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Car-Sharing Services – Part A Taxonomy and Annotated Review

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Abstract. The growth of car-sharing services as a new and more sustainable way of transportation is shifting the private mobility from ownership to service use. Despite the emerging importance of this type of mobility and the large number of papers present in the scientific literature, to the best of our knowledge no extensive and structured analysis has been performed in order to classify the research and determine the mainstreams. Moreover, due to the novelty and the peculiar structure of this type of service both from the business and the operational point of view, the literature analysis should include a business and tariffs models analysis. Aim of this paper is to focus on the existing literature, introducing a taxonomy, considering in it the different aspects, including the specifications of the different car-sharing services and the research questions considered in the papers. Second, we analyze and classify 95 papers appeared in the last fifteen years, giving an insight of the mainstreams. Finally, we deeply study the trends and research perspectives of the literature, showing the unbalancing between the literature related to the operational level and the economic, business development and customer validation aspects.

Keywords: Car-sharing, taxonomy, optimization, business models.

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1 Introduction

In the last years the growth of car-sharing services as a new and more sustainable way of transportation is shifting the private mobility from ownership to service use. Although the first shared used vehicles system can be traced back to 1948 in the city of Zurich (Switzerland), motivated by economic reasons, in the following years other attempts of public car-sharing systems were not successful. Only in the late 1980s the development in the market of communication technology allows the launch of several successful car-sharing programs (such as Mobility car-sharing in Switzerland and Stattauto in Germany). In the early 1990s car-sharing models become popular and nowadays several consolidated programs are operating in more than 600 cities in more than 18 countries. More recently car producers, as Dailmer, BMW and FCA group, are directly involved in car-sharing operations with the scope of finding new channels to market the produced cars [4, 95, 92, 94, 93].

The basic idea of car-sharing is very simple: a fleet of cars can be shared between several users (members of car-sharing programs), which can drive a car when they need it, without the burden of a private car (such as purchase cost, taxation, insurance, maintenance). Even if the idea is conceptually simple, in the last years several business models came to the market and the meaning of the word car-sharing has assumed various declinations, implying different business and operational models. The increasing interest by car producers and private investors in car-sharing services lies in the increasing awareness of public stakeholders to the environmental impact of urban policies, the large amount of funds available in the past decades for innovative solutions for people moves and the maturity level reached by mobile and ICT solutions. Without considering those models referred to the sharing of a private car, the first car-sharing model is the so called traditional (two-way), or station based, i.e., shared vehicles must be picked from a station and returned to the same station. As an evolution of this model, the one way car-sharing model allows members to start and end the rental period in different stations. The last model came to the market is the free floating one. In this case members can pick up and return the vehicle in any parking lot within the operation area (which is normally corresponding to the city boundaries), paying only for the driving time. Introduced in the past recent years, free floating car-sharing systems see a rapid growth, making car-sharing an attractive alternative to a self-owned car and contributing significantly to the worldwide growth in car-sharing. As shown in current studies, free floating car-sharing adoption can lead to positive effects in reduction of urban emissions and city congestion [72], and a recent Europe-wide project funded by European Union estimate that one car-sharing vehicle can replace up to 8 personal cars [64].

Despite the emerging importance of this type of mobility and the large number of papers present in the scientific literature, to the best of our knowledge no extensive and structured analysis has been performed in order to classify the research and determine the mainstreams. Moreover, due to the novelty of this type of service both from the business and the operational point of view, the literature analysis should include a business and tariffs models analysis. In fact, the business in car-sharing typically started focusing on the operational level, disregarding the business development phase. Consequently, the optimal management of the fleets and of the operations were the main issues, being the business sustained by means of public funds (6.3 billion just in the Horizon 2020 programme to support transport researches and innovations, with a strong focus on urban mobility, logistics and intelligent transport systems and applications). Now that the pioneering phase comes at its end, it is necessary a global view of the research and, at the same time, its integration with the business view of the services, in order to build sustainable car-sharing services.

Unfortunately, discuss both the issues in the same paper giving the right insight to each topic while maintaining the size of the paper reasonable was not possible. For this reason we decided to split the analysis in two parts: a first one which derives a taxonomy from the past literature and uses it to present a clear and global view of the literature and a second one focusing on the business models of the existing services and the effect of their decisions in terms of tariffs and service modes in relation with their customer segmentation.

More in detail, in this first paper we want to answer to the following questions:

- Can we find a series of keywords/axes such that we can categorize any paper dealing with car-sharing services?
- Can we organize the papers in a taxonomy and, by means of that taxonomy, highlight the research mainstreams and future directions?
- Can we see any structural lack in the literature?

In order to answer to our research questions, we structured this paper as follows. We first introduce a taxonomy for papers dealing with car-sharing services, considering in it the different aspects, including the specifications of the different car-sharing services and the research questions considered in the papers (Section 2). Second, we analyze and classify 95 papers appeared in the last fifteen years, giving an insight of the mainstreams (Section 3). Third, we deeply study the trends and research perspectives of the literature (Section 4), with a specific focus on four issues related to car-sharing services: the analysis of the user behaviors (Section 4.1), the forecast of the service demand (Section 4.2), the use of optimization tools for the design and the management of the service (Section 4.3) and the business development and its effect it driving the research (4.4). In particular, we demonstrate that there is an imbalance between the literature related to the operational level and the user behaviours and business developement.

2 Search methodology

In the following sections, we present our classification and then its application to the 95 papers we have selected for the analysis.

2.1 Paper selection

The first step for constructing a new taxonomy is the identification of major characterizing factors and the extraction and analysis of trends. Through a qualitative approach, we analyzed the information related to the selected papers and we then organized the information by axes. Each axis, if needed, is then split in categories.

First of all, we looked for reviews and surveys. At our best knowledge, no specific surveys for papers related to car-sharing services. So, we first looked to the best practices defined by other taxonomies in the literature [6, 82, 35]. To select the papers, we used scientific refereed journals and refereed conference proceedings as a source for the car-sharing literature. In order to retrieve the papers, we used the Scopus database because, concerning the transportation field, this bibliographic database contains articles from all major journals dealing with transportation and management. Furthermore, the majority of these journals are also listed in the Excellence in Research for Australia (ERA) 2012 Journal List by the Australian Research Council [24], a known list of scientific journals.

The main keyword used in the research is *car-sharing*, combined with its multiple synonyms used in literature, such as *car sharing* and *carsharing*. The latter was been combined with the following additional keywords: *electric*, *station based*, *one-way*, *free floating*, *business*. We restricted our search to the papers dated from 2001 until 2015 in order to consider the most recent papers.

After an additional screening operation consisted of an analysis of abstracts, main topics, and results of papers, we selected 95 of these. This additional phase was needed in order to remove, for example, the papers that considered specific aspects as the technologies for the charging stations of electric vehicles, powertrains optimization and other technical features used in the car-sharing services, but not pertinent with a topology of car-sharing services.

2.2 Taxonomy dimensions

Figure 1 presents the categorization of research works in this review. The taxonomy describes articles according to five main axes, which constitute the first level of our taxonomy: *Mode*, *Engine*, *Optimization objective*, *Time Horizon* and *Methodologies*. The first two axes concern the car-sharing service specifications, while the remaining three inform on the research problem and the role of the research in the paper under consideration. Then, each axis is organized in a set of categories. This section presents each axis in turn, briefly describing its object and scope.

Service specifications	
Mode	Engine
Two-way (station based)	*Fully thermic*
One-way (station based)	*Green*
Free floating	
Not Applicable	

Research problem		
Optimization objectives	Time horizon	Methodologies
Business and Service	*Design*	*Simulation*
Infrastructure	*Planning*	*Stochastic optimization*
Fleet management	*Operational and real time*	*Combinatorial optimization*
		Statistical analysis

Figure 1: Resume of the taxonomy axes

2.2.1 Mode

Mode identifies the different ways in which a car-sharing service can be provided.

- **Two-way (station based)**: In the *Two-way* [79] mode the available cars are parked in defined spaces and the journey must start and finish in the same parking lot, not considering the intermediate stops that the customer may plan. The set of parking lots is predefined.
- **One-way (station based)**: The *One-way* [79] mode is similar to the traditional mode, but in this case the parking lot in which the journey finish can be different from the parking lot in which it started. The set of parking lots is predefined.
- **Free-floating**: The *Free-floating* [38] mode is the last one came to the market; the cars are freely parked in public spaces within the operational area, and the journey can start and finish in any point in this area.
- **Not Applicable**: This section comprises all the selected papers that cannot be classified in the aforementioned dimensions. Indeed, some papers analyze the car-sharing service without reference to any particular mode.

2.2.2 Engine

This dimension is used to classify the engine type of the cars involved in the car-sharing service.

- **Fully thermic**: in this section are contained papers that analyze fleets with fully thermic engines (gasoline and diesel).
- **Green**: in this section are contained papers that analyze fleets with green engines (electrical, natural gas, liquefied petroleum gas (LPG) or hybrid).

2.2.3 Optimization objectives

The *Optimization objectives* dimension classify the analyzed papers in terms of the aspect of the service to be optimized.

- **Business and service**: papers in this cathegory deals with the service level. In details, we consider here all the papers dealing with the business models and the definition of the car-sahring service, including the identification of the user behaviors and the demand estimation. Special cases are the identification of the user behaviors and the demand estimation.
- **Infrastructure**: papers analyzing the optimal design and location of the car-sharing infrastructures, as the parking stations and, for electrical vehicles, the charging stations.
- **Fleet management**: papers analyzing the operations for the management of the fleet, as determining the fleet size and defining the car relocation strategies.

