Future Mobility Conference
Dubai
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The Transportation Transition Challenge:
EV potential for the UAE

Masdar INSTITUTE

Sgouris Sgouridis
Associate Professor
Engineering Systems and Management

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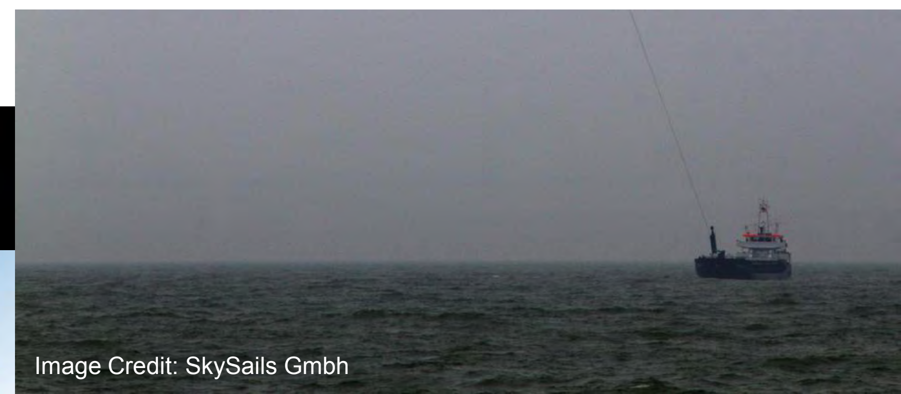
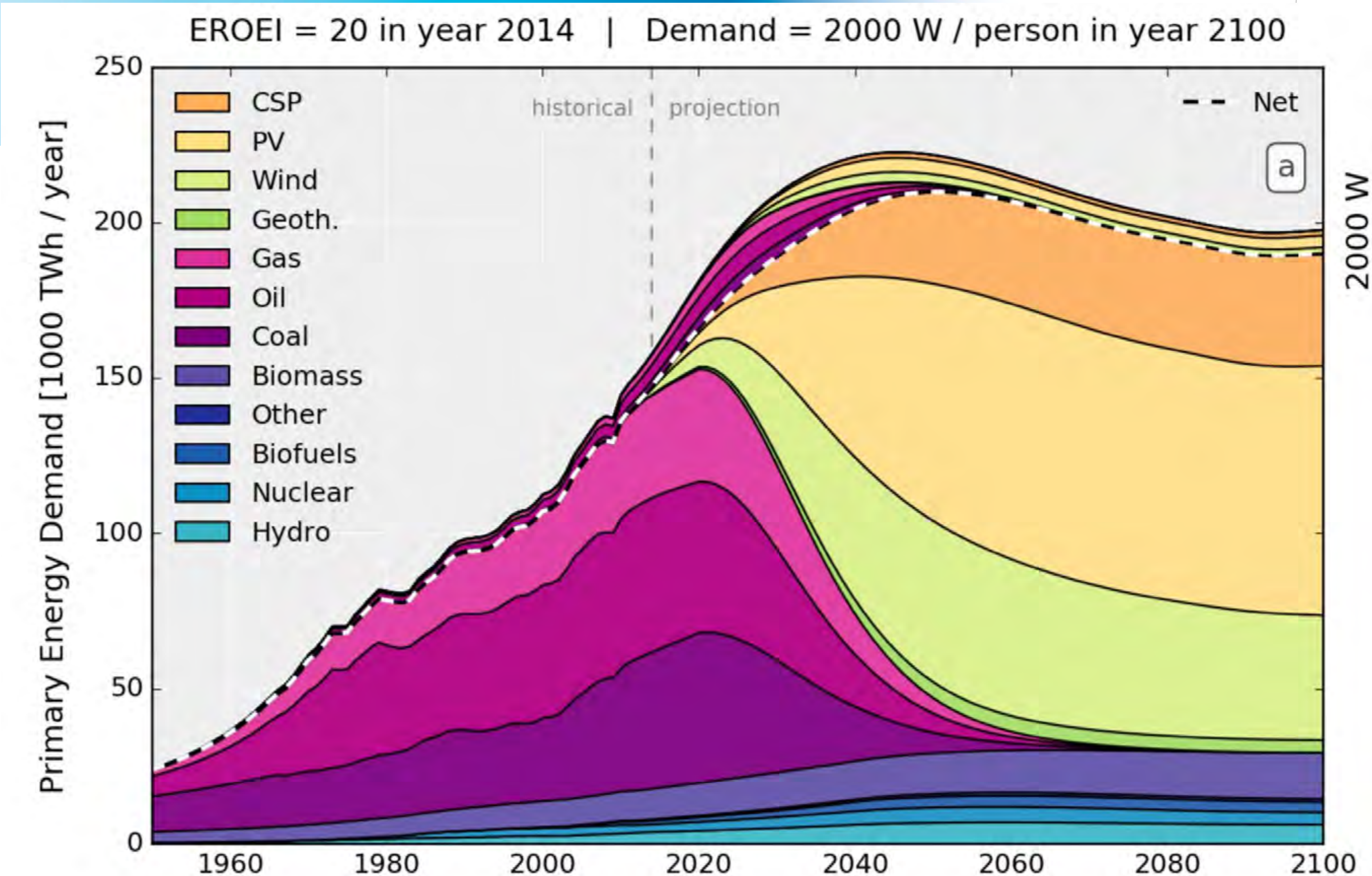


Image Credit: SkySails Gmbh

OUTLINE

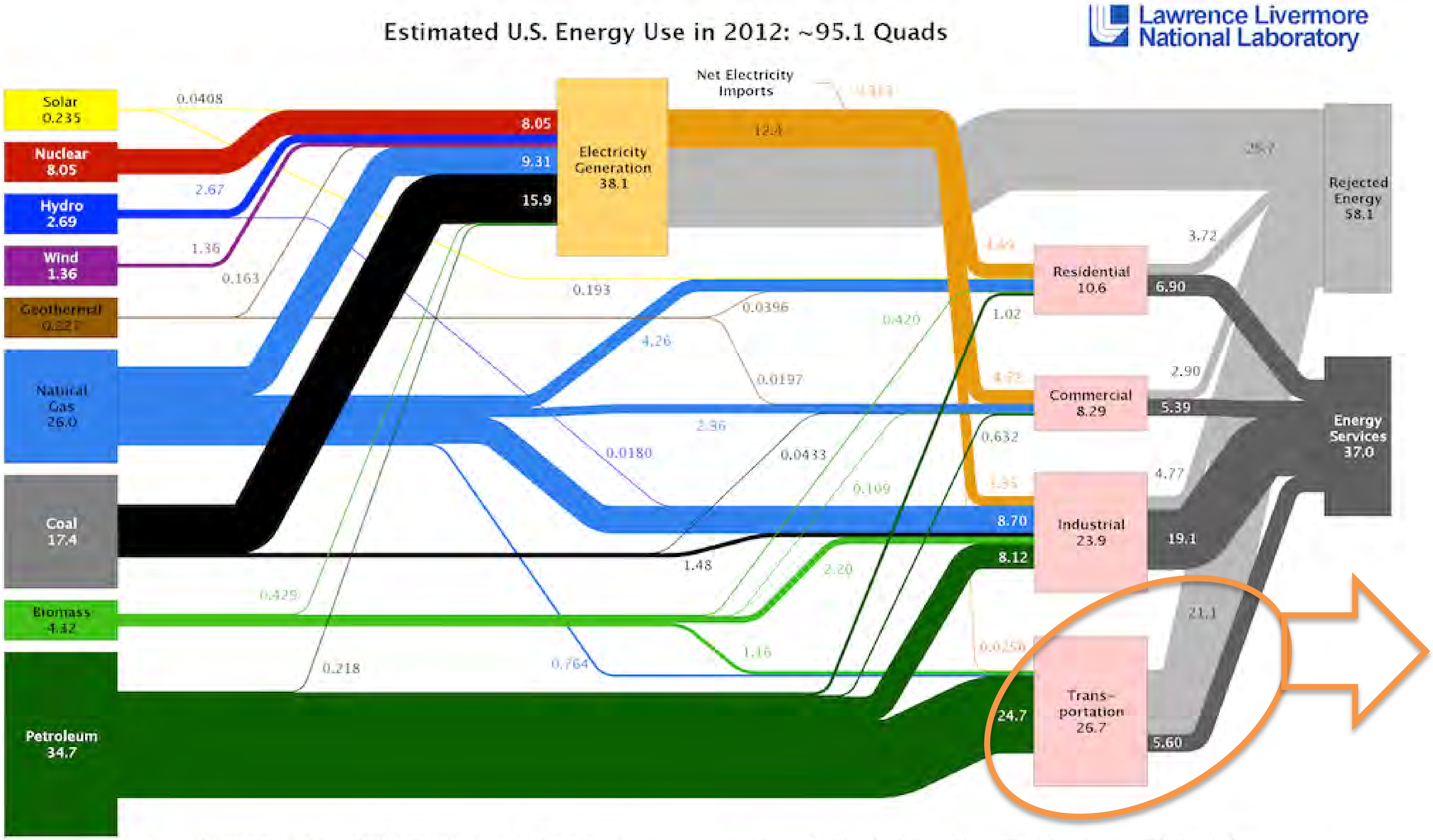
- **The energy transition challenge and transportation electrification**
- **A survey analysis of UAE drivers' perception of EVs**
- **Overcoming technical and economic barriers**
  - Climate and range
  - Charging Infrastructure
- **Potential opportunities and diffusion patterns**



→Fossil fuels *are* on the way out –better design our future infrastructure accordingly

Source: Sgouridis, Csala, Bardi (2016)

A LOOK AT THE ENERGY PICTURE FOR TRANSPORT



Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Largest energy utilizing sector (39%)
Lowest use efficiency (~20%)

