



Weak spots for car-sharing in The Netherlands? The geography of socio-technical regimes and the adoption of niche innovations

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ABSTRACT

A geographical analysis of sustainability transitions allows one to better understand the emergence and up-scaling of sustainable innovations. We first theorize about the spatial heterogeneity of regime, niche and landscape within the Multi-Level Perspective and then apply our framework to car-sharing adoption across all Dutch neighbourhoods. We distinguish between business-to-consumer and peer-to-peer car-sharing, which differ in terms of business model and greenhouse gas reducing impacts. For these two innovations, we demonstrate how the relation between niche innovation and the socio-technical regime of private car ownership affects adoption patterns. Our study can be read as a plea for full-fledged geographical analysis of sustainability transitions equally emphasizing the spatial heterogeneity of niche, regime and landscape.

1. Introduction

In the face of climate change, academic interest in possible pathways to sustainable consumption and production has increased rapidly over the past decade. There is a widespread consensus that a sustainable economy will require major socio-technical transitions in the technologies and practices currently employed across the globe. Such transitions will not automatically unfold evenly when sustainable alternatives are present in specific niches. The prime reason for such inertia holds that pre-existing technologies and practices are maintained due to vested values, routines and interests associated with current unsustainable regimes [1,2].

To understand better the sources of inertia and change, scholars have started to look at the geographies of sustainability transitions [3]. In every transition, one can observe places where innovations pop up and alternatives are tried out, and other places where the current regime is strictly maintained and sometimes even strengthened. These differences stem from local processes of learning and politicking, which in some contexts may favour niche developments while in other contexts support the continuation of the regime technology. To give one example, the popularity of solar panels in Germany differs considerably across regions, which has been attributed to differences in local user activity and subsequent policy responses at different spatial scales [4].

By studying where innovations occur and scale up – so the promise

of the geographical turn in the study of sustainability transitions – it can also become clear how and why transitions occur. However, a recent review of geographical studies of sustainability transitions suggests that this program has not yet entirely lived up to its promise [5]. While a large number of case studies has convincingly shown that place-specificity matters for niche development, such “highly idiosyncratic case stories of specific places” do not “add up” to provide a coherent understanding of transition processes in an entire sector ([5], p. 93). Indeed, there are only few studies that compare places across an entire sector and spatial system [4,6]. Though some studies look at multiple places where niche activity develops and how these places get entangled through various types of networks [7,8], a truly “symmetric” approach would be to study a multitude of places including those in which niche activity is entirely absent.

We argue below that in a multi-level perspective (MLP) on sustainability transitions, an understanding why certain places are breeding grounds for sustainable innovations does not translate into an understanding why many other places remain inactive in innovation development. Inactivity does not necessarily reflect the absence of local supportive conditions, but can also stem from particularly strong regime forces. Thus, we should move away from the implicit assumption that a regime is spatially homogeneous as if regime technologies are equally pervasive across places [9,10]. Innovative activity, or the absence hereof, should be understood as stemming both from innovation-

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supporting factors contesting a regime and from vested regime forces maintaining a regime. Both these supporting and constraining factors have a distinct geography: supporting factors stem from local conditions and initiatives as well as landscape factors that play out favourably in a local context, while constraining factors depend on the pervasiveness of the current regime as well as landscape forces.

As any regime will show variations in its pervasiveness across local contexts, one can also compare *multiple* niche innovations in terms of their sensitivities to vested regime forces. It has been noted before that some niche innovations are fundamentally challenging a regime, while others become integrated over time within the dominant regime [11,12]. Also the potential to reduce greenhouse gas emissions of these types of innovations may differ [13]. In sectors where multiple innovations are being developed in parallel, our framework will allow to assess the sensitivity of innovations vis-à-vis regime presence by analysing to what extent innovation occurs *most* in places where a regime is the *least* pervasive. In particular, one can analyse why the diffusion of some innovations accelerates while others retain their niche status, which links to the recent debate regarding acceleration of transitions [14–16]. From a geography of transitions perspective, one may expect that not just the emergence of niche innovations, but also their diffusion varies across local contexts.

Our empirical context is that of car-sharing in The Netherlands. Car-sharing is a suitable case to apply our framework to as it has the potential to transform the transport system into more sustainable directions [17], emerges against a dominant existing regime, and has two main variations with different relations to the regime. We will look at spatial variations in car-sharing adoption across all Dutch neighbourhoods. We distinguish between the two dominant business models that currently occupy a niche in the car mobility market: business-to-consumer (b2c) car-sharing, where users rent a locally available car from a car-sharing organization and the more recent peer-to-peer (p2p) car-sharing, where users rent a car from an individual car owner in their neighbourhood through an online platform. B2c car-sharing is found to have a larger positive impact on environmental sustainability than p2p car-sharing [13].

Zooming out from single niches in single places to multiple niches across all places in a spatial system asks for a method that allows for comparing many localities. We therefore rely on a quantitative approach in which we count the number of shared cars of both niche types (b2c and p2p) in each Dutch neighbourhood as our variable to be explained. Data was collected for all cars shared via the two business models in The Netherlands. As explanatory variables we collected variables indicating influencing factors at the niche and landscape level as well as a variable indicating the pervasiveness of the vested regime based on individual car ownership. In this way, we are able to apply the multi-level framework for an entire spatial system.

2. Theoretical framework

Developed against the backdrop of societal challenges such as climate change and air-pollution, and rooted in evolutionary economics and science and technology studies, the sustainability transitions perspective is well-suited for the analysis of potentially transformative sustainable innovations such as car-sharing [18]. In the sustainability transitions perspective, the objects of study are socio-technical systems that provide a certain function in society, such as health, water, food and mobility. These systems consist of networks of actors that interact with artefacts, technologies, and resources, guided by a semi-coherent set of rules that is called the *regime* [1,2]. The rules of the regime include norms, user expectations, legislation, as well as search heuristics of engineers.

In the case of mobility, one can conceive of the dominant socio-technical system as that of private car ownership, with key actors including car manufacturers, car dealers, car owners and civil servants working on traffic policy. Examples of regime rules are the image of the

car as a status symbol, daily mobility habits of commuters and ideas of engineers about how to construct a car [18]. The “rules” of the regime ensure that socio-technical change will mostly be incremental. Radical innovations do emerge, but remain confined to *niches*, which are “protected spaces, i.e., specific markets or application domains, in which radical innovations develop without being subject to the selection pressure of the prevailing regime” ([19], p. 957).

