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Dissemination of electric vehicles in urban areas: Major factors for success

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ABSTRACT

Problems of transport become more pressing with increasing urbanisation. Although EVs (electric vehicles) are considered to contribute to reduction of greenhouse gas emissions and local air pollution caused by passenger car transport, their use is still very modest.

The core objective of this paper is to identify the major impact factors for the broader dissemination of EVs in urban areas. We compare and analyse cities selected in nine different countries which are active in dissemination of EVs.

The most important recommendation for policy makers is that all monetary and non-monetary promotion measures implemented should depend on the environmental benignity of the electricity generation mix. From society's point of view the promotion of EVs make sense only if it is ensured that a major share of electricity they use is generated from renewables. Since the final goal is not just to increase the number of EVs but to reduce emissions, cities also have to consider other e-mobility options such as trolleybuses, metros, trams and electro buses, as well as promote walking and biking, especially for short distances.

1. Introduction

The transport sector is one of the major contributors to global energy consumption and GHG (greenhouse gas) emissions [15]. At the time when problems, such as increasing GHG emissions and air pollutions, as well as growing dependency on energy import, related to the conventional passenger cars transport based on fossil fuels, are becoming more and more visible, the use of alternative, environmentally friendly fuels and powertrains seems to be a key strategy for heading towards a sustainable transport system.

Especially in cities, where due to the urbanization trend transport developments are becoming even more important, there is an urgent need for action to cope with transport problems. Some of the problems related to urban areas such as local air pollution and noise, could be reduced by using zero-emission battery electric vehicles.

Since EVs (electric vehicles) have potential to contribute to the better life quality in cities as well as to the reduction of GHG emissions in the transport sector a broad portfolio of different policy measures is already implemented on national as well as local level all over the world with the goal to support their market-penetration.

The need for a more environmentally friendly energy and transport system is already included in the European energy and transport policy design [16]. According to the EU's Energy and Climate Change Packages (2020 and 2030) there is a clear target to reduce GHG emissions, increase energy efficiency and use of RES (renewable energy sources). A 10% share of renewable energy should be achieved in the transport sector by 2020 [51]. Furthermore, according to the Transport White Paper [14] the use of 'conventionally fuelled' cars in urban transport should be reduced by 50% by 2030, and in cities completely phased out by 2050. Looking at the current situation in urban transport, especially the very low share of alternative automotive powertrains and alternative fuels, these targets can be seen as very ambitious. Although different policy measures are implemented worldwide with the goal to reduce GHG emissions, supporting the use of alternative and more environmentally friendly vehicles directly or indirectly, EVs are still rarity in most cities.

Even if EVs were invented more than 150 years ago, and in spite of several attempts to make them more attractive, the passenger vehicle market is dominated by ICE (internal combustion engine)

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vehicles [2,7]. Over this period, many countries have launched extensive research and development programmes for battery and vehicles, and different technologies and business models have been tested [20,31,46].

Previous studies have analysed various aspects of the deployment of EVs especially their economic and environmental assessment (e.g. Refs. [2,18,56,58,59]). Their role in an urban context is analysed by Perujo et al. [43] and Trip and Konings [60]. Newman et al. [40] provided a critical discussion on urbanism and EVs. Similar analysis but with the focus on planning-related issues is documented by van Wee et al. [62]. More detailed investigations of specific electro mobility issues in different cities are provided by Colmenar et al. [10] for the Spanish city of Leon, by Raslavicius et al. [48] for city of Kaunas in Lithuania, by Jian [29] for Being and Perujo et al. [45] for the Province of Milano (Italy). The potential impacts of EVs on air quality in Spanish cities Barcelona and Madrid is documented in Ref. [52]. Public policies and knowledge which can trigger development of electric mobility is also discussed in literature, see e.g. Refs. [1,9,32,34]. A very good assessment of leading EVs promotion activities in US cities is provided by Lutsey et al. [35]. They have analysed the uptake of EVs in relation with different promotion actions set on the state and city level. There are also a few other publications providing an overview of EVs in different countries (e.g. Ref. [8]) and cities (e.g. Refs. [17,23]). Comprehensive assessments of socio-economic and socio-technical issues of EVs have been conducted by Plötz et al. [46] and Steinhilber et al. [57].

The core objective of this paper is to identify major impact factors for the broader dissemination of EVs in urban areas. We compare and analyze cities active in the take-up of EVs based on the literature. In this paper we have selected fourteen cities in nine different countries which are very active in dissemination of EVs. For the cities selected we were able to collect all data required for our analysis. In Europe, we have analyzed the impacts on the dissemination of EVs in Amsterdam, Barcelona, Berlin, Brabantstad, Hamburg, NorthEast, Oslo, Rotterdam, Stockholm, and Vienna; in the United States – Los Angeles, New York City, and Portland; and in Asia – Shanghai (China). All these cities are interested in the reduction of emissions and pollutions caused by transport and they have already implemented different national and local measures which should support the penetration of EVs.

