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CAR AND THE CITY: SOCIO-TECHNICAL PATHWAYS TO 2030

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Car and the city: Socio-technical pathways to 2030

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Abstract

A socio-technical approach is used to show that the future of urban mobility will depend on the competition between coalitions of innovative actors who support alternative transport systems. The current positioning of these coalitions is mapped with reference to innovation and power. The supporting coalition of the 'individual car' system benefits from a dominant position on current alternatives, but faces external pressures for change. Three transition pathways to 2030 are considered: 1) 'AUTO-city', i.e. the reconfiguration of the 'individual car' supporting coalition through the stable integration of producers of batteries; 2) 'ECO-city', i.e. the empowering of local coalitions which integrate all non-car modes, and their diffusion from pioneering to laggard cities; 3) 'ELECTRI-city', i.e. the empowering of a new coalition centered on electric operators which establish a new 'electric vehicles + smart grids' system. The deployment of one or another transition pathway also depends on the ability of supporting coalitions to influence political institutions. Without a political action for the weakening of the dominant position of the 'individual car' system, the 'AUTO-city' transition pathway will prevail. To support the 'ECO-city' and the 'ELECTRI-city' transition pathways, a multilevel transport policy or a national/federal industrial policy is needed, respectively.

Keywords: Urban mobility, socio-technical analysis, socio-technical transition, innovative actor, supporting coalition.
Jel Classification: O18, R40, Q55, L14.

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1. Introduction[1]

In recent years several scholars have tried to analyze the future of the transport sector, also with the aim of understanding how its environmental impacts may be reduced drastically (see e.g. [16,44,84]). This paper contributes to this research stream by providing an analysis of the current and future dynamics of urban mobility which explicitly draws on the socio-technical (ST) field of innovation and future studies ([28]). This paper is part of a specific subset of ST future studies, that is, ST scenarios. ST scenarios differ from other forecasting techniques as they provide a more systemic and genuinely dynamic representations of future changes. In particular – and more relevant here – ST scenarios are useful not so much for the static description of future outcomes, as for the analysis of the multi-dimension and multi-actor dynamics of alternative transition pathways and the role played by public interventions at critical points ([28]). Some ST scenarios have specifically considered the transport sector ([21,35,51]).

This paper provides an original contribution to ST scenarios of transportation by stressing that: a) coalitions of innovative actors motivated by different interests and/or ideas and promoting different transport systems are at the heart of the process of change of urban mobility; b) transition pathways will strongly depends on the ability of both existing and emerging coalitions to leverage their current positioning – which is expressed in terms of competence and power – to transform their networks and influence the evolution of urban mobility. A specific focus is on the relation between the dynamics of coalitions and political institutions, that is, political discourses and practices, politics and formal norms, agendas and actual policies. The analysis is not limited to the car and its future evolutions, but attention is paid to two different dynamics: the reproduction of the currently dominating car-based system of urban mobility, and the embedding into new systems of urban mobility of emerging innovations for low-carbon mobility (such as, electric propulsion, shared systems, stronger integration of all non-car transport modes, etc.).

The paper starts by considering the current situation of urban mobility; then, three alternative transition pathways to 2030 scenarios of urban mobility are considered. 2030 is chosen as the reference year for scenarios because, at the same time, it is near enough to ensure a

[1] Abbreviations: electric vehicle (EV); integrated urban transport system (IUTS); smart grid (SG); socio-technical (ST).

sufficient knowledge of the relevant constituents of future transitions, and it is distant enough to allow alternative transition pathways to deploy. Both transition pathways and scenarios do not refer to a specific geographic situation, while an explicit attempt is made to deliver an analysis which is able to represent global dynamics. The robustness of both inputs and outputs of the analysis may be increased by validation through participatory process.

The rest of the paper is composed of four paragraphs. Paragraph 2 explains the basic concepts of the ST approach; the following paragraph builds the map of the current situation; paragraph 4 develops the three ST transition pathways. The last paragraph provides discussion and conclusions.

2. The socio-technical approach to innovation

2.1. What is specific of this approach

This paper is based on a socio-technical (ST) approach to the analysis of the innovation process. It goes beyond the scope of this paper to review all the contributions coming from scholars who refer to the ST approach; here we just want to stress two of its specificities which are relevant for the subsequent analysis.[2] The first specificity is that the ST approach is not reductionist: complexity is explicitly considered as a relevant feature of the process of innovation; this is why the overall picture is never explained by looking at one or more specific elements. In particular technology is not considered as the core driver of innovation, but just as a structural element of the functioning of the economy which interacts with other institutional and economic constituents, and with agency ([32]). Another specificity is that rather than on functions, the ST approach focuses on actions.[3] At the heart of the analysis one can find the purposeful action of individuals and groups. All relevant attributes which connote action stay at the centre of the analytical scene: power, interests, conflicts, agendas, policies, intentional pressure for – and resistance to – change, etc. ([5,25,80]). This does not mean that the ST approach is deterministic, with individual and collective action as the

[2] For critical analyses of this research field see [53,90]. For an interesting attempt to operationalize this approach see the results of the EU funded 'MATISSE' project ([41]).

[3] For a structured approach to the study of the functions of innovation systems see [48].

cause and innovation as the intended effect; it only means that there is no innovation without human action.

2.2. Socio-technical systems

The ST system is the basic concept of the ST approach to innovation. Societal functions (housing, feeding, production, provision of energy, etc.) are fulfilled by one or more ST systems. All ST systems are (more or less) stable configurations. The ST system is a meso-concept: at the micro level we find its individual constituents (rules, artifacts, knowledge, actors, preferences, financial resources, etc.); at the macro level (which is considered exogenous) socio-economic phenomena and trends can be found.4 The functioning of ST systems can be conceptualized as structured agency ([36]). Two more basic concepts complete the framework: 1) the dominant ST system, that is, a stable and powerful ST system which strongly influences the dynamics of all other subaltern or residual ST systems and generates pervasive lock-in phenomena ([32]); 2) the ST 'niche', that is, a space which is partially or totally protected from the interaction with other ST systems ([77]). ST niches are particularly relevant for the generation and experimentation of innovations and for the gradual structuring and empowerment of new ST systems ([5,82]).5

2.3. Actors, coalitions and power

Actors – all featuring bounded rationality – are the engine of a coevolutionary process of change: through action and learning, they replicate the structure of the ST system; at the same time, they generate – directly or indirectly, intentionally or unintentionally – the variation and selection of structural variables. Every actor features a vector of material and immaterial endowments (physical and financial resources, knowledge and skills, social capital and legitimacy, etc.) and is motivated by his interests, ideas and visions. Every actor's power – hence her/his ability to influence the dynamics of ST systems – is a function of the above vector. In this approach, power is linked to legitimacy, coalition building and access to resources by an endogenous and self-reinforcing process ([23,34,62]). The role of supporting coalitions – that is, groups of actors who are interested into the reproduction or the emergence of ST systems

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[4] This is the 'landscape' in the terminology used by Frank Geels ([28]) and other scholars of the so-called multi-level perspective.