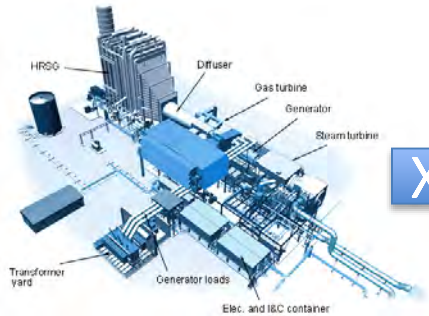
SOURCE TO WHEEL EFFICIENCY

The advantage of electrification

Refinery & dist. efficiency: 83%

ICE efficiency: 20%

ICEV
RTW efficiency: 16.6%



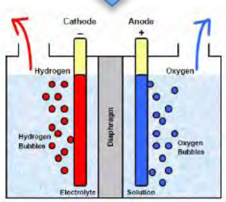
NG CCGT: 45%

Transmission & charging: 92%

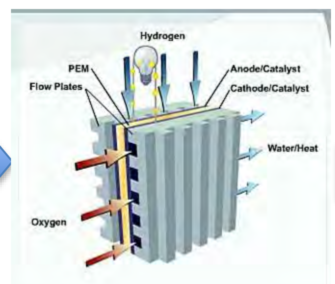
Battery & E-motor efficiency: 80%

BEV
RTW efficiency: 33%

Transmission: 95%



Electrolysis & H2 dist: 70%



Fuel Cell: 70%

E-motor efficiency: 80%

Fuel Cell
RTW efficiency: 16.8%

SOURCE TO WHEEL EFFICIENCY

The advantage of electrification

X

=

ICEV
RTW efficiency: 16.6%

Refinery & dist. efficiency: 83%

ICE efficiency: 20%

X

X

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RE+BEV
RTW efficiency: 66%

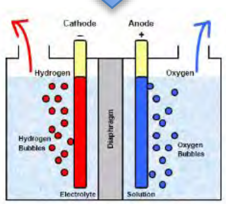
PV and CSP + storage: 90%

Transmission & charging: 92%

Battery & E-motor efficiency: 80%

X

Transmission: 95%



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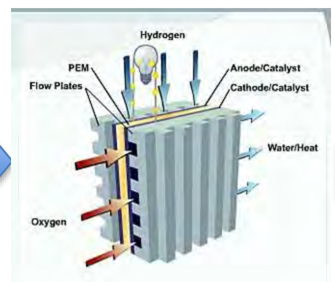

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Fuel Cell
RTW efficiency: 16.8%

Electrolysis & H2 dist: 70%

Fuel Cell: 70%

E-motor efficiency: 80%

→ Higher cycle efficiency → Renewables can be directly integrated

The future of Energy is Renewable (centralized & distributed) so

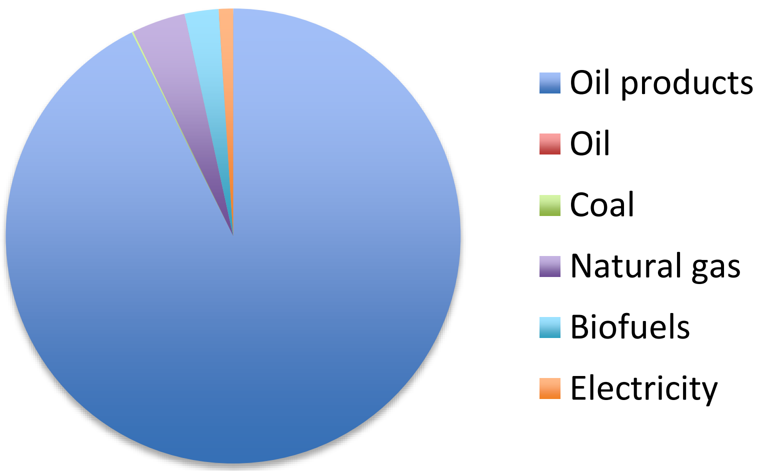
the future of Transport is Electric

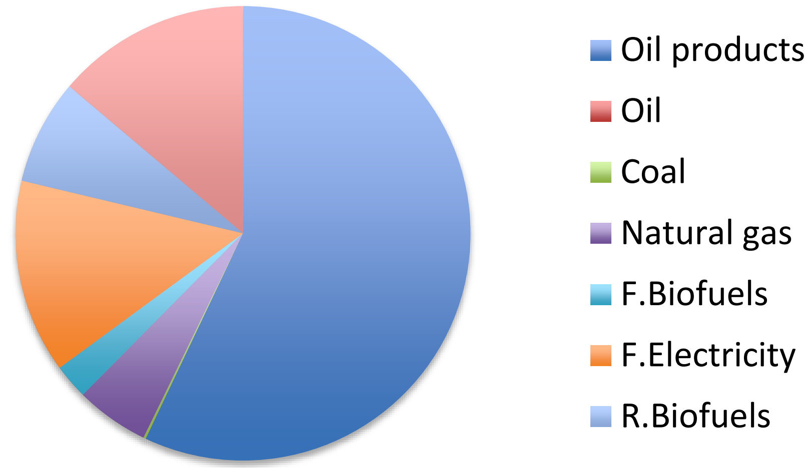
(with some biofuel/ammonia/hydrogen carriers)

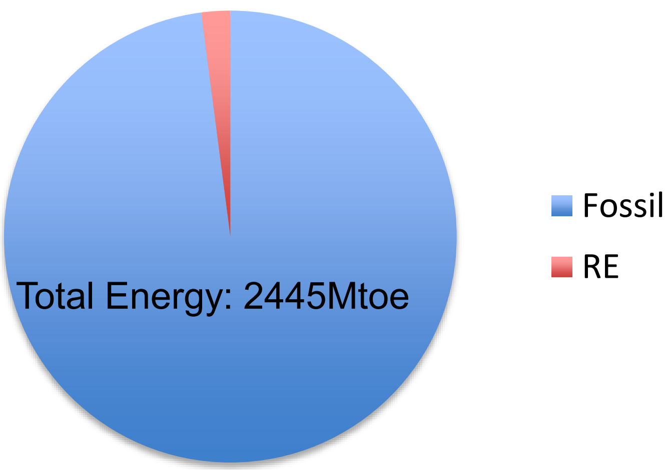
A WHAT IF? CHALLENGE

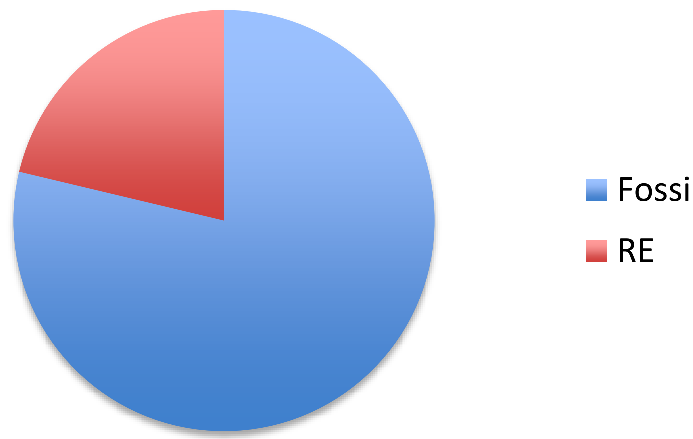
Transport Energy 2011 (IEA data)

50% Electrification
3X Biofuels
24%→ 50% RE in Electricity









Total Energy: 1779Mtoe

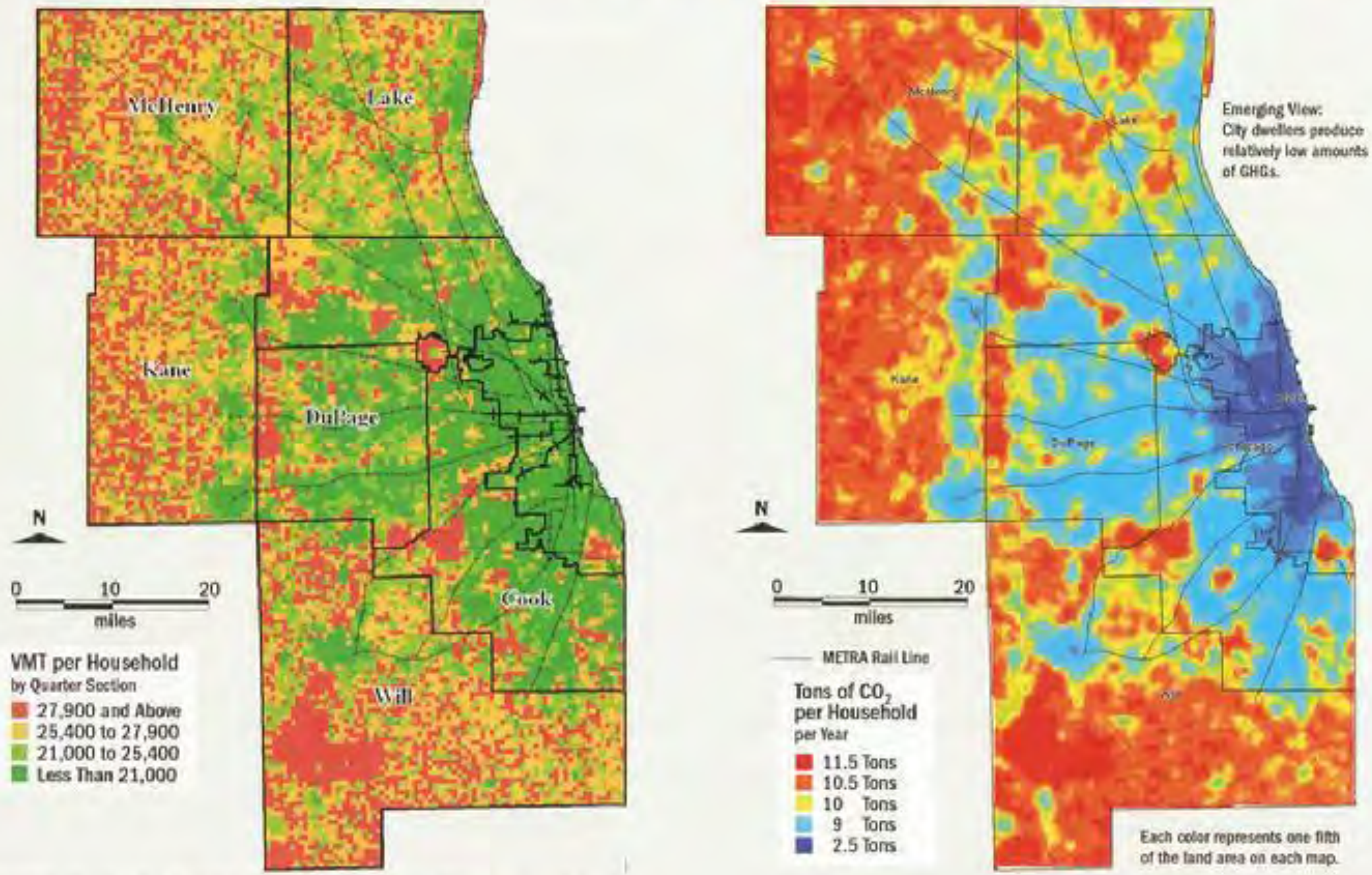
The challenge is that in 5 decades it should be 100%

