Mobility in 2050

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Abstract How our society and in particular our mobility will look like within 30 years from now is hard to predict. The authors take a bold position by looking at how mobility could look like in 2050, disregarding of any temporarily constraint and only then, define the way how to get there by analyzing the different steps, needed to pave the way. This methodology allows them to get rid of the famous tunnel-vision what most studies suffer from. It leads to very interesting and refreshing conclusions, in particular on congestion, traffic jams, car accidents and also on the evolution of the automotive industry in general. The key question, that gets an answer herewith, is "how many vehicles will we have on our roads in 2050?". The answer might be surprising.

Keywords Electric mobility · Battery swap · Automated driving · Innovation · Advanced technologies · Affordable mobility solutions

Acronyms

MaaS	Mobility as a Service
BaaS	Battery as a Service
IoT	Internet of Things
VR	Virtual Reality
AR	Augmented Reality

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AI	Artificial Intelligence
FotA	Firmware over the Air
V2V	Vehicle to Vehicle communication
V2I	Vehicle to Infrastructure communication
ADEM	Autonomous Driving Electric Mobility
BEV	Battery Electric Vehicle
ICE	Internal Combustion Engine
PDC	Person-Driven Car
OEM	Original Equipment Manufacturer (here: Car Manufacturer)
BS	Battery Swap solution
B2C	Business to Consumer (here: Passenger Cars)
B2B	Business to Business
B2B-1	Business to Business (here: Light Utility Vehicles ($\leq$3.5 t))
B2B-2	Business to Business (here: Heavy Utility Vehicles (>3.5 t))
B2B-3	Business to Business (here: Busses and Touring Cars)
CC	Conductive Charging (= charging at an energy pole with a cable)
BRS	Battery Recharging Station

1 Lessons Learned from the Past

Following trends are identified

- Everything, related to environment, gets utmost priority by governments of all kind and gradually by Captains of Industry as well. Reduction of greenhouse gases (CO_2, NO_x, CH_4, etc.) and harmful particles (Black Carbon, PM_{10}, $PM_{2.5}$, etc.) are of utmost importance. The EU Green Deal and the Paris Treaty have to be respected and the objectives have to be realized. The health condition of Planet Earth is getting by far the highest priority. To illustrate this, we just refer at the recent judgement of the court at The Hague against Royal Dutch Shell and the presence of representatives of Engine No. 1 within the Board of Directors of ExxonMobil.
- The younger generation has different ideas about property and ownership of goods, be it an apartment or even a car. While for the baby boomers, ownership of a nice car was a major objective, for the generation x, y and z, this is no longer the case.
- Technology is becoming more and more important in our day-to-day lives. We see new types of technology popping up, like the Internet of Things (IoT), Artificial Intelligence (AI), Virtual and Augmented Reality (VR/AR), Blockchain, Cloud technology, Firmware over the Air (FotA), etc.
- Intermodal transport is not yet a reality, but a number of building blocks are already in place. We expect this to become a reality in 2050, as well for mobility of people as for transport of goods.
- New ways of mobility will be developed within the coming years, like hyperloop, flying taxis, autonomous driving vehicles, etc.

2 Mobility of People in 2050

Imagine following situation:

- In 2050, every single trip (person or goods) will be coordinated by an overall **Mobility Service Platform (MSP).** Interaction with this MSP might look like this:
  - Someone is preparing for a business trip to Brazil. His flight at Heathrow will leave at 14:00 h. The evening before, he contacts the MSP bot, saying: **“ *I have to catch a flight to São Paolo, Brazil, that leaves Heathrow Airport tomorrow at 14:00 h and I have only one bag of roughly 15 kg* ”.** Potentially, the MSP bot will ask a few more questions, in order to prepare this trip as good as possible. Finally, the MSP bot will return following answer **“ *At 09:30h, there will be an ADEM car (Autonomous Driving Electric Mobility) in front of your home, to bring you to the airport* ”**.
  - As he’s heading for a business trip, where he has to make an important presentation at a congress, the ADEM car, which is equipped with 360° video enabled windows, allows him to rehearse his presentation in front of a virtual interactive audience.
  - At his arrival at Heathrow airport, the on-board printer has already printed his boarding documents.

In 2050, the vast majority of vehicles will be autonomous driving vehicles. New wireless technologies, like 5G, 6G, etc., xG and short-range wireless communication like vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and many more will be available and will allow these vehicles to drive from A to B without any risk on car accidents anymore. Indeed, once human beings will stop driving themselves and entirely trust autonomous driving vehicles, the number of car accidents will drastically drop and eventually completely disappear.

This is a nice dream, but chances are real that it will become reality in 2050 or even some earlier.

Continental has produced a very nice clip, outlining their ideas on how the future of mobility may look like: https://youtu.be/mk52AaxofM8.

3 Intermodal Mobility of People

And what about intermodal transport systems?

In the example here above, that person has made use of only one single mode of mobility in order to get into the airport. But let’s take another passenger, who’s living in a small village in the neighborhood of Ghent, Belgium, and is heading for a congress in downtown Antwerp. A day ahead, while preparing her trip, she contacts the MSP bot, saying: **“ *Hello, tomorrow I have to be at the Mobility Congress in Antwerp at 9:00 h, but want to arrive at the Congress Hall at 8:30 h already.* ”** The

MSP bot might return following message: "***At 7:15h, ADEM car with id. 1701 will be in front of your front door. That one will bring you to the Hyperloop station of Ghent, where you will arrive at 7:46h. The hyperloop itself will leave at 7:55h and arrive in Antwerp at 8:05h. At the Antwerp hyperloop station, ADEM car with id. 2043 will wait for you and bring you to the auditorium of the University, where the congress will take place. In the meantime, I already have introduced all these data into your personal calendar on your smart phone. Your alarm clock will go off at 6:15 h. Is that OK for you?***".

Did you notice that we never mentioned any payment so far? Payment handling will also be integrated and secured, in such a way that no one has to take care about. As all data, needed to handle payment transactions in a secure way, are available inside the MSP Central System (place of departure, place of destination, distance, mode of operation, etc.), the MSP Central System will match these with the payment schemes of the different operators, that provide services within the intermodal chain, and initiate the payment transaction. That whole transaction will be transparent for the user and secured via Blockchain transactions.

4 Intermodal Mobility of Goods

And what about transport of goods?

Like with persons, goods can and will be handled in an integrated way as well. Once the goods are stored at the producer plant into an intelligent box, the logistics operator can then get in touch with that same MSP bot and order a transport for that particular intelligent box towards the final destination location. Here, obviously, the operator will have to provide some more details, like size of the box, weight, upper and lower limits of temperature (e.g. in case of drugs, vaccines), … unless all these data are already prepared by the operator and collected into a standardized electronic logistics file, which then can be uploaded at once into the MSP Central System.

All requests will come together within the MSP Central System, where an algorithm will execute an optimization of logistics flows in order to avoid partially filled loads. Hence, the system will only return an answer to the operator, once the optimization routine has been executed. Then again, the answer will be that a large freight ADEM van will arrive at the production site to collect the sealed intelligent box and bring it to its final destination via different modes of mobility (ADEM, Train, Plane, Barge, Drone, etc.), where an authorized person, who's entitled to unseal the intelligent box, will open this intelligent box and collect the goods.

The goods are secured at all time, since the intelligent box is sealed and protected against theft, damage and pilferage. Hence, we can speak about real door-to-door secured logistics trade lanes.

5 Is This Science Fiction or Reality, that Is Becoming True?

Now that we have a better view on how transport of people and goods might look like in 2050, let's elaborate these predictions a little more in detail. We will also take a look at the energy needs, since we may assume that, in case we all drive electric by 2050, the energy production plants and energy grids might be stressed to the limits. No? Let's make some calculations and discover the impact our new model of mobility will have on our day-to-day lives.

6 How Many Vehicles Will We Really Need in 2050?

That's a very important, if not the utmost important question, we have to ask ourselves. Nowadays, the majority of citizens own a private car or use a company car. This makes that 448 million inhabitants of the EU-27 own or use about 247 million passenger cars.[1] Adding to that 29 million Light Utility vehicles ($\leq$3.5 t), 6 million Heavy Utility Vehicles (>3.5 t) and 700,000 busses and touring cars, then we end up with a total figure of 283 million vehicles.[1]

Will we still need that huge number of vehicles in 2050 anymore? The answer is definitely: NO! Here's why:

Have you ever wondered what percentage of the time a car is in use and how much time it is simply parked? The equation is very simple. Let's take following assumptions:

- The average mileage of a vehicle is 15,000 km/year
- The average speed of a vehicle is 60 km/h.

Then we find out that this vehicle is in use during 250 h.

Since a year counts $365 \times 24 = 8760$ h, the vehicle is in use for 0.0285 or 2.85% of the time.

Hence following logical question arises: "Is it still justifiable to make an investment in equipment, which has 97.15% idle time?" Will we continue to own and use a vehicle that is only in use during 2.85%[2] of its time and is unused for the remaining 97.15% of the time?