[5] Brown et al. ([10]) use a similar concept, but with a different terminology: 'bounded socio-technical experiment' instead of niche.

– is stressed by the literature ([5,29,46]). Actors' membership is then crucial to understand the dynamics and interactions of ST systems; in particular: coalitions of 'core-actors' are interested in – and actively act for – the reproduction of an existing ST system ([80]), whilst coalitions of 'enactors' try to transform an innovation into a social practice, in order to establish a new ST system ([85]). Power, legitimacy and networking ability are essential for both kind of coalitions ([5,39,82]): core-actors of a dominant ST system use their endowments to keep "capturing" politics and policy; successful enactors – usually starting from a ST niche – needs to affect shared cultures, political discourses and informal rules, before achieving durable credibility and a stable influence on agendas, formal norms and policies ([7,34]).

2.4. Coalitions, dominance and change

The dynamics of ST systems may be grouped into two large families: the adaptation of a dominant ST systems and the attempt of another ST system to take over the dominant position. Adaptation can be conceptualized as a homeostatic process: changes in institutions, markets and technologies take place along an established trajectory; the alignment of such changes is granted by the structure – which gradually change – and it is supported by a coalition of actors that is internal to the dominant system and is committed to its survival ([88]). Things completely change when a system try to gain the dominant position: a process of extrication is needed to free resources, knowledge, actors, etc., that are locked into the dominant system; intentional and unintentional forces that generate their inertia must be overcome; new institutions, technologies and markets must be built; a new process of multidimensional alignment must be triggered and made viable ([1,8,24]). But no structure is available to coordinate all these efforts, because the structure itself is created through the innovation process; in such a situation, one can even doubt if the establishment of a new dominant position is possible without the purposeful and increasingly coordinated action of a coalition of enactors. ST niches may play a relevant role in both kinds of dynamics: in the case of adaptation, niches may cluster with the dominant ST system; in the case of take-over, niches contribute to threaten the dominant ST system and establish a new dominant position ([41,76,82]). A taxonomy of the dynamics of dominant ST systems, in which the role of actors is explicitly considered ([33]), is at centre stage of the analysis proposed in this paper; Haxeltine et al. ([41])

explains this taxonomy in terms of transformative 'mechanisms' (see Table 1).

Table 1. The dynamics of socio-technical systems: an overview[a]

OVERALL DYNAMICS	TRANSITION PATHWAYS	ACTORS' STRATEGIES	TRANSFORMATIVE MECHANISMS
Adaptation of the dominant system	Transformation	Core-actors react to pressures coming from outsiders or exogenous factors	Internal adjustment and maintenance Clustering of niches (eventually) Absorption of outsiders (eventually)
	Reconfiguration	Suppliers of new components enter the coalition of core-actors of the dominant system	Absorption of outsiders Clustering of niches (eventually)
Creation of a new dominant position	Substitution	Actors of other systems take over and change the dominant system	Competition between the dominant system and a new system Clustering of niches (eventually) Absorption of outsiders (eventually)
	De-alignment and re-alignment	A coalition of enactors establish a new system while the old system is destabilized from exogenous factors	Clustering and empowering of niches Absorption of enactors Absorption of outsiders (eventually)

[a]Adapted from [34] and [42].

2.5. Change and space: the role of the city

ST systems are usually analyzed at a national/international level; sometimes the city – and the local level – is taken into account, but just as a recipient of the implementation of a process of innovation generated at a higher scale. Only in recent years the active role of the city has raised the interest of ST scholars. The city is considered as a place where: coalitions of enactors can be build more easily; local endowments may be mobilized for innovative practices; political deliberation is more fluid –

that is, the city is a friendly environment for the establishment and reproduction of ST niches ([12,45,81,]). But – as clearly stated by Geels ([30]) – the city can feature a more relevant role than the mere hosting of niches: 1) local ST systems may co-exist with a national/international dominant system (e.g., in the case of non-car urban transport systems); 2) ST niches may be located at the local/urban level, but then the dynamics of the dominant system takes place at the national/international level (e.g., in the case of electric cars); 3) the local/urban level is not relevant for the reproduction and change of the dominant ST system (e.g., in the case of the mass production of individual cars).

3. A socio-technical map of urban mobility

3.1. Introducing the socio-technical map

In the rest of the paper a socio-technical map of urban mobility will be used to position innovative actors and systems in the current situation and in scenarios emerging from alternative transition pathways. Starting from their current positioning, actors are able to: a) implement their innovative strategies, b) reconfigure their coalition, and c) modify their influence on institutions and markets. The positioning refers to three variables: the first two (business models and propulsion technologies) represent the technological competence of actors and systems, the third one (power) measures the ability of systems to influence institutions and markets. The representation of power is very simple and based on the outline of the rectangles used to symbolize systems: thicker for the dominant system, normal for other systems and dotted for niches. Other very simple graphic symbols are used: dots represent actors; arrows represent competences.

3.2. Systems of urban mobility and innovative actors: the current situation

Three systems and a niche of urban mobility are represented in the map, when considering the current situation of urban mobility: the 'individual car', 'public transport', the 'individual bicycle' and 'carsharing schemes'.