A smart city should be self-aware of its use intensity of material and energy resources and continuously strive for improving their efficiency

Figure 1.2: Infrared image showing heat loss from New York City buildings

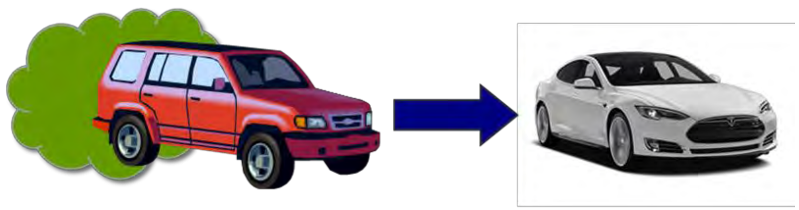
ENERGY AND EMISSIONS BY HOUSEHOLD WITH DENSITY

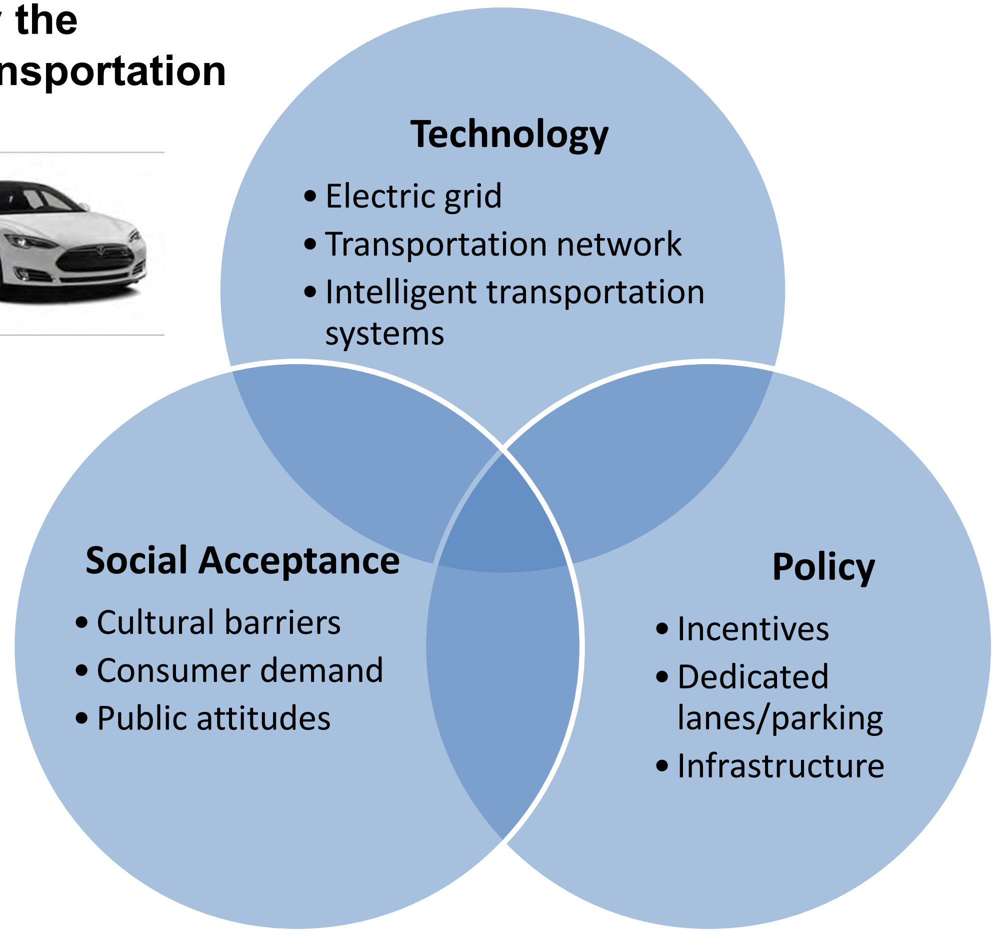
Close Relationship between VMT per Household and CO_2 Emissions in the Chicago Metropolitan Area



SOURCE: Center for Neighborhood Technology, Chicago, undated.

An integrated Approach to Study the Feasibility of EVs and Public Transportation





HOW DO WE GET TO ELECTRIFICATION?

Markets and Infrastructure

Economists advise planners and policy makers that:

- the best choices will be given to consumers automatically (**markets**)
- Consumers will choose the best for themselves (**rational choice theory**) and
- the optimum societal outcome will "magically" emerge (**invisible hand**)

Alas reality is not

A fairy tale …

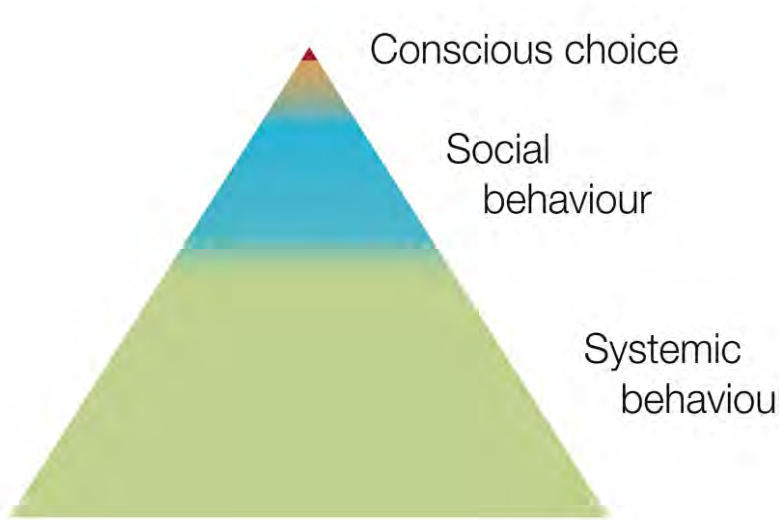
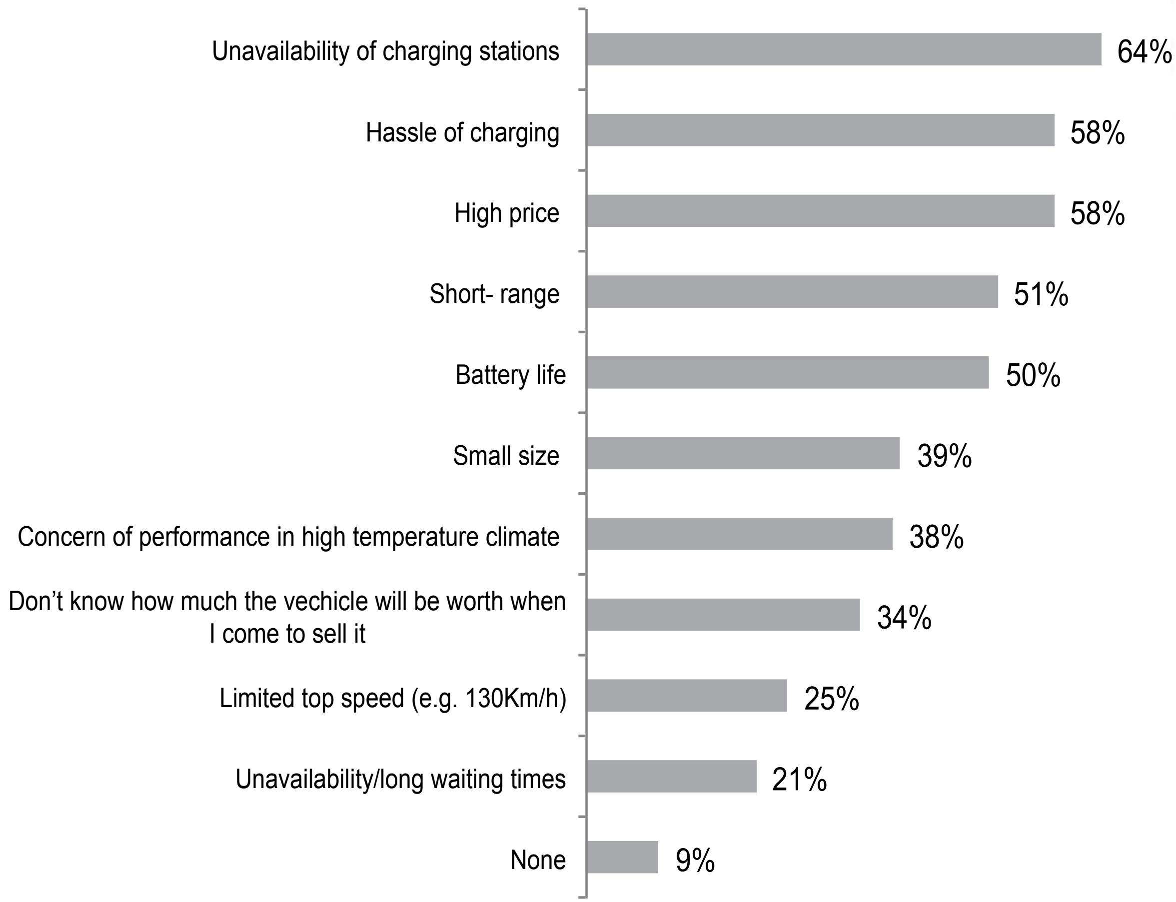