From time to time, socio-technical systems and regimes do change substantially. These changes are enabled by developments on the so-called “landscape” level, that is, the wider context that influences niches and regimes. Relevant for our geographical analysis, the landscape is conceived as landscape in both its literal and metaphorical sense [1,12,18]. It includes spatial structures such as urban form, natural environment and physical resources, but also societal trends, ideologies and other influences (for example awareness about climate change or economic structures). Once a sector experiences a large-scale system change in a sustainable direction, one speaks of a sustainability transition: “a long-term, multi-dimensional, and fundamental transformation process through which established socio-technical systems shift to more sustainable modes of production and consumption” ([19], p. 956). An example of such a transition would be the change from a mobility system based on car ownership towards one based on car-sharing. Importantly, the regime does not have to be entirely replaced for a transition to occur; instead various transition pathways are possible [11,12]. Innovations can for example become integrated as an add-on to the existing regime.

The sustainability transitions field has recently experienced a “geographical turn” [3,5]. Here, the interest lies in understanding where transitions occur and how they evolve at different geographical scales. A recent review of empirical studies showed that most studies identify place-specific factors stimulating niche development, while the regime and landscape are conceptualized as spatially homogenous entities [5]. This is noticeable and somewhat surprising since the strength of the multi-level perspective lies particularly in explaining how interactions between developments on niche, regime and landscape levels lead to the success and failure of sustainable innovations [2,20]. Below, we explore the spatial dimensions of landscape, niche and regime level, and theorise how locally-varying factors at each level can influence the geographical adoption of sustainable innovations. Our framework, then, is made operational by collecting neighbourhood-level statistical data associated with each of the three levels.

Let us first develop a spatially heterogeneous conceptualization of the regime. While early transition studies implicitly assumed a regime in a sector to be equally present across space, recent studies challenged this assumption by emphasizing that the regime may be unstable or even absent in some places. These include places in developing countries where formal transport systems or energy infrastructure are underdeveloped [21,22] or remote areas. Späth and Rohrer [9], for example, study a remote mountain area without gas infrastructure, which is “off the radar” for incumbent actors of the gas energy regime.

Instead of being either totally dominant or absent we can see the presence of the regime as a variable, and indicate for each place the strength of the regime. This is in line with recent geographical and institutional perspectives on regimes, in which it is argued that regimes are present in the routines, practices, technologies and infrastructures of places to different degrees [23,24]. Importantly, given that the regime has less impact on actors in places where it is weak, these places are expected to be the ones where niche innovations emerge and scale up.

We hence conceptualize the geographically heterogeneous regime as a patchwork of localities in which the regime is more or less strong. The spatial heterogeneity of the regime stems from varying degrees of fit with the local context. For example, van Welie et al. [24] show how the regime of the sewage system is less embedded in disadvantaged neighbourhoods in Nairobi, because of the poor fit with local socio-spatial conditions related to income, land ownership and physical

terrain. For the car regime, Nykvist and Nilsson [25] note that it is partly global, with international rule sets such as safety standards, but they maintain that for a transition analysis also the regime at the national and local scale has to be considered. In their example, local municipalities that construct infrastructure are important regime actors. Given the influence of local socio-spatial context structures on the strength of the regime, we expect to observe differences in the strength of the regime even at the local level. At the local level, we will then also be able to identify places where innovations emerge and up-scale thanks to a lower pressure of the regime on actors.

In contrast to regimes, niches are in the transitions literature commonly associated with specific places [5,26,27]. Particular characteristics of a place can provide protection for the innovation to develop and scale up. For example, Dewald and Truffer [4] show how in certain German regions engaged end-users were present, who initiated solar energy collectives enhancing adoption. Niches can also be actively constructed by policy actors [28]. A typical example are municipal policies stimulating the development of sustainable transport innovations through subsidies, regulations and experiments [29,30]. Note, however, that in some cases niche protection also occurs at higher spatial scales. Although niches are often linked with specific localities, niches can also be formed by countries [31] or by multi-scalar networks [7].

Assuming that policies have an effect, their spatially heterogeneous implementation will influence the geographical adoption pattern of sustainable innovations. In this study, factors associated with the niche level are specific protective conditions that are expected to directly contribute to the adoption of the innovation under study. We expect that niche protection is especially important for innovations that challenge a regime rather than complement it.

Finally, in the MLP, the landscape level refers to the wider context that is largely exogenous to the evolution of a socio-technical system in a sector, yet nevertheless affects the chances of sustainable innovations to occur and to scale-up. The landscape can stabilize or destabilize the existing socio-technical regime, providing legitimization for the sustainable innovation or reversely hinder its adoption [32]. As for the levels of niche and regime, the landscape level can also be thought of as spatially heterogeneous. Geels et al. [12] point out the importance of spatial “static” landscape factors when comparing the electricity transition between Germany and the United Kingdom. The static landscape refers to socio-spatial context factors that differ between the two countries. In their example, in Germany environmental awareness, an active civil society, a cooperative institutional structure and the presence of manufacturing industries led to a more radical shift towards renewable energy than in the UK. Also at a more fine-grained spatial scale we can identify such varying socio-spatial context factors possibly influencing the adoption of sustainable innovations, such as income and education levels of the population [33,34]. Hence, it is expected that the geography of the landscape level will be reflected in the spatial adoption pattern of sustainable innovations.

3. The case of car-sharing

In this study, we analyse the adoption of two types of car-sharing in the context of the current regime of individual car ownership [18]. Car-sharing is a relevant case to apply our theoretical framework to because a) it is an innovation that, at least *potentially*, could transform the fairly stable car mobility system into a more sustainable one [17,35], b) it emerges in the context of a clear regime, namely private car ownership, c) it comes in two main varieties, each with a different relation to the regime. The oldest form of car-sharing has become known as traditional or business-to-consumer (b2c) car-sharing which emerged during the 1990s in The Netherlands. In this type of car-sharing, a car-sharing organization owns a fleet of cars that are stationed dispersedly over residential neighbourhoods and users can rent a locally available car. A more recent type of car-sharing, that has emerged in the early 2010s, is

peer-to-peer (p2p) car-sharing. In this business model, users rent a car from an individual car owner in their neighbourhood through an online two-sided platform bringing together supply and demand. The latter kind of sharing is generally considered as part of the sharing economy in which consumers rent out their under-utilized assets to other consumers [36,37].

The key difference between b2c car-sharing and p2p car-sharing holds that a p2p platform does not own any vehicle. Instead, the platform leverages the idle capacity of cars already owned by individuals. Many car owners do not make daily use of their car and thus may choose to offer it for rent for particular days via the platform. This holds *a fortiori* for households owning multiple cars. The leverage of idle capacity of cars explains why p2p car-sharing, despite its recent emergence, already outnumbers b2c car-sharing.¹ Since the supply of cars on a p2p-platform does not require investment in cars by the platform nor investments of the car owner, p2p car-sharing can scale up relatively easily. As such, p2p car-sharing builds on the current regime of car ownership as it provides car owners the possibility to recover part of the fixed costs of owning a car by occasionally renting it out. B2c car-sharing, by contrast, was setup to provide infrequent car owners with an alternative to car ownership by providing locally available cars on a 24/7 basis.

