies supporting circular offerings, as a way to minimize side effects of CE.

Conclusions

In this deliverable, we seek to reply to two research questions, in order to understand *in fine* how we can assess the sustainability impacts of exiting the linear economy:

- How does CE interact with the existing consumption and production modes?
- What are the sustainability impacts of CE initiatives?

We used car sharing as an example of a CE offering to illustrate the issues at stake, and we sought to generalize our findings to CE in general, whenever possible.

Behind the development and support of car sharing, there are many expectations in terms of territorial and environmental impacts (reduction in the fleet size, in the number of demanded vehicles, in car use, increase in the use of public and soft transport modes), one of the condition of the realization of those benefits being that car sharing destabilize the (ownership-based) automotive regime.

Despite a strong growth of car sharing in the last 15 years, there is no evidence of such destabilization, on the basis of the few existing studies on the issue. There is thus a question mark over the environmental benefits of the current development of car sharing. Similarly, on the basis of existing figures regarding the evolution of our economies towards more circularity, it is also not possible to state that the emergence of CE models does destabilize the linear economy.

A main issue with car sharing is the generation of detrimental side effects, arising especially from the non-targeted users, i.e. carless individuals. Those effects can be assimilated with CE rebound (Zink and Geyer 2017), which arises from the 'imperfect substitution effects' of the CE offering with the product it should displace and the so-called 'induction effects', through which additional consumption is induced.

Therefore there is a high risk that policies supporting car sharing (e.g. when car sharing is subsidized) do not reduce the fleet size as expected (because of the market expansion effect) and that car use increases (Chapman, Eyckmans, and Van Acker 2020). The risk in the BCR is high, where car ownership is low and where there is a high share of carless individuals.

Those side effects add to classical rebound effects, which arise when the savings generated by the innovation/energy-saving technology is spent on carbon-intensive consumption. For car sharing, there is a high risk that the savings pass on to travels by plane for leisure, as highlighted by our review.

The results of this review of key trends and impacts of car sharing would confirm the need for policies restraining or exnovating car ownership, car-use and carbon-intensive travels in general, especially when policies favouring car sharing are implemented, so that related rebound effects can be mitigated.

What we have learned from this case study, is that, in general for CE offerings, the impacts depends on i) the variation in the per-unit impacts of the offering (in comparison with the linear one) (product level) and on ii) the variation in consumption and production quantities (overall demand level). Currently, the second layer might be overlooked by researchers (Bocken et al. 2020) and by policy makers. Some CE offerings are gaining ground (such as car sharing, but also e-commerce of second-hand, refurbished products). It seems necessary to assess whether or to which extent those offerings increase the production and consumption quantities of products and services, before supporting them or letting them expand.

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Abbreviations

BCR	Brussels Capital Region
CE	Circular economy
CS	Car sharing
CER	Circular economy rebound
CMU	Circular material use
DMC	Domestic Material Consumption
EC	European Commission
ERE	Environmental rebound effects
GDP	Gross domestic product
GHG	Greenhouse gas emissions
PREC	Programme regional d’économie circulaire
PSS	Product-service systems
RE	Rebound effects
RMC	Resource material consumption
RME	Raw material equivalent

Annexes

Table 8: Variables influencing environmental impacts on the supply side. On the basis of (Rademaekers et al. 2018; Chen and Kockelman 2016; Chapman, Eyckmans, and Van Acker 2020)