<u>a) The 'individual car'.</u>

Authoritative scholars recognize the individual car as the dominant ST system of urban mobility, not only for its striking share of the mobility market (more than 80% of total journeys in all developed countries), as for the ability of its core-actors (automotive and oil companies) to

influence institutions and the society as a whole ([16,84,94]).[6] This system is well centered on the business model of 'selling' cars (and other vehicles) to individuals – nowadays with an increasing attention to emerging economies – but it is already able to span from the propulsion technology of 'internal combustion' (which powers 99% of the today circulating fleet) to that of 'plugged-in electric' (this is the reason of the black vertical arrow in Figure 1) ([26,64,65,96]). The automotive industry is the main core-actor of this system; some individual automotive companies are positioned into the map in order to explicit the existence of different innovative strategies. Fiat and Volkswagen are just two examples of the more conservative – and until today, more diffused – innovation strategy, based on efficient internal combustion and downsizing[7]: a strategy implemented by most leading manufacturers too, such as Daimler, Ford, Hyundai, Nissan, Honda and Toyota ([94]). Toyota and Honda are also the main promoters of the "hybridization" of the car[8]; they have chosen the hybrid propulsion as the entry-point to a process of technological innovation which, at the same time: a) it is compatible with the current core competences, sunk investments, dominant design and interdependencies of the automotive industry, and b) it is flexible enough to allow the future access to full electric cars ([4,42]). Some other leading automotive companies – e.g. Citroen and Mitsubishi – jumped directly into the full electric car technology, but mostly as a residual option to internal combustion cars. On the contrary, this is the strategy implemented by most Chinese newcomers who are entering the technology of full electric propulsion without the sunk costs of previous investments. Also small specialized assemblers and manufacturers (as Heuliez, Pininfarina, Valmet, etc.) are trying to develop their EVs on a limited productive and commercial basis ([93]).
Suppliers of components are another relevant industrial actor of the individual car system; in particular, producers of batteries – and other electric and electronic components – play a more and more relevant role in the trajectory of electrification ([65]): some of them are implementing autonomous strategies, such as Bolloré[9] – who developed the Parisian

[6] Also see Marletto ([54]) for a survey of the literature on this issue.
[7] See Schipper ([75]) for a worldwide analysis of the effects of such a strategy in terms of on-road fuel efficiency and CO_2 emissions.
[8] By April 2012 Toyota (the largest automaker in world) hybrids had sold more than 4 million units (news.toyota.com.au, accessed 06/06/2012).
[9] The Bolloré Group is a producer of batteries and 'supercapacitors' for electric cars, buses and trams. (www.bollore.com, accessed 06/06/2012)

"Autolib" carsharing scheme with Pininfarina (the Italian producer of the electric car "Bluecar") – and BYD (Build Your Dreams), a private Chinese producer of batteries for computers and cellular phones, who is now producing cars[10]. Some other car producers are trying – at very different scale of testing and marketing – to integrate some elements of the 'rent' and 'manage' business models into the car system ([97])[11]: Nissan-Renault already launched the mixed option of selling full-electric cars and renting batteries, in cooperation with Better Place, the emerging manager of battery-charge and battery-swap stations[12]; Daimler (with its electric Mini) and BMW (with its electric Smart) are promoting two vehicle-to-grid (V2G) tests, in cooperation with two energy suppliers: the Italian Enel and the Swedish Vattenfall, respectively[13] ([63]). Moreover, an increasing number of electric utilities is involved in partnership related to the diffusion of EVs ([65]).

b) 'Public transport'

This is one of the two systems of urban mobility that are subaltern to the 'individual car' system in terms of both transport modal split (often less than 10% of total mobility) and influence on national policies; at the urban and regional level this system is usually able to obtain a significant amount of public resources which are used to build dedicated infrastructures and subsidize services ([25,32,51]). This system is mostly centered on the business model of 'managing' networks of transport infrastructures and services, but with a well rooted experience in the

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[10] In China – which is today both the largest producer of cars and the greatest market for cars – most automotive companies are owned by the State or are joint ventures with major foreign car companies (such as BYD), with the relevant exception of Geely, an independent Chinese company ([84,92]).

[11] For detailed and exhaustive analyses of electric car business models, see [40] and [50]. For an overview on traditional and innovative car business models, see [93].

[12] The business model of battery rental (and, eventually, swap) not only reduces the price of electric cars, but also allows to install new batteries with better performances in old EVs ([6]).

[13] With "E-mobility" 100 electric "Smart" and 400 recharging points will be provided in Rome, Milan and Pisa. With "Mini Berlin" 50 electric "Mini" and 100 recharging points are provided in Berlin; in the latter case, electric vehicle batteries are tested as storage capacity to help manage excess wind energy. For more details see: http://www.vattenfall.com/en/electric-cars.htm and http://www.enel.com/en-GB/innovation/ (both accessed 06/06/2012).

'rent' business model, thanks to taxi services – see the horizontal black arrow in Figure 1. Since its birth it has been able to plug-in vehicles (trolleys, tramways, trains, etc.) to the electric grid; again, this is the reason of a black vertical arrow covering all motorized propulsion technologies. Both most relevant actors of this system are local: public transport companies and urban and regional Authorities. Some capital cities are positioned on the map as examples of the several world urban areas where a transition has already taken place from public to multimodal transport (i.e. the integration of individual means and collective modes, including park-and-ride schemes), thus generating a reduction of the use of individual cars down to 40% of total mobility. With the exception of these success cases, 'public transport' is usually associated to the image of "transport for the poor" ([11,16,17,47,67,84]).

c) 'Individual bicycle'.

This is the other subaltern – if not marginal – system of urban mobility: in Northern America, Europe and Australia the bicycle average share of trips is negligible, that is, around 2%. This figure is the result of a declining trend which started several decades ago in developed countries and more recently in emerging economies (where the use of bicycles is much more diffused, but rapidly declining). Starting from the mid-70s the bicycle has experienced a revival supported by public actors and grassroots movements, both aiming at higher level of users' health, urban livability and environmental quality. The Netherlands, Denmark and Germany represent the best national practices, with more than 10% of today mobility assured by bicycles; but it is worth mentioning that in some pro-bike cities in Northern Europe bicycles serve more than the 25% of total trips. These cases of wider diffusion are the result of a multilevel action, combining national plans and guidelines with the local provisions of cycling routes, dedicated parking and other supporting measures (traffic calming, intersection modifications, integration with public transport, training and education, etc.) ([68]). Recent figures signal the increasing use of bicycles in some North American cities too (Portland, Minneapolis, Vancouver, etc.), with a resulting share which is still around 3-5% of commuters, but reaches 6-8% in central areas; these trends are mainly caused by the building of new bike lanes and pathways by local Administrations ([69]). As the 'individual car' system, also the 'individual bicycle' it is centered on the 'sell' business model and – thanks to the increasing diffusion of electric bicycles ([73]) – it is able to cover all propulsion technologies. The Worldwatch Institute reports that more bicycles than cars are produced worldwide[14]: around 130 million and 70 million, respectively; not surprisingly China is the larger producer and buyer of bicycles (including 13 million of e-bikes) ([84]).