2.2.4 Time horizon

This axis considers the interval of time for which the decisions remain valid.

- **Design (strategic)**: strategic decisions that players must keep in account in the designing of the service, including fleet type definition, user behavior, pricing policies, market place identification (green fields and city identification) and demand identification.
- **Planning (tactical)**: this category considers all the papers dealing with service planning decisions, including fleet size definition, location of facilities (parking stations, e-charging stations, etc.), urban areas boundaries, management of uncertainty of local demand.

- **Operational and real time**: operational and day-by-day decisions related to the service provided: relocation strategies, car maintenance, refueling, car washing, etc.

2.2.5 Methodologies

The *Methodologies* axis groups the papers according to the scientific approach used by the authors.

- **Simulation**: *simulation* aims to imitate the operation of the real-world processes. These methodologies are adopted to estimate the demand of the service in order to help the decision making process for new operators. Simulations are mainly based on real data referring the transport behavior of the dwellers of a specific area.

- **Combinatorial optimization**: *combinatorial optimization* consists in modeling, analyzing and solving a decisional problem finding the optimal objective function according to a set of constraints when the data involved in the problem under study can be considered as deterministic. It is used in car-sharing services for the management of the fleet (e.g. relocation of cars) as well as for the design and the planning of the service.

- **Stochastic optimization**: *stochastic optimization* methods are used to solve decisional problems where the data are affected by uncertainty. In the car-sharing services case, uncertainty often affects the service demand or the flows of vehicles between different parking stations or within the service area.

- **Statistical analysis**: *statistical analysis* methods are mainly adopted for analyzing data sets deriving from real observation (such as data sets provided by operators) or from surveys and focus groups; these methods are used to analyze the state of the art in context where at least one operator is working.

3 Literature analysis

In the following, we apply our taxonomy to the 95 selected papers and we use it to derive a first numerical analysis. Table 1 shows the list of sources, grouped in two subsets: journals and peer-reviews proceedings.

Although the plethora of journals that cover topics on car-sharing services is quite broad, it is interesting to note that more representative ones are Transportation research Record and Transportation Research Part A-F. Indeed they contain 45% of papers collected in journals and 26% of the total. Moreover, a large part of literature derives from proceedings (e.g. IEEE international conferences, Procedia - Social and Behavioral Sciences and Transportation research Procedia). About 34% of papers refer to this category and they are usually papers describing real projects and applications of car-sharing services. Thus, the proceedings remain the main sources to have a better insight of the real-world projects.

3.1 Mode analysis

The results of the mode analysis are shown in Figure 2. More than 50% of the analyzed papers are referred to one way mode, 18% are referred to free floating mode and 21% are referred to two way mode, while 7% of the papers have not been classified according to this dimension. Furthermore, in recent years there has been a growing interest in the electric car-sharing. This solution leads to an increase of interest in the one way mode, since this type of vehicles requires the installation of charging stations.

Figure 3 shows how the focus of the papers have changed during the last years. The chart shows an increasing of the interest in car-sharing in the recent years, since 70% of the selected papers were published from 2011 to 2015. The first result is that the one way mode was the first to be analyzed by the selected papers, while free floating mode was analyzed from 2011 with a peak in 2014. Since free floating mode has been studied to meet the growing demand for flexibility from the users of the service, the development of this service was made possible thanks to the development of IT infrastructures such as car positioning in the service area, mapping of the available cars and applications for the final users. Thus, this type of car-sharing mode started to be considered by researchers and practitioners only when the related IT technologies reached a sufficient maturity level.

3.2 Engine analysis

According to this dimension, 57% of the analyzed papers are related to fully thermic engines. Further analysis (Figure 4) show that the interest in green engines (mainly in electric or hybrid vehicles) increased in the recent years; the chart shows also an increase of publications related to fully thermic engines, due to the increased development of free floating car-sharing mode.

The chart in Figure 5 shows that both fully thermic and green engines have been studied mainly referred to one way mode, while free floating mode with green engines (24% of overall green engines publications) are referred to hybrid vehicles. Accordingly to the increasing awareness of public stakeholders to low-emission and eco-friendly solutions, there are more publications related to green engines than publications referred to fully thermic ones in the one way and free floating modes.

3.3 Optimization objectives analysis

According to this dimension, the chart in Figure 6 shows that 70% of these papers are related to business and service optimization, 19% are related to fleet management optimization and 11% are related to infrastructure optimization.

The chart in Figure 7 shows an increased interest in business and service optimization in the last years, with 53% of the papers published from 2011, and 30% of these were published in 2013 and 2014. Infrastructure and fleet management optimization were investigated in the recent years because of their importance for green car-sharing services (infrastructure) and free floating car-sharing services (fleet management).

The chart in Figure 8 shows the results of the optimization objectives analysis referred to the different service modes. Business and service optimization has been analyzed for all the different service modes, but predominantly for one-way mode (in 54% of the papers analyzing business and service optimization). In this case, the analysis is referred to behavioral and demand estimation issues. Also infrastructure and fleet management optimization is mainly referred to the one way car-sharing mode: for this mode is very important to plan the correct location of the stations (in particular for electric/hybrid vehicles) and the relocation and maintenance strategies in order to balance the number of cars in the different stations and cope the users' needs.

Figure 9 shows the relation between optimization objectives and engine type. Business and service optimization and infrastructure optimization analysis are referred both to fully thermic and green engines, while fleet management becomes more studied for the fully thermic vehicle fleets (59% of papers).

3.4 Time horizon analysis

The chart in Figure 10 shows that 68% of the selected papers are related to the design of a car-sharing service, while planning and operational and real time analysis represent the 16% of papers selected. Analyzing the trend over time of publications (see Figure 11), an increased interest in the design (strategical planning) emerges from 2011, with many papers analyzing the user's behaviors and the demand estimation to identify the market places.

The chart in Figure 12 analyzes the time horizon related to the service modes. Since one way mode is the mostly analyzed by the selected papers, the chart shows also how planning and operational and real time are the issues more often analyzed for this service type. In particular, the interest in operational and real time matters is justified by the need of solid relocation strategies and accurate location of the parking stations.

The chart in Figure 13 analyzes the relationship between time horizon and engine type. All the issues in the time horizon dimension are mostly investigated with fully thermic engine vehicles. Furthermore, green engine vehicles are more analyzed according to the service design aspects (e.g. user behavior). This is logic by considering the recent introduction of green car fleets in commercial car-sharing solutions.

3.5 Methodologies analysis

As shown in Figure 14 a little less than 70% of the analyzed papers use a statistical analysis tool, while combinatorial optimization and stochastic programming method have a limited diffusion. This trend seems to be in contrast with the general need of limiting the costs of the service operations. It may be linked to a more general lack of linking between business models, business development, customer discovery and validation and operational models (see Subsection 4.4).

The chart in Figure 15 crosses the methodologies with the year of publication of the selected papers. During the last years statistical analysis tools increased, accordingly to the increase of the number of publications.

Crossing methodologies with the service mode (see Figure 16), the evidence is that statistical analysis is used for all the different service modes, while simulation and optimization (both stochastic and combinatorial one) are mainly used for one way car-sharing service.

The chart in Figure 17 shows the results of the crossing of methodologies with engine type. Simulation tools are largely used in studies related to fully thermic engines, while green engines are mainly analyzed using optimization tools (in particular combinatorial optimization). This behavior can be explained with the need, in the case of electric cars, of a more accurate phase of design of the service and planning of the infrastructures location due to the need of charging stations.

The chart in Figure 18 crosses methodologies with optimization objectives. While statistical analysis is mainly used in studies related to business and service optimization (usually based on time series data collection), infrastructure optimization is largely analyzed using stochastic optimization tools. Fleet management optimization is mainly analyzed with both simulation and stochastic optimization tools.

Finally, Figure 19 shows the results of the crossing of methodologies with time horizon. Design issues are mainly faced with statistical analysis and combinatorial optimization tools; stochastic optimization is largely used for planning issues, while simulation is the main tool for the analysis of design and operational and real time issues.

4 General trends and research perspectives

The aim of this section is to present a picture of the general trends and the research perspectives emerging from the literature. In 4.1 the focus is on the users behavior analysis, used mainly to determine how a car-sharing service could meet the customers mobility needs or the changes in users behavior consequent the introduction of a car-sharing service in a specific area. These studies are mainly aimed to quantify or at least estimate the positive effects (on environment, quality of life, land usage and traffic congestion) of the car-sharing services.

Sub-section 4.2 presents the issues related to the analysis of the demand, a key factor for the car-sharing operators to estimate the potential demand of the service in a specific area necessary to justify investments. In order to correctly address the issue it is important to accurately collect the primary data (Subsection 4.2.1); the two data collection methods mainly used are time series (in which historical data were analyzed to understand the underlying structure of the phenomenon) and qualitative and quantitative surveys (also including direct interviews, focus groups, brain storming sessions). The collected data are then analyzed (Subsection 4.2.2), most commonly by logit models (used in estimating the parameters of a qualitative response model) and logistic regression.

Sub-section 4.3 analyzes the papers according to their optimization objectives: business and service optimization, infrastructure optimization and fleet management.

