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Future Urban Transportation Technologies for Sustainability with an Emphasis on Growing Mega Cities: A Strategic Proposal on Introducing a New Micro Electric Vehicle Segment

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Abstract : The current transportation regime is largely based on two alternatives: (1) fixed route public transit, and (2) private ownership of internal combustion engine (ICE) powered vehicles per households. This paper analyzes one possible transportation alternative, Micro Electric Vehicles or MEVs, and compares with the ICE vehicles in terms of social, economic and environmental benefits, especially emphasizing its environmental advantage over ICE vehicles for future sustainability. While some representative models of MEVs exist in a limited market capacity, but global technical standards are generally insufficient and non-homogenous across nations, which restricts the development of the proposed transportation sector.

The focus of this paper is to analyze the characteristics and potential benefits of MEVs in economical and environmental perspectives, including development status and technical standards, with a particular focus in the E.U., the U.S., Japan, and Korea. Based on the data of analysis, this paper aims to derive and propose a cooperative and adaptive global policy framework designed to speed up adoption and expansion of the global MEV market, including passenger and utility vehicles. We propose MEV to be a new mobility segment in the global transportation market because of their advantage in environmental impact, sustainability, overall cost of ownership, and safety.

Keywords: Micro Electric Vehicle, MEV, Quadricycle, Sustainability, Safety, Fuel Economy, CO2

1. INTRODUCTION

While some new transportation services and technologies have started to disseminate in recent years, the current transportation regime is still largely composed of two alternatives: (1) Fixed route public transportation, and (2) private ownership of one or more all-purpose internal combustion engine (ICE) powered vehicles per household. While these two modes have so far served the personal transportation market reasonably, there is still a large portion of transportation needs which are not adequately served by either and could be adequately served at a significantly reduced financial, social and environmental cost by other modes (Roos and Alshuler 1975). One of the methods to cover this "transportation gap" is by the use of reduced sized and capability vehicles or Minimum Attribute Vehicles (MAVs), particularly those with electric powertrains (Sparrow and Whitford 1984).

The main motivation for electric vehicles is that they are significantly more efficient in terms of cost, space and energy when compared to typical ICE cars. A two passenger car is about ten times more energy efficient than an ICE car, and, if adopted under shared ownership, it can have 70% lower operational costs and 80% lower initial costs than individual ownership of present all-purpose vehicles (Burns 2013).

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These vehicles will be referred to as Micro Electric Vehicles or MEVs throughout this paper. MEVs include small electric vehicles used for the transportation of persons or goods as well as the supply of services in local streets, university campuses, tourist areas, and military bases, etc. These vehicles are larger and heavier than E-bikes and golf karts, but smaller than A-segment cars.

The focus of this paper is to analyze the characteristics and potential benefits of MEVs in view of social, economic and environmental impacts, based on a survey of development status and standards applicable to this type of vehicle, with a particular focus in the E.U., the U.S., Japan, and Korea. Based on the data of analysis, this paper aims to derive and propose a cooperative and adaptive global policy framework designed to speed up adoption and expansion of the global MEV market, including passenger and utility vehicles.

2. CURRENT TRANSPORTATION PARADIGMS

The dominant transportation regime developed throughout the 20th century, the period that witnessed an explosive growth in the usage of private vehicles. After the mass adoption of private vehicle transport had occurred, the externalities of this paradigm had become associated with smog, traffic congestion, use of land, injuries and deaths from accidents, climate change, and urban sprawl, etc. (Cahill et al. 2013).

The most common transportation alternatives to private ownership of an all-purpose car are (1) fixed route transit and (2) personal transport.

2.1 Limitations of personal transport and fixed route transport

Personal transport, such as pedestrian, bicycle, wheelchair, or smaller vehicles, has been negatively affected by the car-centric development of cities in the last hundred years. The sprawl of cities has separated neighborhoods that caused difficulty in crossing highways and bridges, made distances un-walkable, and favored development of distant mega-stores and malls over local commerce (Sperling 1994). Pedestrians, bicyclists and occupants of smaller vehicles are often forced to share roads with these large all-purpose vehicles and their safety is compromised, which is evident in the fact that most pedestrian and cyclist deaths are the result of being hit by a large vehicle (Sparrow and Withford 1984).

Fixed route transport is generally more benign from both social and environmental point of view when compared to all-purpose car ownership and operation. However, a large-scale return to public transit in developed economy is very unlikely (Owen 1976; Sperling 1994). Fixed route transportation is difficult to implement effectively in less densely populated areas and suffers from the last mile problem because transit industry standards dictate that people will walk about 400m (¼mile) to a bus stop and somewhat longer to premium transit services like rapid rail transit (Ewing 1999). In the case of the elderly and disabled, the difficulty in implementing fixed route transportation is further exacerbated. Continuous efforts have been made to transform the fixed transportation more accessible for those with reduced mobility, but fixed route transport continues to be particularly difficult for them. This issue will gain greater attention as the proportion of elderly population in most OECD countries is increasing and expected to further increase in the next years (OECD 2014). Another problem of implementing mass transit systems is it often requires large subsidies to operate; furthermore, fixed route systems also typically operate with little amenity and no privacy, which repel some transportation users to seek other modes of transport (Roos and Alshuler 1975).