d) Sharing schemes

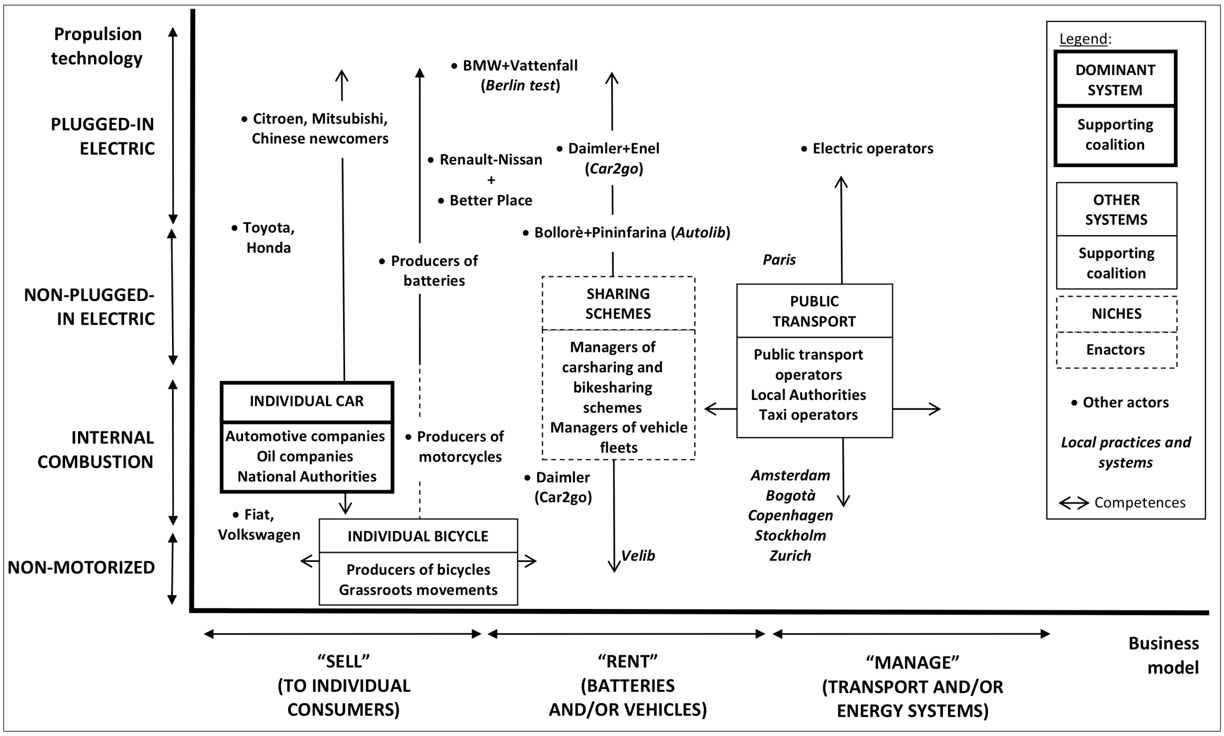
The map of urban mobility is completed by the dotted black rectangle representing the niche of 'sharing schemes', i.e. systems which provide members with access to a vehicle for short-term use, thus reducing the individual costs of car ownership. A fleet of vehicles, a diffused network of dedicated parking and specific technologies for the remote control of vehicles, are the standard equipment of these systems. Such a niche, which is obviously centered on the 'rent' business model, it is now experiencing a rapid extension from cars to bicycles, with the Parisian "Velib" bike-sharing scheme as the most relevant example: the most recent figures count 136 bike-sharing schemes (with 237,000 bicycles) and 1,788,000 carsharing[15] members (with 43,500 vehicles) around the world ([13,77,78]). It must be stressed that most of the pioneering experiences of carsharing were born on a non-profit basis (e.g., ShareCom in Switzerland – then merged in Mobility – and Cambio in Germany); other established carsharing schemes are: 'Greenwheels' in the Netherlands and Germany, 'Zipcar' in the US and UK and the already cited experiences of 'Autolib' in Paris and 'Car2go' in Europe and Northern America[16] (both making use of electric bikes and cars). Innovative managers of large fleets for both passenger and freight transport can be considered part of this niche too ([65]).

[14] http://vitalsigns.worldwatch.org/ (accessed: 31/01/2013)

[15] In the UK carsharing schemes are known as 'car clubs' and carsharing is a synonymous of car-pooling, i.e. the shared use of a car owned by one of the travelers.

[16] Car2go is now available in 20 cities: Amsterdam, Portland and San Diego are the only three locations where the electric version of the 'Smart' is used. (www.car2go.com, accessed 06/06/2012).

Fig. 1. A socio-technical map of urban mobility: systems and actors



4. Alternative transition pathways to 2030

Three transition pathways may emerge from the current situation of urban mobility as the result of different transformative mechanisms: the 'AUTO-city' transition pathway, i.e. the reconfiguration of the 'individual car' system through the integration of producers of batteries and other electric components; the 'ECO-city' transition pathway, i.e. the empowering of local coalitions for low-carbon urban mobility and their diffusion from pioneering to laggard cities; the 'ELECTRI-city' transition pathway, i.e. the competition between the automotive and the electric industries aimed at taking control of a new energy+transport system based on smart grids (SGs) and electric vehicles (EVs).

4.1. Transition pathway 1 – 'AUTO-city'

This first transition pathway emerges from the reconfiguration of the existing 'individual car' system and is generated by the absorption of new industrial actors, in particular producers of batteries. This extension of the coalition is aimed at acquiring crucial competences on the electric car; indeed, this technology is increasingly considered by the automotive industry as the long-term response to the increasing pressure coming from policy response to some "landscape" pressures, such as: climate change, peak oil, degradation of urban space, etc. ([16,21,98]).