The major novelty and contribution of this paper is that it addresses economic, environmental, infrastructural and political issues regarding the prospects for dissemination of EVs in urban areas, using specific data sets from various cities in the major geographical areas of EV use.

We have applied a mix of quantitative and qualitative approaches. For our quantitative approach we have used data from literature (e.g. Refs. [2,21,35], especially data provided by International Energy Agency [23,24,27,28] as well as national statistics [54,55]. We have investigated different indicators aiming to identify best examples for the EVs use in urban areas. For the qualitative analysis we have conducted a comprehensive literature review.

2. Background: Technical, economic and environmental characterstics of electric vehicles

The interest in EVs, which are often presented as ZEV (zero-emission vehicles), has been rapidly increasing over the last decade. EVs can be divided in four major types – BEVs (Battery Electric Vehicles), HEVs (Hybrid Electric Vehicles), PHEVs (Plug-In Hybrid Electric Vehicles), REX (Range Extenders) – with different level of electrification and different possibilities to contribute to emission reduction, see Fig. 1. Only pure BEVs are zero-emission vehicles at the point of use, but not in the whole WTW (well-to-wheel) energy supply chain. The advantages and disadvantages of different types

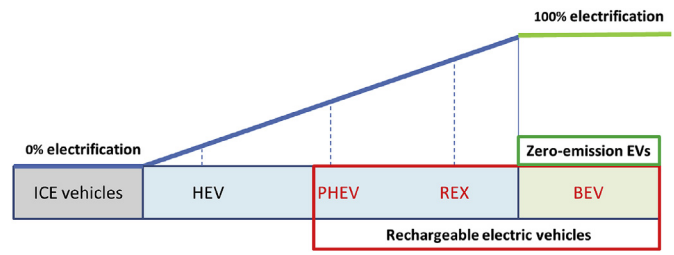

Fig. 1. Level of electrification of electric vehicles.

of EVs are discussed in detail in Ref. [2].

Currently, HEVs have the largest market share [53] since their characteristics as well as mobility costs are very similar to those of conventional ICE vehicles [2]. However, HEVs are powered by fossil fuels and have very low level of electrification, and consequently very limited potential for emission reduction. They can be seen just as an energy efficiency measure and hence are not suitable for urban areas.

There are much higher expectations with respect to EVs with higher electrification level. However, since rechargeable EVs have higher costs, lower operating range, as well as the need for charging infrastructure, their number is currently rather low. Major problems for faster market penetration are low density of battery, high costs and limited infrastructure, as well as acceptance.

To make EVs more economically competitive on the market they are supported by different financial policy measures. However, looking at the TCO (total cost of ownership), which can be calculated using Eq. (1), EVs are still more expensive comparing to conventional cars, mostly due to investment costs [2,22].

$$TCO = \frac{(IC + \tau_{REG}) \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \quad (\text{EUR}/100\ \text{km}) \tag{1}$$

Where IC are investment costs; τ_{REG} is registration tax; α is capital recovery factor; skm is specific number of km driven per car per year; P_f is energy price incl. taxes; $C_{O\&M}$ are operating and maintenance costs; and FI is energy consumption of vehicles.

As can be seen from Eq. (1), TCO depend on specific number of km driven per car per year. This indicates that EVs could be more or less economic depending on travel activity. Vehicles with the high number of kilometre driven, such as taxis, delivery and service vehicles, could be more appropriate for electrification from an economic point of view.

Although EVs have lower or even zero emission at the point of use compared to conventional ICE vehicles, their total environmental benefits are very dependent on primary energy sources used for electricity generation. Yet, all environmental benefits of EVs could be reached only if the electricity used in cars is generated from renewable energy sources [3,56,59]. In case that electricity is generated from fossil energy, especially using old coal power plants, total WTW emissions could be even higher than those of conventional cars [5,11,56], see Fig. 2.

3. Performance of electric vehicles in cities selected

As mentioned by Newman et al. [40], EV City Casebook [23] is a very relevant source of examples of socio-technical experimentation, but a deeper assessment of these results is needed. In this paper we have analyzed cities selected considering not only absolute numbers of EVs and charging stations. We have investigated different indicators such as number of EVs per capita, number of EVs per charging point, relation between EVs per capita and GDP (gross domestic product) per capita, relation between gasoline and

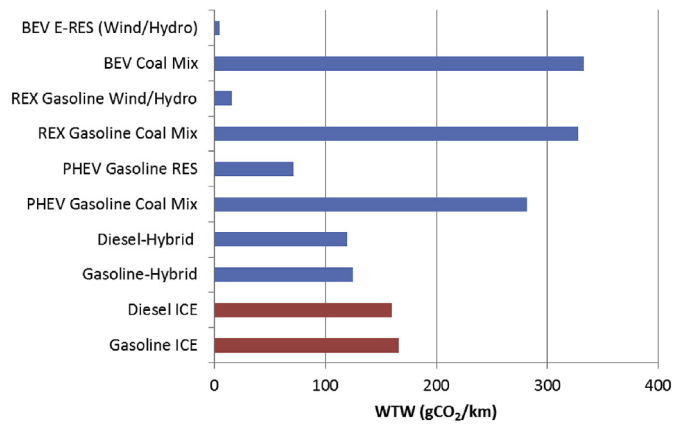

Fig. 2. Well-to-Wheel emissions of different types of EVs in comparison to conventional cars (based on [3]).