2.2 Environmental externalities of on-road transportation

According to IEA data, on-road transportation accounts for about 16% of world CO_2 emissions due to fuel burning, as shown in <Fig. 1>. However, in terms of global warming, the situation is significantly grimmer. In a 2010 study conducted by NASA's Goddard Institute, on-road transportation was found to have the highest total anthropogenic atmospheric radiative forcing effect (RF) of any economic sector, partly be-

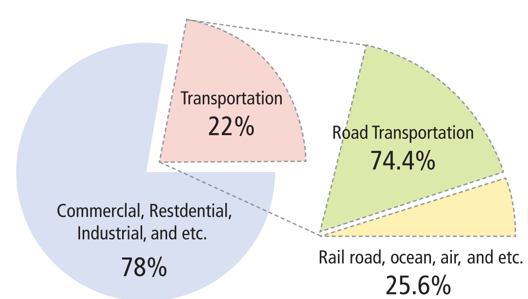

Fig. 1. CO_2 Emissions from road transportation (IEA 2012)

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cause other CO_2 emitting sectors produce significant amounts of sulfates and aerosols which have net cooling effects on the atmosphere. The study also concludes that if the policy goal is reduction of anthropogenic RF, then reducing emissions from on-road transportation is one of the most attractive option as it can yield benefits which are not only rapid and long lasting, but also subject to relatively small uncertainties (Unger et al. 2010).

Internal combustion cars are also significant contributors to other forms of pollution, such as NOx, SOx, and PM10. Electric vehicles, depending on the energy generation mix in their region, may also be an important contributor to these pollutants, and are zero emission vehicles (ZEVs) at the local level. Furthermore, since the energy mix is expected to shift towards greater use of clean and sustainable energy sources in the future, electric vehicles can be expected to become cleaner during their service life (Faria et al. 2012).

A larger and heavier vehicle will use more energy for the same trip; this is further accentuated by the use of oversized electric motors and IC engines in order to make every vehicle capable of highway travel, regardless of most of the vehicle is used in local driving. The excess energy waste translates directly into more pollution and GHG emissions. As a rule of thumb, an MEV, with a weight of one third of that of a conventional car, will use about a tenth of the energy (Burns 2013).

2.3 Transportation in developing markets and mega cities

For developed markets, there is already a significant lock-in effect for the present transportation regime due to the construction of large amounts of infrastructure and the economic sectors dependent on all-purpose ICE cars. Rapidly growing cities in developing countries are copying this style of development, even though the conditions are not the same as the countries where the regime originally came to be. This, together with rapid growth of automobile use threatens to afflict developing economies with the same externalities as developed nations have faced, but at a larger scale and with significantly more limited resources (Cahill et al. 2013).

In the first half of the 1900s, when the automobile was adopted as a central part of the transportation system, more than 50% of the population in developed nations was rural. Industrialization has caused and is expected to continue to cause the increased urbanization of society. As can be seen in <Fig. 2>, the UNDP predicts that by 2050 almost 70% of

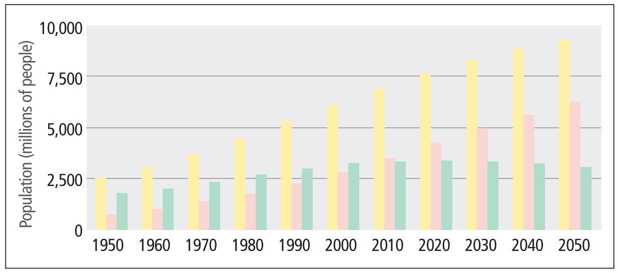

Fig. 2. World urban and rural population trends 1950 until 2050

(Data source: United Nations, Department of Economic and Social Affairs, Population Division 2011)

world population will be living in an urban environment. This dictates that new modes of transportation need to arise and that the functional expectations of cars should adapt accordingly.

2.4 Cost of congestion and parking

In their 2012 Urban Mobility Report, the Texas A&M Transportation Institute calculated congestion costs for the US at $120 billion, including the costs of fuel and delay for 498 urban areas in the US. The report also estimates that for the year 2011, 25.5 million metric tons of CO2 were produced in the US because of burning an unnecessary 10.9 billion liters of fuel due to urban congestion (Schrank et al. 2012). The Asia Development Bank's Sustainable Transport Initiative estimates congestion costs for Asian economies to be equivalent to between 2-5% of the respective nation's GDP (ADB 2010). The European commission estimates urban congestion costs for Europe at around €100 billion annually (European Union 2011). Furthermore, these costs have grown continuously except for a brief dip in 2008, which is due to the economic crisis. MEVs would take less space on a road and even allow for making of a greater numbers of lanes in a similar sized road.