Finally, sub-section 4.4 focuses on one of the biggest lacks in the literature: the absence of studies related to the business models linked to car-sharing services, their business development process, as well as the value proposition and customer segmentation.

4.1 Users behaviors and factors affecting the adoption

Since the early years the car-sharing has entered in the market, several researches are focusing on the impact of car-sharing on the urban mobility. They investigate mainly the characteristics of the services and the impact on users travel patterns an behaviors in order to estimate the potential demand and to investigate the main drivers of adoption [2, 3, 9, 66, 74].

In [3, 63, 66, 78] the authors carry on an overview of the car-sharing service (through experts interviews), focusing on the main involved actors and drivers of adoption. The most relevant factors impacting the growth of the system are related to parking policies, technology, vehicles, fuels and insurance.

Several publications examine mobility behavior of members and potential members of car-sharing services. In different studies [70, 71, 76, 92, 98, 104] the authors use stated preference methods to investigate the awareness and the acceptance of the service among car-sharing members. Then, by regression models, they identify the correlations between membership and social and demographic factors. Similarly, in [21] a binomial regression is used to model a spatial diffusion of car-sharing membership in Quebec City from 1996 to 2008, discovering how socio-economic factors such as education, motorization and family structure affect heavily the membership rate in the covered area.

In [76] Morency et al. estimate the factors affecting awareness and acceptance using both linear and logistic regression models, focusing on multimodal mobility patterns. Shaheen and Cohen present a method for the estimation of the potential market in Germany, analyzing potential users with objective and subjective criteria [92]. Unlike other studies, they focus on the satisfaction level towards other transportation means. Using a logit model, the study reveals that bus travelers are more attracted from car-sharing models, while people traveling with high frequency and through longer distances are less interested.

A more recent study individuates the presence of a latent demand for car-sharing in a specific area, with the consequence that the increase of the number of supplied vehicles combined with a marketing campaign could lead to an increase of car-sharing membership [98].

In [70] and [71] users are asked about their willingness to adopt different hypothetical service plans, with different pricing policies and vehicle distribution, examining the service characteristics and evaluating the economic utility of each plan.

In the last years, the growth of the performances of electric vehicles, the need of an electric mobility trajectory [27] and the increased attention to environmental issues shift the attention towards studies related to electric car-sharing systems, mainly focusing on propensity of the users and barriers to adopt these vehicles [23, 27, 31, 40, 44, 58, 61, 73, 88, 91].

Kumar and Bierlaire investigate the potential demand of these type of services in an academic community, with the result that electric vehicles could be chosen for short distances [61]. Furthermore, the research shows that the main factors of adoption of car-sharing services are related to cost reduction and traffic congestion, and respondents are willing to pay an additional cost for the use of an electric vehicle. Some studies, including [88], consider a specific age target, using factor analysis and ordered logit models to investigate their satisfaction about current travel patterns and to evaluate the willingness to join electric car-sharing services. In [44] the authors employ surveys on expectation and attitudes of users before and after using the services, and then use qualitative methods to identify the motivations leading to successful adoption of hybrid and electric car-sharing services. The results show that electric car-sharing is perceived as part of an integrated transport system for short trips, with the consequence that the issue of range (also called Range Anxiety) have low relevance. In [70] and [71], and more recently in [23], authors investigate about economic utility of round-trip car-sharing services (which include also electric vehicles) employing both multinomial logit and mixed logit. The result is a reluctance to adopt fully electric vehicles, particularly for long distances, even if the distance is lower than the range of the vehicle, maybe because of uncertainty in predicting travel patterns. Similar studies, considering on the impact of electric vehicles in free floating car-sharing services, are presented in [67, 97].

A large number of studies [22, 29, 30, 41, 53, 56, 69, 87] focus on the behavior of current users of car-sharing services all over the world, mainly investigating on drivers of usage, changes in travel behavior before and after joining the service and membership duration. These papers analyze datasets from car-sharing operators or surveys. In [13, 22, 26, 29, 41, 53] and [75] the authors tried to predict the optimal location for the stations in order to maximize the integration of car-sharing service with other public transportation means. Genikomsakis et al., through a Geographic Information System (GIS), analyze regions already covered by the service, correlating factors like parking pressures, population density, age of the neighborhoods and car-sharing service level (defined as the number of vehicle availability) with census data [41].

A similar methodology is recently used in [13]. A GIS-based analysis carried on in several region in the US finds that transportation characteristics are stronger than demographic information as indicators for car-sharing success. The aim of the study is to present a tool to identify neighborhoods and factors, as low vehicle ownership and high rate of one-person households, in which car-sharing could positively operate; the same tool has then been tested in Austin (Texas).

In [53] Kato et al. find out how the success of car-sharing services is strictly correlated with factors like the size of car-sharing stations, seasonal impact, age of the vehicles and multimodal transport network, i.e., presence of different transportation modes nearby the car-sharing stations. Similar results are obtained in [22], where the role of other transportation modes on car-sharing services penetration is investigated, and in [29], where, through a logistic regression and a duration model, the authors quantify the positive correlation with the number of stations and the role of parking costs on the likelihood of vehicles renting. In [87] the authors model and forecast users membership duration and usage patterns, finding out a positive correlation between vehicle availability and frequency of use and between personal car ownership rate and membership duration. [30] and [56] identify the changes in transport behavior before and after joining car-sharing service. In particular Khan et al. show how in areas with population density up to 10000 persons/square kilometer the introduction of car-sharing leads to a slight decrease in public transport usage, an increase of cycling and walking and an average driving reduction [56].

One of the major issues of car-sharing services, because of related behavioral impacts and cost reduction, is the impact of car-sharing in household car ownership. Two opposite trends emerge: some studies state that car-sharing could contribute to a reduction of total number of cars mileage as well as a reduction of car ownership, while other studies affirm that car owners could not forego private car and non-car owners may use car-sharing instead of other public transport modes. [47] and [57] explicitly consider this aspect. In details, the first paper analyzes the de-motorization potential of the service with consequent impacts on environment through surveys to different car-sharing service members in North America, showing the different efficiency between the private car (of which age and model were asked in the surveys) and the car-sharing service. Hildebrandt et al. investigate users travel patterns, vehicle usage and membership duration in correlation to several characteristics of the service, stating that car-sharing users are usually environmental friendly, and that less perceived cost savings usually lead to shorter membership duration and frequency of usage [47].

In [12] both in deep interviews and focus groups are used to investigate the propensity of customers to adopt a bundle of products and services, facing their concerns about the possibility that their needs might be unsatisfied. Results show that it is important for the planners to focus on the interaction with customers, in order to gain their confidence on the service; another important issue is to educate customers on the life cycle costs of the products, in order to increase their awareness on the potential savings related to service adoption.

In the last years the development of information technology have become more relevant, with several studies concerned on the impact of them on the car-sharing system [45, 47, 62]. In [47] the authors show the fundamental role of information systems for the success of the car-sharing systems, allowing real time information on the fleets and helping users in the localization of the available vehicles. Applying an optimization model to a one-way car-sharing service, the authors found out a potential increase of car-sharing operators profits due to users flexibility and real time information. Information systems are analyzed also for electric car-sharing systems in [62], where mobile technology can supply the necessary infrastructure to let the system correctly operate.

Firnkorn and Mller consider the strategy of an automaker entering in the car-sharing market (focusing on the specific case of Car2Go) with the scope to start a new business segment and reach positive effects on branding [37]. After the collection of primary data (all Car2Go members in 2010 in the city of Ulm were invited to answer to an on line survey), empirical analysis are conducted to evaluate the impact on private vehicle holding after 18 months of service. Results show that after 18 months of service Car2Go has contributed to a strong reduction of vehicle ownership, with an even stronger potential impact estimated for the future.

The analysis conducted in [89] studies how the effects of risk perception of products ownership can influence the adoption of access-based services, bringing to the conclusion that a higher usage of access-based services can increase the likelihood in ownership reduction by the customers.

Kopp et al. analyze the travel behavior of members of a free floating car-sharing service, comparing the results with similar results from a sample of non-members. Results show evidence that car-sharing members are more multimodal than non-members, and even the distance traveled are lower for the car-sharing members [59].

4.2 Demand analysis

Car-sharing systems management has a complexity directly linked to the interplay effect of demand and supply. In order to optimize operating issues and to estimate the effects of car-sharing services on mobility management it is useful an accurate model of demand and supply [50].

Due to the strong dependence between the availability of vehicles and the number of trips, it is difficult to correctly model the car-sharing demand. Although various car-sharing simulation models were presented across the last years, it is difficult to represent accurately the supply side, focusing in particular on the cost-benefit analysis necessary to justify investments. Moreover, the recently growth of free floating car-sharing systems introduces further complexity, adding uncertainty as to the location where the vehicles can be picked up and returned. In order to correctly model the service, fundamental parts of the research are the data collection (Subsection 4.2.1), in which a properly recording of the variables must be ensured, and the tools developed to carry on the analysis (Subsection 4.2.2).