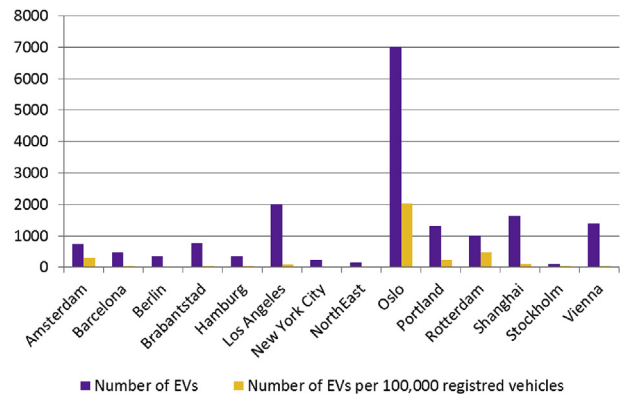

Fig. 4. Numbers of EVs in cities.
Data sources: [23,26,53,54].

electricity prices, etc., aiming to identify best city-examples and policies implemented.

3.1. Number of EVs

As shown in Fig. 3, the number of EVs per capita is highest in Oslo, with almost eleven EVs per thousand inhabitants. EVs-ownership level is much lower in other cities, between 0.03 and 2.23 EVs per thousand inhabitants.

Although the absolute number of EVs in Los Angeles, Shanghai and Vienna is relatively high compared to other cities (between about 1400 and 2000 EVs), it is low in comparison to the total number of registered vehicles, between 30 and 95 EVs per 100,000 registered vehicles. The largest number of EVs per registered vehicles is in Oslo, followed by Rotterdam and Amsterdam, see Fig. 4.

3.2. Charging infrastructure

To increase the attractiveness of EVs the number of charging stations is growing continuosly. However, most of the available stations are slow charging (it takes 7–12 h to complete battery charging) followed by fast charging (battery charging takes approximately 3–4 h). The number of rapid charging stations (charging can be completed within a few minutes) is still very low due to high costs per charging points [2,39,44].

Fig. 5 shows the number of charging stations in relation to the number of EVs in different cities. Although Oslo has the highest number of EVs, the highest number of the charging stations is in

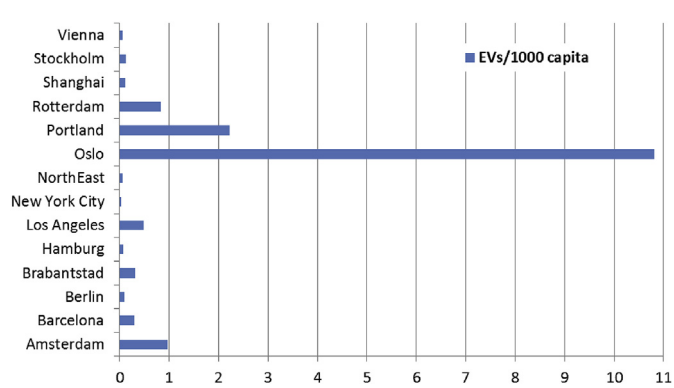

Fig. 3. EVs per capita.
Data sources: [23,26,53,54].

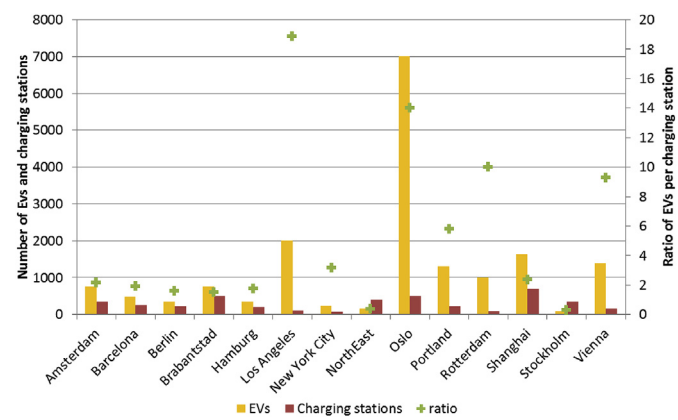

Fig. 5. Number of charging stations vs. number of rechargeable EV, 2012.
Data sources: [23,26,53–55].