Private vehicles spend the ample time in parked position. In the 2005 study, The High Cost of Free Parking, D. Schoup states that the US requires an area the size of Connecticut for parking and the world would waste a paved area the size of England for parking if the world's vehicle ownership levels reached those of the US. The study also estimates that over 8% of all traffic is due to drivers cruising for parking spots (Schoup 2005). From the community perspective, large parking lots create dead spaces that unnecessarily sprawl communities (Calthorpe 1993). MEVs can be parked in as much as 3 times higher density, when compared to full-sized cars (Suh et al. 2013).

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The problem is not exclusive to the US; in a recent paper, Wang and Yuan analyzed parking practices and policies in China and concluded that most city governments are not institutionally prepared to plan, regulate and manage parking issues that are expected to arise due to China's explosive motorization. The city can hardly keep up with increasing demand and parking space growth drops behind motorization (Wang and Yuan 2013). This oversupply of parking, particularly at the initial stages of motorization, is a huge public subsidy, which hides the real cost of driving and skews mobility choices (Schoup 2005).

3. ECONOMIC AND ENVIRONMENTAL CHARACTERISTICS AND BENEFITS OF MEVS

When making policies applicable to MEVs, governments should take into account the benefits that come not only from the switch to electric powertrains, but also from the reduction in size and weight:

- Environmental and energy security benefits;
- Reductions in congestion and parking problems brought about by reduced size vehicles;
- Decreased aggressiveness in the event of a crash, particularly with pedestrians, due to the weight reduction;
- Accessibility benefits for the elderly and disabled and for solving the last mile problem for mass transit users;
- Better quality of service and coverage when compared to public transit, particularly in low-density areas

3.1 Economic, environmental and safety characteristics of MEVs

MEVs can be adopted under private ownership, as station cars at transit stops, car-sharing vehicles in cities, as short-term rentals in tourist areas, etc. Vehicles may even fulfill more than one purpose, e.g. operating as station cars during the hours of transit service operation and taxis during the night hours when fixed route transport may be unavailable. Another possibility would be individual ownership of a Minimum Attribute Vehicle (MAV) per user or household, combined with a shared fleet of vehicles with different purposes (Sparrow and Withford 1984).

Even when generating power entirely from coal, the most polluting fuel for large-scale electrical generation, electric powertrains are cleaner than ICE counterparts (Creutzig et al. 2009). This effect is further accentuated under short urban trips. Electric vehicles do not require warm up time before achieving its characteristic performance, whereas ICE vehicles do require warm up time before reaching its environmentally optimal operating condition because of its catalytic converter (Sperling 1994). Moreover, electric vehicles are better suited for stop and go urban driving, as they are capable of providing torque when starting at zero rpm. This proves that electric vehicles are more efficient than ICE vehicles for urban driving style because electric motors do not waste energy by being in idle as in the case of ICE vehicles. The efficiency curves of electric motors also show that they are more suitable for urban vehicular use than internal combustion counterparts.

In spite of all the advantages listed above, full size electric vehicles still consume more energy, take more space and cost more to both users and society than what is necessary for most trips. The basic Tesla Model S has a driving range of 335 km, can accelerate from 0 to 100 km/h in 5.4 seconds, reach a top speed of 320 km/h and carry five adults (Tesla Motors 2014). Chevy Spark EV has a 130 km driving range, can accelerate to 100km/h in less than eight seconds reaching a top speed of 145 km/h, and carry four adults (General Motors 2014). In contrast, according to the 2009 US National Household Travel Survey (NHTS), the mean trip length in the US was only 15 km (9.3 mi) and daily mean driving distance was only 62 km (38.4 mi) (Krumm 2012). In fact, a significant portion of trips is less than 8 km by a single occupant driving at low speed (Sperling 1994), and 90% of US car journeys carry two or fewer people. Driving distances in the US are generally longer than in most European and Asian countries (Pasaoglu et al. 2012).

One of the main concerns with vehicles with a reduced size and weight is the potential dangers to occupants in the event of a collision with larger vehicle. It is known that, all other things being equal, in a frontal collision the occupants of the vehicle with the smaller mass are likely to suffer the greatest damage (Wood 1997). However, the safety of the occupants of a vehicle is not only a function of size, weight and speed of the vehicle but also of its structural characteristics, such as overall body structural rigidity and strength. Low mass vehicles (LMV), designed with crash compatibility criteria in consideration, can reduce LMV occupant injury severity significantly (Frei et al. 1997). A conclusion of 1994 study of hard-shell low-mass vehicles that executed several frontal crash tests is that it is possible to make low-mass vehicles that meet safety standards in frontal collisions by compensating for the lower mass of the

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car through higher rigidity and the use of improved restraint systems (Kaeser et al. 1994). Safety technologies, which allow occupants to survive very high-energy crashes, have been available in racing for years, and some sub-A segment cars have utilized it.