Only the Happy Few will be able to afford such a "bad investment", while the vast majority of the population will be pushed towards more economically viable solutions. One of these solutions is the ADEM concept, since ADEM allows vehicles to be in use for almost 100% of the time. Obviously, an investment that can be depreciated over 100% of its time, is much more economic justifiable than one that is only in use for 2.85% of its time. This means that mobility will become much cheaper than it is today and that far less vehicles will be needed to satisfy the mobility needs of the population.

7 Autonomous Driving Electric Mobility (ADEM)

Let's concentrate for a while on the ADEM concept.

At first, we're looking at the **Autonomous Driving** vehicle, which means that fatigue or distraction of the driver is no longer an issue. This vehicle can be in use 24/7 and thus at 100% of the time. The only moment, when this vehicle is not in use, is when maintenance and cleaning is ongoing or at an unexpected breakdown of the equipment. Hence, this vehicle is unavailable only during planned and unplanned outages. But apart from that, the vehicle can be in use all time.

As ADEM handles about **Electric Mobility** and Battery Swap technology provides a full "recharge" in less than 2 min, queueing and long waiting times at energy charging poles will be a concept of the past. All business models, based on conductive charging of electric vehicles are doomed to fail, be it car sharing, taxi, ambulance, etc., since a vehicle, standing in front of a charging pole—even a fast charger—is economically speaking "dead" for a longer period of time. As long as there is no battery swap alternative, these business models will never fly. Hence, we assume that by 2050 the only way of charging will be by swapping batteries.

The driverless ADEM car, based on battery swap, is capable of being in use for almost 100% of the time. With this in mind, one can ask following question: "In that case, how many ADEM vehicles do we need in 2050 to offer a high quality MaaS (Mobility as a Service)?" The answer is "Less than you might imagine".

Indeed, as pointed out earlier, we, nowadays have 247 million passenger cars within EU-27, who are in use for only 2.85% of the time. Suppose that we are able to replace this fleet by vehicles, which are in use all time, then we only need about 7 million passenger vehicles to fulfill the mobility needs from the whole EU-27 population.

As this 7 million is theoretically speaking correct and is an optimization by a factor of 35, this number is not realistic, since there is cleaning and maintenance time needed, as well as very little time to perform the battery swaps as well. Moreover, there are hours of "low demand" for transportation of people. Between 1 a.m. and 5 a.m., there will be little need for mobility of people, even if price/km drops drastically within this timeslot. Hence, we assume an optimization of 25 as being realistic and yet of great improvement.

The biggest challenge within the years to come will be to guide the transition from the actual situation towards this projected situation in 2050. Let's take a closer look at it.

8 How to Move from ICE to BEV with Battery Swap and Ultimately to ADEM Between Now and 2050?

Today, we have about 247 million passenger cars registered in EU-27, of which only 0.2% or 0.5 million are BEV (Battery Electric Vehicles).[1] This means that 99.8%

are still equipped with an ICE (Internal Combustion Engine) and will have to be converted within the coming years towards Electric Mobility.

We may expect that, by 2050, the energy utilities will have made their turn-around as well and that at that very moment the electric energy will be provided for 100% from renewable energy sources (solar, wind, tide, bio, etc.).

Let's take a closer look at the usage mix of vehicles. The vast majority might be converted to ADEM, while some cannot be converted by 2050 from PDC (Person-Driven Car) to ADEM for obvious reasons:

- A medical doctor, who will have to visit patients at home, will always need an individually owned car, which will be available at any time.
- Home care givers will also need to have a dedicated car.
- Technicians (plumbers, HVAC-technicians, etc.) as well will have the need for an individual vehicle, although most of them will make use of a Light Utility vehicle ($\leq$3.5 t), of which there are about 29 million enrolled today within EU-27.

Let's assume this figure being around 10% or 25 million units within EU-27. These vehicles will evolve over time from ICE towards Battery Swap BEV (BEV-BS). Anyhow, we assume that even these vehicles might evolve, within the time frame between 2050 and 2060 towards an ADEM equivalent. In the event this comes thru by 2060 we'll have only automated driving vehicles on the roads, thus removing almost every single risk for a car accident.

The remaining 222 million passenger vehicles are candidate for an "investment optimization" through the ADEM MaaS offering. This will not happen overnight, but will take some time. We assume that the first roll-out of ADEM will only start in 2030, with 50% conversion in 2040 and finally a 100% conversion in 2050. As we anticipate a 25 times improvement in efficiency, we can assume that the number of vehicles needed will be about 25 times smaller. Overcrowded routes will then be a concept of the past and some roads will be redesigned to host more pedestrians, bikes, steps, etc.

In the intermediate timeframe between now and 2030, a number of ICE cars will be converted towards the intermediate Conductive Charging technology of Battery Electric Vehicle (BEV-CC), thus bringing the BEV penetration ratio from a 0.2% in 2020 towards about 5% in 2030 before being halved in 2040 and completely disappear and being replaced by the more effective and efficient Battery Swap solution. At that moment, the millions of charging poles will also disappear from our streets, freeing space for trees.

On top of these 247 million passenger cars, we also have nearly 36 million Utility vehicles on the European streets, including busses and touring cars. Over time, they will all have to become green as well and thus migrate to a battery swap model too in order to be economic viable.

Likewise, this evolution will not happen overnight, but will need "some time". We foresee a start of this migration in 2030, with a 50% uptake in 2040 and a 100% completion in 2050. Mission accomplished!

But before we'll reach this point, quite a number of hurdles will have to be taken, as well technical as political or societal. Not everyone is yet ready to abandon private ownership of a car.

The key trigger will be an economic one, since owning a car is expensive, as we have illustrated, and will become many times more expensive in the future. Or, said in a different way, standard individual mobility will become much cheaper once we can make use of a vehicle for nearly 100% of its time, instead of only 2.85% as of today. Will it become 35 times cheaper? No, certainly not, but in case we are able to offer a 25 times cheaper mobility, the vast majority of the population will be interested in moving that way. Don't you think so?

As you can see in Table 1, the number of vehicles will drop considerably by 2050. There will be nearly 80 million vehicles on the European roads, compared to the 283

Table 1 Overview of the actual vehicle mix in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full MaaS and ADEM based mobility model by 2050

			Actual		Forecast			
			2020		2030	2040	2050	2060
B2C	B2C-ICE	(1)	222,000,000	78.39%	210,900,000	105,400,000	0	
		(2)	25,000,000	8.83%	23,750,000	11,875,000	0	
	BEV-CC	(3)	500,000	0.18%	12,850,000	6,425,000	0	
	BEV-BS	(4)			0	18,300,000	36,600,000	*
	ADEM	(5)			0	4,218,000	8,436,000	
B2B-1	B2B-1	(6)	29,000,000	10.24%	29,000,000	14,500,000	0	
		(7)				14,500,000	29,000,000	*
B2B-2	B2B-2	(8)	6,000,000	2.12%	6,000,000	3,000,000	0	
		(9)				3,000,000	6,000,000	*
B2B-3	B2B-3	(10)	700,000	0.25%	700,000	350,000	0	
		(11)				350,000	700,000	*
Total			283,200,000		283,200,000	181,968,000	80,736,000	
PDC			283,200,000		283,200,000	177,750,000	72,300,000	

* Over time, these vehicles can also become autonomous driving, thus also becoming ADEM, in which case PDC will be reduced to 0% and ADEM becoming 100% by 2060
(1) ICE cars (convertible from PDC towards ADEM)
(2) ICE cars (convertible from ICE towards battery swap)
(3) BEV cars (from conductive charging towards battery swap)
(4) BEV cars (battery swap)
(5) ADEM (autonomous driving electric mobility)
(6) Light utility vehicles ($\leq$3.5 t)
(7) LUV conversion from ICE towards battery swap
(8) Heavy utility vehicles (>3.5 t)
(9) HUV conversion from ICE towards battery swap
(10) Busses and touring cars
(11) B&TC conversion from ICE towards battery swap

million nowadays, of which 8.5 million will be Automated Driving (ADEM) and the remaining 72 million will still be Person Driven. Hence, traffic jams will definitely be a concept of the past at that moment in time. Road works can be executed without any problem during daytime. Car accidents will also disappear to a large extend, since Automated Driving vehicles do not suffer from distraction, fatigue, hubris, … as humans do. Searching for a free parking spot will become a concept of the past as well since ADEM cars do not park for a longer time at the road side. They will just collect or drop passengers and immediately continue driving towards the next mission. And, last but not least, moving from A to B will no longer be a waste of time, since, while being inside the ADEM vehicle, one can do many useful things, from attending a video conference, rehearsing a presentation up to enjoying the landscape or listening to music, podcasts, etc. And the tiring job of conducting a car will finally be delegated to the onboard computer.

In a plotted format, Fig. 1a and b looks like this.

9 How Much Energy Will Be Needed to Power All These BEVs?

Next question that will pop-up is: "How many GWh do we need to power this Electric Mobility in Europe?". The answer is not obvious and needs some more in-depth reflection, but here is the answer.