4.2.1 Data collection

Data collection, i.e., the detection of the variables that are the object of study, is a key activity. To produce good results it must be ensured that the variables under study are recorded properly. Some variables, such as age and gender can be detected easily, others are more difficult (such as variables related to cognitive, emotional, behavioral, learning, etc). In the literature, data are mainly collected by two methods: time series and questionnaires/focus groups/interview/brainstorming. Time series is a forecasting technique that is based on historical data from which the analyst tries to understand the underlying structure of the phenomenon. It is composed of numerical data recorded at regular intervals of time. The questionnaires contain both open and closed questions. In the first case, the subject has to choose between the various alternatives proposed, while in the second may express his views freely. In focus groups a selected group of users are asked about their opinion, perception, beliefs and attitude towards the service, with free interaction between different group members, while in brainstorming a specific problem is addressed by a group of experts and users, with the scope to gather a list of potential solutions. Finally, in direct interviews an operator interview users and non-users of the service in order to collect the information.

The most common method for collecting data in order to analyze them and such to capture the latent demand is the questionnaire. It is used in 2003 by Cervero [16] and by Barth et al. [5] on a macro sample that includes business and neighborhood car-sharing. Later, Zhou and Kockelman administer a questionnaire to the city of Austin, Texas [105]. The purpose of this study is to investigate the latent demand during the launch of the car-sharing service in Austin. In 2004 Huwer places the emphasis on the combination of public transport with car-sharing service. Members and non-members of car-sharing service are selected randomly and interviewed [48]. Catalano et al. publish a study reporting a stated-preference survey in Palermo [11]. The respondents can choose from different transportation alternatives, which include private car, public transport, car-sharing and carpooling. Then a random utility model is estimated using the survey data. The authors infer that in a future scenario characterized by active policies to limit private transport use the car-sharing market could increase up to 10%. In 2013 Sioui et al. use two types of survey to gather data on travel behaviors on a typical day, widespread in Montreal, Canada, in order to analyze the car-sharing demand [96]. The first one is a regional, large-scale household travel survey and an internet survey, started after the introduction of the service, while the second one includes both former members and current members of the service. The study makes a comparison between respondents of two types of survey with similar characteristics and located in the same municipal sector. Herrmann et al. solve the problem of car relocation in free floating car-sharing [46]. For this purpose, a survey is conducted among users of the Car2Go system in Hamburg, Germany. The survey is intended for users and potential users of free-floating car-sharing service. The same method, extending the analysis also to electric car-sharing, is used by Wappelhorst et al., with 311 persons interviewed for the first project and 280 persons in additional personal short interviews for the second one [101]. To test the potential of car-sharing or electric car-sharing in rural areas, in 2012 a new telephone survey is conducted in big city as Berlin, Hamburg, Munich and Frankfurt. Still in Germany, Firnkorn and Müller compare the results of two methods measuring the impact of car-sharing on other transportation modes, using the same sample [38]. The first method estimates how the mobility behavior of respondents would be at the present time with the assumption of unavailability of Car2Go, while the second one determines the respondents past mobility behavior using Car2Go.

Rabbitt and Ghosh conduct a survey in Ireland, with 2639 respondents among population of likely users concentrated in areas of higher population densities [85]. They present a new methodology for estimating the potential market and the impact of car-sharing system in Ireland. Accordingly to their results, all the small areas in the Republic of Ireland are sub-divided into groups based on the viability of introduction of car-sharing system in the area. In the same year, Ohta et al. cluster the 1095 respondents of web-based survey into similar sized groups based on the number of cars owned and on the residential area to investigate the effects of community size [80]. In the survey, respondents are provided with car-sharing and eco-cars information and subsequently are asked questions about both car-sharing services and eco-cars. Shaheen et al. [95] and later Kortum and Machemehl [60] survey 26 of all car-sharing actors with mail questionnaires, telephone interviews and other internet information, in order to compare Canadian car-sharing demand with North American car-sharing demand.

In [37] primary data were collected by an online survey, in which all Car2Go members (in the City of Ulm in 2010) are invited, with the aim to analyze the variations in users behavior after the introduction of the service. Focus groups, combined with in deep interviews of car-sharing experts, are used in [12] to investigate the propensity of the customers to adopt bundles of services as a substitute of products. Unlike other studies, in [59] data are collected by a survey based on a GPS tracking smartphone application with the scope to analyze the travel patterns of both by members and non-members of a car-sharing service.

4.2.2 Tools of analysis

In this section we highlight the main trends in the literature related to the tools used to analyze the data gathered in the research.

Logit and linear regressions One of the most productive streams of research on car-sharing has been the study of the characteristics of its users. In several works the population characteristics are modeled using a sample of car-sharing users, analyzing these data with a logit model. Binomial logit analysis is used in 2003 by Cervero [16] in order to control variable factors such as price of gasoline and weather, while a matched-pair analytically approach is adopted in [90]. In order to understand the drivers of adoption of an urban car-sharing program, and to establish which modeling approach was the most effective, De Luca and Di Pace [28] investigate multinomial logit, hierarchical logit, cross nested logit and mixed multinomial logit models. Frost and Sullivan outline the role the car-sharing sector can play in reducing the private car usage in London to 2020. Statistical analysis (multiple linear regression and a compound annual growth rate) show which existing socio-demographic and neighborhood factors have most affected car-sharing membership. Ohta [80] in his study on Japan, uses a multiple linear regression analysis, to examine the effects of individual attributes, including gender, age, number of cars per household and area of residence, with the purpose of finding information on behavioral intentions regarding joining a car-sharing organization in different situations. In 2014, Schmoller and Bogenberger [90] analyze the differences of the booking behavior between free floating car-sharing and hybrid car-sharing. Hybrid car-sharing differs for the size of parking area where cars can park (e.g. 1 km^2 areas predefined by the city). Free floating car-sharing includes information about time, data and coordinates of beginning and ending of the corresponding booking, while hybrid car-sharing contain only name of the area but not the actual coordinates.

Simulation Ciari et al. in [19] and again, the following year, the same authors in [18] propose an Activity-Based Microsimulation Approach called MATSim, based on two features of car-sharing system: the access to rental car and the time dependent fee. Starting from micro level, model can determinate macro behavior of the system. A test was carried on in Greater Zurich where the car-sharing stations are 276. Instead, the second paper use the multi-agent simulation MATSim to evaluate different car-sharing scenarios for the city of Berlin. The likelihood of the whole representation is guaranteed by the fact that the artificial population is based on census data and on travel diaries surveys. The first scenario considers only station-based car-sharing available, while the second scenario suggests that there is a peak around 8am, and in the third scenario seems that the addition of free floating to traditional car-sharing does not affect the latter. In 2013 Weikl and Bogenberger present a new integrate two-step model for optimal vehicle positioning and relocation and apply an optimization algorithm for finding the best relocation strategy in case of deviation [102]. The empirical basis of this work are real historical vehicle data of a real-life free-floating car-sharing system in Munich, Germany, The historical data consists of the geo-referenced start and end locations of the conducted trips, booking times and booking duration, satisfied and unsatisfied booking requests (online requests/searches by mobile phone or internet which did not lead to a booking), trip distances and parking duration. In order to predict the potential market demand for the car-sharing operator impact, [67] developed a simulation model based on Stated Preference experiments in order to obtain the necessary insights for this newly proposed transport mode. In 2012, an agent-based scheduling and energy management system was used to optimize the utilization of the energy produced locally and of the batteries in an electric car-sharing fleet

[39]. In 2014 Lopes et al. [65] apply an agent based model to represent the daily operation of a hypothetical car-sharing program operating in the city of Lisbon. Some indicators were chosen to evaluate the performance of the system, both from an economic perspective and from an operational point of view. [42] combines technology road-map and system dynamics simulation to evaluate the environmental, social and economic perspectives of car-sharing in Korea for a long-term period of 50 months. This work represents the first attempt to simulate the demand and behavior changes of users, which are expected to be a major barrier for the car-sharing business. Recently, in 2015 Danielis et al. [25] focus on a particular demand segment for car-sharing: college students. They use two surveys distributed at the University of Trieste (the sample was of 344 respondents), using a Monte Carlo simulation procedure to estimate the probability that a person would use car-sharing. In [43] three scenarios of car-sharing services are developed and analyzed by the authors as an illustrative example of a scenario-planning approach to develop technology road-maps. Using system dynamics each strategic model for technology road-map is then transferred to the operational viewpoint.

Neural network In 2007, Xu et al. [103] propose an evolutionary neural network to address the problem of forecasting net flow of car-sharing systems. The forecast is made according to the data obtained by real case of Singapore car-sharing. For the forecast, it's important to choose an appropriate neural network structure, including the number of hidden layers, and the number of nodes in each hidden layer. The common approach is to fix the structure and then use genetic algorithm to search the global minimum and back propagation method to speed up the convergence around the local minimum.

The literature shows a large usage of logit model, with all its variations (binomial logit, multinomial logit, hierarchical logit, cross nested logit and mixed multinomial logit), used in estimating the parameters of a qualitative response model. Logistic regression is used to refer specifically to problems in which the dependent variable is binary, while problems with more than two categories are referred to multinomial logistic regression, or, if the multiple categories are ordered, to ordinal logistic regression. Another methodology heavily used is the simulation-based approach, while only one paper adopts neural networks [103]. It is not clear if this trend is due to the specific expertise of the authors or by a clear predominance of logit models over the remaining methods. Thus, a possible and suggested research line might be to better explore new tools, as neural networks, or hybridized simulation-optimization methods, that proved their efficacy in several applications [42, 83, 103].

4.3 Optimization in car-sharing services

As stated in Section 3, the use of optimization tools (i.e., combinatorial and stochastic optimization and simulation) is very limited for car-sharing services and usually is applied for the management of fleet of cars.