Variables, mechanisms and affected impacts	Results	Sector - Geography	References
Variable: intensity level of use of cars/Functional lifetime of vehicles **Mechanism**: (+) Increase in mileage due to higher use intensity (-) Automobile lifetime shift effect since shared cars could have a lower lifetime, leading to an unintended preservation of the manufacturing rates (Amatuni et al. 2020) **Affected impact categories:** -Environmental impacts related to the manufacturing of vehicles and to land-use -Economic activity of car manufacturers and services and corresponding jobs	From own review		
	225000 km for shared cars, as opposed to 150000 km for traditional cars	EU	(Rademaekers et al. 2018)
	17500/year for shared vehicles, compared to 15000/year for	Sweden	(Nurhadi et al. 2017)
	Use of scenarios that vary according to the total mileage and to the lifetime of vehicles	The Netherlands (all the services)	(Amatuni et al. 2020)
Variable: vehicle age/fuel efficiency **Mechanism:** (+) Shared cars tend to be more recent and thus fuel efficient than private cars because of their faster replacement rate (as a result of their higher utilization rates). They also tend to be smaller and to have electric engines. (-) Less-fuel efficient shared cars are then sold into the second-hand market. **Affected impact categories**: -Environmental impacts related to the use of vehicles (e.g. GHG and air pollutant emissions from fuel production and combustion)	From (Rademaekers et al. 2018)		
	shared cars are approximately 24% more fuel efficient than the average car	The Netherlands	Meijkamp (1998)
	average car sharing vehicle is 17% more fuel efficient than the average private vehicle	Germany and Belgium	Ryden and Morin (2005)
	car sharing fleets register up to 15 to 20 percent lower specific CO2 emissions, in some cases up to 25 percent lower	Europe	Loose (2010)

NB: Only European studies considered and additional references added following own review.

Table 9: Variables influencing environmental impacts on the demand side. Based on (Rademaekers et al. 2018; Chen and Kockelman 2016; Chapman, Eyckmans, and Van Acker 2020)

Variables and mechanisms	Results	Geography	References
Variables: evolution of vehicle ownership/of fleet size **Mechanisms**: (+) Decrease in vehicle ownership for car owners or cannibalization effect (Ke, Chai, and Cheng 2019) (-) Increase in the total number of vehicles since customers who originally do not own cars may expand the market through their membership to car sharing (Ke, Chai, and Cheng 2019, 12471).	From (Rademaekers et al. 2018), also based on (Chen and Kockelman 2016)		
	each car sharing vehicle replaces at least 4 to 8 personal cars	Europe	Loose (2010)
	net reduction of 1995 cars for 17,000 members of free-floating car sharing	Ulm, Germany	Firnkorn and Müller (2011)
	each car sharing vehicle replaces 6 private vehicles	Lisbon	Baptista et al. (2013)
	From (Chapman, Eyckmans, and Van Acker 2020)		
	Free-floating: 23% reduction in vehicle ownership, 1 car replaces 3 private cars Roundtrip: 67 % reduction in vehicle ownership, 1 car replaces 7 cars	Paris	6T-Bureau De Recherche (2014)
	6% of free-floating car-sharing households gave up a car	Basel, Switzerland	Becker et al. (2018)
	Between 4.7% and 11.4% of free-floating car-sharing users have one fewer car because of car-sharing	Ulm, Germany	Firnkorn and Müller (2012)
	13.6% of free-floating car-sharing users and 23.6% of round-trip car-sharing users either have or plan to shed a car	Germany	Giesel and Nobis (2016)
	car ownership decreases by 30% amongst car sharers (including both B2C and P2P)	Netherlands	Nijland and van Meerkerk (2017)
	32% of round-trip users reduced their car-ownership after joining car-sharing	London, UK	Wu et al. (2020)
	37% of free-floating users reported car-sharing caused them to own fewer cars	London, UK	Le Vine and Polak (2019)
	From own review		
	each car sharing car replaces 4-6 private cars	Brussels, Wallonia	Ryden and Morin (2005)
	Due to car-sharing, between 12.6 and 69.3% of car-sharing users reduce their car-ownership, depending on the level of confidence in the self-assessed counterfactual	Flanders	(Chapman et al. 2020)
	Only when the producing cost and transportation need are below some thresholds and the market size is greater than a threshold, can car sharing decrease the total number of vehicles (trade-off between the market expansion effect and the cannibalization effect)	na	(Ke et al. 2019)
Variable: **Influence on other modes of transport/ modal shift effect** **Mechanism**: (+) Increase in use of soft and public modes by car owners (-) Decrease in travelled km in soft or public modes by car-less people	From (Rademaekers et al. 2018), also based on (Chen and Kockelman 2016)		
	14% increase in bicycling, 36% increase in rail transit use, and 34% increase in bus transit use among car sharing members	The Netherlands	Meijkamp (1998)
	Car sharing members use public transportation 35–47% more during weekdays (1100 km more per car sharing member and year)	Bremen and Belgium	Ryden and Morin (2005)
	For car owners, no significant changes in the modal split. For carless users, biking decreases from 23.7% to 19.4%, while the share of walking and public transport remain unchanged.	Germany	Gsell et al. (2015)
	"Roundtrip carsharing increased public transit use and walking slightly, whereas free-floating carsharing reduced public transit use (-18%) and walking (-7%).	Paris, France	6T-Bureau De Recherche (2014)
	From own review		
	Increase in vkm travelled by all modes (+2.5%) and by alternative modes, including bus and train (+114% each), after participating in carsharing.	The Netherlands	(Amatuni et al. 2020)
	From (Rademaekers et al. 2018), also based on (Chen and Kockelman 2016)		