As some analysts suggest, the battery may become the most important element in the electric car value chain ([97]); consequently, producers of batteries may become 'core-actors' of this system. At the same time – because of the changing mix of energy sources used to power cars –oil companies should lose their position as a core-actor or eventually change their core-business, while managers of electric grids may evolve their role from mere suppliers of an essential utility to members of the coalition supporting the system.

Along the transition pathway the business model remains focused on selling cars to individual consumers, but – if also the emerging niche of carsharing schemes is steadily integrated – it could be extended to the 'rent' option too. The share of electric cars steadily increases along the transition pathway and in 2030 reaches the threshold of 35% of car sales. Two different global phenomena can be detected: in developed countries, where the rapid diffusion of hybrid cars is made possible by consumers and producers who gradually unlock from internal combustion; in emerging economies, where the boom of full EVs is supported by newcomers – with new Chinese automotive companies playing a relevant role – who benefit from the lower barriers to entry which are associated to the technology of electric car compared to internal combustion. Newly urbanized families in emerging economies contributes to support the demand side of these rising markets ([14,17,66,71]). These industrial global trends are eased by national (e.g., China) and federal (e.g., EU, USA, India) policy schemes which incentive car buyers and fund the building of recharging infrastructure.

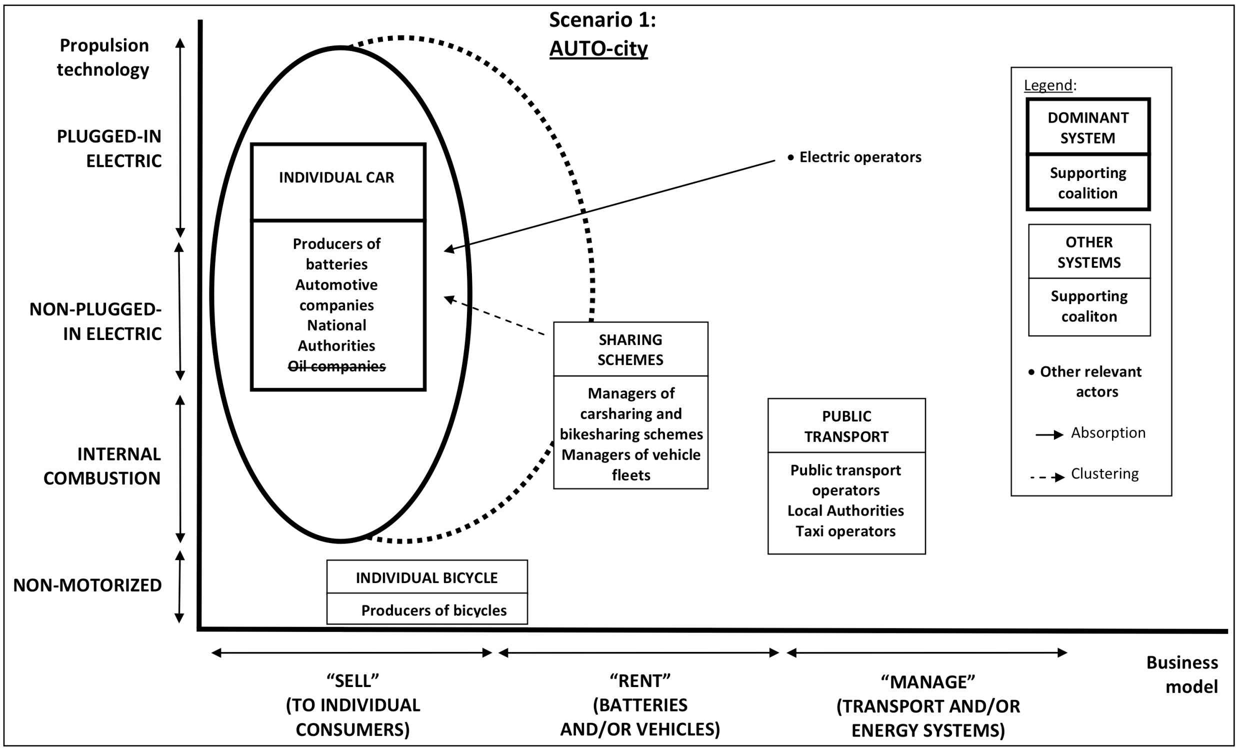
If one look at a likely ending-point of this first transition pathway (see Figure 2) the 'individual car' system keeps its dominant position on urban mobility, but – also thanks to a partially changed supporting coalition – its technological and commercial competences significantly change. Other systems of urban mobility – public transport, the individual bicycle – remain in a subaltern position.

It must be stressed that the 'AUTO-city' transition pathway is the more probable because of the pervasive lock-in and pathway-dependence phenomena linked to the dominant position held by the 'individual car'

in the current situation of urban mobility; in particular, the ability to influence the policy arena is crucial to keep benefiting from rich public incentives and loose environmental standards[17] ([47,52,79,94]). Moreover, consumers do not need to change their behavior radically but they just have to gradually adapt to recharging ([2]). At the same time, it is under dispute if this transition pathway will reach the decarbonization targets set by an increasing number of legislations; several factors play against this possibility: the too low rate of diffusion of electric cars; the "rebound" effect on energy consumption that may be generated by an increasing amount of kilometers driven by cars; the high-carbon energy-mix used to power electric cars in some countries, with China as a global worst-practice ([18,86]).
Because of these considerations one should consider how this transition pathway will change if more stringent environmental targets and faster changes in mobility behavior take place: will the 'individual car' system increase its ability to change its technological and commercial approach (e.g., a faster move to full EVs and/or a radical "jump" towards the management of sharing schemes)? Or will it decline, leaving room to the emergence of alternative transition pathways?

[17] As noticed by Angela Hull ([47]) in her last book, automotive industries and Governments share a mutual convenience: the former benefit from public subsidies and infrastructures, the latter raise a large amount of tax revenues from car sell and use.