Shanghai. The number of electric vehicle per charging station is very different in the cities analyzed, in the range from 0.3 to 19 vehicles per one charging station. This ratio is highest in Los Angeles, Oslo and Rotterdam. However, there are also cases where the number of charging stations is higher than number of EVs. For example, the number of charging stations in Stockholm is more than three times higher than the number of EVs.

As discussed in literature, due to limited infrastructure as well as restricted driving range of EVs, it appears that consumers are applying strategy of "little and often" [40]. The vehicles are usually charged as soon as possible, mostly as a 50% charge level is reached. Using this strategy, EVs could block recharge points for the whole working day, but perhaps only be recharging for 2 h. Capacity utilization is the biggest challenge for infrastructure provides. Moreover, in most of urban areas possibilities for use of home charging and the provision of charging cables from the mains may not be practicable in apartment blokes or terraced houses with limited off-street parking [30,47].

3.3. Driving range

In literature it is often discussed that EVs have restricted driving range and drivers can experience "range anxiety" [6,37]. In urban areas, due to the limited driving needs, this should not be a significant problem. Daily travel need of majority of population in urban areas is below 40 km, see Fig. 6 [23]. This distance could be easily covered with all types of EVs. However, there is still a gap

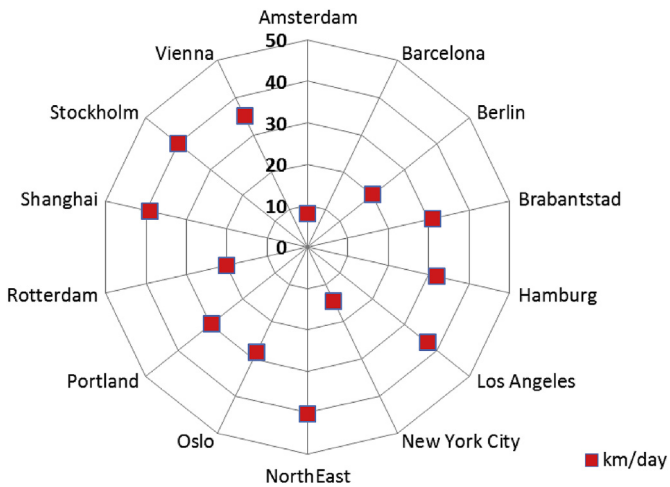

Fig. 6. Average daily travel need in cities.
Data sources: [23,54,55].

between individual expectations of the driving range of EVs and actual daily driving distance [13].

As discussed above, total costs of ownership are dependent on the number of kilometres driven per year. The core problem is that typically EVs in urban areas do not drive enough kilometres per year to become cost-effective [46]. On the other hand, sub-urban commuter ranges are between 30 and 80 km per day. This driving range is very suitable for EVs fitting the discharge-recharge cycle more effectively [40].

3.4. Economic conditions

As mentioned before, the number of EVs is very different in the cities analyzed. This is to some extent due to different goals, policies implemented, investments in R&D, but also due to different economic conditions.

Fig. 7 shows the relation between the number of EVs and income of a country. Available amount of money per capita can make EVs more or less attractive. It can be noticed that in countries with higher GDP (e.g. in Norway) willingness to pay for environmentally friendly but more expensive EVs is higher. However, this does not mean that all rich cities have a high number of EVs.

Total costs of ownership of EVs have been calculated in different papers [2,22,56] and it is obvious that the largest amount of total transport costs is due to the investment cost of vehicles. Although

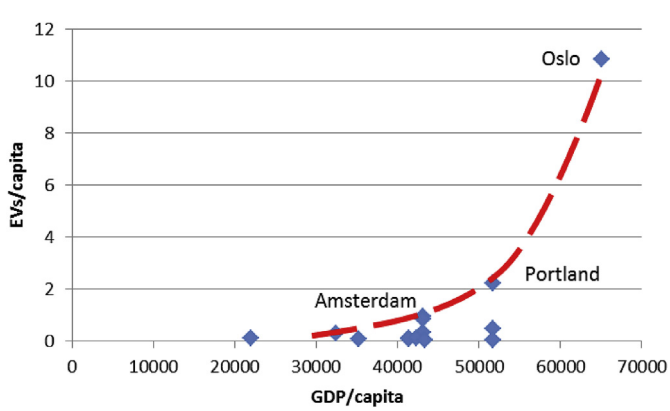

Fig. 7. EVs per capita depending on GDP/capita.
Source for GDP: [42]; converted via PPP.