First, we have to agree on some assumptions[2]:

- An electric PDC, as we know it actually (BEV-CC), will need to have a battery capacity onboard of at least 90 kWh, in order to remove range anxiety (e.g. Tesla, Audi e-tron, etc.).
- A car, equipped with a Battery Swap solution (BEV-BS), will only need an onboard capacity of about 30 kWh, since for these passenger vehicles, range anxiety won't exist anymore.
- As each of them will drive on average 15,000 km/year and consume about 0.2 kWh/km, they will each consume 3000 kWh or 3 MWh per year.
- For an ADEM vehicle, we consider likewise a 30 kWh-battery capacity, although models with higher capacity (e.g. 2×30 kWh … up to 6×30 kWh) might be designed as well, thus considerably reducing the number of swap-stops.
- An ADEM vehicle, which is operating 24/7, will cross 375,000 km/year and will thus consume 75,000 kWh or 75 MWh.
- We will include the Utility Vehicles as well, in order to be complete:
  - A B2B-1 Light Utility Vehicle ($\leq$3.5 t) has a battery capacity of 2×30 kWh $=$ 60 kWh and has an average energy consumption of 0.5 kWh/km.
  - A B2B-2 Heavy Utility Vehicle (>3.5 t) has a battery capacity of 8×30 kWh $=$ 240 kWh and an average energy consumption of 1 kWh/km.

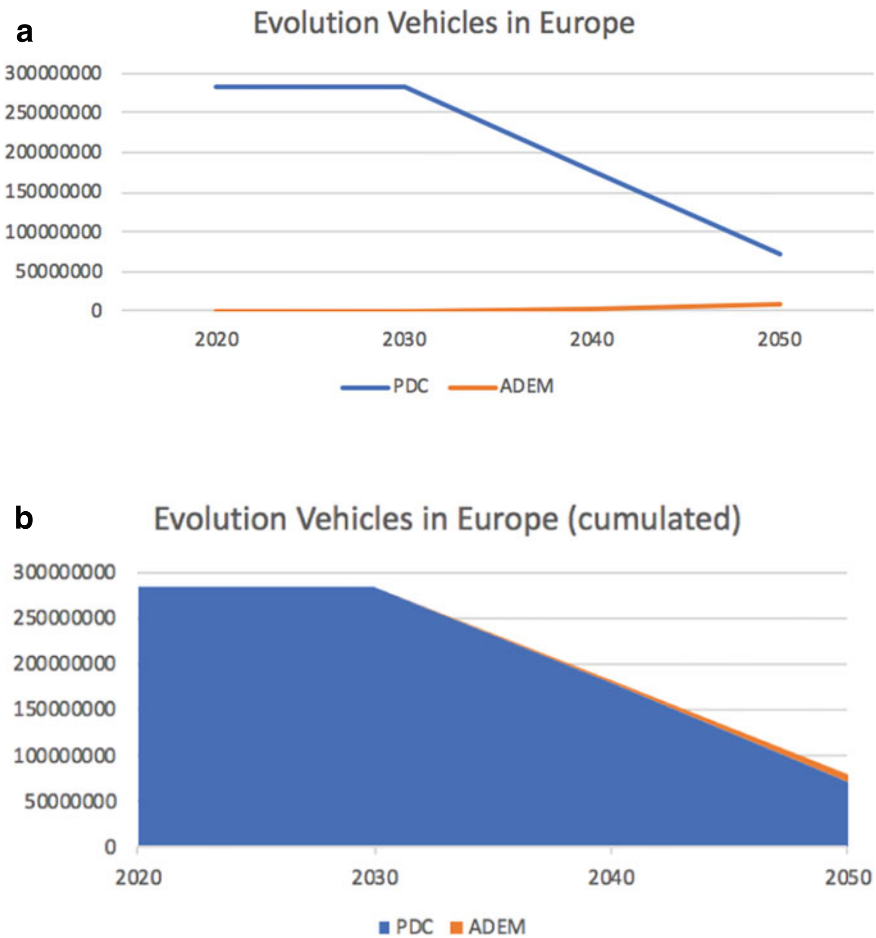


Fig. 1 **a** Forecast on the evolution of the vehicles in Europe. **b** Forecast of the evolution of the vehicles in Europe (cumulated view)

– A B2B-3 Bus and Touring Car needs a much larger battery capacity. Here we anticipate a total battery capacity of 1000 kWh and an average energy consumption of 1 kWh/km.

With all these figures combined, we can forecast the potential energy need as follows (Table 2 and Fig. 2).

Table 2 Forecast of the energy requirements for mobility in Europe, in the event of a total shift towards electric mobility by 2050

	Battery capacity	Distance (km/year)	Consump. (kWh/km)	Annual El. (kWh)	Energy need (GWh)			
					2020	2030	2040	2050
BEV-CC	90	15,000	0.2	3000	1500	38,550	19,275	0
BEV-BS	30	15,000	0.2	3000	0	0	54,900	109,800
ADEM	30	375,000	0.2	75,000	0	0	316,350	632,700
B2B-1	60	30,000	0.5	15,000	0	0	217,500	435,000
B2B-2	240	10,000	1.0	10,000	0	0	30,000	60,000
B2B-3	1000	50,000	1.0	50,000	0	0	17,500	35,000
Totals (GWh)					1500	38,550	655,525	1,272,500

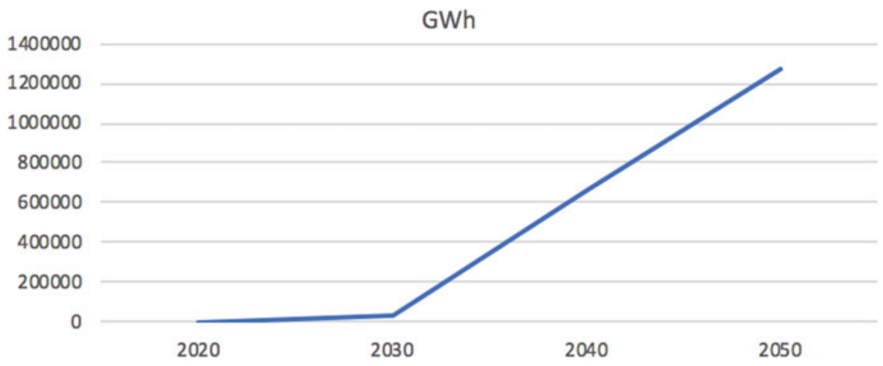


Fig. 2 Graphical representation of the energy requirements for mobility in Europe EU-27, in the event of a total shift towards electric mobility by 2050

9.1 More Than 1272 TWh by 2050, You Say?

To make it a little more tangible, we will now take a look at the European energy production. According to Eurostat, the Gross Electricity Production for EU-27 in 2018 was 2941.47 TWh.

This means that, in case our energy production capacity remains unchanged until 2050, at that moment, almost 43% of our generated energy have to be allocated to mobility. Since it would be naïve to suppose that energy needs for all other purposes except mobility will decrease in that same period by 43%, we have to grow our production capacity to catch up with the transition from ICE towards BEV (Fig. 3).

Observe, while looking up this table, that Energy Utilities across Europe still have a long way to go in order to reach the 2050 target of 100% renewable energy. Hence, we may conclude that Energy Utilities worldwide have multiple major challenges ahead within the coming 30 years.