Image: http://www.smallanddeliciouslife.com

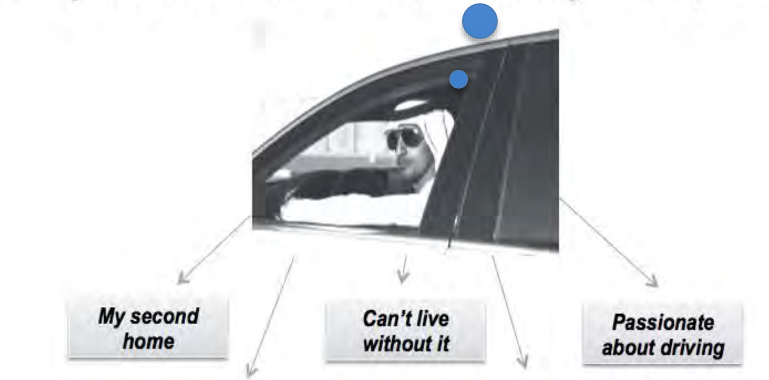
MARKETS INFRASTRUCTURE AND SOCIETY

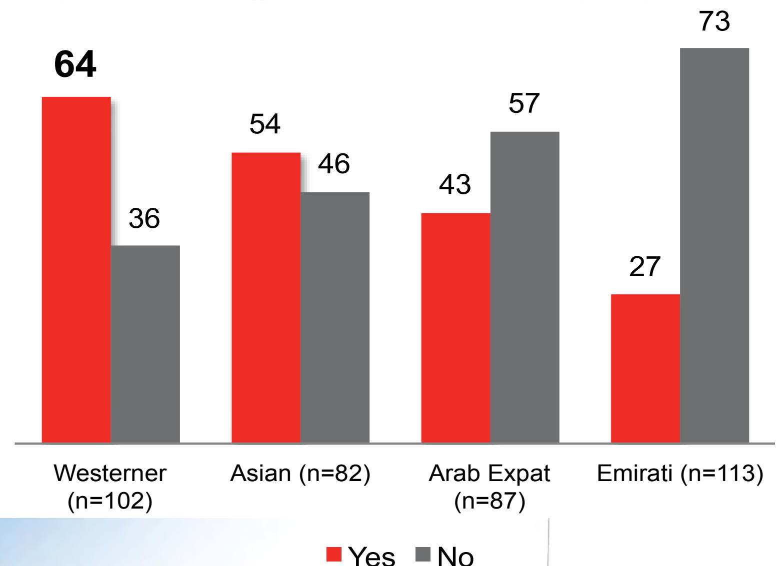
Survey Responses

To EV or not to EV?



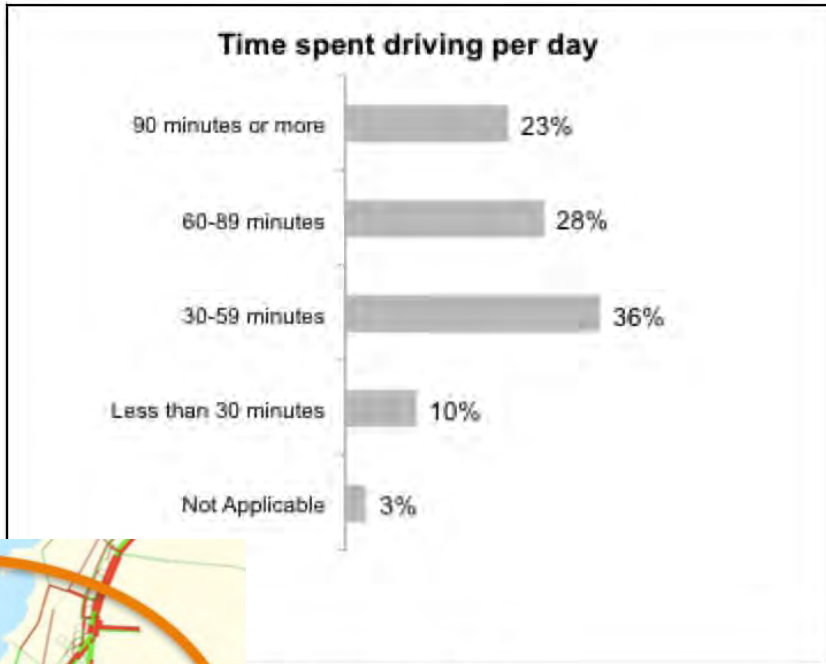
Emirati Males are passionate about their cars: They are an extension of their lifestyle and personality

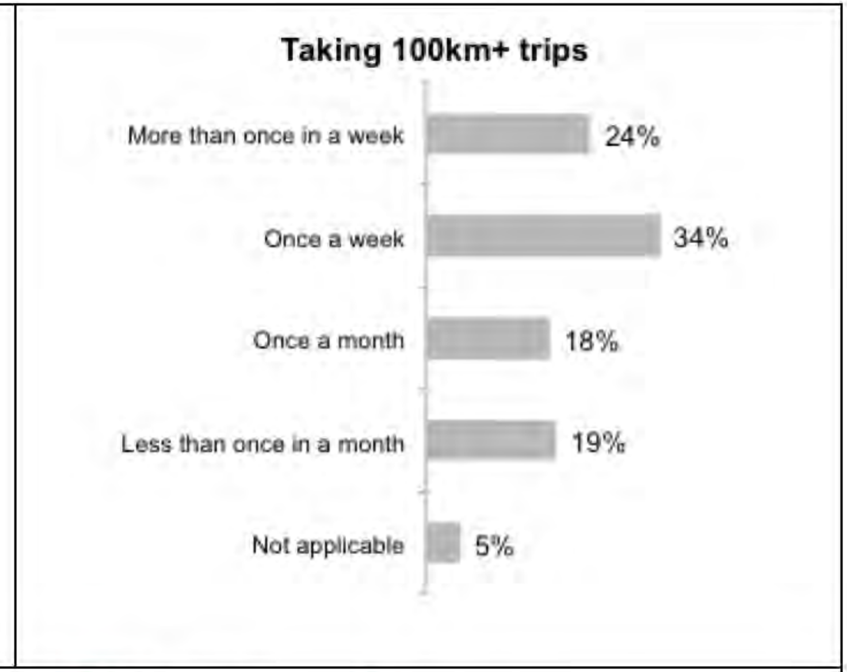


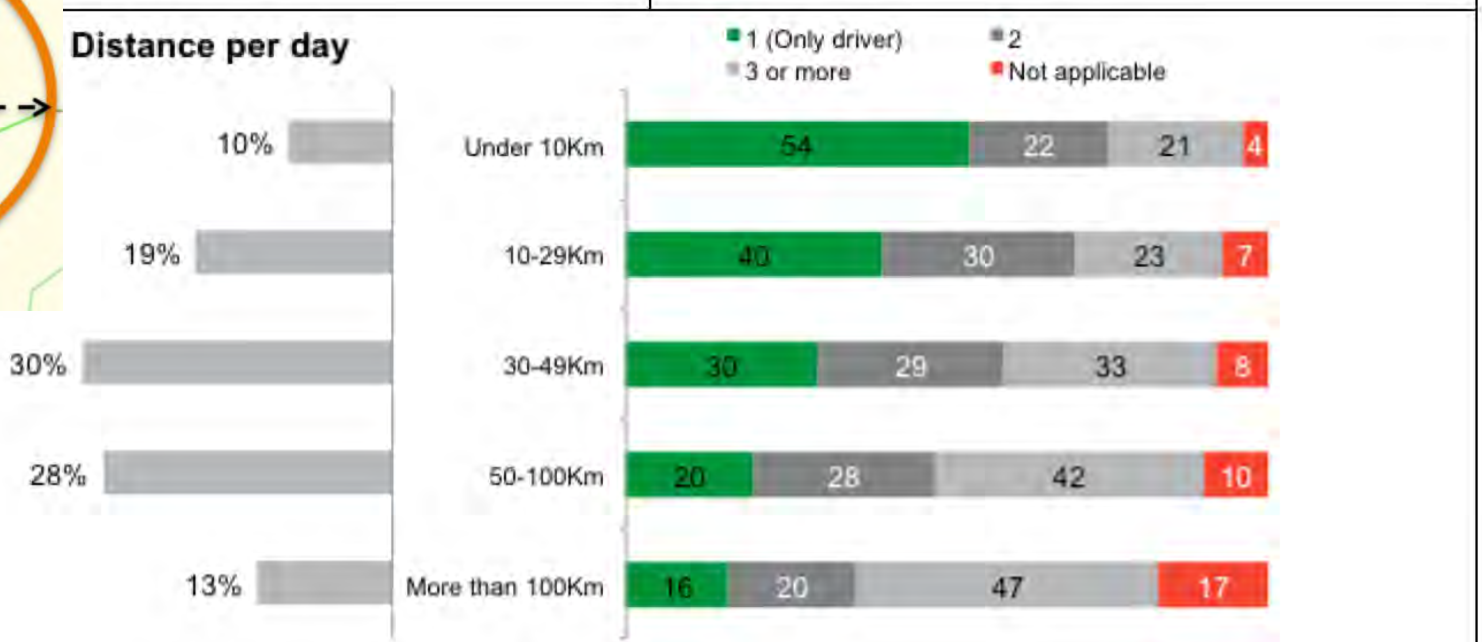


Source: Sgouridis, Al Hadrhami (2012)

SURVEY



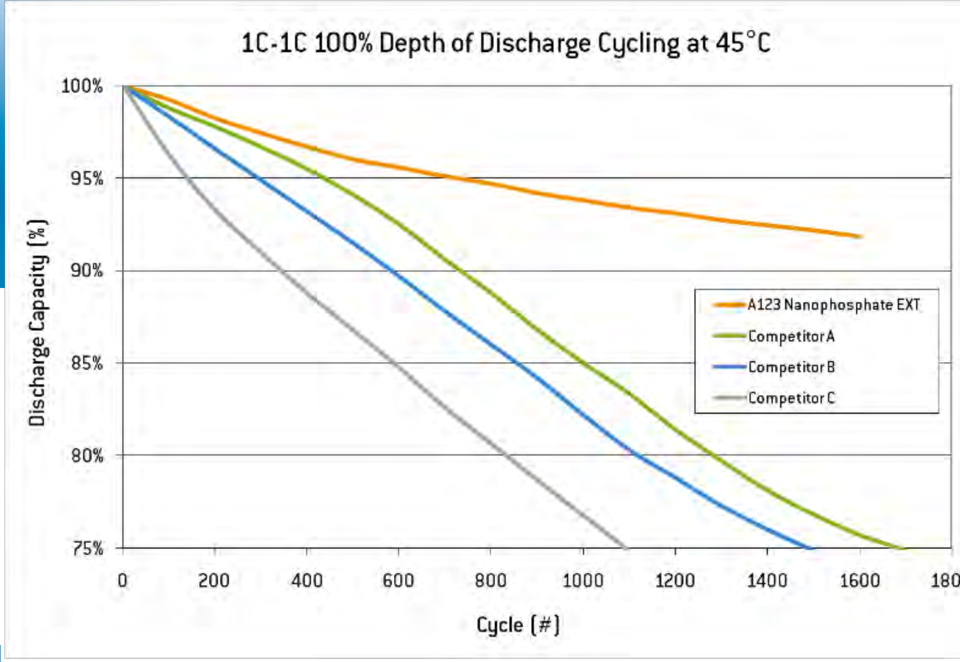




>70% of average daily trips could be covered by current EV s

Source: Sgouridis, Al Hadrhami (2012)