Car-sharing can, in potential, contribute to environmental and social dimensions of sustainability. In terms of environmental impacts differences are observed between b2c and p2p car-sharing. Shaheen et al. [35] reviewed 18 North-American b2c car-sharing studies and found that most studies report around 25% of participants selling their car after joining the program. However, there is considerable variation in the observed reduction in kilometres driven, with findings ranging from 3 to 79.8%. Nijland and van Meerkerk [13] compared the impacts of p2p and b2c car-sharing. They surveyed 363 Dutch users who engaged in car-sharing for at least one year. They find on average no reduction in car ownership for the p2p users, while a reduction is observed for b2c. What is more, the decrease in car kilometres driven in a year for p2p car-sharing is only around half of that of b2c car-sharing users. The stronger sustainability profile of b2c car-sharing resonates with reports of b2c car-sharing organizations that started as environmentally motivated cooperatives [38–40]. For the entire sample consisting of both p2p and b2c cars, Nijland and van Meerkerk [13] estimate a reduction between 240 and 390 kg in CO₂, i.e. 13 to 18% of emissions related to car ownership and use. About one third to half of the reduction is related to less car use, the remainder to car ownership reduction.

In terms of social impacts, car-sharing can provide certain social groups access to car-mobility for satisfying basic needs, hence contributing to social dimensions of sustainability. Because of a lack of alternatives, households in rural and suburban areas are often dependent on the car for transport. Limited access to transport can result in social exclusion: “the inability to participate in economic, social and cultural life” ([41], p. 15). Mattioli [42] identifies two forms of car-related transport disadvantage: car deprivation and car-related economic stress. In the case of the former people do not have access to a car. The latter refers to the problems households have in paying for fuel, insurance and car maintenance. Both forms of car-sharing can contribute to reducing car deprivation, by providing car access to people not able to afford a car. Peer-to-peer car-sharing could additionally reduce economic stress for car owners, by providing them an opportunity to rent out a car [36]. Obviously, there are also limitations to the benefits car-sharing brings. A large share of car-deprived households in

¹ Note, however, that the utilization rate of cars rented out via the b2c model is considerably higher than of cars rented out via the p2p model. The reason for this difference in utilization rate holds that a business that rents out cars will only place cars in neighbourhoods with sufficient demand, while a car owner may supply his/her car even if local demand is low given zero marginal costs.

car-dependent areas do not have a driving license, so car-sharing will not be a solution for them [42]. Other forms of communal shared transport might form an alternative here [43].

Conflicts may exist between realizing social and environmental sustainability goals in transport [44,45,42]. Nijland and van Meerkerk [13] note that the reduction in CO₂ emissions because of car-sharing results mainly from a sharp drop in car mileage travelled by people who previously owned a car. However, car sharing may also lead to increases in car mileage, especially for people who previously did not own a car and substitute public transport trips by car-sharing. Further note that car deprivation is especially critical for low-income households in peripheral areas. People living without car access in these areas experience a larger “mobility gap” as compared to car owners, than their peers who live in cities and have access to alternative transport modes [42]. Car-sharing may thus yield most social benefits in peripheral areas, yet may also increase car dependence even more if planners would reason that the new possibilities granted by car-sharing make investments in alternative modes of transport less urgent.

In our analysis, we measure the local pervasiveness of the private car ownership regime by a neighbourhood’s motorization rate, which is the average number of cars owned per inhabitant. The regime in this study is defined as the rule-set that comes into effect in local routines, practices, technologies and infrastructures [23]. We consider the motorization rate as the most direct and locally available measure of the regime. The use of this measure, like every methodological choice, limits the scope of the analysis. Notably, we are not able to assess the effects of different dimensions (cultural, cognitive) of the regime separately. Here we had to make a trade-off between a nation-wide analysis including all localities, versus a detailed analysis of a particular locality. Given that our paper is an attempt to build bridges between transition studies and quantitative adoption analyses, we chose the former. We would argue that at least our measure covers various regime dimensions, as the socio-cultural (e.g. image of car ownership as a status symbol), cognitive (e.g. number of driving licences) and legislative (e.g. car regulation) elements of the regime eventually all materialize in a certain motorization rate i.e. the degree of private car ownership in a neighbourhood.

Given the differences between the two car-sharing business models, our *key hypothesis* holds that b2c car-sharing is most popular in neighbourhoods where the current regime of car ownership is weak. If few cars are being owned, people are more inclined to use alternative transport forms such as car-sharing [34]. The relationship between p2p car-sharing and regime presence is more complex. On the one hand, a low motorization rate may lead to a larger demand for car-sharing, including for cars that are being shared among peers. On the other hand, a higher motorization rate means that more cars are available in a neighbourhood that are potentially offered for rent through a p2p platform.

On the niche level, we expect two factors to influence spatial adoption. Local policies have been used as the primary *explanans* for geographical differences in sustainability transitions [5]. With regard to car-sharing, municipalities have developed information-related policy instruments to stimulate public awareness around car-sharing [46]. A typical example is the “Utrecht shares” campaign in which the Dutch municipality of Utrecht provided information about car-sharing in various media, which also received input of local car-sharing firms [47]. It is expected that municipalities that have implemented these policies show higher adoption levels of the respective form of car-sharing. We further expect university towns to provide niche protection for car-sharing.² These localities provide exceptional opportunities for car-sharing as students are over-represented [48]. University students can be expected to be among early users, being young and highly

educated, and generally aware and open to sustainable innovation. What is more, most universities are located in medieval city centres or on campuses with parking restrictions, and are well served by public transport. Car-sharing provides students with an alternative for occasional car use to supplement their daily use of bikes and public transport.

The place-specific factors associated with the landscape level are not influenced in the short-run by regime actors nor by those supporting a niche [32]. Whereas niches are areas expected to provide direct and specific protection to the innovation of car-sharing, landscape factors are background factors that can influence adoption both positively and negatively. Population density and distance to facilities (such as retail or schools) are two landscape factors in the literal sense. These can be expected to vary highly between neighbourhoods, especially across rural, suburban and urban areas. Note that, over the past century, the car regime contributed itself to these factors, especially to the rise of suburbia with low population density and long distances to facilities [49]. Nevertheless, we consider these two factors to be part of the wider landscape given their durability and given that many other factors besides car ownership have contributed to population density and distance to facilities (see also [18]).

We expect that population density only affects the adoption of b2c car-sharing. For this form of car-sharing, a certain population density is necessary to ensure a user base that is large enough to cover the cost for a rental organization to place a dedicated car-sharing vehicle [34,50]. For p2p car-sharing, instead, a density requirement is absent, because the supply of one’s own car comes at very low marginal cost. Hence, no effect of population density on local p2p car-sharing is expected. Neighbourhoods with many facilities have been found to have higher levels of car-sharing [34], so we expect that a larger distance to these facilities negatively affects car-sharing adoption.