Gross electricity production by fuel, EU-27, 2000-2018
(GWh)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
GROSS ELECTRICITY PRODUCTION	**2 656 927**	**2 732 678**	**2 755 285**	**2 833 403**	**2 902 652**	**2 917 663**	**2 968 344**	**2 982 997**	**2 994 599**	**2 842 557**
SOLID FOSSIL FUELS	**800 340**	**792 906**	**814 354**	**849 144**	**835 571**	**808 882**	**816 172**	**828 867**	**757 053**	**703 575**
Anthracite	0	0	0	7 249	19 018	18 184	15 389	18 495	16 686	12 716
Coking coal	37 874	35 142	37 020	40 232	41 321	37 230	34 552	37 871	29 654	20 950
Other bituminous coal	411 018	402 964	416 136	440 687	417 580	403 719	423 037	420 769	369 868	344 745
Sub-bituminous coal	6 380	4 818	5 934	5 061	6 155	5 771	5 262	6 640	4 227	4 263
Lignite	344 081	348 959	354 183	353 416	349 221	341 163	335 090	341 578	333 265	318 172
Coke oven coke	0	0	8	104	165	0	6	68	10	17
Gas coke	0	0	0	0	0	0	0	0	0	0
Patent fuel	0	0	4	0	0	0	0	0	14	0
Brown coal briquettes	923	968	950	2 276	2 005	2 716	2 775	3 388	3 299	2 694
Coal tar	64	55	119	119	106	100	61	58	30	18
PEAT & PEAT PRODUCTS	**5 902**	**8 562**	**8 826**	**9 584**	**8 735**	**7 486**	**9 273**	**9 975**	**8 597**	**7 804**
Peat	5 902	8 562	8 826	9 584	8 735	7 486	9 273	9 975	8 592	7 799
Peat products	0	0	0	0	0	0	0	0	5	5
OIL SHALE & OIL SANDS	**7 663**	**7 627**	**7 649**	**9 292**	**9 500**	**9 288**	**8 774**	**11 399**	**9 630**	**7 625**
OIL & PETROLEUM PRODUCTS	**172 850**	**168 918**	**181 704**	**166 817**	**143 653**	**137 435**	**130 043**	**109 455**	**101 545**	**92 938**
Natural gas liquids	0	0	0	0	0	0	0	0	0	0
Refinery gas	3 798	3 652	3 340	4 049	6 350	6 579	6 350	6 311	7 425	7 164
Liquefied petroleum gases	22	38	50	487	501	490	503	899	505	564
Naphtha	0	0	0	0	0	0	2	0	105	159
Kerosene-type jet fuel	0	0	0	0	0	1	0	0	1	1
Other kerosene	0	3	3	20	1	2	11	14	13	12
Gas oil and diesel oil	4 109	7 325	7 223	8 487	5 277	5 250	14 004	10 390	9 663	10 558
Fuel oil	140 496	127 846	143 617	127 389	105 302	100 097	84 938	67 154	62 646	54 987
Petroleum coke	336	137	337	1 242	4 246	4 754	3 699	3 006	3 233	3 996
Bitumen	3 776	3 378	2 646	246	1 312	223	126	125	4	0
Other oil products	20 313	26 539	24 488	24 897	20 650	20 024	20 388	21 534	17 947	15 497
NATURAL GAS & MANUFACTURED GASES	**362 721**	**386 554**	**403 483**	**453 375**	**493 977**	**549 669**	**576 653**	**609 553**	**648 264**	**590 183**
Natural gas	331 482	354 282	372 732	420 267	461 325	515 570	543 030	573 786	613 884	565 815
Coke oven gas	7 456	6 844	5 878	6 685	6 782	6 264	6 638	7 588	7 210	5 760
Gas works gas	1 615	1 757	1 874	1 914	1 839	2 115	1 965	2 051	2 308	2 354
Blast furnace gas	21 549	22 904	22 183	22 628	22 378	24 002	23 468	24 361	23 451	14 982
Other recovered gases	619	767	816	1 881	1 653	1 719	1 552	1 768	1 412	1 271
NUCLEAR	**859 930**	**888 892**	**902 348**	**907 174**	**928 438**	**916 081**	**914 426**	**872 249**	**884 729**	**824 912**
RENEWABLES & BIOFUELS	**435 914**	**464 914**	**423 070**	**428 541**	**472 244**	**476 989**	**499 867**	**527 245**	**569 808**	**599 552**
Hydro	379 103	401 998	345 681	335 722	355 268	340 546	342 708	338 894	354 878	357 687
Geothermal	4 785	4 612	4 761	5 434	5 523	5 398	5 616	5 773	5 732	5 546
Wind	21 276	25 738	35 063	43 307	57 526	68 094	78 711	99 908	113 235	124 556
Solar thermal	0	0	0	0	0	0	0	8	16	103
Solar photovoltaic	113	181	266	415	691	1 459	2 489	3 767	7 421	14 001
Tide, wave, ocean	507	485	494	490	470	481	464	465	465	448
Primary solid biofuels	19 767	20 164	23 474	28 033	36 251	40 583	45 163	47 667	53 178	57 347
Pure biodiesels	0	0	0	0	0	0	0	0	0	1
Other liquid biofuels	0	15	104	56	572	1 768	2 914	1 506	1 861	3 831
Biogases	3 872	4 587	5 853	6 876	7 092	8 064	10 152	15 950	19 107	22 295
Renewable municipal waste	6 491	7 134	7 372	8 206	8 850	10 597	11 648	13 307	13 915	13 737
NON-RENEWABLE WASTE	**11 607**	**14 304**	**13 851**	**9 477**	**10 534**	**11 833**	**13 137**	**14 254**	**14 972**	**15 968**
Industrial waste (non-renewable)	5 204	7 167	6 460	1 070	1 251	839	839	1 232	1 390	2 467
Non-renewable municipal waste	6 403	7 137	7 391	8 406	9 283	10 994	12 297	13 022	13 582	13 501

	2010	2011	2012	2013	2014	2015	2016	2017	2018
GROSS ELECTRICITY PRODUCTION	**2 980 266**	**2 937 269**	**2 934 222**	**2 916 087**	**2 856 412**	**2 902 315**	**2 923 612**	**2 955 894**	**2 941 465**
SOLID FOSSIL FUELS	**701 230**	**725 240**	**742 708**	**728 918**	**692 754**	**704 993**	**659 172**	**638 843**	**595 611**
Anthracite	10 494	18 384	16 987	11 102	12 531	12 238	4 878	4 103	4 013
Coking coal	16 232	18 570	24 142	5 338	9 440	1 073	8 638	11 164	8 805
Other bituminous coal	355 200	347 412	357 031	382 352	347 927	370 667	340 950	316 147	286 638
Sub-bituminous coal	3 378	5 631	5 292	4 076	4 613	4 722	2 634	3 170	2 394
Lignite	313 437	333 068	336 840	323 123	315 467	313 662	299 424	301 921	291 618
Coke oven coke	2	4	3	2	2	1	0	0	0
Gas coke	0	0	0	0	0	0	0	0	0
Patent fuel	0	0	0	0	0	0	0	0	0
Brown coal briquettes	2 464	2 167	2 411	2 924	2 766	2 616	2 631	2 329	2 132
Coal tar	23	4	2	1	8	14	17	8	11
PEAT & PEAT PRODUCTS	**9 332**	**8 258**	**6 607**	**5 854**	**6 168**	**5 840**	**5 488**	**5 243**	**5 926**
Peat	9 332	8 253	6 604	5 850	6 163	5 834	5 487	5 243	5 926
Peat products	0	5	3	4	5	6	1	0	0
OIL SHALE & OIL SANDS	**11 045**	**10 902**	**9 702**	**11 406**	**10 302**	**7 992**	**9 623**	**9 912**	**9 380**
OIL & PETROLEUM PRODUCTS	**82 090**	**74 594**	**72 566**	**63 096**	**60 516**	**63 383**	**61 998**	**58 686**	**54 836**
Natural gas liquids	0	0	0	0	0	0	0	0	0
Refinery gas	7 121	6 474	5 926	6 019	6 348	6 431	7 112	6 554	7 176
Liquefied petroleum gases	460	592	649	398	389	414	552	452	237
Naphtha	99	98	64	66	16	0	0	0	0
Kerosene-type jet fuel	1	0	1	0	1	0	0	0	1
Other kerosene	23	14	10	22	14	10	7	13	13
Gas oil and diesel oil	10 928	10 621	10 872	11 281	10 461	10 003	9 844	10 523	9 999
Fuel oil	45 027	39 616	36 543	29 756	29 034	31 226	30 209	28 737	25 614
Petroleum coke	2 006	2 333	2 717	1 687	1 642	4 158	3 598	2 280	1 577
Bitumen	0	0	0	0	0	0	0	0	0
Other oil products	16 424	14 845	15 785	13 866	12 611	11 140	10 677	10 127	10 219
NATURAL GAS & MANUFACTURED GASES	**622 630**	**591 393**	**516 138**	**446 723**	**388 672**	**430 138**	**499 547**	**559 264**	**523 189**
Natural gas	589 373	558 174	484 083	415 197	357 003	397 793	467 640	526 772	491 445
Coke oven gas	6 701	6 619	6 694	6 309	5 769	6 820	6 862	6 937	7 488
Gas works gas	2 499	2 526	2 453	2 158	2 511	2 552	2 527	2 529	1 793
Blast furnace gas	22 485	22 425	21 034	21 233	21 495	20 730	20 566	20 844	20 301
Other recovered gases	1 571	1 649	1 875	1 826	1 894	2 243	1 950	2 183	2 163
NUCLEAR	**854 470**	**837 769**	**811 961**	**806 223**	**812 550**	**786 675**	**767 958**	**759 383**	**761 943**
RENEWABLES & BIOFUELS	**681 854**	**670 966**	**756 274**	**835 621**	**866 164**	**883 770**	**898 948**	**903 582**	**968 800**
Hydro	401 267	332 849	359 552	396 653	398 609	363 238	372 711	322 463	370 651
Geothermal	5 602	5 947	5 820	6 026	6 303	6 614	6 733	6 715	6 658
Wind	139 842	165 347	187 461	209 475	222 357	263 205	266 833	312 306	320 519
Solar thermal	761	1 959	3 775	4 770	5 455	5 593	5 579	5 883	4 867
Solar photovoltaic	22 463	45 330	66 402	79 334	88 714	95 264	95 455	102 046	110 115
Tide, wave, ocean	476	477	458	414	481	487	501	522	480
Primary solid biofuels	64 907	67 133	72 076	70 516	70 732	72 069	72 394	74 239	75 958
Pure biodiesels	2	27	23	24	26	28	29	27	30
Other liquid biofuels	4 887	3 306	3 500	4 269	4 793	5 468	5 264	4 963	4 890
Biogases	26 206	32 054	40 640	47 184	50 888	53 791	55 044	55 668	55 325
Renewable municipal waste	15 440	16 537	16 567	16 956	17 807	18 012	18 406	18 749	19 308
NON-RENEWABLE WASTE	**17 616**	**18 148**	**18 266**	**18 247**	**19 285**	**19 525**	**20 878**	**20 982**	**21 781**
Industrial waste (non-renewable)	2 874	2 927	2 949	2 398	2 529	2 605	2 893	2 588	2 851
Non-renewable municipal waste	14 742	15 221	15 317	15 849	16 756	16 920	17 986	18 394	18 930

Source: Eurostat (online data code: nrg_bal_peh)

eurostat

Fig. 3 Gross electricity production by fuel, EU-27, 2000–2018. *Source* Eurostat

Another assumption, we can make is following: suppose we intend to generate our energy for mobility solely from wind energy and we assume that a 3 MW wind turbine on land generates on average 6.5 GWh, then to produce the required 1272 TWh, Europe needs to have **195,692** 3 MW wind turbines, dedicated to mobility. Given the European surface of 4,272,000 km^2, this means on average 1 turbine per 22 km^2. Since a number of area's are not suited to install turbines, the density in other areas will be much higher. It's clear that the needed energy will have to come from other sources as well.