Battery Life and Range



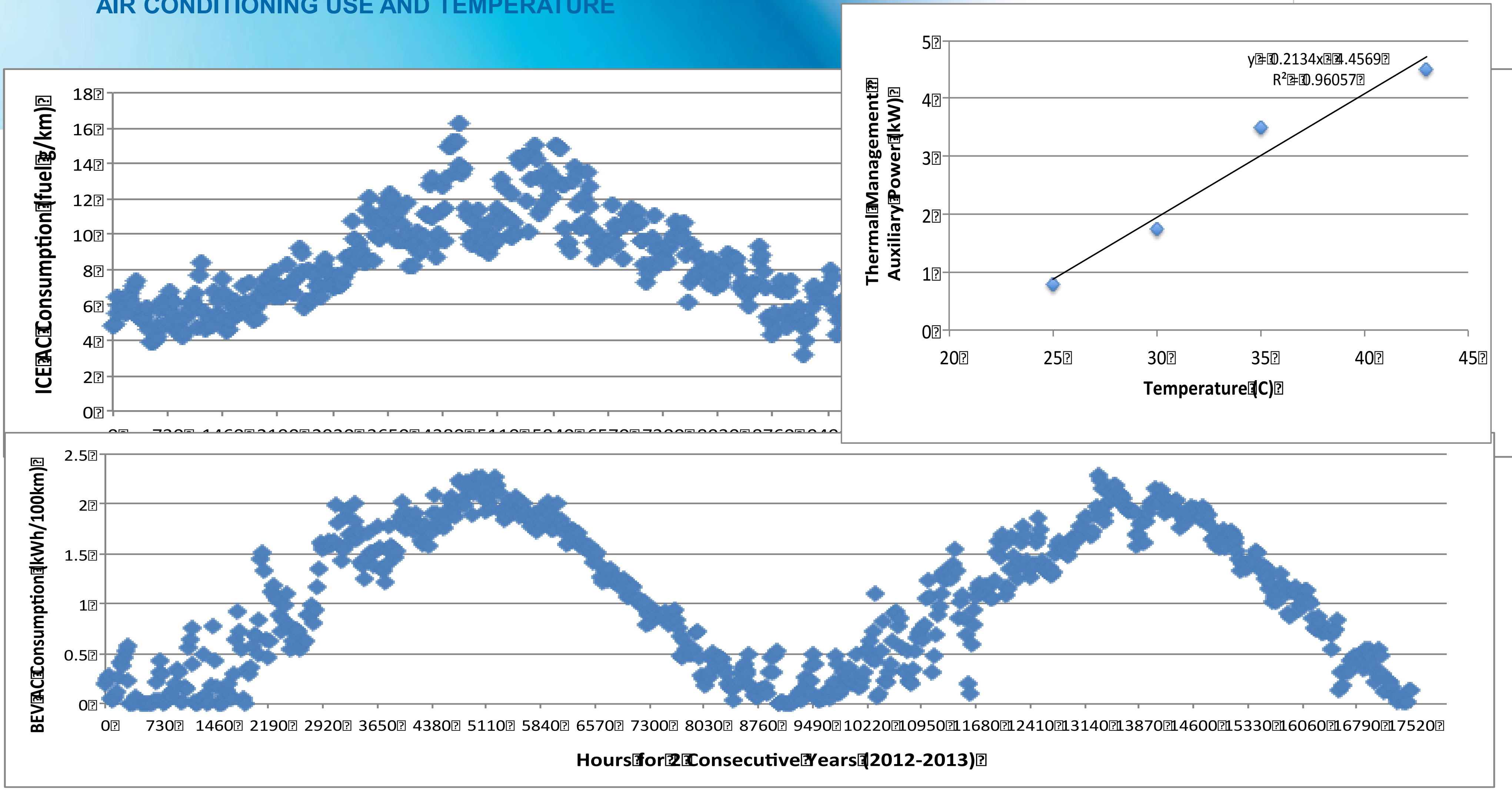
Reduced battery lifetime due higher operating temperatures?

- Li-Ion batteries are sensitive to overheating.
- Operating temperatures **max of 50C** to prevent accelerated cell deterioration – ambient outdoor parking temperature in UAE!
- Options include:

- **active cooling (e.g. Tesla Model S),**
- **air cooling (Nissan Leaf 2014-16)**
- **advanced battery chemistry (e.g.** Nanophosphate EXT Li-Ion allows higher operating temps)

Fig. source: http://www.a123systems.com/lithium-ion-battery-technology.htm

AIR CONDITIONING USE AND TEMPERATURE



→ AC use reaches about 10% of the fuel consumption of the vehicle in the warmest days

Source: Sgouridis, Al Hadrhami, Helmers (2016)

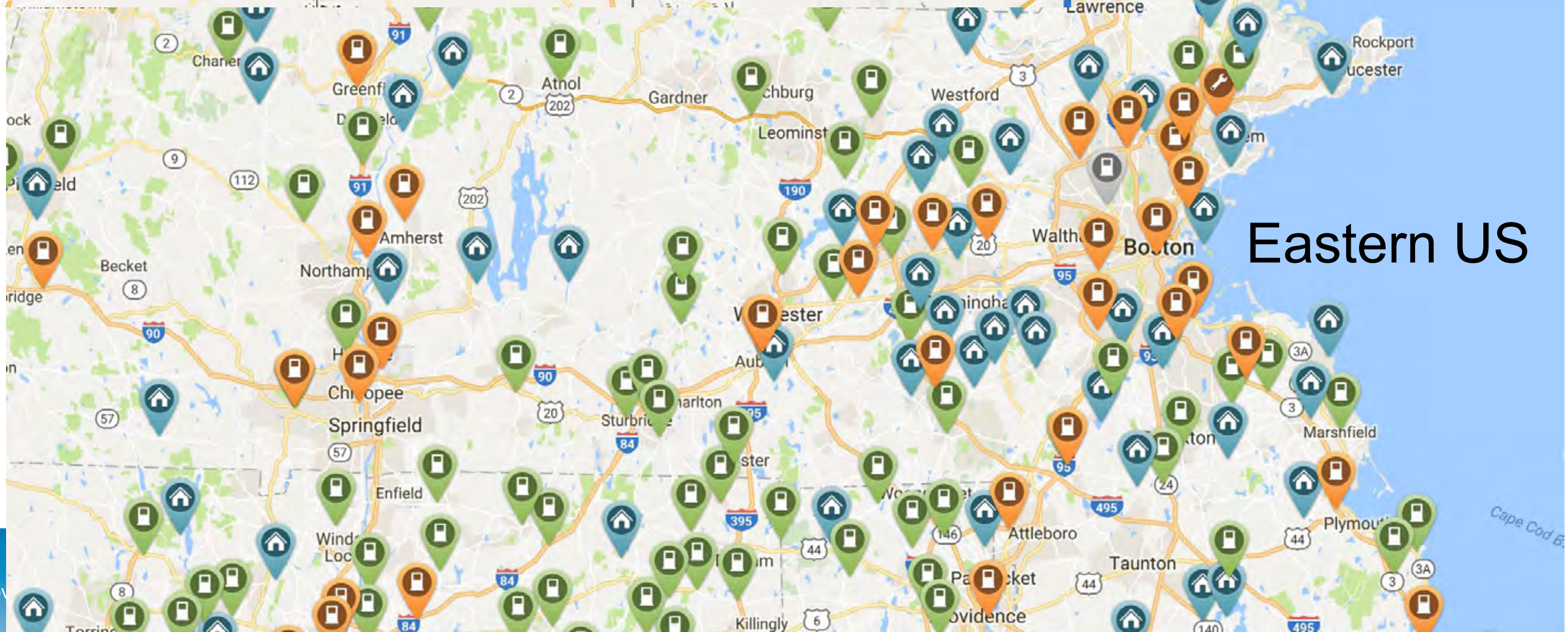
Infrastructure Support

- **Availability of Electric Vehicle Supply Equipment (EVSE):**
  - Providing the required infrastructure is essential to incentivize the public to adopt the new technology
    - **Amsterdam 1000 public charging stations in 2013**
    - **Barcelona: 4400 slow charging stations and 20 fast charging stations in 2014**
    - **UK: 8,500 charging points**
    - **Shanghai: ratio of 1.2-1.5 charging stations per EV**
    - **Kanagawa: install 1,000 100/200V outlets and 100 DC quick in 2014.**
    - **Dubai: 100 public charging stations in 2016**

Source (CO2 Emissions Mix): City of Portland and Multnomah County Climate Action Plan, 2009. EV & EVSE photo provided by Portland General Electric

UAE does not have to follow exactly the same with longer-range EVs coming online but still charging infrastructure will be needed


UAE
Sharjah
الشارقة
Falaj Al Mualla
فلج المعلا
Masafi
مسافي
Khor Fakkan
خور فكان
Fujairah
الفجيرة
Kalba
كلباء
Al Madam
المدام
Bu Baqarah
Hadf
Shinas
ولاية شناص
Al Shuwaib
الشويب
Al Faqa
الفقع
Al Samha
السمحة
Ash Shiyah
Al Ajban
العجبان
Nahil
ناهل
Abud
Dawanji
Liwa
لوى
AL DANAH
ZONE 1
MASDAR CITY
Sweihan
Mahdah
E88
E84
E66
E77
E44
E55
E11
E12
E16


Residential Chargers
Shared by PlugShare members
Public Stations
Installed by business or government
High Power Stations
DC fast charge or Superchargers
In-Use Stations
Currently in-use
More Options
Eastern US
Rochester
Newburyport
Lawrence
Rockport
Westford
Gardner
Leominster
Athol
Greenfield
Amherst
Northampton
Becket
Waltham
Boston
Chicopee
Springfield
Enfield
Marshfield
Plymouth
Attleboro
Taunton
Killingly
Torrington
Cape Cod Bay