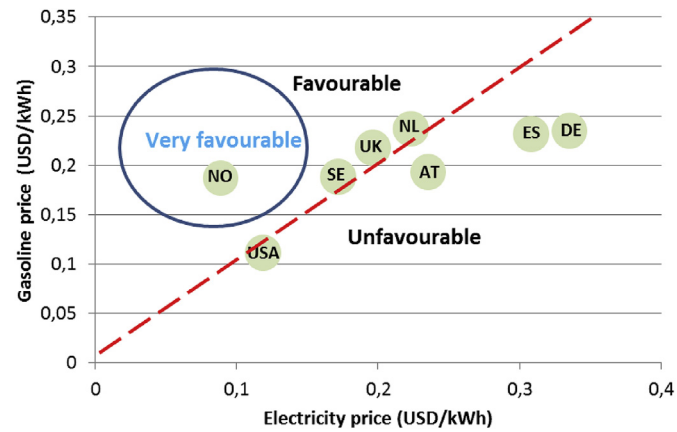

Fig. 8. Gasoline vs electricity prices in different countries as of 2012 including taxes
Source: [27,28]; converted via PPP.

energy costs contribute a relatively small part of total transport costs, especially with EVs, high gasoline prices and low electricity prices could be motivation for the switch to EVs. Energy prices serve as the most visible signal for consumers to think about energy saving and energy economy. Variations, especially increases, in gasoline prices could lead to changes in EV-adoption patterns [12].

Gasoline versus electricity prices in different countries, including all taxes (as of 2012), are shown in Fig. 8. If gasoline price is high and electricity price is low this could be one incentive for switching to EVs. As it can be seen from Fig. 8 this ratio is very favourable for cities in Norway, followed by Sweden, United Kingdom and The Netherlands, and less favourable for Austria, Spain and Germany. For the United States it is ambiguous.

To close current technical and economic gap, and to increase the use of EVs different policies and measures are implemented with the goal to raise their attractiveness. However, monetary measures may disproportionally benefit higher income consumers which are in contrary to lower income consumers able to afford more expensive EVs [12].

3.5. Environmental impact

It should be bear in mind that the final goal of transport electrification is not just to increase the number of EVs but to reduce GHG emissions and air pollution. How environmentally friendly EVs are depends on the type of the EVs (see Fig. 1) as well as the electricity mix used in cars. This mix is very different in countries analyzed,[1] see Fig. 9.

From environmental point of view, the most favourable cities for the use of EVs are Oslo, Stockholm and Vienna. The contribution of EVs to the reduction of GHG emissions in China, United Kingdom and the Netherlands is relatively limited due to the low share of RES in total electricity mix. However, in some of the cities (e.g. Shanghai) EVs could significantly contribute to the reduction of local air pollution. Yet, full environmental benefits of EVs could be reached only in combination with electricity from RES.

4. Policies and measures implemented

Many local and national governments worldwide have implemented different strategies for the promotion of EVs. In addition to the mostly used monetary measures such as exemptions (or

[1] For some of the cities we have used overall electricity mix of the country.

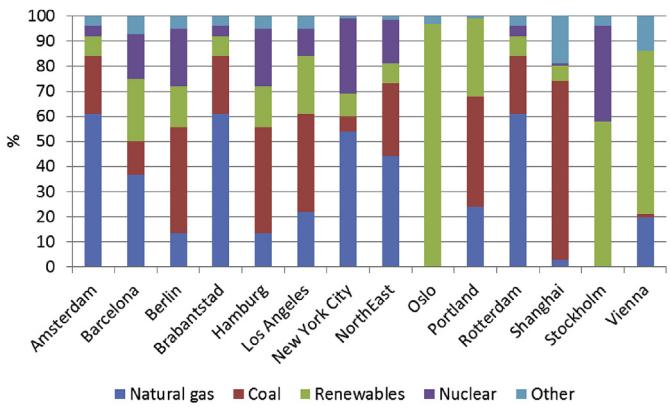

Fig. 9. Electricity generation mix in the cities investigated.
Data sources: [23,54,55].

reductions) from road taxes, annual circulation tax, company car taxes, registration tax, fuel consumption tax, congestion charges, etc., which are usually implemented on the country level, there are also different non-monetary measures implemented on the city level. The most important non-monetary measures are:

- free parking spaces,
- possibility for EVs drivers to use bus lanes,
- wide availability of fast charging stations,
- permission for EVs to enter city centres and zero emission zones.

Currently, the major drivers for increasing use of EVs in cities are policies. In the following major supporting measures implemented in Europe, the USA and China are presented.

4.1. Europe

Due to the increasing emissions of transport sector many European countries have implemented a broad portfolio of policies and measures which should support use of more environmentally friendly vehicles and lead to the reduction of GHG emissions.

Some of these measures are set at the EU level and are the same for all Member States, for example standards for CO_2 emissions from new passenger cars. Basically, measures based on CO_2 emissions could have impact on consumers as well as on the car producers. For vehicles with low level of CO_2 emissions different types of tax credits and exceptions are provided to consumers, and super credits and subsidies for manufactures. The measures implemented on local level are very different from city to city.

Major tax incentives and policies for EVs implemented on a national and local level in selected countries and cities are presented in Table 1.