Variable: **evolution of car use/ Vehicle kilometers travelled** **Mechanism:** (+) Decrease by car owners (-) Increase by car-less drivers	72% reduction	Switzerland	Muheim (1998)
	33% reduction	The Netherlands	Meijkamp (1998)
	28 (Belgium) and 45% (Bremen) reduction (average decrease of 3000 km per year)	Belgium & Bremen	Ryden and Morin (2005)
	From (Chapman, Eyckmans, and Van Acker 2020)		
	11% reduction in km driven per month (free floating) 45% reduction in km driven per month (roundtrip)	Paris, France	6T-Bureau De Recherche (2014)
	38% of users reduced car usage frequency; 16% of users increased car usage frequency	Switzerland	Becker et al. (2018)
	Average 1750 km reduction in km travelled by car per member per year (7460 instead of 9220). Car sharers drive 15% to 20% fewer car kilometres than prior to car sharing	Netherlands	Nijland and van Meerkerk (2017)
	Round-trip car-sharing users reduce vehicle miles travelled by 564 miles (902 km) per user per year	London, UK	Wu et al. (2020)
	From own review		
	Ranging from a reduction of car-use by 54 km per user per week (assuming that car-sharing has a large effect on car-ownership), to an increase by 24 km (assuming that car-sharing does not). -For users whose ownership is affected: decrease in car use between 54.3 and 93.8 km. -For users whose ownership is not affected: increase in car use between 31.5 and 35.6 km	Flanders	(Chapman et al. 2020)

NB: Only European studies considered and additional references added following own review.

Table 10: Review of rebound effects from car sharing (as assessed by the literature)

	Results	Country	References
Indirect RE **Mechanism**: Increase in the consumption of other (polluting) goods given increased available budget freed by lower car sharing costs	Car sharers have high rebound emissions and if the rebound expenditure is spent on air travel, car-sharers have overall higher emissions than car owners. Rebound magnitude in terms GWP emissions of 75 %	Norway	(Briceno et al. 2005)
	Overall increase in GWP emissions due to the diffusion of car sharing schemes in Europe (40 %). ERE of 135 %, because of the lower transport costs of CSS (42% lower), which liberated 391 € per year and user, driven by the indirect effect and of consumption with higher environmental intensities.	Europe	(Font Vivanco et al. 2015)
	Estimated average GHG RE: - for giving up car ownership and use: 68% for an average working middle-income driver (from 32% for services to 122 % for other travels). - for reduced driving: 23% (from 11 to 41 %). Average CF of car owners is 8% higher than their car-free counterparts, but CFs of “light drivers” is lower than those of car-free individuals.	Finland	(Ottelin et al. 2017)
	Consumption pattern of reduced ownership decreases the carbon and material footprints of low- but not middle-income households. Among the latter, owners have clearly higher emissions in private vehicle category, but the sharers have higher emissions from the vacation travel and public transit categories, which alone almost compensates for the lower emissions from the private vehicle category (high RE)	Finland	(Junnila et al. 2018)