Type	Level 1	Level 2	Level 3 (Fast Charg
Picture			
Charging Rate	2 to 5 miles/hour	10 to 20 miles /hour	60 to 80 miles in 20 minutes
Charging Time (for a 20kWh, 82-mile of range EV)	16.4 to 41 hours	4 to 8 hours	16 to 22 minutes (80% fast charge)
Power (kW)	< 3	3 to 25	>50
Current	AC	AC	DC
Voltage	120 v	240 v or 208 v	480 v input to EVSE

Range of EV Infrastructure Equipment

Type	Level 1	Level 2	Level 3 (Fast Charger)
Price of Unit ($)	Less than 500	1,000 to 7,000	20,000 to 50,000
Installation Cost ($)	500 to 860	1,000 to 7,400	7,400 upwards
Reported Total Installed Cost ($)	Up to 1,000	12,000 to 18,000	45,000 to 100,000
Cost of Additional Unit ($)	-	4,000 – 8,000	-
Cost of Maintenance ($)	25 to 50 per year	25 to 50 per year	25 to 50 per year

LDV	BEV			ICEV		
Rated Battery size / Fuel Tank	23 kWh (Li-ion, liquid-cooled) available 25 kWh nominal (max discharge 92%)			47 liters		
Rated battery cycles	2500			N/A		
Power	107kW (143 hp)			119kW (160 hp)		
Glider cost (incl. engine) ($USD)	24,500 (estimated)			25,500		
Battery cost ($USD) (@$425/kWh)	10,625			N/A		
Vehicle cost ($USD)	35,125 (including 6.6kW on-board charger)			25,500		
Maintenance cost ($USD)	$50/10,000km			$250/10,000km		
Charging efficiency	92%			N/A		
Motor efficiency	90%			33%		
Estimated Consumption (EPA-cycle based)	kWh/100km			l/100km (kWh/100km)		
	City	Highway	Combined	City	Highway	Combined
	19.2	21.4	20.1*	8.7 (78.3)	6.4 (57.1)	7.6 (68.2)
Curb weight (kg)	1633			1380		
Range (km)	City	Highway	Combined	City	Highway	Combined
	120	108	114	540	740	620

Battery capacity will be much higher in the next iterations. Tesla Model 3 > 300km. Same for Chevy Bolt and the new Leaf

Source: Sgouridis, Al Hadrhami, Helmers (2016)

Bus (2-axle)	EB (long-range)	EB (short-range with rapid charging)	ICEB (Euro 4)
Rated Battery size / Fuel Tank	220 kWh (Nominal) 203 kWh (available @ 92% discharge) Li-Fe, Liquid Cooled	110 kWh (Nominal) 101 kWh (available @ 92% discharge) Li-Fe, Liquid Cooled	300liters
Rated battery cycles	3000	3000	N/A
Power	2x110kW	2x110kW	199kW
Glider cost (incl. engine) ($USD)	290,000	290,000	300,000
Battery cost ($USD) (@ S425/kWh)	93,500	46,750	N/A
Vehicle cost ($USD)	383,500	336,750	300,000
Maintenance cost ($USD/yr)	30,000	30,000	66,500
Estimated Consumption Urban Cycle	115kWh/100km	115kWh/100km	550 kWh /100km (50 l/100km)
Curb weight (kg)	14300	13300	12180
Range per full charge (km)	176	88	600

Buses present a very different business case but require fast charging and charge-at-stops

Source: Sgouridis, Al Hadrhami, Helmers (2016)

Key parameters for a single EV evaluation

Vehicle characteristics	Battery	Battery capacity	20	kWh		
		Usable battery capacity ratio	0.9			
		Cycles	4000			
		Hot weather battery life penalty	0.9	ratio of actual to spec cycles		
		Battery life	3312	days	9.1	years
		Max vehicle life	7	years		
		Battery-dependent vehicle life	7.0			
	Consumption	Consumption (combined assuming reg	150	Wh/km		
		Hot Weather effective consumption	216.7	Wh/km		
		Average effective consumption	195.7	Wh/km		
	Displaced ICEV	Consumption	10	l/100km		
		Maintenance penalty ICEV	100	$/10,000km		
	EV Range	Standard	120	km		
		Hot weather range	83.1	km		
Vehicle Economics		Battery cost	500	$/kWh		
		Base vehicle cost	10000	$		
		Incremental premium for EV	0	$/vehicle		
		EV cost	20000	$		
		EV Premium	10000	$		
Vehicle utilization		Average speed	60	km/h		
		Vehicle utilization	100	km/day		
Environmental		# days with average temp > 25C	250	days/year		
		Hot weather AC consumption penalty	4000	Wh/hour		
Regulatory	Liquid fuel	Gasoline price	0.47	$/lit	1.72	AED/lit
		Unsubsidized gasoline cost	0.79	$/lit	2.9	AED/lit
		Gasoline subsidy	0.32	$/lit		
	Electricity	Electricty price	0.027	$/kWh	0.1	AED/kWh
		Unsubsidized electricity cost	0.10	$/kWh	0.367	AED/kWh
		Electricity subsidy	0.07	$/kWh	0.27	AED/kWh
		Electric grid CO2 intensity	0.4	kg/kWh		
		CO2 price	30	$/tonne		
	EV Inventives	Infrastructure cost share by user	30%			
		EV premium share by govt	5%			
		Discount rate	5%			
Infrastructure	Chargers	Level 2 charging station cost	2000	$		
		Level 3 charging station cost	50000	$		
		Level 2 stations per vehicle	0.8			
		Level 3 stations per vehicle	0.02			
		Charger life	10	years		

	Gasoline ICE Vehicle (combined)	Diesel Bus Vehicle	Electricity Grid	EV auto (combined)	e-bus (combined)	Suggested UAE value (USD/ton)
	g/km	g/km	g/KWh	g/km	g/km	
CO_2	174.8	1150	499.0	100.3	573.8	88
CO	1.0000	4.6	0.0328	0.00659	0.0377	886
VOC	0.1000	1.265	0.0020	0.0004	0.0023	5,289
NO_x	0.0600	8.05	0.0738	0.01483	0.0849	6,888
SO_2	0.0033	0.01	0.0024	0.000478	0.00274	20,418
PM	0.0045	0.1725	0.0019	0.000391	0.00224	397,397

Monetizing the emissions makes sense for buses more than LDVs

Source: Sgouridis, Al Hadrhami, Helmers (2016)