10 Next Steps

10.1 Quick Look Backwards

Now that we've a better view on where we are going at, it's good to ask ourselves: "where are we today?". Quite remarkably, one can find very diverging figures, depending on the source and the interpretation of these figures. In order to create a common ground, the figures we use herewith are coming from the ACEA report[1] "Vehicles in Use in Europe—January 2021". We can consider these figures as recent, objective and undisputable.

When figures are different from these, it is very often due to the fact that PHEV (Plug-in Hybrid Electric Vehicles) are considered as well as "Electric Vehicles", although they aren't. In most cases, drivers are using them the same way they are driving a traditional ICE-vehicle, thus generating 140 g CO_2/km or more, instead of the figures, mentioned within the marketing brochures. Hence, these vehicles are NOT a contributor to the Clean Air efforts, we all have to make within the coming decades, … on the contrary! PHEVs are jeopardizing most efforts! We expect them to disappear very rapidly.

But, let's look backwards for a short while and have a look at where it all started. In an article on the website of the US Energy Department,[3] we read: "By 1900, electric cars were at their heyday, accounting for around a third of all vehicles on the road. During the next 10 years, they continued to show strong sales." So, back in 1900, the market share of the BEV was about 33%. Today, in Europe, the actual market share is 0.2%.[1] This is 150 times smaller! Hence, we can only conclude that so far, it went completely wrong.

10.2 The Ambition Is to Evolve Towards 100% BEV by 2050!

When we hear politicians of all color declare that we will have energy neutrality by 2050 and that we need to have an emission free mobility by that moment in time, it's clear that the way ahead will be steep and long. Is the European Green Deal a dream?

Is the Paris Climate agreement an unrealistic ambition? Maybe. In case we continue to tackle the problems the same way, we did during past decades, for sure it will! Hence, we have to change our approach, make a 180° U-turn and make BEV "sexy" enough for citizens to move from ICE towards BEV. That's the real challenge. A challenge that—surprisingly enough—the OEMs didn't discover so far.

10.3 How to Close the Gap?

How to close the gap between 0.2% and 100% … and do this between now and 2050? Let's take a closer look on how a smooth transition between our actual mobility model and what it is supposed to be in 2050 and beyond may look like. In this chapter, we will formulate an answer to the overall sounding question: "How to get there?".

At first, we will come back on Table 1 and elaborate this one a little more in detail. At that table, it was mentioned, and indicated with a (*), that the very last PDCs (Person Driven Cars) might also become Autonomous Driving, hence ending up with a 100% automated fleet on our roads. Although Automation is not the key subject of this chapter, we'll include it for a while and extend our forecast onto 2060, when the last PDC might be converted into its ADEM equivalent and road mobility will be completely automated.

10.4 The Evolution of the Fleet on Our Roads Within the Coming Decades

The different categories of vehicles will be split up a little more in detail in order to have a better view on the individual evolutions (Table 3 and Fig. 4).

Remark: We deliberately do not make any projection on growth in population or on increase or decrease in mobility, which both might influence our mobility as well. That's completely out of scope and might being influenced by factors, which are hard to predict. The Corona pandemic and consequent home office labor has made mobility drop significantly in 2020, compared to 2019. In this analysis, total distance/year per person has remained unchanged, as well as the number of vehicles in the B2B-categories. It's only within the B2C-category, that we've projected an increase in efficiency from 2.85% per car towards nearly 100% of efficiency.

Table 3 Overview of the vehicle mix in in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full MaaS and 100% ADEM based mobility model by 2060

			Actual		Forecast			
			2020		2030	2040	2050	2060
B2C	B2C-ICE	(1)	222,000,000	78.39%	210,900,000	105,400,000	0	0
		(2)	25,000,000	8.83%	23,750,000	11,875,000	0	0
	BEV-CC	(3)	500,000	0.18%	12,850,000	6,425,000	0	0
	BEV-BS	(4)			0	18,300,000	36,600,000	0
	ADEM	(5)			0	4,218,000	8,436,000	45,036,000
B2B-1	B2B-1	(6)	29,000,000	10.24%	29,000,000	14,500,000	0	0
		(7)				14,500,000	29,000,000	0
		(12)						29,000,000
B2B-2	B2B-2	(8)	6,000,000	2.12%	6,000,000	3,000,000	0	0
		(9)				3,000,000	6,000,000	0
		(13)						6,000,000
B2B-3	B2B-3	(10)	700,000	0.25%	700,000	350,000	0	0
		(11)				350,000	700,000	0
		(14)						700,000
Total			283,200,000		283,200,000	181,968,000	80,736,000	80,736,000

(continued)

Table 3 (continued)

	Actual		Forecast			
	2020		2030	2040	2050	2060
PDC	283,200,000		283,200,000	177,750,000	72,300,000	0

(1) ICE cars (convertible from PDC towards ADEM)
(2) ICE cars (convertible from ICE towards battery swap)
(3) BEV cars (from conductive charging towards battery swap)
(4) BEV cars (battery swap)
(5) ADEM (autonomous driving electric mobility)
(6) Light utility vehicles (≤3.5 t) with ICE
(7) LUV conversion from ICE towards PDC with battery swap
(8) Heavy utility vehicles (>3.5 t) with ICE
(9) HUV conversion from ICE towards PDC with battery swap
(10) Busses and touring cars with ICE
(11) B&TC conversion from ICE towards PDC with battery swap
(12) LUV conversion from PDC with battery swap towards ADEM
(13) HUV conversion from PDC with battery swap towards ADEM
(14) B&TC conversion from PDC with battery swap towards ADEM

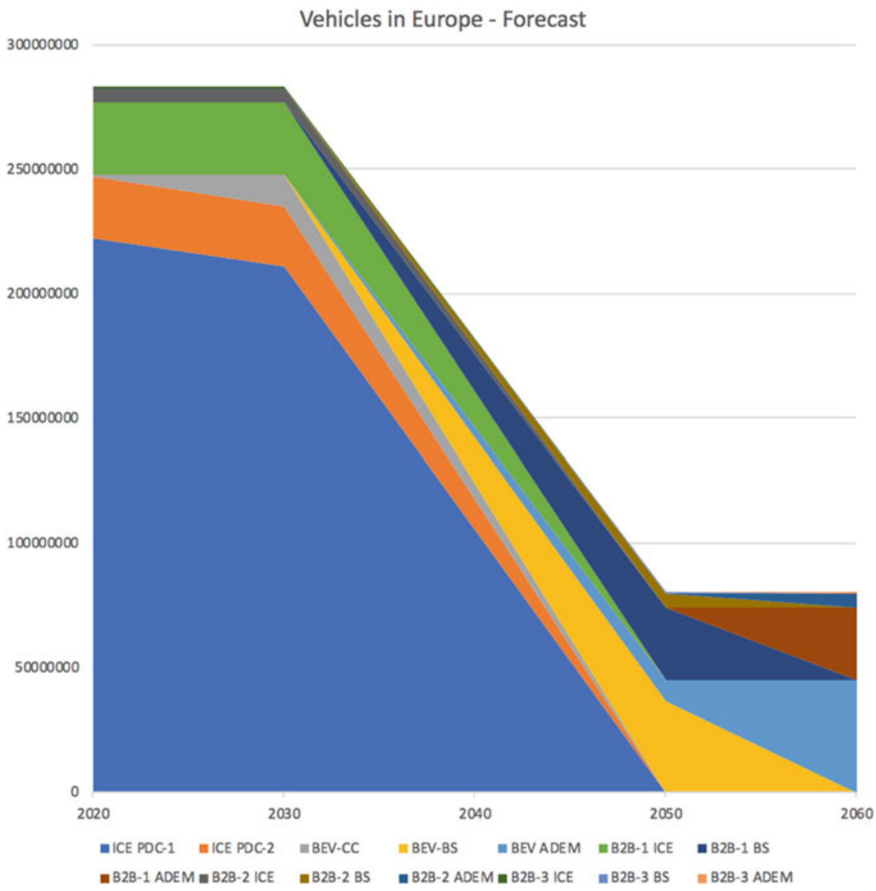


Fig. 4 Graphical representation of the vehicle mix in in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full MaaS and 100% ADEM based mobility model by 2060

10.5 B2C Vehicles, Also Called Passenger Cars

At first, we'll take a closer look at the passenger cars. This includes all type of passenger cars (Table 4):

- Individually owned
- Collectively owned fleets (e.g. company cars, etc.)
- Professional used cars
- Car sharing
- Taxi
- etc.