In [49] the aim of the authors is to create, starting from modeling the preferences of the potential users, a helpful approach for decision makers to correctly plan the implementation of an electric car-sharing service. Optimization tools are used to minimize the number of scenarios for the decision framework. Xu and Lim propose a mixed genetic algorithm with back-propagation as a tool for designing car-sharing service in Singapore [103]. The authors forecast demand and supply in the near future with the aim to identify initial positions of cars and relocation strategies. In order to support planners of car-sharing services, Geum et al. use a strategic model to deal with the uncertainty of the business environment and design a technology road-map [42]. Moreover, a system dynamics approach is developed to evaluate the plan from the operational point of view. The authors combine the two approaches in an optimization-simulation framework. Recently, a similar approach is used in [65] for simulating one-way car-sharing services. A p-median formulation is proposed, which incorporates strategic, tactical and operative decisions. Other papers address business and service objectives, but using only simulation approaches. [19] and [18] use a micro-simulator to evaluate scenarios for station-based and free floating car-sharing. A Monte Carlo simulations is used in [25] to estimate the potential demand for car-sharing services in an university context.

Infrastructure optimization mainly refers to find the optimal location of car-sharing stations or of charging stations for the electric vehicles. In [26], three Mixed Integer Programs (MIPs) are used for determining the optimal locations for depots of a one-way car-sharing operator in Lisbon, Portugal. The objective of the models considers both revenues from clients' subscriptions and trips and operative and maintenance costs. The difference among the models lies in the constraints used for the demand satisfaction. Selecting the set of candidate locations and defining realistic scenarios, the authors show how the location of depots is strictly related to the profit of the operator. The latter may incur in severe financial losses or high costs for clients if the location problem is not treated accurately. In [20] the authors analyze car-sharing as an opportunity for local planners to address infrastructural issues (such as parking requirements and traffic congestion) and environmental issues (such as pollution an overall quality of life). In this study the positive impacts of car-sharing are analyzed using data taken from real operational contexts of car-sharing companies. Kaspi et al. focus in improving the performance of a one-way car-sharing system by incorporating parking policies in which users were required to state their destination and reserve a parking space [52]. An equilibrium network design model is formulated in [77] in order to determine the optimal configuration of a vehicle sharing system. Also in this case the aim is to maximize the revenues through the optimization of station locations, vehicles management and station capacities. Referred to the optimization of the station locations, [86] aims to find the best location and size of car-sharing stations while satisfying users demand and preferences and minimizing total costs for the car-sharing companies.

Fleet management optimization analyzes the planning of the fleet size and the relocation strategies of the vehicles. Boyacı et al. develop a multi objective model for planning one-way car-sharing systems, considering the constraints of vehicle relocation strategies and electric vehicles charging requirements [8]. The study starts from an aggregate model that used the concept of virtual hub, with the objective to generate an efficient frontier that allows decision makers to examine the trade-off between operators and users benefits. In [14] a comparison between operators based and users based relocation strategies is performed. The same authors evaluate a scenario in which fully automated vehicles can move among different stations when relocation is required in [15]. The development of these technologies could mainly impact positively on the efficiency of the transport system, optimizing landscape usage and increasing the transportation safety. Alessandrini et al. examine car-sharing development and future mobility scenarios, including automated vehicles used for private mobility and freight transportation [1]. However, the authors only analyze the impacts of the automation in car-sharing, without providing any guideline for car-sharing services planners. In [33] the dynamic vehicle allocation problem is addressed both in time and space with the aim to maximize the revenues of the car-sharing companies. The same authors of [32] aim to optimize allocation of cars for one-way car-sharing systems when future demand is affected by uncertainty. The authors develop a multi-stage stochastic linear programming model to maximize the expected profit of the service. Using this tool, an operator of car-sharing can strategically plan the allocation and relocation considering dynamics both in time and space. The problem of vehicle unbalance across the stations in one-way car-sharing systems is also addressed in [51], with the development of an optimization-simulation framework that keeps in account demand variability and vehicle relocation policies. Jorge et al. use a MIP for the optimization part, while a Monte Carlo method simulate the variability of the demand. In [34] the authors address the problem of determining the optimal fleet size of an electric car-sharing service. The system is modeled as a discrete event system in a closed queuing network, considering the specific requirements of the electric vehicles utilization. Operators-based relocation systems are analyzed in [54] to evaluate the effectiveness of different relocation strategies, starting from real operational data of local car-sharing operators. Herrmann et al. address the same problem using a discrete-event simulation model [46]. It defines a set of scenarios for car-sharing demand and evaluates different relocation strategies, showing the importance of relocation for the business. A decision support system (DSS) based on an optimization-simulation environment for car-sharing is presented in [55]. The DSS aims to evaluate the effects of different relocation strategies and to determine manpower and operating parameters. Marouf et al. solve the vehicle distribution problem focusing on automatic parking and platooning of the vehicles [68]. In details, a leader vehicle, driven by a human, is used to pick up and drop off vehicles across different stations. In [100] the authors propose a method for optimizing vehicle assignment according to distribution balance of parked vehicles for one-way car-sharing systems. More recently, [10] use a MIP to model the relocation of 30 electric vehicles in Milan, which are directly moved by the staff of the car-sharing service according to the solution of the MIP model. The authors show that the use of an optimization model reduces the average working time for the operations. In fact, two people are enough to satisfy to the 86% of requests.

From this quick analysis emerges how, even if the uncertainty is a key factor in optimizing and planning car-sharing operations, it is usually surrogated by simulation-based method. Just a few papers make use of more sophisticated methods, as stochastic programming or non-linear approximations of the uncertainty should be considered [84, 99].

4.4 Business models, business development and economics

To our knowledge, [7] is the only paper that partially analyze the business of sharing mobility services, in particular of car-pooling, using a framework linking business factors and service strategies. The framework mainly focuses on service aspects and does not consider explicitly more complex aspects, as the business model, its link to the business development model, as well as the value proposition of the different car-sharing companies. This, in fact, impacts on the tariff schemes, as well as on the service penetration in the market. As this lack can be partially tolerated in a pioneering phase, it must be compulsorily considered in a more mature phase of the market [81].

5 Conclusions

In the last years car-sharing services have become increasingly popular all over the world: old operators have increased their fleets and approached new market places, and new operators have started their business. Furthermore, the growing attention in environmental issues involved an increased attention in the usage of electric and hybrid vehicles. In addition, the development of information and communication technologies allowed the market penetration of new car-sharing models, such as free floating car-sharing services.

In this paper we introduced a taxonomy able to categorize the existing literature and, by applying it, to derive some trends and directions for the future research. In particular, it emerges a gap between the literature and the business development of the market. This gap becomes more and more evident when we look at the revenues generated by the companies, still marginal compared to the capital in use. As stated in the introduction, a taxonomy is only the first step. In fact, the business model and the link between the business and the operations models, the tariff scheme, need to be integrated. These issues are considered in the part B of this paper.

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Journal Name	**Count**
Transportation Research Record	15
Transportation Research Part A-F	10
International Journal of Sustainable Transportation	6
Computers and Industrial Engineering	2
European Journal of Operational Research	2
International Journal of Automotive Technology and Management	2
Transportation	2
Transport Policy	2
Business Strategy and the Environment, Computational Logistics, Energies, Ecological Economics, European Journal of Transport and Infrastructure Research, European Transport, European Transport Research Review, Institute of Transportation Studies, Intelligent Transportation Systems, Intelligent Transportation Systems Magazine, Journal of Intelligent Transportation Systems, Journal of Manufacturing Technology Management, Journal of the Eastern Asia Society for Transportation Studies, Journal of the Transportation Research Forum, Journal of Transport Geography, Marketing Letters	1
Subtotal	**57**
Proceedings	**Count**
Proceedings of the IEEE International	6
Procedia - Social and Behavioral Sciences	4
Transportation Research Procedia	4
Proceeding of international conferences	18
Subtotal	**32**
Others	**Count**
Techinal reports	6
Total	**95**

Table 1: Pubblications in car-sharing literature.