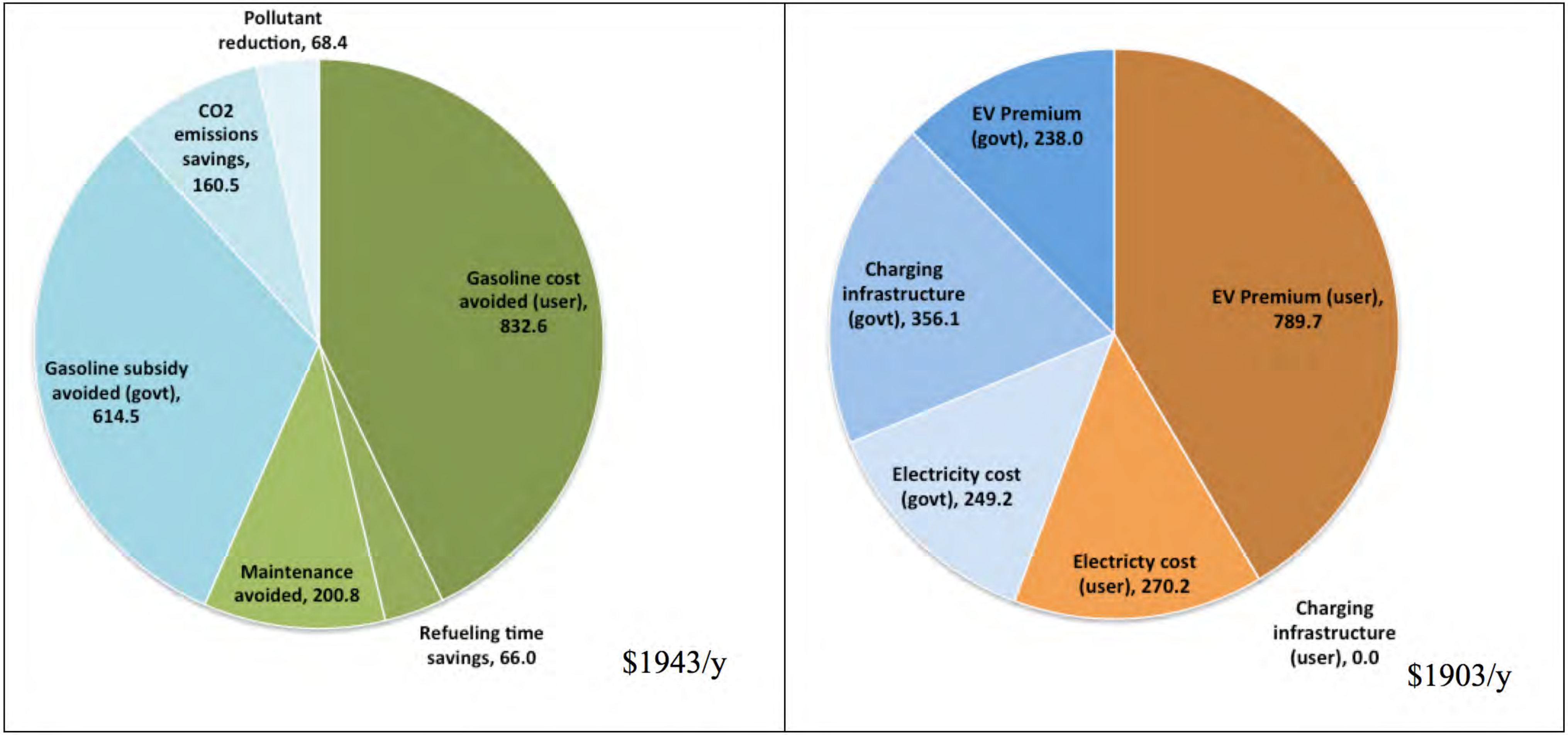


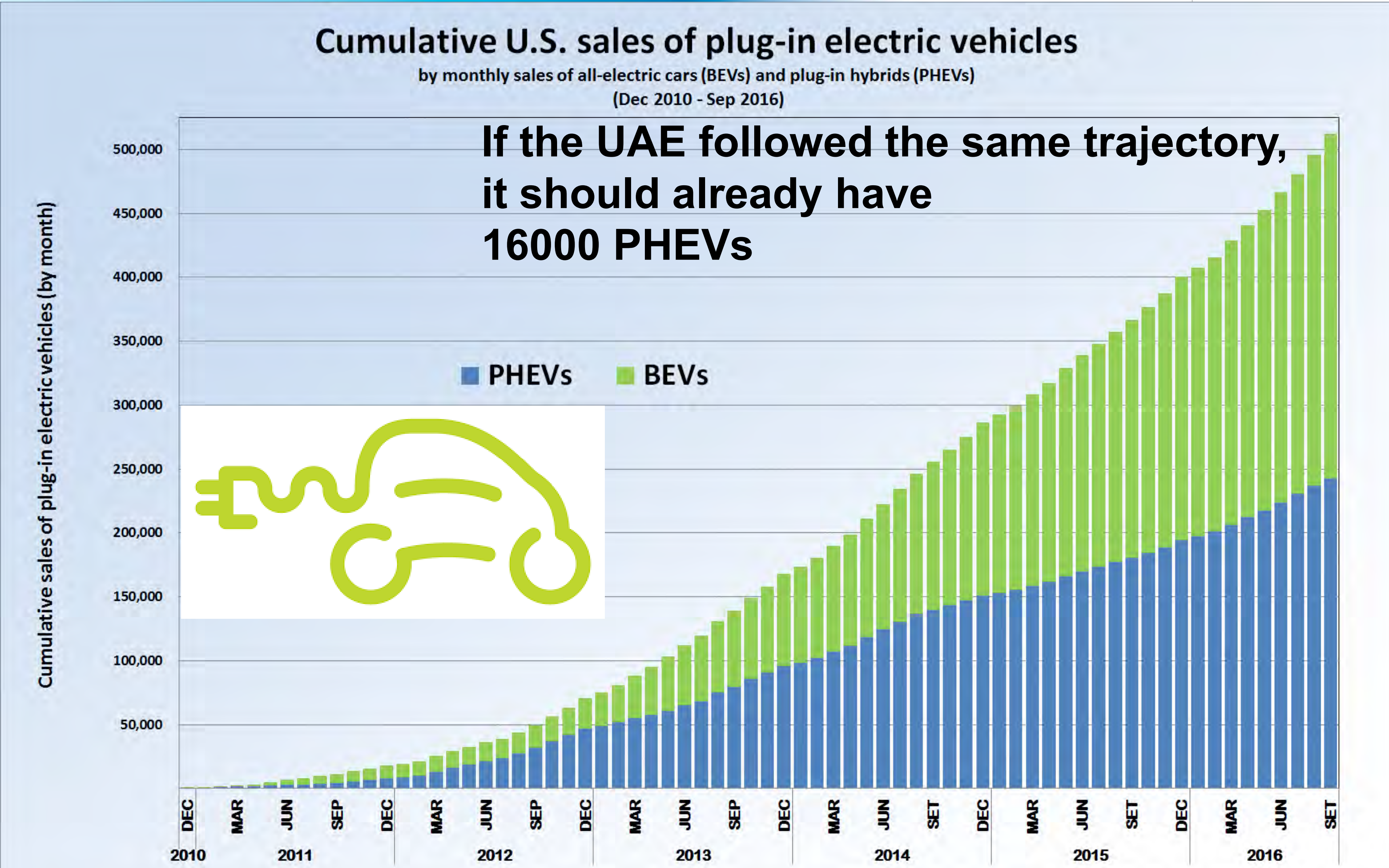
Figure 4 Comparative Annual Benefits (left) and Costs (right) of LDV EV Operations in UAE (for 55km/d average use, $325/kWh battery cost). Blue hues denote government and the orange and green private user.

Source: Sgouridis, Al Hadrhami, Helmers (2016)

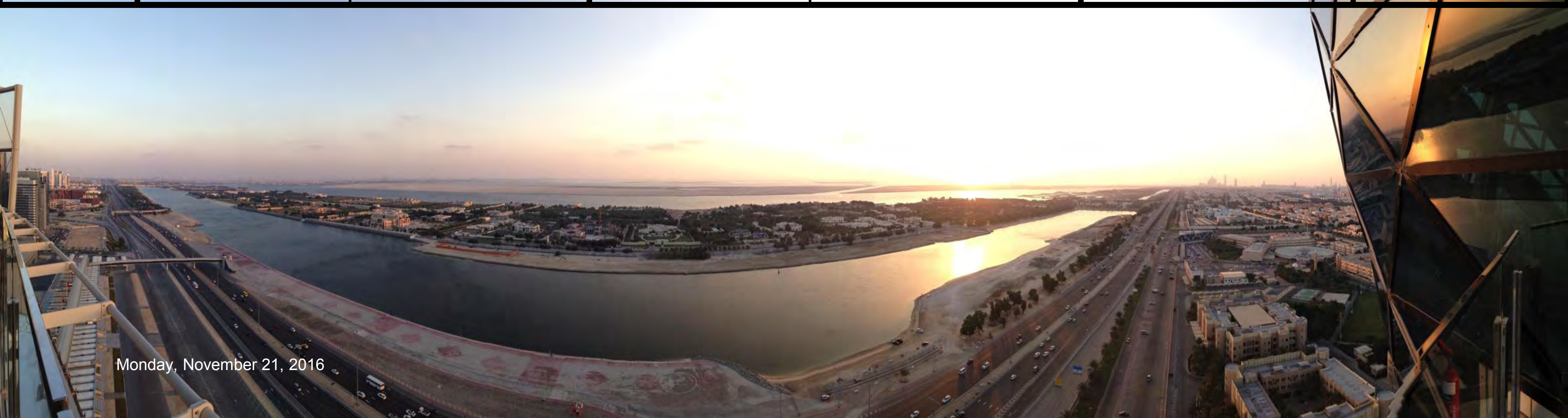
Vehicle Utilization (km/day)	Battery Cost ($/kWh)					
km/day	100	200	300	400	500	600
40	462.6	102.0	-258.6	-619.2	-979.8	-1340.5
50	721.4	360.8	0.2	-360.4	-721.1	-1081.7
60	980.2	619.6	259.0	-101.6	-462.3	-822.9
70	1239.0	878.4	517.8	157.1	-203.5	-564.1
80	1497.8	1137.2	776.6	415.9	55.3	-305.3
90	1756.6	1396.0	1035.4	674.7	314.1	-46.5
100	2002.6	1620.6	1238.5	856.5	474.5	92.5
110	2242.9	1830.3	1417.6	1004.9	592.2	179.5
120	2483.3	2039.9	1596.5	1153.1	709.6	266.2

Benefits directly correlate to utilization!

Source: Sgouridis, Al Hadrhami, Helmers (2016)


Cumulative U.S. sales of plug-in electric vehicles
by monthly sales of all-electric cars (BEVs) and plug-in hybrids (PHEVs)
(Dec 2010 - Sep 2016)
If the UAE followed the same trajectory,
it should already have
16000 PHEVs
PHEVs
BEVs
Cumulative sales of plug-in electric vehicles (by month)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SET
DEC
MAR
JUN
SET
DEC
MAR
JUN
SET
2010
2011
2012
2013
2014
2015
2016

Year	Cumulative Costs (discounted $2012)		Cumulative Benefits (discounted $2012)		Net Benefit	
	EV Premium	Infrastructure	Fuel Savings	Ancillary		
2015	$ 428,596	$ 81,720	$ 208,227	$ 102,304	$ (199,784)	
2020	$ 33,250,967	$ 26,025,861	$ 59,977,300	$ 58,167,663	$ 58,868,135	
2025	$ 135,927,670	$ 95,910,390	$ 238,557,485	$ 203,129,832	$ 209,849,256	
2030	$ 258,568,606	$ 195,104,139	$ 513,405,170	$ 403,675,042	$ 463,407,467	
Year	# Car EV	# Bus EV	Cumulative Gasoline/Diesel Saved (000 lit)	Cumulative CO2 avoided (tonnes)	Annual Electricity Consumed (MWh)	Peak Power Equivalent (MW)
2015	166	0	442	431	642	0.2
2020	8101	303	107,951	146,790	100,193	34.3
2025	28258	621	513,019	656,384	270,204	92.5
2030	51604	956	1,269,034	1,585,536	461,603	158.1



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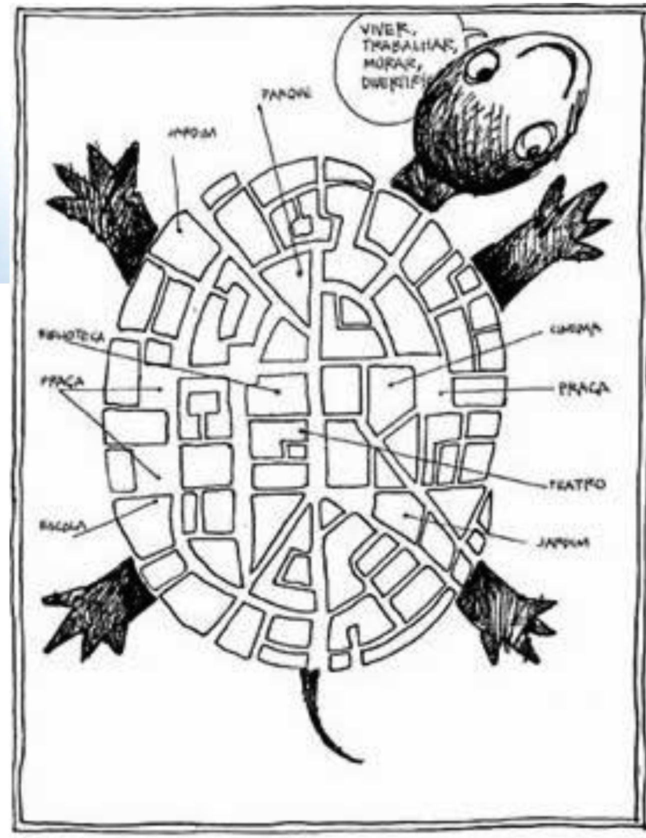


"It is important to have an integrated view of the city.

It is like the turtle embodying life, work and movement.

If the turtle's shell is fragmented it will die."

"If you want creativity cut one zero from your budget.

If you want sustainability cut two zeroes.

If you want to make it happen, do it fast!"