Next to the literal landscape factors, other landscape factors may affect the adoption of car-sharing at the neighbourhood level. Notably, car-sharing is known to appeal to people with higher environmental awareness [50]. Hence, we expect that both forms of car-sharing are adopted more often in localities with a higher share of people that are environmentally aware. A similar positive effect on car-sharing adoption is expected for localities with many highly educated people and younger people who tend to be more open to innovation more generally [51].

Concerning income, higher income households generally have higher likelihoods of innovation adoption given their purchasing power. However, the effects of income on car-sharing adoption are still unclear [34,52]. Particularly, when looking at p2p car-sharing, cost-saving considerations are an important motive to supply one’s car. In that case, one would expect lower incomes in neighbourhood to be associated with a higher number of p2p shared cars [36,53].

We consider two further landscape factors that are expected to affect b2c and p2p car-sharing adoption alike. First, it has been claimed that car-sharing particularly suits expatriates, as car-sharing provides them with a temporary mobility solution [54]. Finally, Celsor and Millard-Ball [55] look at household characteristics and find that the percentage of one person households correlates positively with the number of shared cars. A likely explanation holds that families with children have special requirements for their car such as children seats or large trunks which makes them less likely to engage in car-sharing.³ Hence, one would expect that neighbourhoods with a lower average household size, have higher adoption levels of car-sharing.

Table 1 shows a summary of all expected effects of the niche, regime and landscape factors we discussed, distinguishing between b2c and p2p car-sharing adoption.

² Amsterdam, Delft, Eindhoven, Enschede, Groningen, Leiden, Maastricht, Nijmegen, Rotterdam, Tilburg, Utrecht, Wageningen.

³ Coll et al. [34] on the other hand, did not find more use of car-sharing in areas with many one-person households, but they studied a car-sharing program where all cars were equipped with children seats.

Table 1

Expected effects of regime, landscape and niche factors on car-sharing adoption.

	b2c car-sharing	p2p car-sharing
<i>Regime</i>		
Motorization rate	–	+ / –
<i>Niche</i>		
Municipal car-sharing policy	+	+
University city	+	+
<i>Landscape</i>		
Population density	+	
Distance to facilities	–	–
Environmental awareness	+	+
Age group 25–45	+	+
Highly educated	+	+
Income		–
Household size	–	–
Immigrants from Western countries	+	+

4. Methodology

As we aim to explore the two niches and the regime across a whole spatial system, we use a quantitative method in our analysis. Not yet often used in sustainability transition studies, our method allows for the comparison of developments in a transition across many localities as well as for an assessment of the relative importance of each of the variables by using statistical tests. As such, our approach can be considered as an attempt to build bridges between the geography of transitions literature and the field of quantitative innovation adoption studies. In this latter field, numerous variables such as socio-demographics or attitudes are linked to innovation adoption, mostly using regression models (e.g. [33,34]). As noted by Sovacool [56] and Sarrica et al. [57] much energy scholarship sticks to using a specific disciplinary method, and it seems hard to produce cross-overs between approaches that take a user-oriented versus a systemic perspective. By combining variables measuring user-characteristics as well as the socio-technical regime, we hope to contribute to more integration across perspectives.

In our analyses, the dependent variables are the number of b2c and p2p shared cars in Dutch neighbourhoods. The data were collected at the postal code area (4-digit) for the entire country of The Netherlands during the months of March, April and May 2014. The Netherlands is divided in 4047 of such postcode areas, which have on average approximately 4000 inhabitants. Data about the location of shared cars was obtained via the websites of car-sharing firms. These websites publicly list the addresses of the cars. From one car-sharing firm the data could be obtained directly. All firms that were, to our knowledge, active in car-sharing in The Netherlands were included.⁴

The independent variables are the place-specific factors associated with the regime, landscape and niches as discussed in the previous section. In addition, to control for the varying number of inhabitants per postcode area, the number of inhabitants was added as a control variable in all models. Data for the variables were collected from the Dutch statistical office [58–62]. For the environmental awareness variable, the number of members of a large environmental organization was taken. For the policy variable in all Dutch municipalities ($n = 408$) the presence and content of car-sharing policies was investigated. Hereto, during the summer months of 2014, we systematically searched for the terms of *autodelen* or *autodate* (most common Dutch terms for car-sharing) on municipal websites, and for the combination of these terms and the municipality name in the newspaper database LexisNexis and on Google Search. A dummy variable was created indicating the presence of an information-related policy, i.e. communication about

car-sharing through a municipal website or other communication channel. Table 2 reports descriptive statistics of the variables.

We use zero-inflated negative binomial models to model the spatial adoption patterns of p2p and b2c car-sharing [63]. The dependent variable in the models is a count (the number of cars in a postcode area). When dealing with count data Poisson or negative binomial models are typically used. The negative binomial model is preferred over the Poisson model if overdispersion is present (i.e. if the conditional variance is larger than the conditional mean). As this was the case for our dependent variable, the negative binomial model was chosen.⁵ More specifically, we opted for the zero-inflated negative binomial model (ZINB), able of handling the large amount of zeros (postcode areas with no shared cars in our data). Vuong [64] tests showed that the zero-inflated negative binomial model indeed fits the data better than the negative binomial model. A ZINB model consists of two parts. First, a logit model (zero-inflated part) for estimating the probability of a postcode having zero shared cars. Second, a negative binomial model for estimating the counts of shared cars for postcode areas with a non-zero probability for having shared cars. Hence, the ZINB model allows us to investigate separately 1) what factors influence the availability of the of p2p car-sharing and b2c car-sharing in an area (zero-inflated part) 2) For the areas in which it is likely that cars are shared, what factors influence the numbers of cars that are shared (see [33,34]). In the models, the standard errors are clustered at the municipal level [65].⁶

5. Results

Before turning to the results of our statistical analysis, we provide some historical context about the growth of car-sharing in The Netherlands. As noted before, p2p car-sharing was initiated later than b2c car-sharing, but has already overtaken it in terms of available cars. This is also clear from Fig. 1, which depicts the growth in the number of b2c and p2p shared cars. As of July 2014, 8369 cars were shared via the p2p model, whereas 2290 cars were shared via the b2c model in The Netherlands. B2c car-sharing has been around since the mid 1990s, but has seen relatively limited growth. In the past years, the number of cars shared via the b2c business model showed very modest growth. P2p car-sharing, on the other hand, grew rapidly. Growth percentages of the number of available p2p cars were about 200–300% in the years before 2014. These divergent dynamics continued after 2014. The most recent figures of shared cars in 2018 indicates that b2c car-sharing has reached approximately 3000 cars while p2p car sharing includes approximately 34,000 cars by now.⁷

To get a better understanding of this upscaling process, Fig. 2 shows the spatial heterogeneity of the socio-technical regime in terms of private car ownership, as well as the adoption levels of b2c and p2p car-sharing. The regime is strongest in the rural areas in the east and north near the border. It is weaker in the urbanized west, with the notable exception of some commuter towns. Stark differences can also be observed in the geographical adoption patterns of p2p and b2c based car-sharing (Fig. 3A and B). As one familiar with the geography of the Netherlands would recognize the adoption of business-to-consumer car-

⁵ The significant values for the overdispersion parameter α indicate that the negative binomial model fits the data better than the Poisson model.