Furthermore, if the goal is to improve the overall safety record of the system, then smaller vehicles can reduce the number of severe injuries and fatalities, especially in low speed urban settings. In an urban environment, a significant portion of the on-road injuries and casualties are borne by pedestrians, and smaller cars have been linked to fewer pedestrian deaths (Robertson and Baher 1974). For example, in highly urban South Korea, the OECD nation with the poorest vehicular safety record, 29% of 5229 fatalities due to on-road accidents in the year 2011, which is equivalent to 2044, were borne by pedestrians; in contrast, occupants of passenger cars accounted for a relatively small 22% of fatalities (OECD IRTAD 2013). Therefore, in order to increase the overall safety of the system, it is important to direct our attention to the safety of both pedestrians and drivers.

3.2 Regulatory vehicle category of MEVs

A few vehicles, that satisfy the proposed definition of MEV, are already available on the market. The specifications for some of the vehicles are shown as examples in <Table 1>.

Several full-sized demo models of all the vehicles below are available for purchase by end consumers. Several of these vehicles exceed the capabilities necessary for an MEV, and, thus, fail to be classified into standardized categories in various different legislations. This may be due to the result of poor standardiza-

Table 1. MEV examples available on the market

No.	Model [Name]	Maker [OEM]	Length [mm]	Width [mm]	Curb Weight [kg]	Seats	Power [kW]	Max. speed [km/h]
1	Twizy Z.E.	Renault (France)	2,338	1,240	350	2	15	75
2	BB1	Peugeot (France)	2,500	1,600	600	4	15	90
3	City	Aixam (France)	2,720	1,500	400	2	4	45
4	Smera	Lumeneo (France)	2,500	960	630	630	30	110
5	Neoma	Lumeneo (France)	2,690	1,660	870	870	35	110
6	Tazzari Zero	Tazzari Group (Italy)	2,880	1,560	542	542	15	80
7	Estrima Biro	Newton (Italy)	1,740	1,030	220	220	4	45
8	Smart Electric Drive	Mercedes-benz (Germany)	2,695	1,559	920	920	35	125
9	Urban Commuter	Rinspeed (Swiss)	2,590	1,627	980	980	30	120
10	Hiriko	Hiriko (Spain)	2,630	1,750	400	400	15	70
11	E-zone	CT&T (Korea)	2,665	1,440	620	620	7	60
12	Murray T.27	Gordon (U.S.)	2,500	1,300	680	680	25	105
13	Micro Commuter	Honda (Japan)	2,500	1,250	400	400	15	80
14	Mobility Concept	Nissan (Japan)	2,337	1,230	450	450	8	80
15	E2o	Mahindra (India)	3,280	1,514	830	830	19	81
16	eS	Polaris (U.S.)	2,743	1,397	535*	535*	5	40
17	eM1400	Polaris (U.S.)	2,921	1,437	680*	680*	5	40
18	ATX110E	Alke (Italy)	2,950	1,270	760*	760*	6	30
19	ATX210E	Alke (Italy)	3,205	1,270	865*	865*	14	44
20	Might-E truck	Canadian Electric Vehicles	3,480	1,530	955*	955*	27	40
Average			2,571	1,415	593	593	18	85

tion. The first 15 vehicles are passenger cars and the last five represent utility vehicles. There are fewer examples of utility vehicles because each represents a platform rather than a specific vehicle. Each utility vehicle can be outfitted in configurations from a simple flat-bed to a refrigerated compartment. For example, the ATX100E is often outfitted and used as a compact electric ambulance in use in sporting stadiums around the world, the eS can be bought equipped with a siren and PA system for security functions and the Might-E truck can be equipped as a small dump truck. <Fig. 3> presents the vehicle outline sizes of the example vehicles included in Table 1. The numbering corresponds to that of Table 1. Sizes of the example vehicles are compared to the maximum allowable sizes in different sub-categories of the European heavy quadricycle class. Some nations have one or more vehicle classes or segments adequate for MEVs. <Table 2> presents a summary of these categories and the vehicular characteristics specified within them.

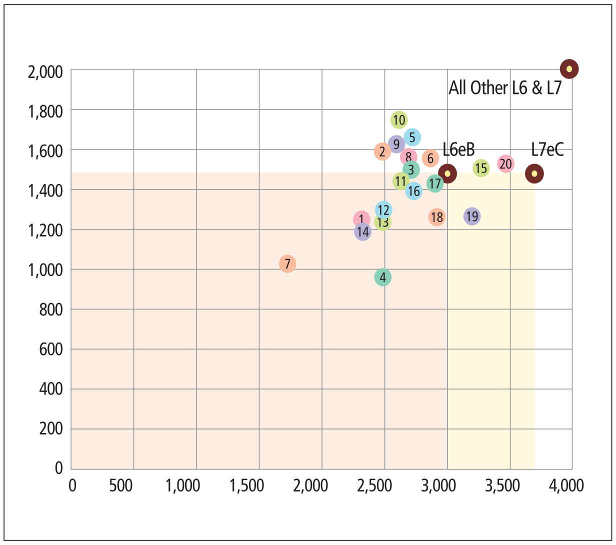

Fig. 3. Outline size of example MEVs vs maximum L6 and L7 sizes

Table 2. Parameters specified in MEV regulations

Country	Classification	Dimension (L*W*H)	Curb weight	Maximum speed	Rated power	Seats	others[*2]
U.S.	Low-speed vehicle	X	X[*3]	O	X	X	X
	Medium-speed vehicle	X	X[*3]	O	X	X	X
UN/ECE (2010)	Category-L6e	X	O	O	O	X	X
	Category-L7e	X	O	O	O	X	X
*EU (2016)	Category-L6e	O	O	O	O	O	O
	Category-L7e	O	O	O	O	O	O
Japan	Micro mobility		X	X			X
Korea	Low-speed electric vehicle	X	O	O	X	X	X