Table 4 Overview of the B2C vehicle mix (passenger cars) in in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full MaaS and 100% ADEM based mobility model by 2060

			Actual		Forecast			
			2020		2030	2040	2050	2060
B2C	B2C-ICE	(1)	222,000,000	89.70%	210,900,000	105,400,000	0	0
		(2)	25,000,000	10.10%	23,750,000	11,875,000	0	0
	BEV-CC	(3)	500,000	0.20%	12,850,000	6,425,000	0	0
	BEV-BS	(4)			0	18,300,000	36,600,000	0
	ADEM	(5)			0	4,218,000	8,436,000	45,036,000
Total			247,500,000		247,500,000	146,268,000	45,036,000	45,036,000
PDC			247,500,000		247,500,000	146,268,000	36,600,000	0

(1) ICE PDC-1 cars (convertible from PDC with ICE towards ADEM)
(2) ICE PDC-2 cars (convertible from ICE towards battery swap)
(3) BEV cars (from conductive charging towards battery swap)
(4) BEV cars (battery swap)
(5) ADEM (autonomous driving electric mobility)

We make distinction between cars, used by professionals, whose job is exclusively possible thanks to the use of that car and cars, used by users, be it private or even professional ones, for whom the use of that car is fantastic, but an instantaneous availability is not really necessary. This last type of users might make use of a so-called ***On Demand*** vehicle and is thus candidate to make use of an ADEM car as soon as this one becomes available.

We indicate them as **ICE PDC-1** and indicate them as "***convertible from PDC with ICE towards ADEM***". We estimate their number at roughly 90% of the European B2C-fleet or 222 million. As the ADEM cars will only be available between 2030 and 2040, we have to consider an intermediate step, where a number of them will first migrate from ICE towards BEV-CC (Conductive Charging) in 2030, before being converted into Battery Swap (BEV-BS) from 2030 onwards. That's why we see an increase of BEV-CC in 2030, up to 5% of the global B2C fleet, before being halved by 2040 and finally completely disappear by 2050.

The other group of drivers, indicated as **ICE PDC-2** and estimated at roughly 10% or 25 million cars, will continue to drive an ICE until 2030, before starting to migrate towards BEV. Since we expect at that moment Battery Swap to be available, we proclaim them as "***convertible from ICE towards Battery Swap***". We expect them to be converted for 50% by 2040 from ICE towards Battery Swap, before the ICE finally will completely fade away by 2050.

The 3rd group, indicated as **BEV-CC**, is the group of BEV as we know them actually, equipped with Conductive Charging capability. Despite the limited success of this group so far, we expect them anyhow to grow still within the coming 10 years, before fading away, being halved by 2040 and disappear completely by 2050. At that moment, the charging poles can be removed as well, thus freeing our streets from these hindering installations.

So far, the actually existing categories B2C cars: the ICE vehicles and the BEV-CC.

What about the newcomers: **BEV-BS** and **BEV-ADEM**?

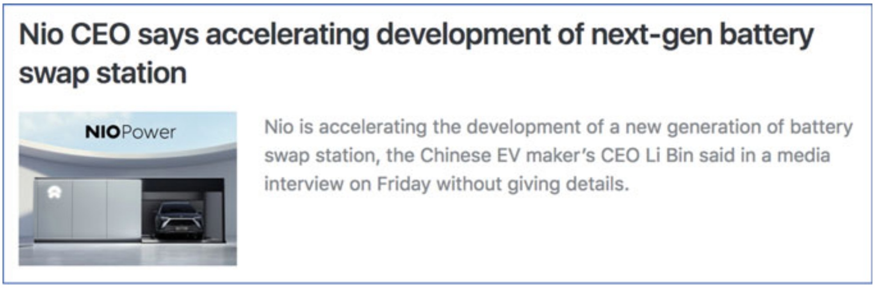
First, we have to clarify that ADEM is equipped with Battery Swap as well, but on top of that is also equipped with Automated Driving, hence the denomination Automated Driving Electric Mobility or ADEM.

Actually, both categories are not yet present on the European market, while Battery Swap is gaining momentum in China with protagonists like NIO, Beijing EV (subsidiary of the BAIC Group), Geely and others.[4] This whole development is pushed forward by China's Ministry of Industry and Information Technology (MIIT) through research at the China Automotive Technology Research Center. It is clear that the Chines EV industry is cementing a leadership position onto the future of the global EV market. Moreover, the Chinese Government recently approved the first official swappable EV battery standard and safety guidelines, which are set to go into effect on Nov. 1, 2021.

Nio even introduced an own Battery as a Service (BaaS) model, comparable to the European Swap2drivE model (Fig. 5).

More recently, Geely has announced the "1-min Swap station" (Fig. 6).

In the event that Europe very soon does realize it has to change strategy, in order to avoid leadership from China and thus embrace Battery Swap and ADEM, we might see a quick take off with roughly 105.5 million ICE passenger cars in Europe


Nio CEO says accelerating development of next-gen battery swap station

Nio is accelerating the development of a new generation of battery swap station, the Chinese EV maker's CEO Li Bin said in a media interview on Friday without giving details.

Fig. 5 Screen shot from an article on Nio's efforts to accelerate development of the next-gen battery swap station

Fig. 6 Screen shot from Geely's commercial on their 1-min Battery Swap solution

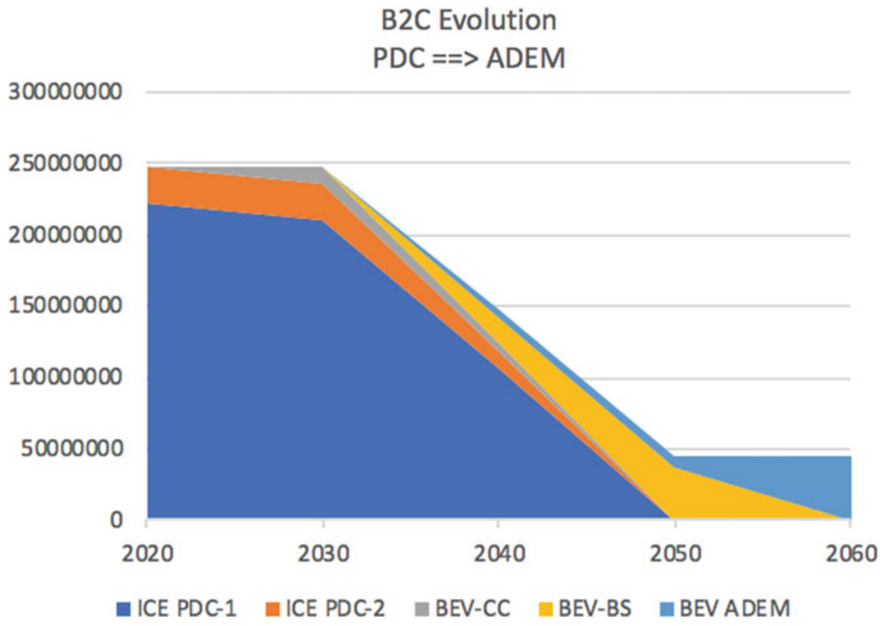


Fig. 7 Graphical representation of the B2C vehicle mix in in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full MaaS and 100% ADEM based mobility model by 2060

converted towards ADEM by 2040 and the remaining 105.5 million finally by 2050. This will result in about 8.5 million ADEM vehicles, since they are available at nearly 100% of the time and thus about 25 times more efficient, as we already mentioned here above.

The ADEM itself, which strongly depends on the progress on Level 5 Automated Driving, may be expected to become certified and start to appear on our roads by 2030 and take-off within the decade that follows. By 2040, we can expect to have already roughly 4 million units on our roads and this will be doubled between 2040 and 2050 (Fig. 7).

Hence, by 2050, we will thus be able to enjoy a 100% clean fleet in our streets, which will be much smaller than today's fleet, due to vehicle usage optimization.

To some, this may look strange, but clearly, this is the only way to get there!

10.6 B2B-1 Vehicles, Also Called Light Utility Vehicles (≤3.5 t)

We will now take a closer look at the Light Utility Vehicles, of which there are about 29 million units in Europe.[1] We expect these to evolve from a full ICE fleet towards

Table 5 Overview of the B2B-1 vehicle mix [light utility vehicles (≤3.5 t)] in in Europe (*source* ACEA—The European Automotive Manufacturers Association) in 2020 and forecast for an evolution towards a fully electrified fleet by 2050 and 100% ADEM by 2060

			Actual		Forecast			
			2020		2030	2040	2050	2060
B2B-1	B2B-1	(6)	29,000,000	100%	29,000,000	14,500,000	0	0
		(7)				14,500,000	29,000,000	0
		(12)						29,000,000
Total			29,000,000		29,000,000	29,000,000	29,000,000	29,000,000
PDC			29,000,000		29,000,000	29,000,000	29,000,000	0

(6) Light utility vehicles (≤ 3.5 t) with ICE
(7) LUV conversion from ICE towards PDC with battery swap
(12) LUV conversion from PDC with battery swap towards ADEM

a full BEV fleet by 2050, with an intermediate step of roughly 50% penetration in 2040. Ultimately, this fleet might also become Automated Driving by 2060, but that's not the subject of this document, as outlined earlier on.