Jaime Lerner, Architect and Mayor of Curitiba

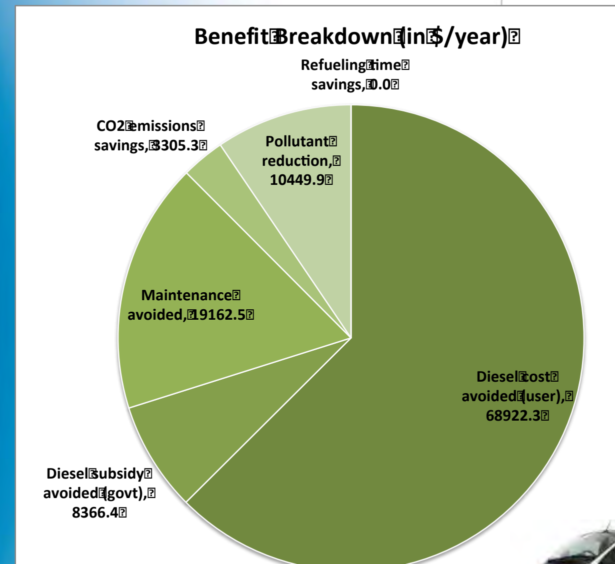
Source: http://vimeo.com/12499536, http://development.thinkaboutit.eu/think3/post/an_internationally_famous_city/

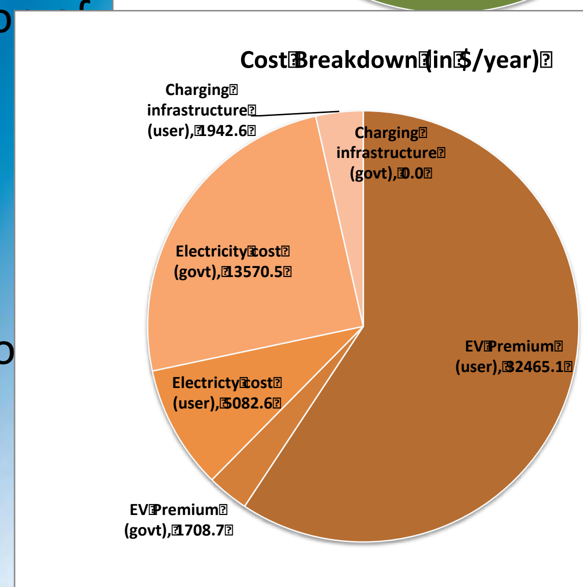
iCenter for Smart and Sustainable Systems

Sample Sponsored Research Project: Transportation

Potential for BEV Adoption in Abu Dhabi and Implications to the Grid (2013)

- Researchers involved
  - A. Farid, S. Sgouridis & Reem al Junaibi, M. Al Hadrhami
- Sponsors / Stakeholders
  - METI, Japan / Mitsubishi Heavy Industries, AD DOT
- Objectives
  - Investigate policy options for supporting the adoption of BEVs and examine their societal, economic, and technical challenges.
- Outcomes to date
  - Completed analysis of policy options, survey local drivers and users, BEV economic model, and adoption rates. EV use simulation and grid limitations.





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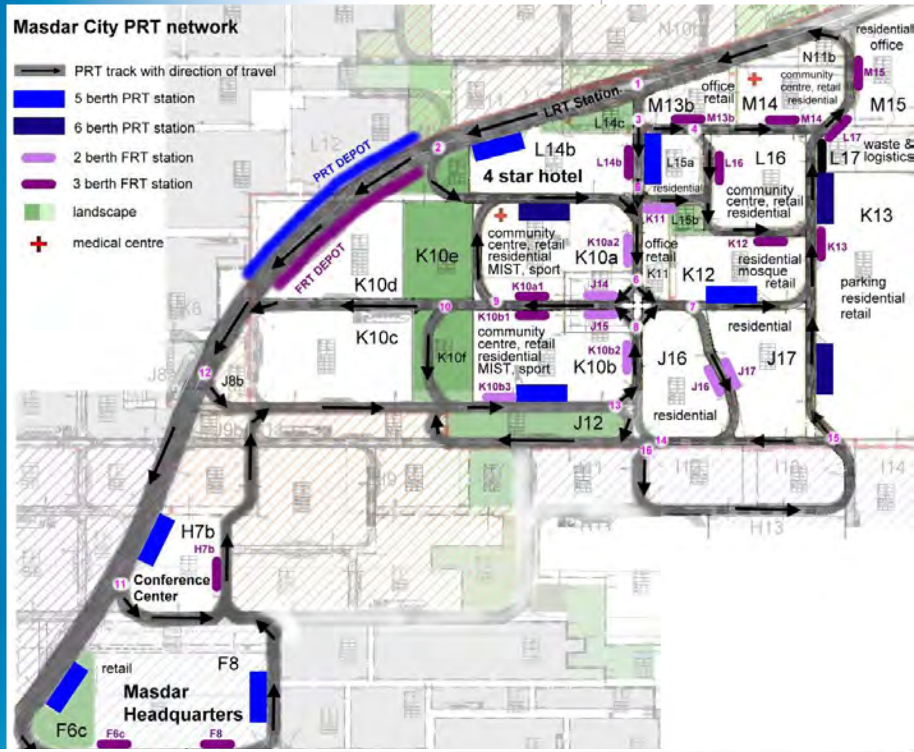
Sample Research Project: Transportation

Personal Rapid Transit Simulation Mobility (2010)

- Researchers involved
  - S. Sgouridis & K. Mueller (MSc)
- Sponsors / Stakeholders
  - Masdar City
- Objectives
  - Investigate the PRT system capability and operational optimization under diverse loads.
- Outcomes
  - Advanced PRT simulator (discrete-event) completed. BRT sensible for key OD and peak times



Setup options	Basic	Plus10	Plus20	Plus30
Demand increase	0%	10%	20%	30%
PRT vehicles	120	120	140	120
Station charging	No	No	Yes	Yes
Supercapacitor	None	None	None	1 kWh
PRT Allocation	Energy	Energy	Service	Service
Mean passenger throughput (pax/h)	715	755	790	840
Max passenger throughput (pax/h)	1240	1270	1350	1430
Average PRT (trips per day)	13 800	14 520	15 270	16 170
Total Freight (t/day)	81	89	97	105
Total Waste (t/day)	22	24	26.5	28
Experimental results	Basic	Plus10	Plus20	Plus30
PRT utilization (driving full)	37%	34%	25%	21%
Energy consumption	4270 kWh/day	4950 kWh/day	6940 kWh/day	10 000 kWh/day
Tw_{mean} in system	<7 seconds	<62 seconds	<22 seconds	<30 seconds
Tw_{max} at station 10	<720 seconds	<1500 seconds	<420 seconds	<480 seconds

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Sample Research Project: Transportation

Effects of Public Transportation on Transport Demand (2013)

Researchers involved

- S. Sgouridis & M. Sharhan (MSc)

Stakeholders

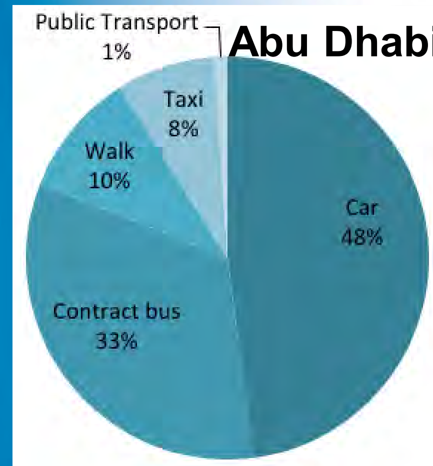
- AD DOT, RTA

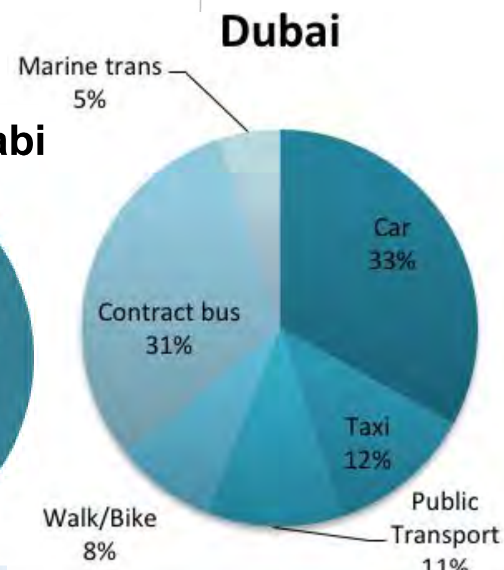
Objectives

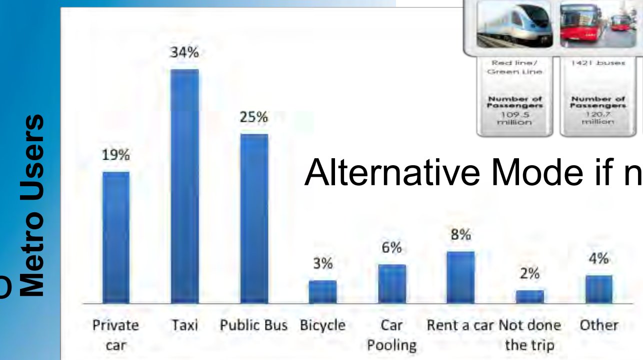
- Investigate the preferences and perceptions of UAE transport users for public transit.

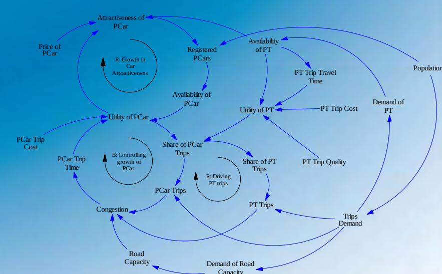
Outcomes

- Car owners entrenched. Less than 25% of Dubai Metro users surveys owned a car. Metro increases mobility – provides alternative to car for ~50% of the pax trips.
- System dynamics model initiated.









Car Owners

	Work (Base 288)	School drop/pick up (Base 83)	Leisure (Base 316)	Shopping (Base 321)	Sports activities (Base 152)
Private vehicle	92	81	92	93	86
Taxi	1	2	2	1	1
Bus	2	12	2	2	5
Car pooling	2	4	1	2	3
Metro	1	1	1	2	1
Bicycle	0	0	0	0	3
Other	2	0	1	0	1