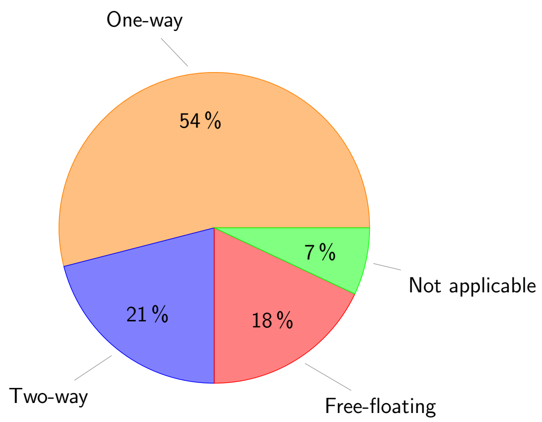


Figure 2: Modes

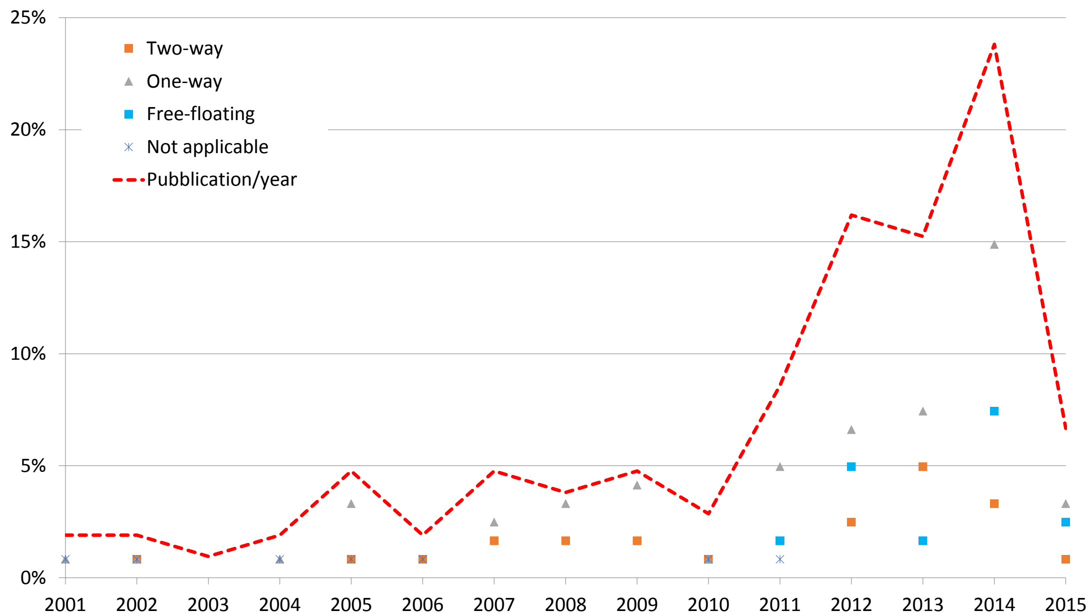


Figure 3: Number of papers referring to modes of car-sharing services

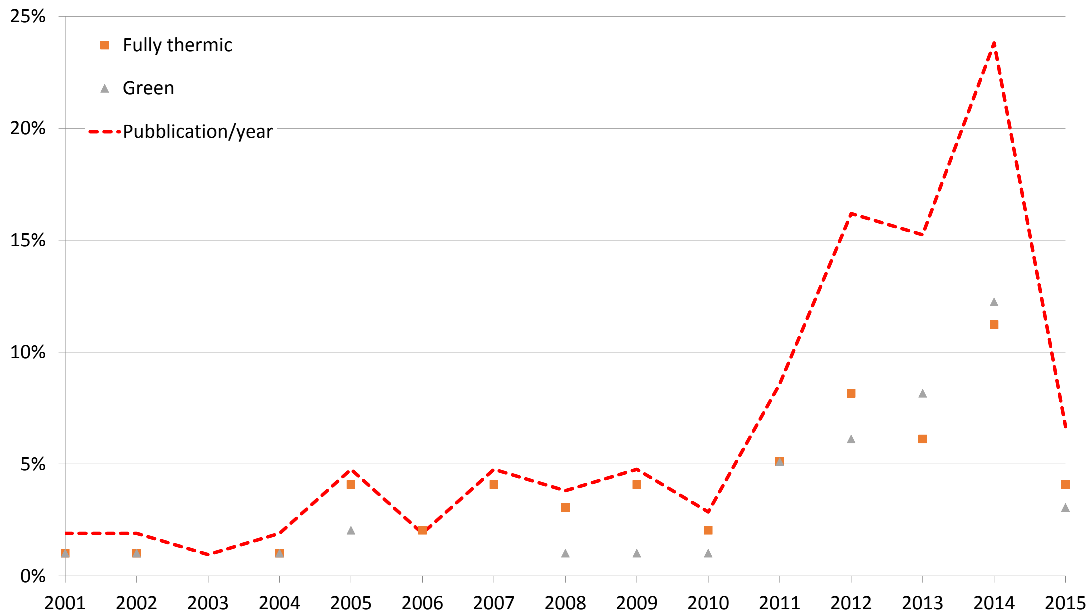
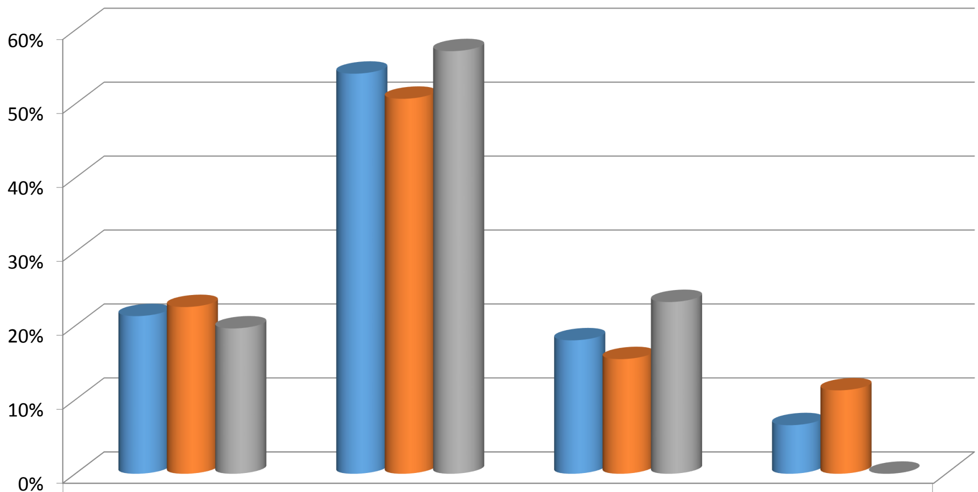


Figure 4: Number of papers referring to types of engine in car-sharing services



	Two-way	One-way	Free-floating	Not applicable
Overall	21%	54%	18%	7%
Fully thermic	23%	51%	15%	11%
Green	20%	57%	23%	0%

Figure 5: Cross analysis of engine and modes

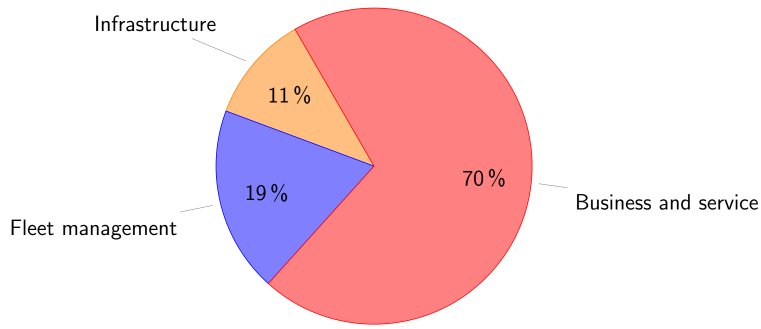


Figure 6: Optimization objectives

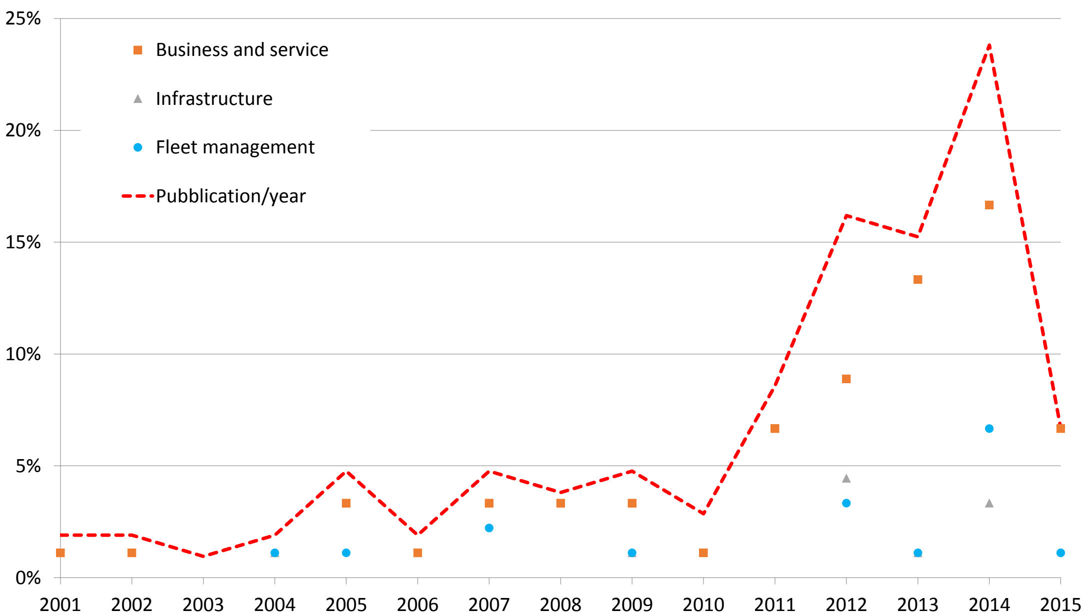
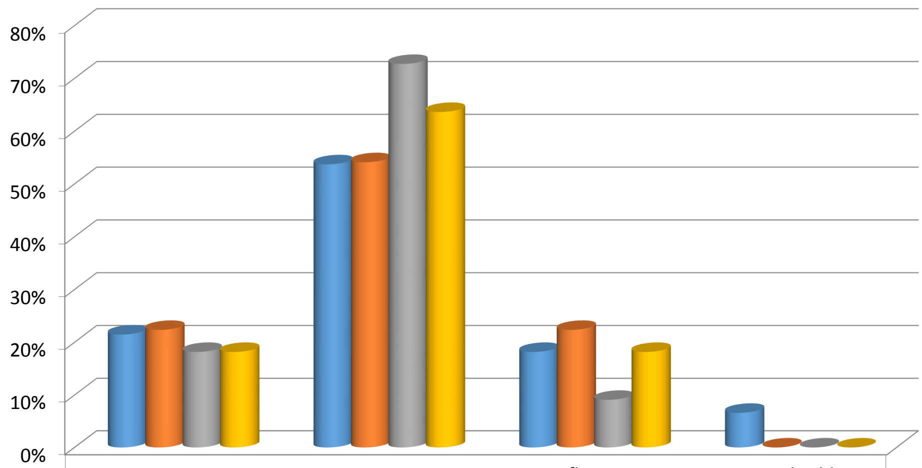
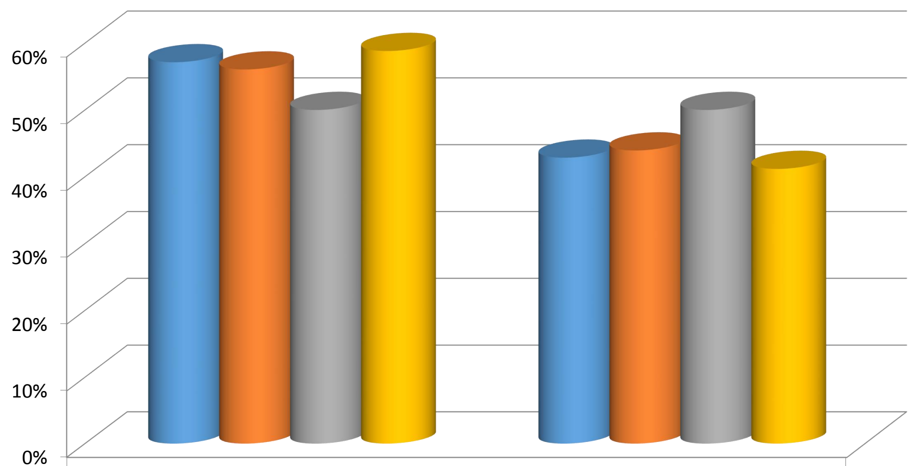