- *EU regulation No 168/2013 is an upgraded version of the UN/ECE classification scheduled to take effect in 2016.
- [*2] others: application (carrying passenger or goods), seat types (straddle or non-straddle), number of doors, ground clearance, clearance ratio, steering type, etc.
- [*3] Weight is only limited at 1,361 kg (3,000 lbs).
- Items marked as △ are currently under deliberation.

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The most complete MEV standardization framework is found in the form of the European light and heavy quadricycle categories, known as L6 and L7 respectively. In 2005, though the Consolidated Resolution on the Construction of Vehicles (R.E.3), vehicular categories L6 for light quadricycles and L7 for heavy quadricycles were instated. Categories L6 and L7 best reflect the characteristics of an MEV. <Tables 3 and 4> display the specific requirements and sub-categories of these vehicular segments. The L6 category is for vehicles with a maximum speed of 45 km/h and a weight of less than 425 Kg. The stated weight excludes battery weight in the case of electric vehicles. The Axiam by City and Estrima Biro by Newton are two examples from Table 1 with the requirements of this category. The L7 category includes vehicles ranging from ATVs to small tractor vehicles. The common limitation that applies to all vehicles in the category is maximum vehicular weight of 450 kg for passenger vehicles and 600 kg for freight vehicles, in both cases excluding the weight of batteries. This vehicle category is limited to either: a maximum speed of 90 km/h, a maximum continuous power rating of 15 kW, or both. Representative vehicles in this class are Renault Twizy Z.E., Alke's ATX 110E, and 210E.

In the US, following a 1996 request for regulatory relief submitted by Bombardier, Inc., the NHTSA instated the Low Speed Vehicle (LSV) category as specified in 49 CFR part 571.500 in 1998 (NHTSA 1998). However, this category reflects MEVs poorly as these vehicles are speed limited to 40 km/h, but on the other hand, they are allowed to have a mass of up to 1400 Kg. This is in contrast with the European L6 category where vehicles with a maximum mass of up to 425 Kg

Table 3. Requirements of category-L6e (European Parliament and Council 2013)

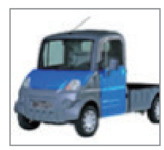
Parameters	Category-L6e (light quadricycle)		
	L6e A	L6e B	
		L6e BP	L6e BU
Example			
Length	≤ 4,000 mm	≤ 3,000 mm	
Width	≤ 2,000 mm	≤ 1,500 mm	
Height	≤ 2,500 mm		
Mass in running order	≤ 425 kg		
Maximum Design Speed	≤ 45 km/h		
Engine Capacity	≤ 50cm^3 if a Gasoline engine ≤ 500cm^3 if a Diesel engine		
Maximum Continuous rated power	4 kW	6 kW	
Number of seats	1+Driver	1+Driver	
Special Remarks	-	Enclosed driving and passenger compartment accessible by maximum three sides	

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Table 4. Specific conditions of category-L7e (European Parliament and Council, 2013)

Parameters	Category-L7e (heavy quadricycle)					
	L7e A		L7e B		L7e C	
	L7e A1	L7e A2	L7e B1	L7e B2	L7e CP	L7e CU
Example						
Length	≤ 4,000 mm		≤ 4,000 mm		≤ 3,700 mm	
Width	≤ 2,000 mm		≤ 2,000 mm		≤ 1,500 mm	
Height	≤ 2,500 mm					
Curb Weight	≤ 450 kg for passengers carrier		≤ 450 kg for passengers carrier ≤ 600 kg for goods carrier			
Maximum Speed	-		≤ 90km/h	-	≤ 90km/h	
Power*	≤ 15kW		-	≤ 15kW	≤ 15kW	
Number of seats	1+D		1+D	2+D	3+D	1+D
	straddle seats	non-straddle seats	straddle seats	non-straddle seats	non-straddle seats	non-straddle seats
Special Remarks	Vehicle designed for the transport of passengers only		Ground clearance ≥180 mm		Enclosed driving and passenger compartment accessible via maximum three sides	
			wheelbase to ground clearance ratio ≤ 6	Wheelbase to ground clearance ratio ≤ 8		
	handlebar steering	-	handlebar steering	-		

*Power : Maximum continuous power rating

are allowed to operate at speeds of up to 45 km/h. NHTSA subsequently denied several requests to create a Medium Speed Vehicle (MSV) category in 2008. Yet, the need for these vehicles clearly exists. This has led nine US states to implement their own MSV regulations, independent of NHTSA, allowing MSVs in some portions of their roads (IIHS 2014). These vehicles are not required to meet any criteria for crash-worthiness, though they must be equipped with basic safety equipment, such as seat belts and headlamps. <Table 5> presents the characteristics of LSVs and MSVs.