Fig. 2. 'AUTO-city' transition pathway: 2030 final scenario



4.2. Transition pathway 2 – 'ECO-city'

In this transition pathway coalitions of urban enactors (public transport companies, local Authorities, providers of technologies, NGOs, etc.) support a new vision for sustainable cities[18] and foster the creation of new integrated urban transport systems (IUTSs) ([91]). Along the pathway the main transformative mechanism in place is the clustering – first locally and then nationally – of existing and emerging niches and systems of low-carbon mobility, such as: public transport, sharing schemes, the individual bicycle, etc.; producers of EVs are gradually absorbed into the system, mostly as suppliers of all kind of

[18] Other synonymous attributes may be used, such as: livable, smart, green, etc.

vehicles for sharing schemes and fleet operators; providers of ICT devices for individual transport planning are absorbed too ([17]). Both clustering and absorption mechanisms spans over all technologies and the 'rent' and 'manage' business models.

The actual dynamics of the 'ECO-city' transition is the result of two parallel forces which must be analyzed with a spatial key: at the national/international level the gradual de-alignment of most institutional, economics and technological constituents of the 'individual car' system takes place; at the same time, these and other elements are gradually 're-aligned' into an increasing number of IUTSs. To get a better understanding of these processes of change, the transition pathway can be divided into three stages.

Stage 1 (2013-2018)

Referring to the already existing best-practices of non-car urban systems, other local coalitions of enactors gain local legitimacy and policy support to implement restrictions and disincentives to car use and create new IUTSs; in these urban niches car sales and ownership steadily decrease. Even if these results are not sufficient to confront the world dominant position of the 'individual car', mounting concerns about overall phenomena (climate change, local pollution, congestion, etc.) weaken the political discourse in favor of the car; in particular, incentive schemes to "green" the car are increasingly under dispute. In some cases, electric operators (producers of batteries, managers of electric grids, managers of swapping and recharging stations) take part in urban coalitions for IUTSs.

Stage 2 (2019-2025)

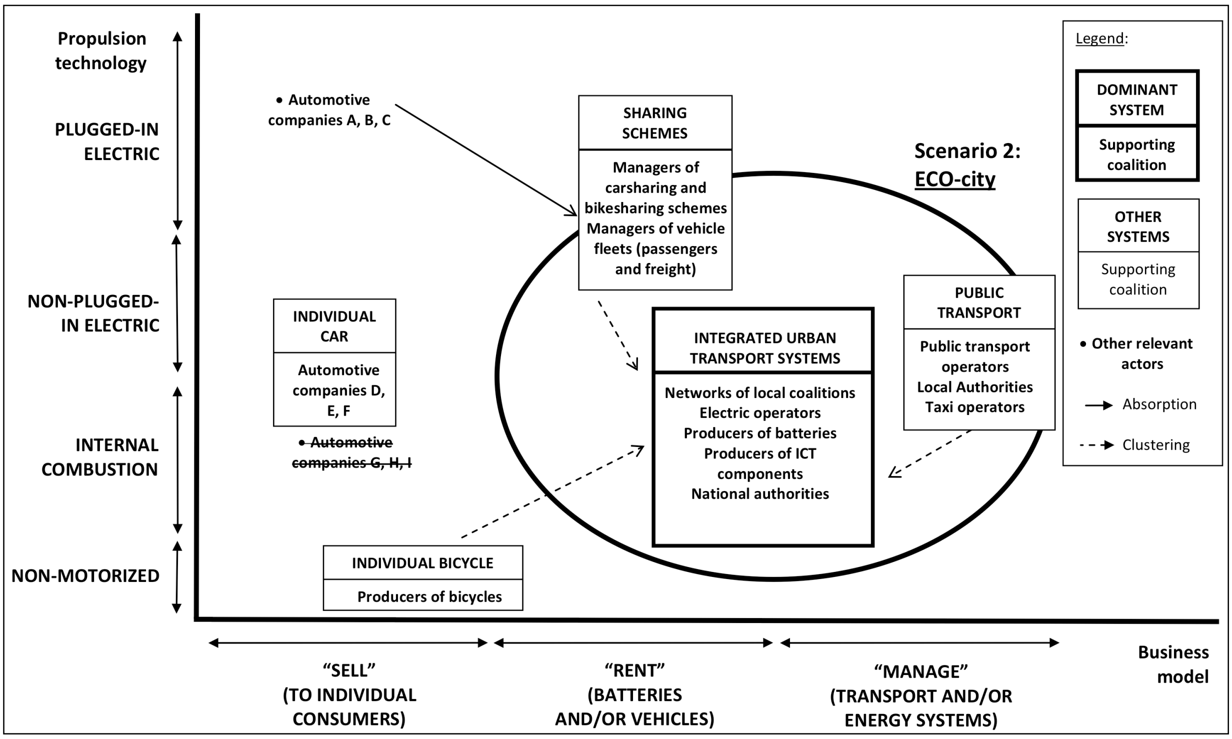
Urban niches where IUTSs are implemented grow rapidly in number. In some countries (Germany, France, Turkey, Canada, Colombia, India, South Africa, etc.) formal national networks of local coalitions of enactors are created and gain legitimacy and policy support; in these countries, national schemes are implemented to foster the diffusion of IUTSs to "laggard" cities. The World Bank and other regional development banks fund the diffusion of IUTSs in developing and under developed countries; the same approach is implemented in China. Electric operators show an increasing interest towards IUTSs and enter in some national networks. More and more countries abolish incentives to buy cars, whilst national schemes for the restriction of car use enter into force. As a result, car sales begin to decrease worldwide.

Stage 3 (2026-2030)

More national networks of enactors are created; a worldwide association is launched. Electric operators are involved in an increasing number of IUTSs and play an active role in national networks. Some big countries (the USA, Russia, Brazil, etc.) implement national schemes for the diffusion of IUTSs; in some other countries (Germany, France, Japan, etc.) these schemes are integrated with public investments for electric infrastructures. Car sales continue to decrease worldwide and in many countries a reduction in car ownership is reported; as an effect of these trends, some big automotive companies fail, while others re-reconvert to the management of sharing schemes.