⁶ By estimating clustered standard errors at the level of municipalities, we take into account that postal code areas within municipalities may share unobserved characteristics with each other and these may not be independent from each other. This makes our assessment of statistical significance more conservative and reduces the risk of Type I errors. Recently, count regression models have been developed with more complex spatial error structures [73]. These models are mostly developed in a Bayesian context and will not be employed in this study.

⁷ See CROW's website: <https://www.crow.nl/dashboard-autodelen/home/aanbod/aanbod-resultaat>.

⁴ Firms included are Car2Go, CareCar, Connect Car, Drive, Greenwheels, MyWheels, SnappCar, StudentCar and WeGo.

Table 2
Descriptive statistics.

Variable	Description	N	Mean	Standard Deviation	Min	Max
Shared cars (p2p)	Number of cars per postcode area shared via the peer-to-peer model	4,028	2.078	4.476	0	61
Shared cars (b2c)	Number of cars per postcode area shared via the business-to-consumer model	4,026	0.569	3.141	0	55
Motorization ^a	The number of cars per 100 inhabitants	3,910	49.267	9.642	7.727	97.849
Population density ($\times 1000$)	The number of inhabitants per km ²	4,033	1.684	3.015	0	44.230
Distance to facilities	The average of the standardized distance to a child care center, primary school, high school for vocational education, high school and supermarket	3,837	−0.000	0.787	−1.111	5.784
Environmental awareness (as measured by % members environmental organization)	The percentage of people member of a large environmental organization	4,025	2.649	1.658	0	30
Household size	The average number of people in a household	4,033	2.346	0.349	1	5
Income ($\times 1000$)	The average household income	3,575	35.899	6.662	11.800	106.800
% Highly educated	Percentage of people in postcode holding a higher vocational, bachelor, master or PhD degree	2,623	18.442	9.035	4	60
% age 25–45	Percentage of people between 25 and 45 years old	4,024	23.626	6.932	0	100
% Immigrants from Western countries	Percentage of people from a country in Europe (excl. Turkey), North America, Oceania, Indonesia or Japan	4,025	7.745	5.481	0	66.67
Municipal car-sharing policy (p2p)	Dummy variable (0/1) for the presence of an information-related policy for car-sharing in the municipality	4,019	0.137	0.344	0	1
Municipal car-sharing policy (b2c)	Dummy variable (0/1) for the presence of an information-related policy for car-sharing in the municipality	4,019	0.207	0.405	0	1
University city	Dummy variable (0/1) for university city	4,047	0.099	0.298	0	1
Population ($\times 1000$)	Number of inhabitants of the postcode area (to control for the varying number of inhabitants per postcode area)	4,033	4.160	4.134	0	28.600

^a The data also includes cars registered on behalf of some lease and car companies. The Dutch statistics agency has also published a cleaned dataset with only private cars on the “neighbourhood” (N = 3096) level [74]. This is on a slightly higher, yet still comparable aggregation level as the (N = 4048) postcode areas of this study. In the cleaned dataset the maximum motorization level in a neighbourhood was 0.952 cars per inhabitant. Values in our dataset above one car per inhabitant were therefore considered as resulting from the presence of lease and car companies and excluded from the analysis (116).

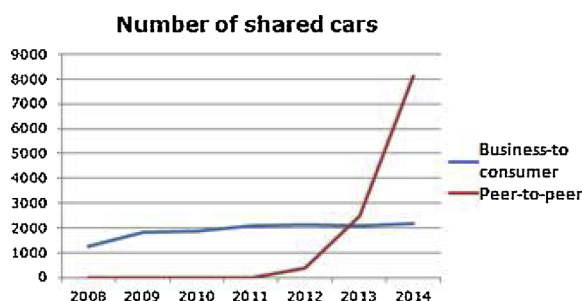


Fig. 1. The uptake of business-to-consumer and peer-to-peer car-sharing in the Netherlands [75].

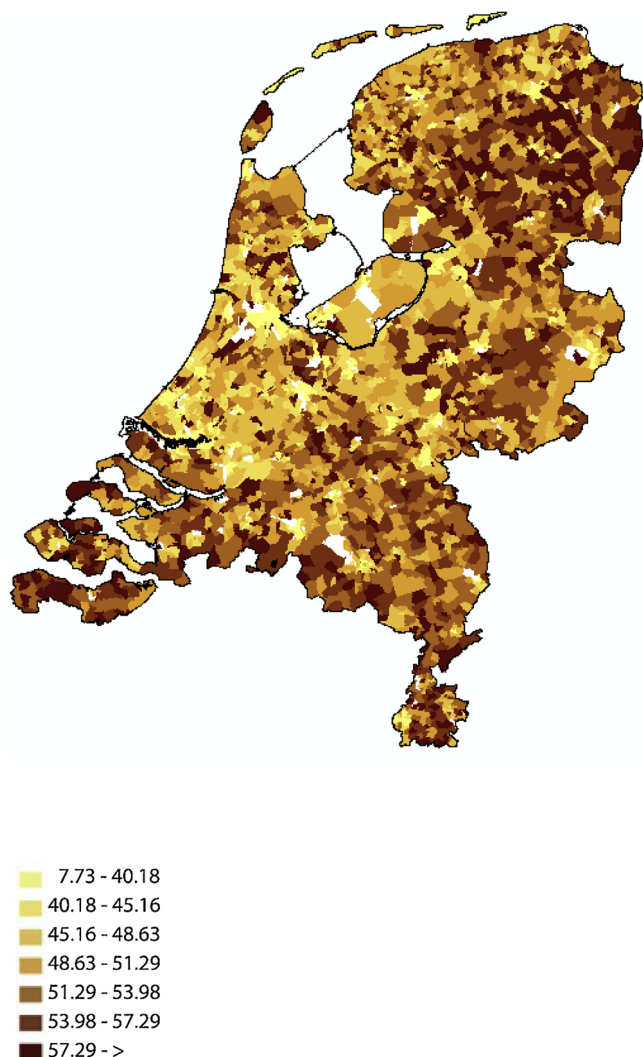


Fig. 2. The motorization regime (cars per 100 inhabitants).

sharing is restricted to the major cities in the Netherlands, and particularly clustered around the capital city of Amsterdam. The adoption of p2p car-sharing is higher in and around the main cities, but p2p car-sharing is also present outside the large cities, even in rural postcode areas in the east and north of the country. A pattern thus emerges of b2c car-sharing supply that is concentrated in cities, while the supply of a p2p shared cars occurs anywhere where car owners live, including rural areas.