Japan has a long history with small vehicles. The so called "kei cars" have been present in Japanese regulation since 1949. However, following Japan's economic development, kei cars have grown to be similar to sub-compact vehicles, with upper power limits of a full 47 kW. Another category of 4-wheel vehicles, intended for vehicles with less than 0.6 kW of power also existed in Japanese regulation. Japanese government planned and executed 10 demo projects with different MEVs in different regions and under different usages.

<Table 6> shows a summary of the findings from these demo projects. After evaluation of these demo projects showed positive results, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) released their "guidelines for the introduction of micro mobility" in 2012. The document introduces a new, intermediate vehicular segment, with a maximum continuous power output of 8 kW.

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Table 5. Vehicle classification criteria for LSV and MSV in US (IIHS, 2014)

Segment	Description
Low-speed vehicle (LSV)	• Vehicle with a top speed of 32~40km/h • Classified one segment above than a golf kart • Gross vehicle weight rating ("GVWR") of less than 3000 pounds (1,361kg) • 45 states allow LSV use on specified portions of their public roads
Medium-speed vehicle (MSV)	• Vehicle with a top speed of 56km/h • Allowed to drive not only EV driveways, but also most local roads • Gross vehicle weight rating of 5,000 pounds (2,268kg) or less • NHTSA in 2008 denied petitions to create a new medium-speed vehicle (MSV) class • 9 states specifically allow MSV use on specified portions of their public roads

Table 6. Results of MEV demonstration projects in Japan (MLIT, 2013)

General	• 80% of users would use MEVs again (n=440) • 70 % of trips were less than 10km
Logistics	• Increased delivery efficiency for small amounts of goods
Tourism	• 90% of the users want to use MEVs again next visit (n=258) • Increase in the number of places visited: ✓ Without MEVs: 1.95 places (average, n=122) ✓ With MEVs: 4.17 places (average, n=214)
Daily use	• Cases of no more than 2 people boarding on MEV account for 85% when going shopping. (n=68) • Cases of no more than 2 people boarding on MEV account for 95% when commuting. (n=41)
Handicapped and elderly	• Frequency of going out was increased.
With room for improvement	• Low of visibility • Torque on ramps lacking • An alarm for pedestrians might be necessary to ensure safety

Table 7. Japanese small vehicle classification (MLIT, 2013)

Type of Vehicle	Wheeled Walking Aids	Quadricycle	New Mobility Category	Mini Vehicle (Kei car)
Electrical Rated Power	any	≤ 0.6kW	≤ 8 kW*	≤ 47kW
Engine Size	any	≤ 50cc	≤ 125cc	≤ 660cc
Number of passengers	1	1	2	4
Maximum length (mm)	1,200	2,500	3,400	3,400
Maximum width (mm)	700	1,300	1,480	1,480
Maximum height (mm)	1,090	2,000	2,000	2,000
Highway access	No	No	No	Yes
Vehicle Inspection	No	Unspecified		Yes
Notes	6 km/h top speed	Driving license required		

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MLIT states that because of different power rating methods, an 8 kW continuous power output measured under Japanese standards is roughly equivalent to the 15 kW maximum rating specified in the European L7 category. <Table 7> shows the available vehicular categories in the Japanese market.

In terms of MEV regulation, Korea is a particular case because MEVs can actually be classified under two different categories, either as light vehicles or as a Low Speed Electric Vehicle (LSEV). It should be noted that based on size, in particular their width, several of the vehicles listed in Table 1 do not qualify under light vehicles and must thus be classified either as medium sized vehicles or LSEVs, as this category has an upper weight limit, but no size limitations. <Table 8> shows Korean vehicular categories.

Table 8. Vehicle classification criteria in Korea (Korean ministry of environment 2013)

	Unit	Light Vehicle	Small Vehicle	Medium Vehicle	Large Vehicle	Low-speed electric vehicle (LSEV)*
Length	mm	≤ 3,600	≤ 4,700	Any dimension exceeding that of small-size classification criteria		-
Width	mm	≤ 1,600	≤ 1,700			-
Height	mm	≤ 2,000	≤ 2,000			-
Engine capacity	cc	≤ 1,000	1,000-1,600	1,600-2,000	≥ 2,000	-
Maximum speed	km/h	-	-	-	-	≤ 60
Propulsion type	Type	-	-	-	-	Motor
Weight	kg	-	-	-	-	≤ 1,361
Number of seats	-	≤ 10	≤ 10	≤ 10	≤ 10	-
Number of wheels	-	-	-	-	-	-
Number of doors	-	2-4	2-4	2-4	2-4	-
Purpose	-	For passenger transportation				

*Except for those meeting the LSEV requirements, all other electric vehicles are classified as high-speed electric vehicle.