Figure 3 represents the ending point of the transition. In 2030 stable networks of local coalitions support the worldwide reproduction of IUTSs, while the individual car is in a subordinate position, supported by the few surviving world automotive companies. The 'ECO-city' scenario is more sustainable than the 'AUTO-city' because of the effective combination of several actions: the substitution of car use with non-motorized transport, shared vehicles and public transport – together with the diffusion of electric propulsion – not only can meet tight environmental targets without the need of an aggressive decarbonization of electric generation, but can also significantly increase urban livability ([2,9,43,58,70]). But the 'ECO-city' scenario is less probable than the 'AUTO-city' because its actual deployment depends on changes taking place at all level of social life: at the macro level, the delegitimation and destabilization of the 'individual car' system; at the micro level, the spread of urban lifestyles which are no more based on the use of individual cars ([2,21]); at the meso (i.e. systemic) level, the creation and empowering of coalitions and networks of enactors of IUTSs in pioneering cities and the implementation of policies that support their diffusion to laggard cities. IUTSs will come out from urban niches – and reach a dominant position in urban mobility – only if these processes will mutually reinforce and generate a multilevel critical mass for change ([55]).

Fig. 3. 'ECO-city' transition pathway: 2030 final scenario



4.3. Transition pathway 3 – 'ELECTRI-city'

In this transition pathway local and national electric operators are interested in the adaptation of their systems to the diffusion of EVs, because they aim at the new frontier of smart grids (SGs), that is, grids which are able to exchange electricity with distributed energy resources, also in order to increase grid stability and reducing demand-supply unbalances, in particular in the case of renewable sources ([3,61,87])[19].

The "ELECTRI-city" transition pathway can be divided into two phases: the first one for local testing (2013-2020) and the second one for consolidation at the global scale (2021-2030).

[19] For an extensive report on European SV projects, see [38]; details on SG+EV projects can be found at pp. 34-37 and in the Annex IV.

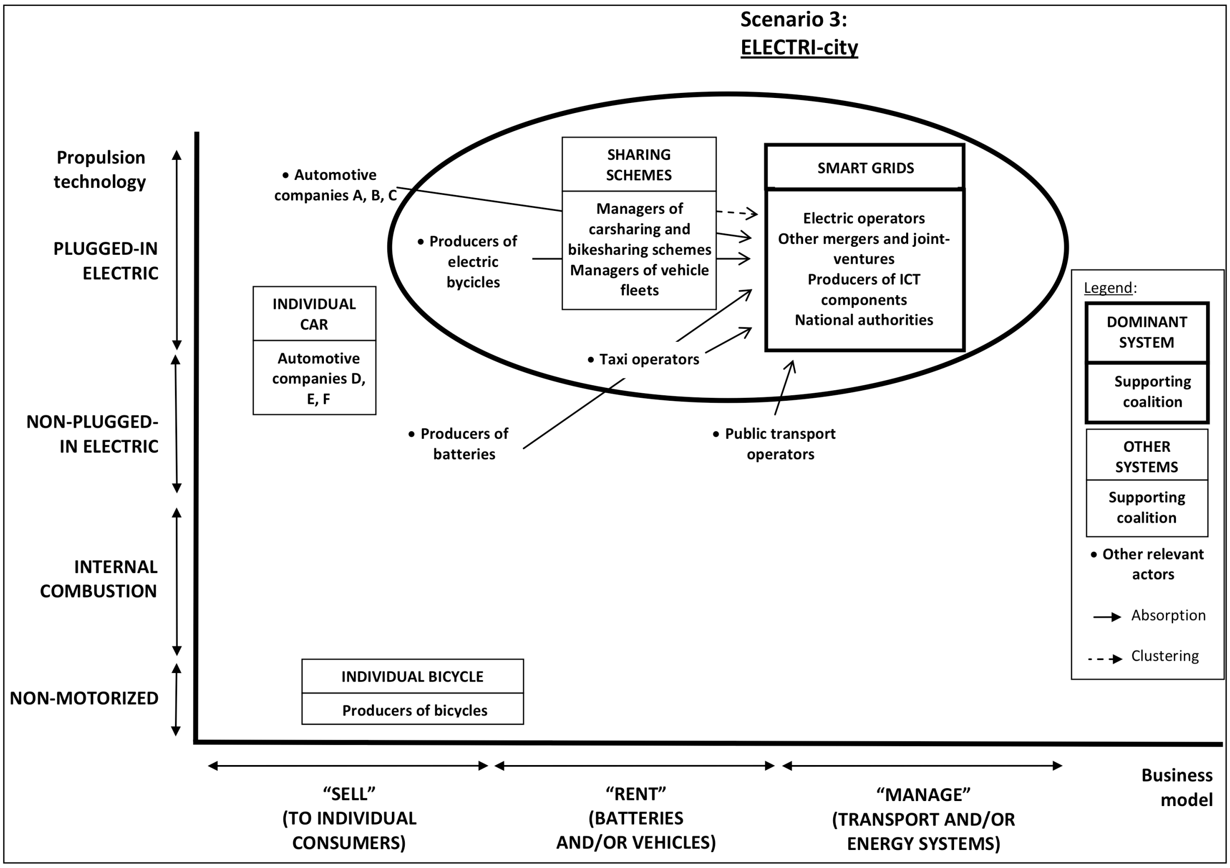
In the first phase, cities initially play a relevant role as niches for both technological/organizational testing and coalition building. Several experiments take place, in particular: a) to adapt the electric system to the function of mobility and to understand if it is more profitable to connect SGs to vehicles or to battery-swap stations, and b) to check the functioning of coalitions of actors which alternatively include: managers of sharing schemes, public transport operators, managers of battery-swap stations, research bodies, etc. ([37,63,83]). Some global new actors (as the Israeli Better Place) and networks (as the C40 Cities Climate Leadership Group) play a relevant role in this first part of the transition as promoter of tests at all urban scales, from medium towns to megacities ([15,95]). After several years of testing and experimenting, more and more consumers and producers are involved in the building of a new market and it is increasingly apparent that SG+EV systems generate network externalities on both its demand and supply sides ([72]).