Figure 7: Number of papers referring to the objectives of optimization



	Two-way	One-way	Free-floating	Not applicable
Overall	21%	54%	18%	7%
Business and service	22%	54%	22%	0%
Infrastructure	18%	73%	9%	0%
Fleet management	18%	64%	18%	0%

Figure 8: Cross analysis of optimization objectives and modes



	Fully thermic	Green
Overall	57%	43%
Business and service	56%	44%
Infrastructure	50%	50%
Fleet management	59%	41%

Figure 9: Cross analysis of optimization objectives and types of engine

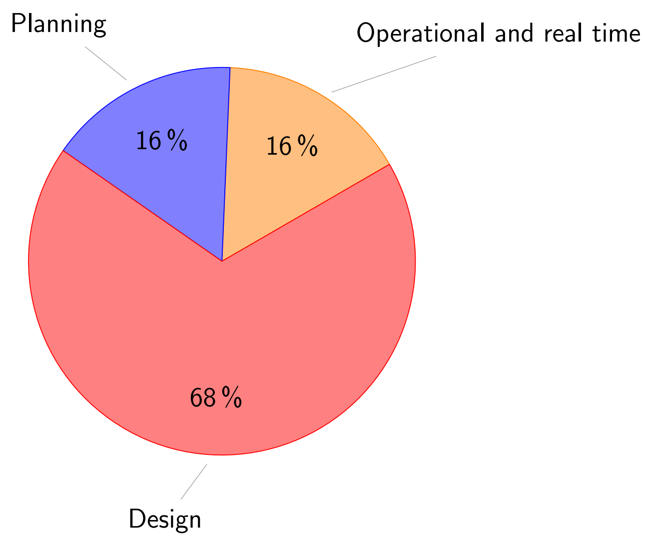


Figure 10: Time horizon analysis

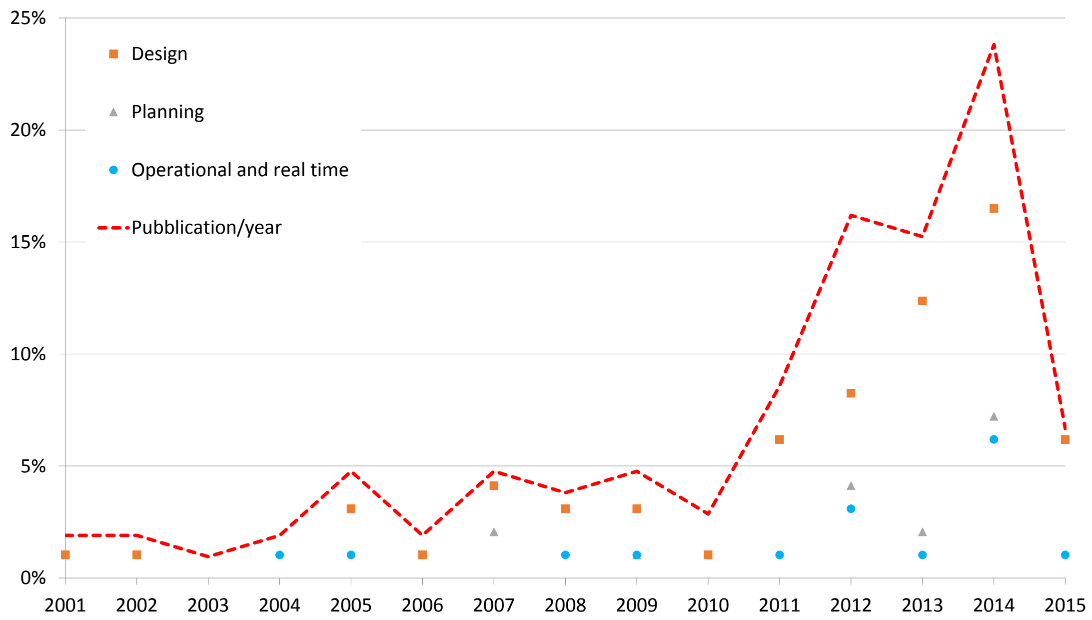
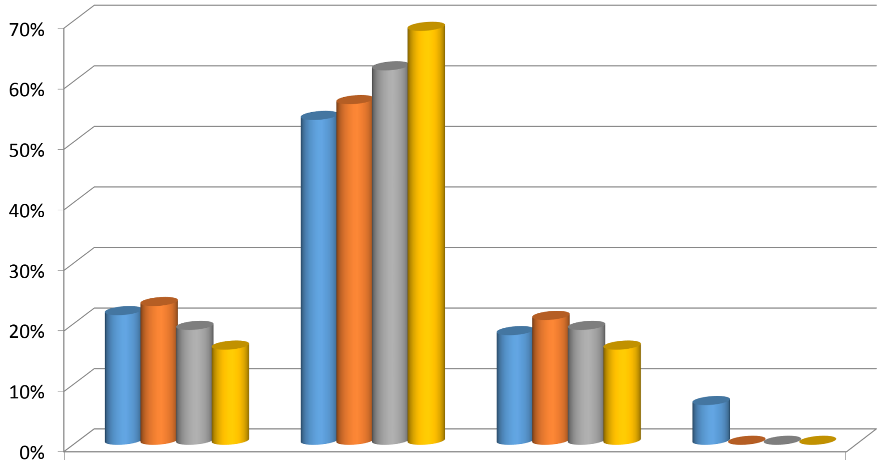
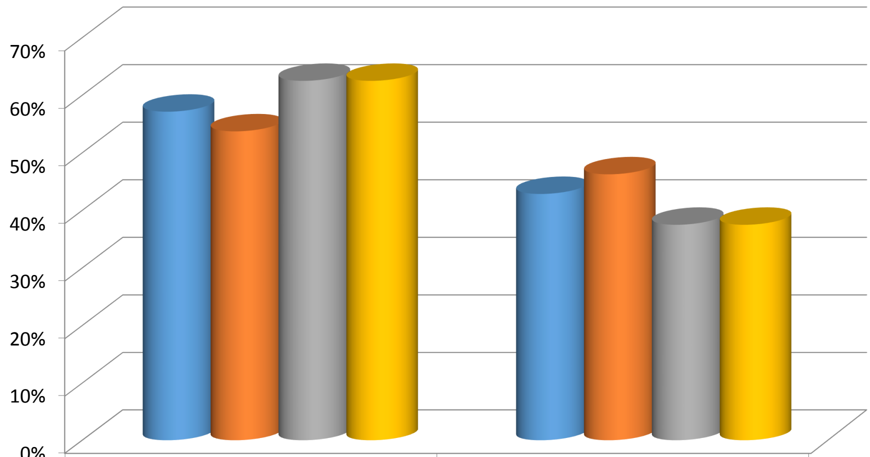


Figure 11: Number of papers referring to the time horizon analysis



	Two-way	One-way	Free-floating	Not applicable
Overall	21%	54%	18%	7%
Design	23%	56%	21%	0%
Planning	19%	62%	19%	0%
Operational and real time	16%	68%	16%	0%

Figure 12: Cross analysis of time horizon and modes



	Fully thermic	Green
Overall	57%	43%
Design	54%	46%
Planning	63%	38%
Operational and real time	63%	38%