3.3 Regulatory certification procedure on fuel economy measurement and safety requirement

Fuel economy certification can be divided into two parts: a driving cycle and procedure. Electric vehicles have no tail-out exhaust emissions, so fuel economy and range are determined based on power consumption and range to battery depletion, obtained from the repetitive operation of the test vehicle on a dynamometer. <Table 9> presents the driving cycles used for the different categories of MEVs in the relevant countries. It should be noted that the US does not make use of a reduced speed cycle for EVs, but test them to the same Urban Dynamometer Driving Schedule (UDDS) and Highway Fuel Economy Driving Schedule (HFEDS) for ICE vehicles. However, NHTSA does not enforce any fuel economy standard for LSVs since "they are expected to have very high fuel economy because of their small size" and because "...present EPA test procedure specifies that test vehicles must operate during testing at speeds that are above the capability of LSVs." (NHTSA 1998)

MEVs follow the fuel economy certification procedures outlined for electric vehicle because they are classified as an electric vehicle in most of the countries. <Table 9> summarizes the criteria and the specific testing procedures. If the maximum vehicle speed is insufficient to meet the target curve in the driving schedule, the vehicle is required to operate at its top speed. In the case of the EU, fuel economy and electric range are then calculated based on the measured range and power consumption from the test using equations 1 and 2 below:

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$$\text{Electric range (km, per charge)} = \text{Test end position-Test start position (km)} \quad (1)$$

$$\text{Fuel economy}\left(\frac{km}{kwh}\right) = \text{Electric range (km) / energy consumed during test (kwh)} \quad (2)$$

The United States and Korea do not use measured range but rather "electric range" in their standards, which is equal to the measured range multiplied by a correction factor of 0.7. Intention of the correction factor of 0.7 is to curtail the error between measured range and the real-life range of an electric vehicle. However, the currently applied 0.7 correction factor was defined for full-size electric vehicles. Applying the same value of correction factor to MEVs may not accurately reflect the driving characteristics of smaller vehicles. Further studies may be necessary to determine an appropriate correction factor for MEVs based on analysis of actual driving data.

An international effort to standardize fuel economy measurement procedure and cycles is already underway in the form of the Worldwide Harmonized Light Vehicle Test Procedures (WLTP). Under the WLTP, test procedures applicable to a specific vehicle are determined using a maximum speed and power over mass ratio matrix; this allows for equivalent application of the included tests to still inexistent vehicle categories, as graphically described in <Fig. 4>. The WLTP testing

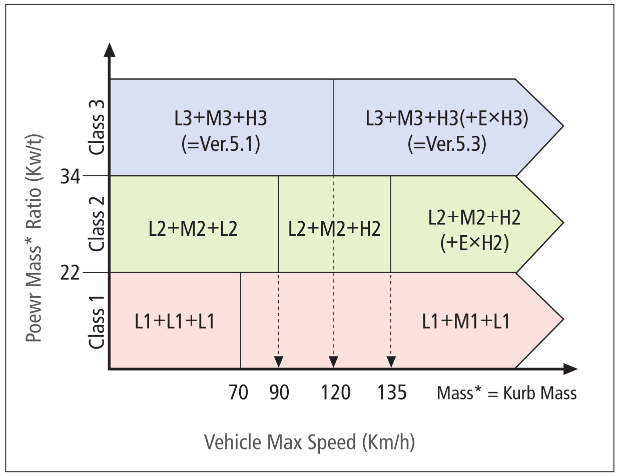

Fig. 4. WLTP driving cycle allocation (Tutuianu et al. 2013)

Table 9. Procedure for fuel economy certification by country

		Korea	US (FTP)	UN/ECE	
Driving cycle		• CVS_75(UDDS) • HFEDS cycle (Highway)	• UDDS cycle (City) • HFEDS cycle (Highway)	• ECE-P47 (category- L6e)	• ECE-R40 (category-L7e)
Test tolerances		• Speed(±2mph) • Time(± 1s)	• Speed(±2mph) • Time(±1s)	• Speed(±1kph) • Time(±0.5s)	
Soaking time between each cycle		• 10min soak time	• Up to 30 min soak time (four-bag FTP, HFET, etc.)	-	
End of test criteria	Max. design speed ≥ Max. cycle speed	• When the vehicle is not able to meet the target curve	• The vehicle can no longer meet the specified speed tolerances	• When the vehicle is not able to meet the target curve, up to 50 km/h	
	Max. design speed ≤ Max. cycle speed	• The vehicle can no longer meet the 95 percent of maximum speed	• The vehicle can no longer meet the specified speed (maximum speed of vehicle) tolerances	• When the vehicle is not able to meet the target curve, up to 50 km/h, or the maximum speed in pure electric mode	
Electric range		• Electric range = (The range from start of test to end of test) × 0.7	• Electric range = (The range from start of test to end of test) × 0.7	• Electric range = The range from start of test to end of test	
Special Remarks		• Low speed electric vehicle only follows UDDS cycle test.	-	-	

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procedure is a good example of performance based testing and standardization. Low (L), Medium (L), High (H) and Extra High (ExH) driving cycles are joined together to make a full driving schedule which is believed to be representative of the average use of a vehicle in that weight, power and speed class. The WLPT is still in progress.