In the following decade, the positive results of previous testing fuel the interest of operators coming from different sectors: not only managers of electric grids, but also producers of batteries, suppliers of ICT components and – last but not least – producers of plug-in cars ([19]). Also as a result of the increasing pressures of all these operators on political institutions, national schemes to support SG+EV systems are successfully implemented in several countries, starting with those which feature higher shares of electric generation from renewable sources (Denmark, Germany, Spain, France, etc.) ([52]). Already established purchase subsidies are restricted to plug-in electric cars only and are integrated with investments on old and new infrastructures (e.g., metropolitan railway networks and SGs). Moreover, common standards on grids, plugs and batteries are introduced to further catalyze the diffusion of SG+EV systems ([19]). Year by year this integrated approach to energy and transport policies is followed by an increasing number of states and federations, including California, Oregon, the EU and China. Because of the need of large investments to exploit latent economies of scale, big players gradually reach a dominant position in a global oligopoly, but both spontaneous and publicly-driven mechanisms are changing the profile of these market leaders: a big merge has involved General Motors and General Electric; a global joint-venture company has been created by Renault/Nissan, Better Place and a transnational group of producers of renewables; the EU – taking advantage of the Airbus experience – has promoted the clustering of all relevant European actors in the AV ("Alessandro Volta") consortium for electric mobility, which may eventual transform in an entrepreneurial initiative[20]; the creation of a global player for the market of SGs is one of the main goals of the 2020-2025 Chinese plan.

The final scenario emerging from this transition pathway is represented in figure 4. This is the result of a successful "takeover bid" on the 'individual car' system which is launched by enactors (then core-actors) coming from another sector. The environmental sustainability of this scenario is conditioned by the energy mix used to generate electricity and – what matters most – its likelihood is crucially conditioned by two factors: 1) a long period of testing and experimentation is needed because almost no experience is accumulated in the field of urban transport by electric operators: during all this time alternative transition pathways may become dominant; 2) because of latent economies of scale the new SG+EV system cannot merely emerge from imitation and diffusion (as in the case of the 'ECO-city' transition pathway), but must be implemented at a national/international level: the needed huge public and private investments may not be available (also because of macroeconomic issues). The only strength of electric operators in the early stages of the transition pathway is that they own an essential facility for the diffusion of electric cars: the electric grid. Both the sustainability and the likelihood of this transition pathway will benefit from an acceleration of the global diffusion of renewables and even more from the stable technological and economic integration of renewables and ICT ([57]).

[20] Something similar is already taking place on a local basis in Barcelona, Berlin, Brabanstad (NL), Goto Islands (J), Hamburg and on a national basis in Denmark, Finland, Israeli and USA ([52,63,93]).

Fig. 4. 'ELECTRI-city' transition pathway: 2030 final scenario



5. Discussion and conclusions

5.1. Differences from other socio-technical studies

This short section is aimed at stressing how the results provided above differ from those of other ST studies on the future of urban mobility.

The first difference is the key reference to the impact of the dynamics of coalitions of core-actors and enactors on the evolution of existing and emerging ST systems, respectively. In most ST studies on urban mobility attention is mainly paid to single actors, while supporting coalitions are seldom considered and their dynamics is almost ignored. Probably, the only relevant attempt to deal with this issue is the application of the MATISSE project to sustainable mobility ([51]): but also here the dynamics of transitions mostly depends on the ability of competing multi-actor systems and niches to gain support from consumers, while both the internal and external dynamics of these coalitions remain in the shadows.

We have also seen – and this is the second difference – that such a dynamics of coalitions is crucial to understand how policies change along the transition pathway. In many ST studies policies stay centre stage, but mostly as exogenous factors or external pressures ([17,21,51]); only Geels ([31]) stresses that policies are the result of pressure for (and resistance to) change coming from relevant actors. Here we went further and showed that – because of the cumulative causation between coalition building, legitimacy, supporting policies and coalition's resources – policies are endogenous to transition pathways.

The last difference is that in all other ST studies on the future of mobility only two alternative pathways are considered. The first pathway is almost always technology-driven and based on the integration of the electric technology into the car system; in particular, some studies try to understand which kind of electric car – hybrid, battery, fuel cell, etc.– will prevail in the future ([17,22,51]). The second pathway usually lead to the emergence of a new multimodal system – e.g. see 'Citrans' ([21]) – which gains support from coherent changes in mobility behavior and lifestyles ([2]). The consideration of a third alternative pathway – as the 'ELECTRI-city' proposed here – is then something original; in particular because scholarly attention is drawn on the ST dynamics of another societal function (i.e., the provision of energy) which may become endogenous to the future of urban mobility.

5.2. Transition pathways and policy options

The analysis of alternative transition pathways shows that the configuration of 2030 urban mobility will depend on three elements: 1) The current positioning of socio-technical systems and their supporting coalitions; 2) The future competition between three supporting coalitions and their strategies; 3) Which supporting coalition will accumulate enough power to win the battle over political institutions.

Three policy options can be derived from these elements: a) Any intervention for the greening of urban mobility which, at the same time, do not destabilize the dominant position of the 'individual car' will result in an 'AUTO-city' scenario centered on electric cars; b) A multilevel transport policy is necessary to ease the diffusion of integrated urban transport systems and the emergence of an 'ECO-city' scenario where electric cars will play a secondary role; c) An industrial policy is necessary to create the conditions for the establishment of an 'ELECTRI-city' scenario, in which the electric car will be nothing but an element of an energy+transport system. As a corollary of what is stated in policy option a), both the b) and c) policy options must be complemented by interventions specifically aimed at weakening the dominant position of the 'individual car' system.

5.3. Hints for the integration of the ST approach

The above results have been possible thanks to the ST analysis of the co-evolution of structural changes and coalitions of innovative actors. This analysis also provided some hints for further research that might be relevant not only in the domain of urban mobility. In particular, if the mutual causation between the dynamics of supporting coalitions and the generation of coherent institutional changes is key to understand the actual evolution of transition pathways, then it should play a more relevant role into ST studies of innovation. As suggested by some scholars (e.g. [74,89]) the stable integration of a group (multilevel) selection mechanism into the representation of ST transitions may help to highlight how the dynamics of supporting coalitions interacts with the overall evolution of a societal function. Inter alia, this may help respond to some relevant research issues: the integration of institutions, politics and policy into future studies ([25,49,59,81]); the explicit consideration of individuals, not so much as consumers or users, but rather as citizens who votes and – maybe more important – participate to NGOs, advocating groups, grassroots movements, and so on ([60,91]); and – last but not least – the solution to an apparent "chicken-and-egg" policy problem: if supporting coalitions are needed to induce societal change, will a policy to nurse supporting coalitions ever emerge? ([56])

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