In or around 2030, some of them might make an intermediate stop at CC, prior to move to Battery Swap, although chances are very little since these are commercially used vehicles and a commercial vehicle, standing still at a charging pole, in order to get energized, is considered as "dead capital" and no single entrepreneur is interested in dead capital. That's why we deliberately ignore this option as the likelihood is really negligible (Table 5 and Fig. 8).

10.7 B2B-2 Vehicles, Also Called Heavy Utility Vehicles (>3.5 t)

When looking at the Heavy Utility Vehicles, of which there are about 6 million units in Europe,[1] the situation is even more outspoken. Likewise, they will evolve from a full ICE fleet towards a full Electric fleet by 2050, with an intermediate step of roughly 50% penetration in 2040. Ultimately, this fleet might also become Automated Driving by 2060, once all other vehicles are becoming Automated Driving, but that's not the subject of this document, as outlined earlier on.

In this category, the likeliness of an intermediate stop at CC, prior to move to Battery Swap, is for sure not going to happen, since these are 100% commercially used vehicles and a commercial vehicle, standing still at a charging pole, in order to get energized, is "dead capital". No single entrepreneur will invest in dead capital. That's why this option is completely ignored, since the likelihood is really nonexistent (Table 6 and Fig. 9).

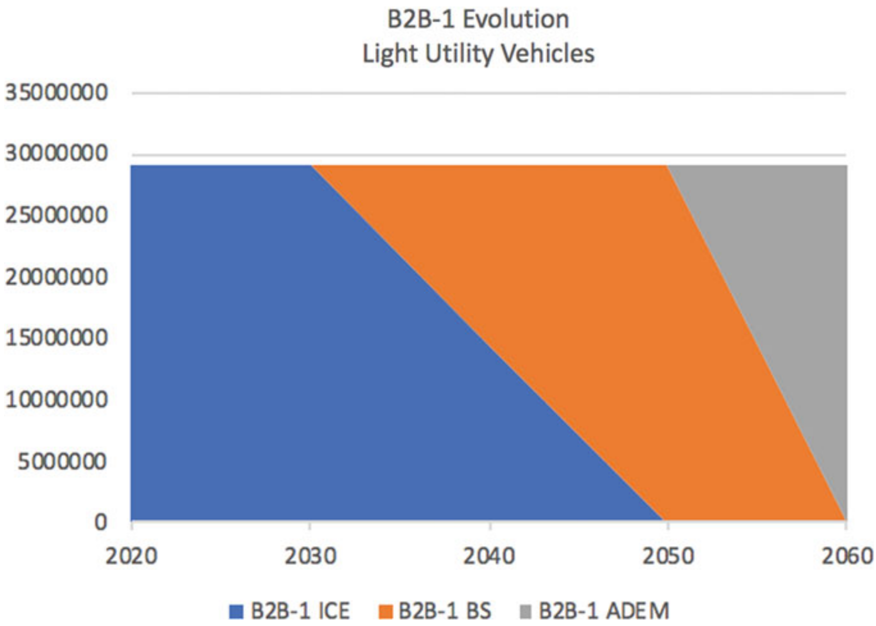


Fig. 8 Graphical representation of B2B-1 vehicle mix in in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full electric fleet by 2050 and 100% ADEM based mobility model by 2060

Table 6 Overview of the B2B-2 vehicle mix [heavy utility vehicles (>3.5 t)] in Europe (*source* ACEA—The European Automotive Manufacturers Association) in 2020 and forecast for an evolution towards a fully electrified fleet by 2050 and 100% ADEM by 2060

			Actual		Forecast			
			2020		2030	2040	2050	2060
B2B-2	B2B-2	(8)	6,000,000	100%	6,000,000	3,000,000	0	0
		(9)				3,000,000	6,000,000	0
		(13)						6,000,000
Total			6,000,000		6,000,000	6,000,000	6,000,000	6,000,000
PDC			6,000,000		6,000,000	6,000,000	6,000,000	0

(8) Heavy utility vehicles (>3.5 t) with ICE
(9) HUV conversion from ICE towards PDC with battery swap
(13) HUV conversion from PDC with battery swap towards ADEM

A Heavy Utility Vehicle will contain multiple 30 kWh batteries, thus giving it an autonomy of several hundreds of km, which is sufficient for a full working day (Fig. 10).[2]

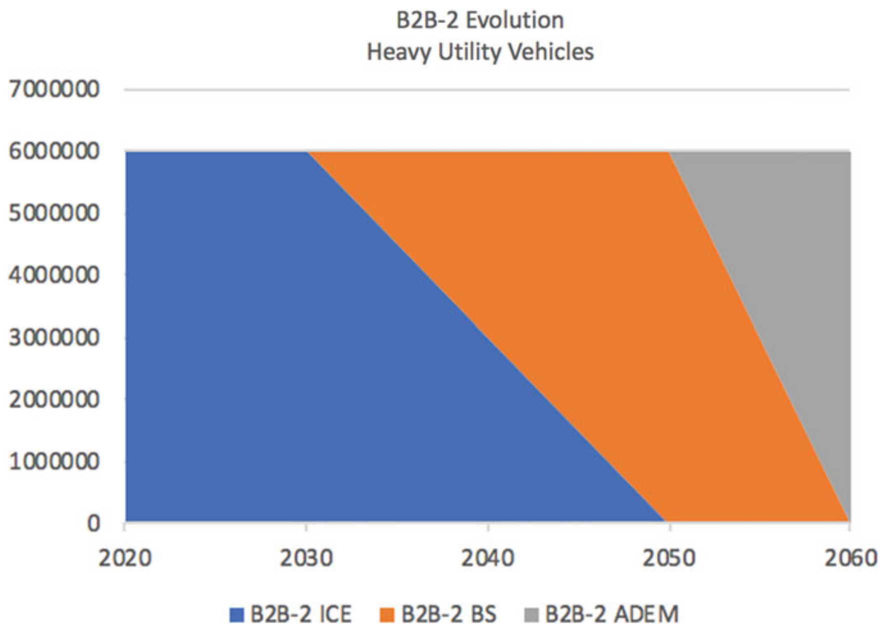


Fig. 9 Graphical representation of B2B-2 vehicle mix () in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full electric fleet by 2050 and 100% ADEM based mobility model by 2060

10.8 B2B-3 Vehicles, Also Called Busses and Touring Cars

While Busses have completely different needs than Touring Cars, they mostly are accumulated within the same category. The total number for Europe is about 700,000 units.[1]

A Bus might need an autonomy of a few hundred km/day, while a Touring Car needs a lot more. In some cases, when it's driven by a team of drivers, this can go up to 2000 km within 24 h. Those Touring Cars, once they evolve towards electric propulsion, not only need "swappable drivers" but also swappable batteries.

For both categories, multiple technical implementations are possible.[2] Here, we'll only look at the numbers (Table 7 and Fig. 11).

11 Which Are the Success Factors?

We've asked ourselves: "Where are we today?" and the hard but honest answer is "Almost nowhere!". It's hard to attribute to a market penetration of only 0.2% a more appealing predictive than this one. One can ask at the very same moment "How could it come so far?".

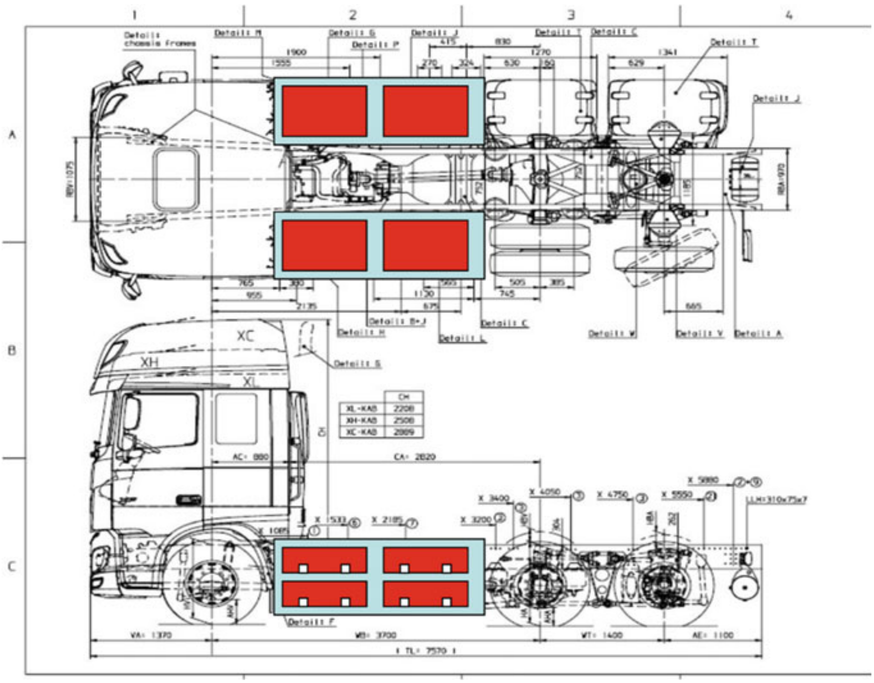


Fig. 10 A heavy utility vehicle, transformed to contain up to 8 × 30 kWh swappable batteries, giving it an autonomy of about 240 km after a full swap. *Courtesy* DAF Trucks