We now turn to the results of the Zero-Inflated Negative Binomial (ZINB) models. These models allow us to analyse the simultaneous influence of various factors on adoption. The ZINB models consist of two

parts: one to estimate the probability that zero cars are shared in an area (zero-inflated part), and one to estimate the count of cars in areas where it is likely that cars are shared. The results of the zero-inflated part of the models are shown in Table 3. Here the probability is estimated for postcode areas to belong to the “strictly zero group” (postcode areas without shared cars).

A stronger socio-technical regime increases the likelihood of the non-availability of b2c car-sharing. As can be seen in Table 3, the higher the motorization level, the higher the likelihood of having no shared cars in the neighbourhood. On the other hand, there is no such relationship between the socio-technical regime and the non-availability of p2p car-sharing. This indeed indicates that the b2c car-sharing niche is stronger in areas where the existing regime is less pervasive, while the p2p car-sharing niche – making use of existing idle capacity of private cars – does not mirror the weakness of the car regime.

Some landscape factors affect the adoption of b2c car-sharing: a larger average household size increases the chances for zero shared cars, as expected. Higher environmental awareness and higher education decrease the probability of having zero shared cars, also as expected. Strikingly, for p2p car-sharing no significant effect of any landscape factor is observed.

Finally, the niche level factors affect neither form of car-sharing. The chances of zero shared cars in a neighbourhood are unaffected by municipality policies nor by university presence.

To sum up, the sheer presence of b2c shared cars in an area relates to certain regime and landscape factors. In areas where these are unfavourable, this form of car-sharing is less likely to be present. On the other hand, for p2p car-sharing none of the landscape, regime or niche influences the sheer presence of p2p shared cars.

Table 4 shows the results of the negative binomial part of the models. As described in Section 3, the ZINB model splits the postcode areas into two groups. The negative binomial part of the models estimates the counts of shared cars for the group of postcode areas for which it is likely that cars are shared. Let us first consider the effect of the socio-technical regime on the expected number of shared cars. As expected, for b2c car-sharing, the number of shared cars is lower in areas where the existing regime, as measured by the motorization rate, is stronger. Table 4 also gives some impression of the magnitude of the effects. If the number of cars owned per hundred people is one car higher, this leads to a decrease of 2.4% in the expected number of shared cars. For p2p car-sharing, a weaker (but also negative) relation between the motorization regime and the presence of p2p car-sharing is found. As can be seen in Table 4, if one car more is owned per hundred persons in a neighbourhood, this leads to a decrease of the expected number of cars with one percent.

Let us now turn to the landscape level. When coming to the literal landscape, for b2c car-sharing no clear effect of population density and distance to facilities on the number of cars is observed. For p2p car-sharing, the distance to facilities (such as supermarkets and schools) in an area has a negative relationship with the number of shared cars. Considering the metaphorical landscape, a large positive effect of environmental awareness on b2c car-sharing adoption is observed. If the percentage of people that are members of the environmental organization used in this study is one unit higher (e.g., 3.5 instead of the average of 2.5% of the population), this goes together with a 51% increase in the number of shared cars in the postcode area. A positive effect is also observed for p2p car-sharing. Contrary to our expectation that car-sharing is less prevalent among households with children, no effect of household size on the number of shared cars was observed for both forms of car-sharing.

Income is found to have a positive relationship with the number of cars shared for both forms of car-sharing. A positive relationship of education is only observed for p2p car-sharing. Also the percentage of 25–45 years olds relates positively to the number of shared cars. For b2c car-sharing, in line with claims that expatriates make more use of car-sharing services, the percentage of Western immigrants positively

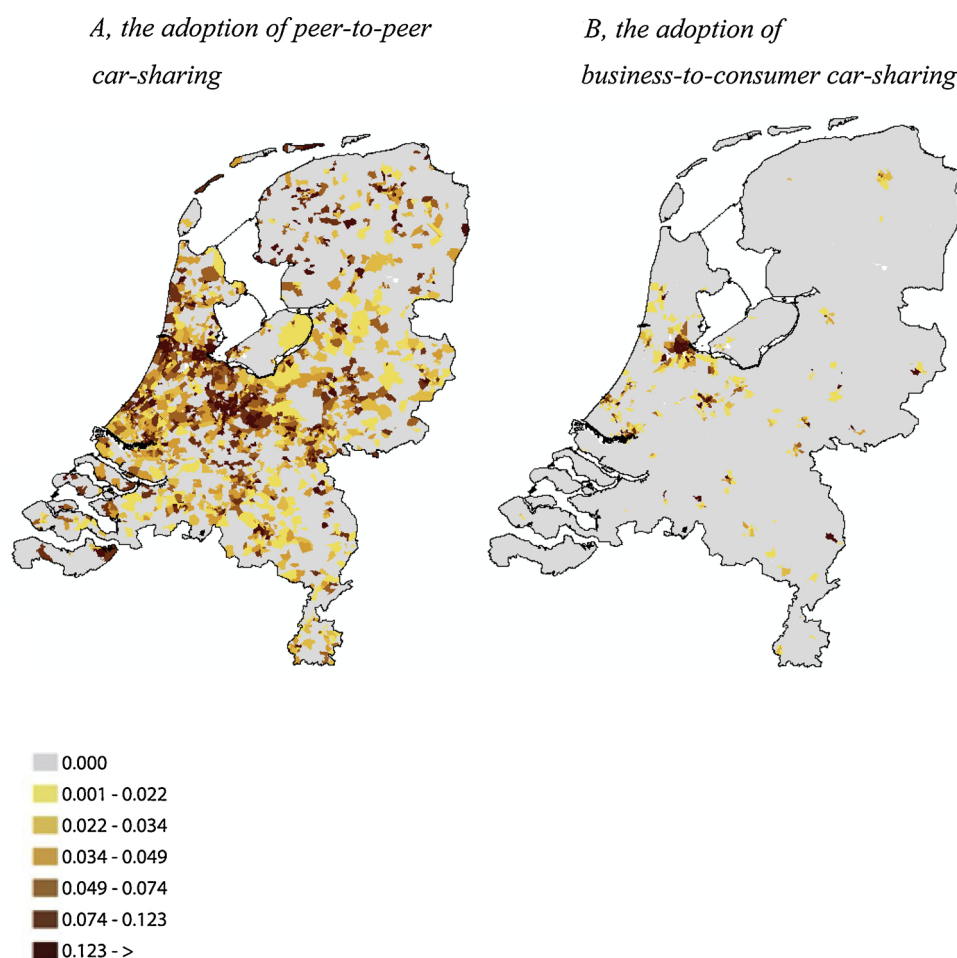


Fig. 3. A, the adoption of peer-to-peer car-sharing. B, the adoption of business-to-consumer car-sharing (shared cars per 100 inhabitants).

Table 3

Coefficient estimates for the zero-inflated model part.