Figure 13: Cross analysis of time horizon and engine type

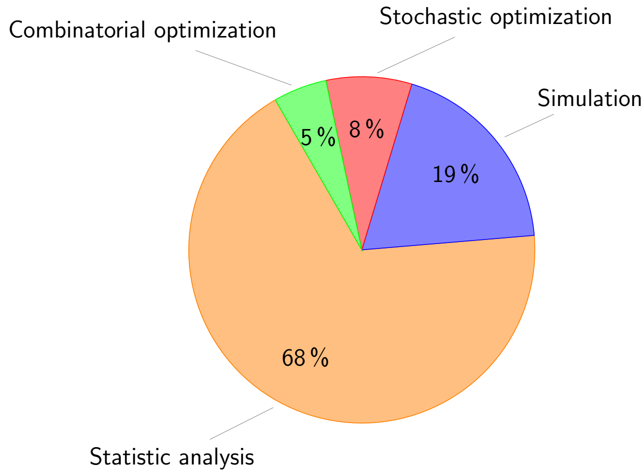


Figure 14: Methodology analysis

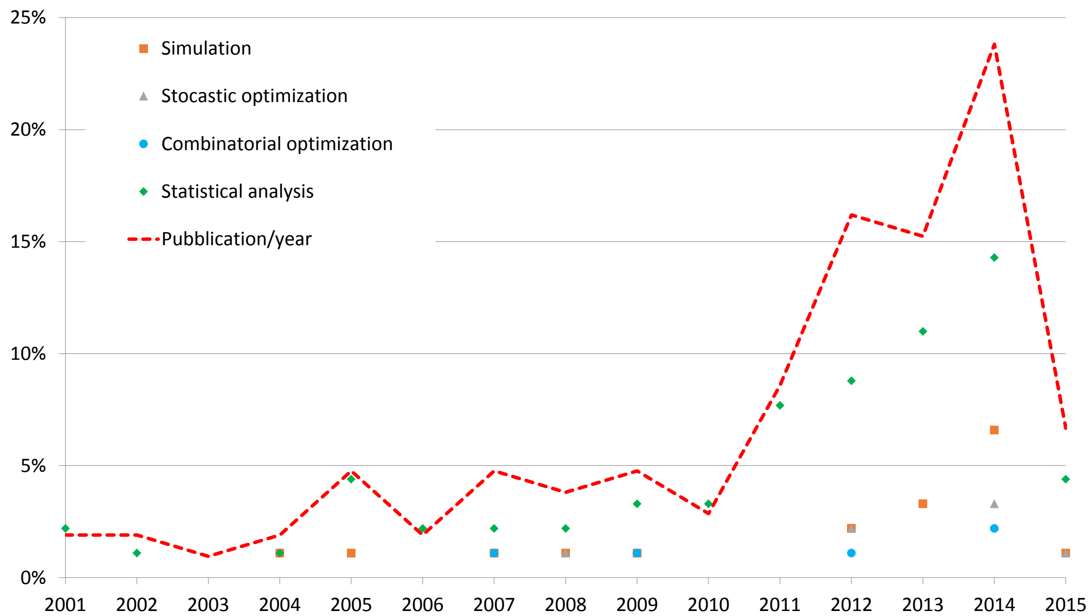
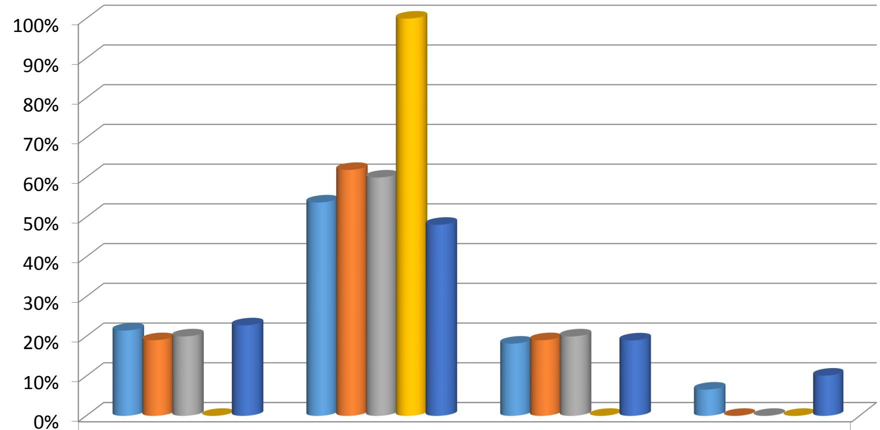
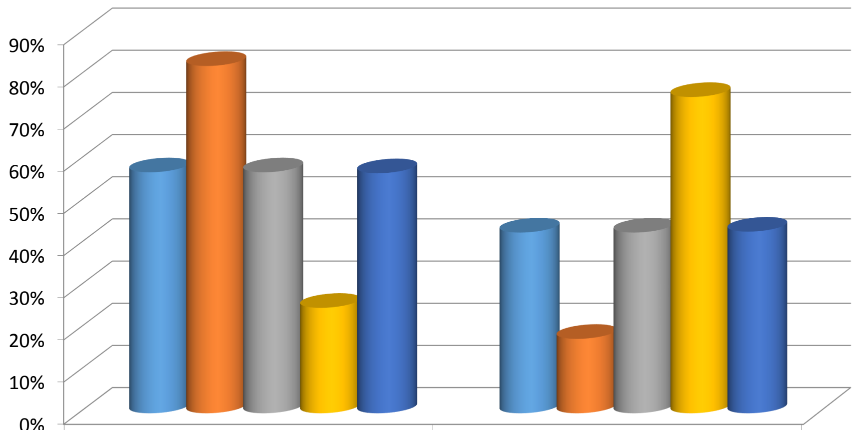


Figure 15: Number of papers referring to the methodology analysis



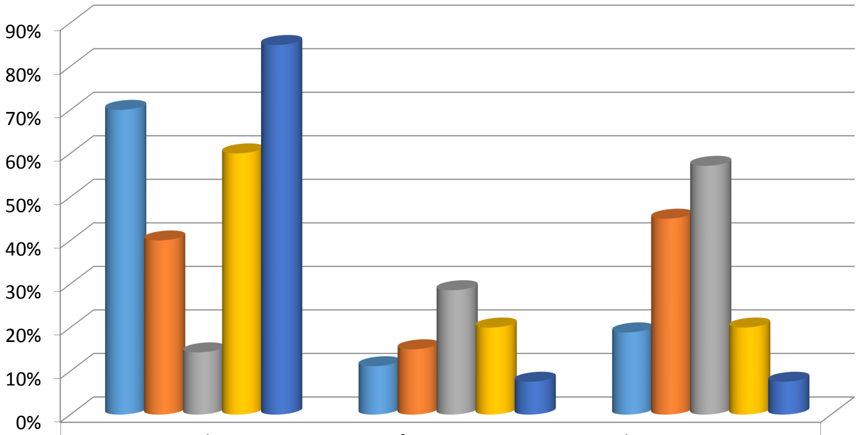
	Two-way	One-way	Free-floating	Not applicable
Overall	21%	54%	18%	7%
Simulation	19%	62%	19%	0%
Stocastic optimization	20%	60%	20%	0%
Combinatorial optimization	0%	100%	0%	0%
Statistical analysis	23%	48%	19%	10%

Figure 16: Cross analysis of methodologies and modes



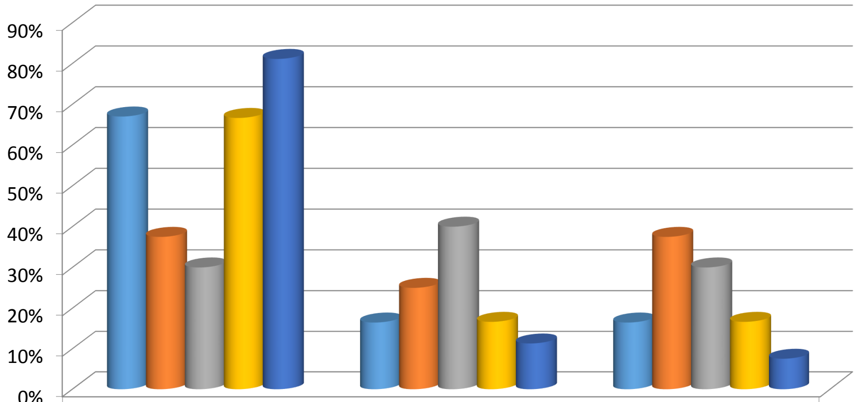
	Fully thermic	Green
Overall	57%	43%
Simulation	82%	18%
Stocastic optimization	57%	43%
Combinatorial optimization	25%	75%
Statistical analysis	57%	43%

Figure 17: Cross analysis of methodologies and types of engine



	Business and service	Infrastructure	Fleet management
Overall	70%	11%	19%
Simulation	40%	15%	45%
Stocastic optimization	14%	29%	57%
Combinatorial optimization	60%	20%	20%
Statistical analysis	85%	8%	8%

Figure 18: Cross analysis of methodologies and objectives of the optimization



	Design	Planning	Operational and real time
Overall	67%	16%	16%
Simulation	38%	25%	38%
Stocastic optimization	30%	40%	30%
Combinatorial optimization	67%	17%	17%
Statistical analysis	81%	11%	8%

Figure 19: Cross analysis of methodologies and time horizons of the decisions