4.2. The United States

The U.S. Federal government policies and legislations are designed to promote and support EVs. In the United States leading cities regarding the deployment of EVs (such as San Francisco, Atlanta, Los Angeles, San Diego, Portland, etc.) have adopted California's Zero Emission Vehicle program and have attractive consumer incentives. For the three USA cities discussed in this paper major promotion actions are presented in Table 2.

As shown in Table 2 Los Angeles has a broad portfolio of implemented policies at the state and city-level. Since the Los Angeles region has the highest level of ozone in the US, increasing use of EVs is recognized as a high priority. An additional motivation is that in 2010 Los Angeles became headquarters to two electric vehicle manufacturers, and numerous other companies related to e-mobility [23]. Using electricity from California's grid mix EVs and PHEVs produce about 70 and 50% fewer emissions per mile than gas vehicles, respectively. Since the use of renewable energy is growing dramatically in Los Angeles (with the goal of 33% by 2020) environmental benefits of EVs will be even better [23].

In the United States Los Angeles (L.A.) has the highest sale of PHEVs supported by the highest monetary benefits. In addition, L.A. has one of best BEVs and PHEVs model availability [35].

In Portland transportation accounts for about 38% of GHG emissions. According to Portland's Climate Action Plan CO_2 emissions have to be reduced for a 40% below 1990 levels by 2030. To reach this goal increased use of public transit as well as EVs will play a key role [23]. In the USA Portland has the highest number of electric chargers per capita [35].

In New York the major driver for supporting measures for EVs is the need for better air quality. Although only 44% of New York City households own a vehicle, EVs will play an important role in the future. To meet the goal of a 30% reduction in CO_2 fleet emissions by 2017, the city is adding EVs to its fleet [23]. Comparing to other US cities New York have less charging infrastructure and state subsidies, but high electric vehicle availability [35].

4.3. China

China is the world's most populous country with a rapidly growing economy (China's GDP grow at about 10% annually between 2000 and 2010). China is the world's second largest oil consumer after the US, and the largest global energy consumer, according to International Energy Agency [24]. Policies and financial support in China are mostly focused on the industrialization of new vehicles (PHEVs, BEVs as well as FCVs (fuel cell vehicles)).

The Chinese government provides national subsidies for PHEVs and pure EVs. The City of Shanghai offers additional subsidies on the local level for these vehicles. Public service vehicles, such as light duty commercial trucks and buses, also receive subsidies. These incentives are part of a larger effort to encourage the adoption of EVs. Besides Shanghai, there are five other demonstration cities (including Beijing and Shenzhen) which also provide local subsidies of their own [23].

5. Synthesis and discussion

As shown above, different policies and measures are used to increase the attractiveness of EVs, and majority of them, especially non-monetary measures, are implemented in urban areas.

The best example regarding the use of EVs is Oslo. In Norway EVs are exempted from registration tax, value-added tax, annual car tax, road toll and congestion charges. Norway is the most generous country, offering subsidies which make EVs competitive with ICE vehicles on a TCO basis.

In addition, drivers of EVs in Oslo have access to bus lanes and free parking spaces [36,49]. Moreover, a good public charging network is provided, with about 10,000 charging stations [33]. At the same time the gasoline price in Norway is high (e.g. 1.78 EUR/l in Norway vs. 1.18 EUR/l in Austria -13. March 2015) [19], and electricity price is relatively low.

Furthermore, a very important fact with respect to environmental benignity is that carbon intensity of electricity mix in Norway is very low. In 2011 CO_2 emissions per kWh from electricity generation in Norway were just 13 gCO_2 per kWh vs. for example 215 gCO_2 per kWh in Austria or 764 gCO_2 per kWh in China [25].

Moreover, Norway goes beyond promotion of e-mobility in urban areas, and has started initiatives to add more fast-charging

Table 1
National and local EVs supporting measures in European countries and cities (data sources: [1,23,38,50,63]).