	Business to consumer-car-sharing		Peer-to-peer car-sharing	
<i>Regime</i>				
Motorization rate	0.147**	(0.0487)	0.0237	(0.0203)
<i>Landscape</i>				
Population density ($\times 1000$)	−0.0104	(0.0730)	−0.0667	(0.119)
Distance to facilities (standardized composite measure)	0.0279	(1.414)	−0.0696	(0.280)
Environmental organization membership (%)	−1.012**	(0.342)	−0.0570	(0.158)
Household size	3.434*	(1.392)	0.994	(0.912)
Household income ($\times 1000$)	0.0327	(0.0752)	−0.0616	(0.0502)
Highly educated (%)	−0.193*	(0.0957)	−0.0366	(0.0275)
Age between 25–45 (%)	−0.0429	(0.0575)	−0.0224	(0.0336)
Western immigrant (%)	0.0464	(0.0571)	0.0175	(0.0336)
<i>Niche</i>				
University city (yes/no)	1.202	(0.639)	−0.443	(0.519)
Policy (yes/no)	−0.697	(0.520)	−0.199	(0.500)
<i>Control</i>				
Population ($\times 1000$)	−0.0968	(0.0582)	−0.578**	(0.194)
Constant	−7.333	(5.035)	0.964	(2.524)
Observations (total model)	2,516		2,516	

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

relates to the number of shared cars. However, this is not the case for p2p car-sharing where a negative effect is observed.

Finally, niche level factors are considered. Municipal information-related policies are positively associated with the adoption of both forms of car-sharing. No difference between university cities and other

areas was found.

When comparing the results for p2p car-sharing and b2c car-sharing, most differences are observed in the zero-inflated part of the model. Whereas the regime (and some landscape) factors relate to the non-availability of b2c car-sharing, none of the factors in this study did

Table 4

Estimates for the count (negative binomial) model part.

	Business to consumer-car-sharing				Peer-to-peer car-sharing			
	Coefficient		% expected change in count per unit increase	% change in count per standard deviation increase	Coefficient		% expected change in count per unit increase	% change in count per standard deviation increase
<i>Regime</i>								
Motorization rate	−0.0248**	(0.00825)	−2.4	−19.3	−0.00991*	(0.00441)	−1.0	−8.2
<i>Landscape</i>								
Population density (×1000)	−0.0246	(0.0156)	−2.4	−7.8	0.00274	(0.0131)	0.3	0.9
Distance to facilities (standardized composite measure) ^a	−0.549	(0.371)	−42.3	−27.7	−0.280***	(0.0709)	−24.4	−15.2
Environmental organization membership (%)	0.415***	(0.0543)	51.4	62.0	0.271***	(0.0312)	31.1	37.0
Household size	−0.441	(0.497)	−35.6	−13.0	−0.147	(0.140)	−13.7	−4.5
Household income (×1000)	0.0414*	(0.0197)	4.2	30.5	0.0146*	(0.00732)	1.5	9.8
Highly educated (%)	−0.0256	(0.0151)	−2.5	−20.7	0.0108*	(0.00516)	1.1	10.3
Age between 25–45 (%)	0.0542***	(0.00994)	5.6	35.7	0.0370***	(0.00490)	3.8	23.2
Western immigrant (%)	0.0756***	(0.0213)	7.9	43.9	−0.0231**	(0.00730)	−2.3	−10.5
<i>Niche</i>								
University city (yes/no)	0.487	(0.290)	62.8	17.7	−0.0393	(0.0634)	−3.8	−1.3
Policy (yes/no)	0.583***	(0.150)	79.1	29.3	0.192*	(0.0748)	21.2	7.6
<i>Control</i>								
Population (×1000)	0.136***	(0.0181)	14.6	71.0	0.110***	(0.00896)	11.6	54.3
Constant	−4.551***	(0.792)			−1.351***	(0.366)		
Observations (total model)	2,516				2,516			

*** p < 0.001.

** p < 0.01.

* p < 0.05.

^a The distance to facilities variable is composed of the standardized versions of variables measuring the distance to multiple facilities (such as schools, daycare etc.). The “Per unit” value can therefore not be interpreted as kilometer distance.

so for p2p car-sharing. The results of the negative binomial part of the model suggest that the motorization regime hampers the scaling of both car-sharing niches, but more so for b2c sharing than for p2p sharing. P2p car-sharing then is less constrained by the prevailing regime based on private car ownership than b2c car-sharing, which is also in line with the rapid growth of p2p sharing and the much slower development of b2c sharing (Fig. 2).

6. Concluding remarks

The geography of sustainability transitions is a rapidly emerging topic of scientific interest [3,5]. We applied this framework to the study of car-sharing against the background of the current regime of private car ownership. The main novelties in our study are 1) the development of a spatially heterogeneous notion of the regime, niche and landscape levels of the Multi-Level Perspective (MLP), b) the analysis of two competing niche innovations and their respective relations to the current regime, and c) the deployment of a quantitative approach to sustainability transitions by studying the adoption of all cars shared via the b2c and p2p model, in all Dutch neighbourhoods.

The findings show that the geography of the regime indeed relates to the adoption of car-sharing across neighbourhoods. In areas with lower rates of motorization we find a higher number of shared cars. A stronger regime also increases the chances of having zero shared cars in a neighbourhood. Importantly, this latter finding was confined to b2c car-sharing as the availability of p2p car-sharing is insensitive to the motorization rate. These findings indicate that p2p car-sharing can be understood both as challenging the regime of private car ownership by allowing people to rent cars from peers instead of owning cars and as extending the current regime by enabling car owners to draw on the existing idle regime capacity of cars. We further found evidence consistent with the hypothesis that niche-creation policies by municipalities stimulate the adoption of shared cars. This holds for both types of car-sharing. Finally, we were able to explore multiple landscape factors ranging from physical factors such as population density and

distance to facilities to attitudes towards sustainability and more classic socio-demographic factors. These findings exemplify the soft pressures exerted by generic landscape factors that are largely exogenous to the specific development of niches in the context of a regime. Environmental awareness had a significant positive relationship to car-sharing adoption, a finding in line with the role of ideological motivations among car sharers identified in previous studies [38,50].

This study enhances our understanding of transition processes in the following ways. First, we conceptually and empirically demonstrate the geographical heterogeneity of the socio-technical regime. Herewith we contribute to a further unpacking of the regime concept. In this study the global regime of private car ownership is seen as present to different extents locally. With our approach we also identify the weak spots in the regime that form an environment conducive to the emergence and upscaling of innovation [66]. Second, the paper demonstrates the influence of the innovation-regime relationship on spatial adoption. It is shown how an innovation that is largely symbiotic with the regime is more likely to emerge in a variety of places, and also where the regime is strong. Herewith we provide insight in the pathways through which transitions unfold [11,12]. Geels et al. [12] point out how static landscape factors (i.e. the socio-spatial context), influence transition pathways. We add here that this influence of the socio-spatial context is dependent on the innovation-regime relationship. Niche innovations that are more symbiotic with the regime depend less on specific landscape-level stimuli, and hence emerge in a larger variety of places. Third, many of the landscape variables we took into account were based on the characteristics of the user base. In the (geography of) transition literature users and market structures remain understudied [5]. With our inclusion of user characteristics we hope to stimulate more acknowledgment of differences between user groups and their importance for innovation upscaling in transition studies. The landscape variables can equally help to unpack the effects of car-sharing on social groups or areas that are currently disadvantaged in terms of access to transport. While harder to observe from our aggregated analysis, further studies might here consider the uptake of car-sharing in socially disadvantaged

peri-urban areas, in which car dependence is high.