Table 7 Overview of the B2B-3 vehicle mix (busses and touring cars) in Europe (*source* ACEA—The European Automotive Manufacturers Association) in 2020 and forecast for an evolution towards a fully electrified fleet by 2050 and 100% ADEM by 2060

			Actual		Forecast			
			2020		2030	2040	2050	2060
B2B-3	B2B-3	−10	700,000	100%	700,000	350,000	0	0
		−11				350,000	700,000	0
		−14						700,000
Total			700,000		700,000	700,000	700,000	700,000
PDC			700,000		700,000	700,000	700,000	0

(10) Busses & touring cars with ICE
(11) B&TC conversion from ICE towards PDC with battery swap
(14) B&TC conversion from PDC with battery swap towards ADEM

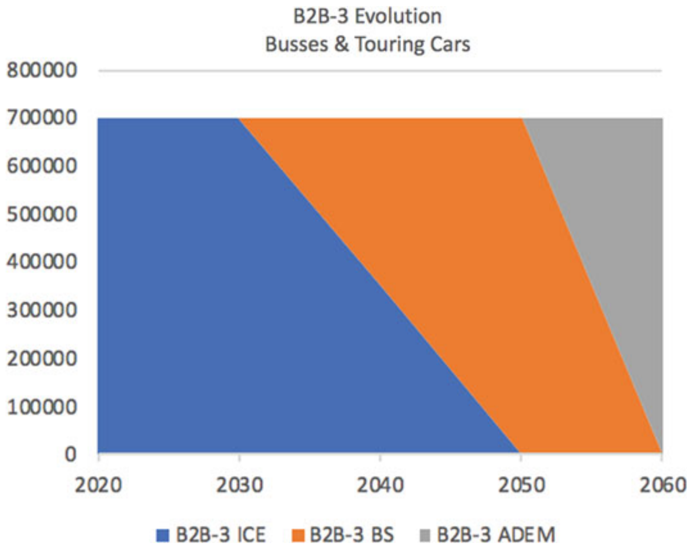


Fig. 11 Graphical representation of B2B-3 vehicle mix in in Europe (*source* ACEA—The European Automotive Manufacturers Association) and forecast for an evolution towards a full electric fleet by 2050 and 100% ADEM based mobility model by 2060

But then pops up next question: "What can we do to improve this situation?" and "How do we intend to reach the objectives of the EU Green Deal and the Paris Climate agreement?".

Here are the answers:

On the 1st set of questions, as said earlier, the OEMs didn't discover so far how to get their offering appealing and sexy. Indeed, up to now, the guys and girls in the executive boardrooms didn't go out and talk with their prospects and clients. They only looked up their spreadsheets and decided to add another year "of the same stuff" on top of it. Pushed by the governments, they only found out some software tricks, now indicated as Dieselgate or published some misleading documents, indicated as Astongate or buy "regulatory credits" at Tesla. By the way, Tesla generated in 2020 a net profit of 438 million $, coming from these regulatory credits, that they sold to other OEMs.

When you hear OEMs saying: "Citizens have **fear** to move towards EV", one should correct this phrase and tell them, they have to say: "Citizens have **fear** to move towards **our** EV". They should stop blaming the citizen, but instead start talking to him or her, start listening and once they've clearly understood the requirements, return to the drawing tables and design an appealing and sexy BEV.

Here's why! Up to now, all BEVs have the same inconveniences:

1. Their **range** is limited. In order to overcome this inconvenience, they bring more battery capacity on board, thus increasing the weight and by consequence the energy consumption/km, as well as the price. On top of that, heavy vehicles

produce more Black Carbon and Fine Dust (PM_{10} and $PM_{2.5}$) compared to lighter vehicles.

2. The **charging time** still is a huge inconvenience, since "Time = Money". Even for unemployed or retired people, time still = money. The OEMs, jointly with the "charging pole lobby", are increasing the charging capacity per charging pole up to fast chargers, who charge at 150 kW and more. This is killing the lifetime of the battery, which in the end is by far the most expensive component of the vehicle. On top of that, it's killing the energy grids as well. Moreover, the hassle of handling a cable in all weather conditions is also a burden.
3. The **acquisition cost** of such a BEV-CC is very high. The more battery capacity they install, in order to cope with the range issue, the more expensive the vehicle becomes. Hence a BEV-CC is much more expensive than an ICE equivalent car. Subsidies might help for a while, but in the end, these are coming from taxes and excises. Hence, this is a Shifting of Funds transaction.

On the 2nd set of questions, the answer is quite obvious as well: by migrating towards a Battery Swap model. In that case, all the inconveniences, mentioned here above, are disappearing at once and new business models are becoming available, like Battery as a Service (BaaS). Moreover, the Battery Recharging Stations (BRS) will act as energy storage hubs within the Smart Energy Grids, once they're fully powered by Renewable Energy (Solar, Wind, etc.). At the same time, these hubs can be used by the Energy Utilities to perform Peak Shaving, at moments when Demand is higher than Supply. It can even be used to offer Frequency Regulation as well, thus allowing energy utilities to keep full control on the grid.

12 Would You Buy an EV from Sony[5]?

This question may surprise, but it's the title of an article, published recently on Autoweek.com.[5] The barrier between electronics giants and automakers might soon fade away, as the industry turns to EVs. Indeed, after newcomers like Tesla and Nio and after also Apple announced having some interest in becoming a Car Producer and Seller, other companies, like Sony, are knocking on the door and announcing their interest in this new and very promising BEV opportunity. A car nowadays is becoming more and more an "ICT-solution on wheels", rather than a vehicle and since those companies have learned to listen to their clients and seduce them with equipment that responds to their needs, they might have a good chance to beat the traditional OEMs onto their own battleground. Very surprising, but inspiring at the time.

13 Conclusions

Mobility will be quite different in 2050, compared to the one we know and use actually. Changes will take place within the coming years in order to evolve towards a 100% green mobility. How this will look like, is hard to predict. Will it be the one, that we have described herewith? Nobody knows. But this is for sure: in case we move towards a 100% electric mobility, in order to make it viable and economically feasible, we have to anticipate a number of evolutions:

- We have to anticipate huge additional energy production capacity. The actual energy production in Europe of 2941 TWh will get an additional load of nearly 43%, in order to satisfy the upcoming mobility needs.
- Automation is gaining momentum everywhere. Mobility will follow as well:
  - Automated Driving will become standard
  - Automated battery swapping will also become mainstream
- Once this automation realized, a multimodal MaaS concept can be put in place, in which moving from A to B will be an enjoyment and idle time of equipment will be reduced as much as possible. Hence, mobility will become much cheaper and thus more affordable for everyone.

We're living a pivotal moment in history at which the future of mobility is taking shape. But prior to that, industry and government jointly have to take a number of bold decisions.

Notes

1. Figures, coming from ACEA Report "Vehicles in Use in Europe"—January 2021. https://www.acea.be/uploads/publications/report-vehicles-in-use-europe-january-2021.pdf.

   Remark: note that figures from European Countries Bulgaria, Cyprus and Malta are missing within the ACEA report. We have calculated them, based on the average number of vehicles per capita within the remaining 24 countries of the EU, thus giving us a quite correct number of the total amount of vehicles, available within the EU-27.
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5. Would you buy an EV from Sony? https://www.autoweek.com/news/green-cars/a35226640/would-you-buy-an-ev-from-sony/.

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Hashtags

#futureofmobility #automotive #innovation #sustainability #technology #mobility #elektrischrijden #electromobility

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Sten Corfitsen is a Swedish citizen born 1952 in Stockholm with a MSc degree from Royal Institute of Technology. With background from a inventor family with creations as the pace maker, the inkjet print technology, Sten has innovations in his blood. After having built his first flying gyrocopter followed by a number of employments at IBM and Philips, Sten became the pioneer with developing automatic fueling of ICE cars (Fuelmatics). Lateron he spun-off Powerswap AB, a company dedicated to launch battery swapping as the solution to speed up the transition to electric vehicles. He has extensive experiences with automation, the innovation process and to introduce new technology in conservative industries.

Henk G. Hilders (1940) studied Biochemistry and Medicine and worked for almost 10 years in a Coronary Care Unit of an Amsterdam NL hospital. He made a career switch in 1986 into advanced composites with focus on aerospace applications. He has several patents on his name, the first one, based on multi-axial warp knitted fabrics received an EU grant in 1988.

He invented the Cargobox in the early years of the 21st Century and is still working on improvements and technical additions.