Country/city	National and local measures
AT Vienna	***National***: Electric vehicles are exempt from the fuel consumption tax and from the monthly vehicle tax. ***Local***: In Vienna only the purchase of electric bicycles, mopeds, and motorcycles was subsidized until the end of 2011.
DE Berlin	***National***: Electric vehicles are exempt from the annual circulation tax for a period of ten years from the date of their first registration. ***Local***: Strategic overall conception: city development plan for transport. Designation of laboratory areas. Development of a uniform platform for information and data. Conceptualized city 'map' for expanding the public charging structure. Participation in future demonstration projects with state funds. Conversion of the senate's vehicle fleet to sustainable drives.
Hamburg	***Local***: The Hamburg Senate, the local state government, launched an ambitious masterplan in November 2011. This includes: promoting EVs in municipal fleet procurement, installing charging spots at public buildings, and considering EV-driven concepts in tender procedures, for example, offering public plots.
ES Barcelona	***National***: Direct subsidies for purchase. Changes in registration tax. Free parking in controlled parking lots. Lower electricity tax. ***Local***: Tax benefits (lower vehicle registration tax). Free recharging for electric vehicles at all municipal points on public roads (until the end of 2012). Free parking in regulated areas for Barcelona residents with BEVs. New public car parks with 2% of the spaces reserved for electric vehicles and facilities ready for the future inclusion of points in the rest of the spaces.
SE Stockholm	***National***: Tax exemptions for the first five years. Reduction of company car taxation. "Super green car premium" is available for the purchase of new cars with CO_2 emissions of maximum 50 g/km. The premium is applied both for the purchase by private persons and companies. The premium will be paid for a total of maximum 5000 cars. ***Local***: The City of Stockholm is procuring approximately 20 EVs each year for its fleet and is encouraging more national incentives.
UK NorthEast	***National***: Purchasers of electric vehicles and plug-in hybrid vehicles with CO_2 emissions below 75 g/km receive a premium of £ 5000 (maximum) or 25% of the value of a new car or £ 8000 (maximum) or 20% of the value of a new low carbon vehicle meeting eligibility criteria. Electric vehicles are exempt from the annual circulation tax. This tax is based on CO_2 emissions and all vehicles with emissions below 100 g/km are exempt from it. Electric vehicles and other vehicles emitting less than 95 g/km of CO_2 can claim a 100% first-year allowance for depreciation. ***Local***: North East England offers a comprehensive package, including manufacturing and battery development, R&D, skills, training, as well as a leading supply chain—making it the place to be for low carbon vehicle development and maintenance.
NL Amsterdam	***National***: EVs are exempt from the registration tax. Vehicles emitting maximum 50 g/km of CO_2 are exempt from the annual circulation tax. ***Local***: The City of Amsterdam has launched a subsidy scheme to support companies intending to use electric cars, taxis and trucks as a key means of transportation around the city.
Brabantstad	***Local***: €100 million in public/private investment and tax benefits for EV drivers. BrabantStad supports the development and implementation of electric mobility solutions not only by creating demand but by incorporating the support of a technology-driven industry.
Rotterdam	***Local***: The public charging stations installed by the City of Rotterdam on the streets and in car parks are part of a national network of charging stations and can be used by anyone with an electric vehicle. Companies, organizations and owners of an electric vehicle parked on private property can apply for a grant towards the purchase of the equipment for an electric charging station, up to a maximum of € 1000 per station. If green energy is used to charge the vehicle, the municipality will reimburse the energy costs for the first year that the charging station is in use, up to a total of € 450. Owners of an electric vehicle, who cannot park on their own property, can apply to the City of Rotterdam to have a public charging station provided.
NO Oslo	***National***: Norway is the most generous country, offering a broad package of subsidies amounting to ~EUR 17,000 when compared to the purchase of a compact class ICE car. In Norway, EVs are more attractive than ICEs on a total costs of ownership basis as a result of subsidies that include exemption from purchase tax, VAT (value-added tax), toll road charges, registration tax, and annual circulation tax. Norway has started initiatives to add more fast-charging stations along highways to facilitate intercity travel. ***Local***: Oslo use local incentives to increase popularity of electric vehicles and to encourage their widespread adoption. Most important initiatives are exemptions from road charges, free travel on road ferries, free electricity, and free on- and off-street parking in all municipal spaces. These incentives should remain in place until 2017 or when 50,000 electric vehicles are registered in Norway. Exemptions from all non-recurring vehicles fees, including road tax, parking fees and toll payments are provided for EVs as well as access to bus and taxi lines.

stations along highways to facilitate intercity travel, see Table 1.

Although, due to limited infrastructure as well as driving range EVs seems to be the best choice for urban areas, there are critical discussions about this issue [40]. European cities are characterized by relatively low automobile dependence and public transport plays a significant role already since centuries. In recent decades other modes such as cycling caught up [41]. In spite the fact that EVs have the potentials to reduce local air pollutions and noise in urban areas, they cannot solve emerging problems such as congestion and parking spaces (reduced liveability). Public transport and cycling require much less land, and are much more efficient transport modes [62].

Fig. 10 shows transportation mix in cities analysed. The use of passenger cars is in the range from 20% in Shanghai to almost 80% in Los Angeles. In the United States, in contrast to Los Angeles and Portland where share of passenger vehicles is very high, public transport has dominance in New York. The percentage of walking, biking and other urban transport modes is only in Rotterdam above 50%.

In cities such as New York, Shanghai and Stockholm where the share of private vehicles is relatively low, electrification of public transport, commercial vehicles and municipal fleet could become more important. However, in the cities with the high use of private cars (e.g. Los Angeles, Portland) it is important to improve and

Table 2
Promotion actions for electric vehicles [35].