This research has taken a quantitative approach to transitions. Our study thus speaks to recurrent calls for more methodological diversity in transition studies [32,67,68] and for making cross-overs between perspectives in the broader energy debate [56,57]. This study exploits the geographical variation at all levels of the MLP to explain the transition to car-sharing. This is an addition to current process-based approaches dominant in transition studies. These explain transitions almost exclusively using sequences of events in time, which risks an overemphasis on historical particularities. Our approach allows to compare all places cross-sectionally, also including places where innovative activity is absent, and to analyse the effect of niche, regime and landscape factors as these vary across places. Particularly now that various sustainable innovations have started to scale up, our perspective is relevant as it enables to go beyond the study of one or some particular niche experiments. Specifically, for the geography of transitions field our approach not only enables us to show *that* place-specificity matters, but also *how* it matters across areas by identifying relevant factors that influence adoption [5].

We also hope to show that the Multi-Level Perspective has something to offer to classic adoption studies. Prior spatial adoption analyses generally use solely a set of socio-demographic factors in combination with built-environment variables to analyse adoption [33,69,34]. A critique of this approach is that it ignores the institutional embeddedness of the innovation adoption process [70]. The contribution of the MLP lens, then, is to explicitly take into account the embeddedness of the adoption process in the context of an existing socio-technical regime. By doing so, it also allows one to analyze multiple niche innovations and their respective relations with the current regime.

Studying a complex phenomenon such as a sustainability transition in a quantitative manner necessarily involves simplifications and focus. First, from the many factors associated in the literature with niches, regimes and landscapes (politics, markets, infrastructure, values, technologies, actors etc.) in our explorative study only some were operationalized. In particular, the strength of the socio-technical regime, was only measured by the motorization rate. Future research might use an approach consistent with the recent operationalization of regimes as developed by Fünfschilling and Truffer [71] and map the strength of multiple regime dimensions (i.e. their institutionalization) in multiple localities. Second, we were only able to investigate the number of the shared cars, and not the intensity of their use over a certain time period. Such data are, however, not made publicly available. Our modelling approach was limited to the static analysis of regime, landscape and niche factors on the adoption of car-sharing. Future research could attempt to model feedback loops between developments on regime, niche and landscape levels over time, for example using structural equation modelling (which allows for modelling of various causal pathways). This would also help to better single out the direction of causality in the case of the motorization and policy variables. In the case of motorization, with the growth of car-sharing, there could be an increasing effect of car-sharing adoption on motorization levels.

Appendix A. Correlation table

	Shared cars (p2p)	Shared cars (b2c)	Motorization	Population density	Distance to facilities	Environmental awareness	Household size
Shared cars (p2p)	1						
Shared cars (b2c)	0.679	1					
Motorization	−0.497	−0.386	1				
Population density	0.527	0.451	−0.721	1			
Distance to facilities	−0.373	−0.214	0.576	−0.589	1		
Environmental awareness	0.457	0.374	−0.178	0.210	−0.220	1	
Household size	−0.380	−0.336	0.493	−0.492	0.468	−0.412	1
Income	−0.058	−0.057	0.455	−0.349	0.246	0.231	0.527
Highly educated	0.533	0.448	−0.217	0.295	−0.306	0.763	−0.384
Age 25–45	0.481	0.396	−0.627	0.620	−0.413	0.013	−0.3611
Immigrants from Western countries	0.334	0.346	−0.332	0.429	−0.408	0.268	−0.588

Third, the problem of “ecological fallacy” is inherent to our type of research that makes use of aggregates such as postcode areas [72]. Although the four-level postcode is a fairly detailed level of analysis, it should be reminded that we measure the averages for the postcodes areas and do not study individual users. There is thus always a risk of misinterpretation when analysing characteristics of users and adoption. For further research on car-sharing adoption it would be worthwhile to gather data on individual car-sharing users instead. Also note that our research was an attempt to complement MLP studies that look only at one specific region, and instead compare developments in multiple localities. Still we only consider one country. It would be worthwhile to see to what extent the approach taken here provides useful insights when applied to different countries or technologies.

Coming to policy development, both the multi-level approach to the geography of sustainability transitions and its combination with a quantitative methodology can provide guidance. From establishing the regime as a spatially heterogeneous entity influencing local adoption processes, it follows that apart from policies stimulating niches, complementary local policies that weaken the regime can be equally important. Examples of regime-weakening policies in the case of car-sharing could be increasing cost of private ownership (e.g., by raising taxes on ownership or residential parking fees) and withholding of parking permits of second or third cars per household. As shown, also niche level policies fostering car-sharing awareness can have a positive effect on adoption. For policy practitioners and entrepreneurs, our quantitative approach can be useful for identifying locations suitable for the execution of niche experiments by taking into account not only niche opportunities but also regime and landscape factors. Such an approach might also be useful for identifying areas for the “spatial acceleration” of transitions, implementing measures first in areas in which the innovation is likely highly accepted and then moving towards areas with increasing resistance. All in all, our analysis here could be helpful in the identification of leverage points for stimulating transitions at a highly disaggregated scale.

Declaration of interest

None.

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Municipal car-sharing policy(p2p)	0.451	0.366	−0.468	0.453	−0.334	0.317	−0.391
Municipal car-sharing policy(b2c)	0.434	0.323	−0.511	0.529	−0.423	0.307	−0.419
University city	0.438	0.414	−0.500	0.445	−0.308	0.271	−0.440
Population	0.512	0.306	−0.488	0.443	−0.502	0.054	−0.256

	Income	Highly edu- cated	Age 25–45	Immigrants Western countries	Municipal car-sharing policy (p2p)	Municipal car-sharing policy (b2c)	University city	Population
Shared cars (p2p)								
Shared cars (b2c)								
Motorization								
Population density								
Distance to facilities								
Environmental awareness								
Household size								
Income	1							
Highly educated	0.383	1						
Age 25–45	−0.407	0.206	1					
Immigrants from Western countries	−0.149	0.413	0.316	1				
Municipal car-sharing policy (p2p)	−0.159	0.390	0.418	0.366	1			
Municipal car-sharing policy (b2c)	−0.161	0.390	0.454	0.387	0.772	1		
University city	−0.213	0.386	0.420	0.338	0.472	0.542	1	
Population	−0.186	0.149	0.342	0.272	0.255	0.332	0.278	1

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