The safety regulations applicable to vehicles can be divided into device and component standards and collision standards. Device and component standards dictate the minimal safety devices which must be installed into a vehicle for it to be considered road-worthy. Collision standards specify the protection that a vehicle must give to its occupants in the event of a crash. As a general rule, MEVs are exempt from collision requirements, with the exception of Korea, where LSEVs are required to pass one frontal crash test at a reduced speed of 40 km/h (versus the typical 56 km/h the Korean NCAP program usually requires). Legislations that still wish to include crash tests in their certification procedure for MEVs should design tests that consider the real life application of MEVs and compatibility in collisions between cars of different size and weight (Frei 1997).

4. POLICY SUGGESTIONS

4.1 Technical standards and policies

The transportation options intended to close the gap between private ownership of all-purpose vehicles and fixed route transportation systems are not new, and neither are the regulatory constraints that have prevented or at least not fostered these alternatives for development (Roos and Alschuler 1975). Like with every other new transportation mode, the impact of MEVs will depend on the standards, which they are required to fulfill. Internationally consistent standards can increase the economic efficiency of development through increased economies-of-scale benefits and potential increases in trade in the automotive and automotive parts market (Brown et al. 2010). Brown also points out that since several technologies are at different stages of development, any standards created should be performance-based in order to avoid the stifling of possible further innovations.

The importance of policy's influence on mobility decisions cannot be overstated, as policy decisions lead to mobility decisions which in turn lead to further policy decisions. Mobility decisions imply the purchase of a vehicle or relocation to housing closer to a regular destination like work; travel decisions imply modal choices for single trips. Long-term mobility decisions rarely occur separately from major turning points in life (Grimsrud and El-Geneidy 2014). This means that the longer mobility policies stay the same, the harder it is to change them.

A performance based policy framework, which is at least mostly homogenous across legislations, is suggested. Performance based standards have several advantages. They allow earlier use of new technologies and do not stifle innovation. They reduce barriers to trade, as parts and components can be used across legislations so long as they meet the required performance criteria. They are more transparent as it is less likely

Table 10. Incentive policy of electric vehicle segment by country

Country	Details
USA	• Insurance premiums : 10% reduction • 100% tax deductible in purchase • Private organization support : 7,500 USD subsidy
Japan	• Automobile tax 50% reduction • Private organization support : 14,000 USD (1,390,000 JPY)
China	• Acquisition tax : 50% reduction • Private organization support : about 10,000 USD (60,000 CHY)
England	• Private organization support : about 3,000~8,000 USD (2,000~5,000 GBP)
France	• Private organization support : about 6,700 USD (5,000 EUR) refunds
Korea	• LSEV:$5,375 (5,780,000 KRW) • HSEV:$13,950 (15,000,000 KRW)

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that clauses intended to favor particular players will be introduced into the standards and finally they are more efficient, as requirements related to a characteristic need only be set once (ASME 2004).

4.2 Proposed policy framework

Tailored vehicles, made to suit the needs of specific user groups to a high level rather than to serve the needs of every user to acceptable levels, are expected to grow importantly in the next few years (Schrank 2012; Burns 2013). This necessitates a regulatory framework, which not only guarantees the road-worthiness of vehicles, but also does not stifle innovation or creates an unintended unbalanced market by favoring a particular segment of vehicle over another by creating applicable categories earlier.

A performance based policy framework, which attaches requirements to specific vehicle characteristics rather than categories, is proposed. Such a framework could be based on a power to mass ratio vs. maximum speed matrix, like the one used under WLTP testing procedures; with each level subjecting vehicles to increasingly stringent regulations and lower levels having limited access to high speed roads. Vehicles within each matrix cell would have to fulfill a certain set of requirements, depending on the specific function of the vehicle. Other characteristics may be regulated with either maximum and minimum boundaries or additional matrix variables. A homogenous international framework can also increase the speed of international development and adoption.

5. CONCLUSIONS

This paper analyzes the social, economic and environmental characteristics and benefits of micro electric vehicles (MEVs) in comparison with the private all-purpose ICE vehicles, emphasizes the urbanization trend in most countries, and proposes the global harmonization of regulatory requirement and policies for future sustainability. MEVs have clear potential to improve the current transportation issues on limited public transportation and unsustainable private transportation system, especially for those with reduced mobility. MEV's relatively lower cost of ownership on personal and social basis can also provide a significant potential in the vehicle electrification on road transportation.

For the future sustainable transportation, governmental bodies are requested to establish a series of regulatory definition of the vehicle category, certification requirements in fuel economy measurement and safety requirement based upon the expected social benefit and performance-based policy. Global harmonization on regulatory framework is also a key enabler for introducing MEVs in global market for the sustainability.

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