	Los Angeles	Portland	New York
State actions			
ZEV program	X	X	X
BEV purchase subsidy	X	X	X
PHEV purchase subsidy	X	X	
Home charger incentive, support	X	X	
Public charging	X	X	X
Fleet purchasing incentive	X	X	
Manufacturing incentive	X		
Low carbon fuel policy	X	X	
City-level actions			
Parking benefit			X
City fleet purchasing	X	X	X
Carpool lane access	X		X
Car sharing program link		X	
City electric vehicle strategy		X	X
City website or informational materials	X	X	X
Outreach or education events			X
City-owned EV chargers	X	X	X
US DOE EV project key area	X	X	
Streamlined EVSE[a] permitting process		X	
EV-ready building code[b]	X		
Workplace charging	X	X	X

[a] Electric Vehicle Supply Equipment.
[b] City building codes contain EV-readiness requirements for all new construction as of Jan. 1, 2011 [23].

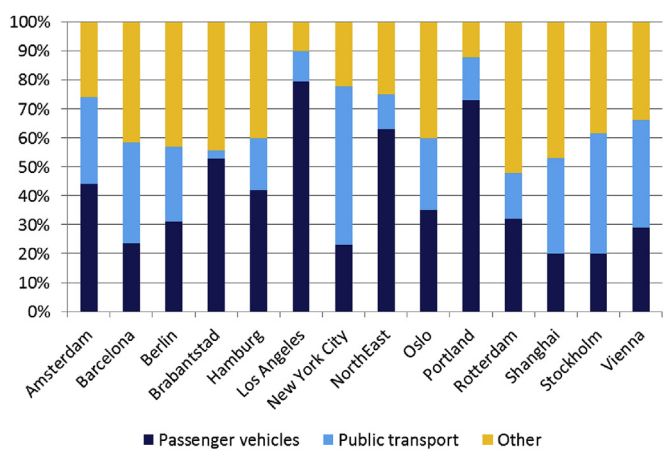

Fig. 10. Transportation mix.
Data sources: [23,54,55].

extend public transport network and reduce need for private cars.

In many cities it has been already recognised that e-mobility is actually much more than mobility provided by private EVs. In the electrification of transport of specific interest are urban light commercial delivery and service vehicles where the duty cycle is clear so that limited charging infrastructure is not a problem. In addition, this type of vehicles has high number of kilometres driven per year so that the high initial purchase cost can be offset by lower running costs [61,63].

Moreover, large parts of the public transport system in many cities are powered by electricity. For example, since 1989 Rome's bus system has been running all-electric and is one of Europe's largest fleets of electric busses. Electric minibuses which can navigate the narrow streets in city centre are using battery swapping. Electrification of urban buses is expanding rapidly (e.g. in Vienna) contributing to the reduction of local pollution and noise level. The improvement and electrification of public transport are very important issues in order to reduce the need for private cars in urban areas.

Summing up, the most important findings of this analysis are:

- The environmental benefits depend very strongly on the electricity generation mix. They are highest in the case of 100% use of renewable energy for electricity generation;
- The economic attractiveness of EVs depends on policies implemented, travel activity as well as the ratio of fossil fuels and electricity prices;
- The statement that cities are more preferable for starting the dissemination of EVs is two-sided. The reason is that a low number of daily km driven adjusts to the driving range of EVs. However, longer distances would lead to higher economic attractiveness;
- Subsidies and tax incentives for EVs are an important tool for dissemination. However, we do not think that these are recommendable measures for cities' governments. The reason is that it is not clear whether EVs are really the best option from economic, environmental and infrastructural point of view. Before implementing such policies, it has to be identified whether other options – e.g. promoting public transport or biking – would not be more preferable alternatives.

6. Conclusions

The use of EVs is currently supported by broad portfolio of financial and policy-related benefits such as possibility to drive in bus lanes or have free parking spaces. It is clear that most of the monetary incentives as well as of the non-monetary policies currently implemented will be abolished with the increasing number of EVs and that in the long run the attractiveness of EVs could be increased remarkably only with improvement of battery characteristics, continuous reduction of purchase costs, and the expansion of infrastructure, also beyond urban areas.

The fact that BEVs do not produce emissions at the point of use is an important feature for many cities and reason that most of them provide financial and other incentives for their purchase. However, EVs contribute to emission reduction but the corresponding cost-benefit ratio is very high [4].

All environmental benefits of EVs could be reached only if the electricity used is generated from renewable energy sources. In case that electricity is generated from fossil energy especially coal, total WTW emissions will be even higher than those of conventional cars.

The most important recommendation for policy makers is that all monetary and non-monetary promotion measures implemented should depend on the environmental benignity of the electricity generation mix. From society's point of view the promotion of EVs make sense only if it is ensured that a major share of electricity they use is generated from renewables. Since the final goal is not just to increase the number of EVs but to reduce emissions, cities have to consider also other e-mobility options such as trolleybuses, metros, trams and electro buses, as well as promote walking and biking, especially for short distances.

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