Exploring European Strategies for the Optimization of the Benefits and Cost-Effectiveness of Private Electric Mobility

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Abstract. All over the world the e-mobility phenomenon is expanding, both on the supply and demand side. Leading global car manufacturers have introduced electric models at increasingly competitive prices and many people are interested in benefits and cost-effectiveness that the new technology could bring them. Even if from March to June 2020, due to the COVID-19 mobility restrictions, sales of electric cars have fallen below 2019's levels, in the last few months the rate of sales recovered strongly. Governments of various countries, in compliance with EU directives, have introduced strict rules to reduce CO2 emission. For the same purpose, to increase the demand for private electric vehicles they are providing incentives and subsidies to encourage EV sales. The paper focuses on private electric vehicles total costs and investigates the European and United Kingdom tax benefits and purchase incentives. The aim is to understand how the demand growth is related with the policies of the European countries by analyzing existing data referred to all EU member states. Whether subsidies policies prove insufficient to achieve the set objectives, it will be appropriate to plan educational strategies to promote environmentally sustainable habits for citizens.

Keywords: Electric vehicles benefits · Cost-effectiveness · European incentives

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1 Introduction

Climate change is a central focus of the Intergovernmental Panel's special report [1], which highlights the 1.5 °C increase in global warming as one of the critical environmental issues. Compared to the levels monitored in 2015, this report suggests that CO2 emissions from transport must be reduced by at least 70% to 80% to meet the targets set in the Paris Agreement.

The climate change is one of the most important environmental issues and transport contributes about one quarter of the EU's total greenhouse gas emissions. Reducing the environmental impact of transport can be addressed by reducing the demand for travel, presenting cleaner technologies and shifting towards less ecologically damaging transport modes [2]. Therefore, it is central to track this sector in detail and project changes in GHG emissions based on the reductions possible with policy measures that have already been adopted or are planned in the EU member States.

Figure 1 shows the evolution of EU greenhouse gas emissions from transport the 1990–2020 period as reported by member states:

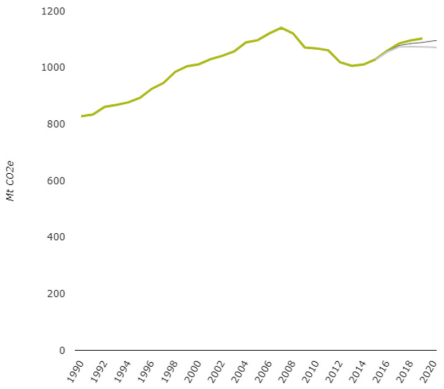

Fig. 1. Greenhouse gas emissions from transport in the EU (Source: [3])

According to preliminary estimates, the EU's transport emissions increased in 2020 by 0.8%. This follows a 0.9% increase in 2018. These rates of increase are the slowest since 2014. Figure 2a shows how road transport account for 72% of total greenhouse gas emissions of the sector. Railway emissions establish only a small portion of overall transport emissions (below 1%) such as domestic navigation emissions which constitute under 2% of overall transport emissions. If only the part relating to road transport is analysed, the percentages are divided as follows (Fig. 2b): motorcycles (0.9%), heavy duty trucks and buses (19.2%), light duty trucks (8.7%) and cars (44.3%).

In this context, a sustainable trail for the transport sector is possible using a mix of policy actions to reduce the need for transport trips, encouraging changes toward more efficient transport modes, and improve vehicle efficiency through low-carbon technologies [4, 5].

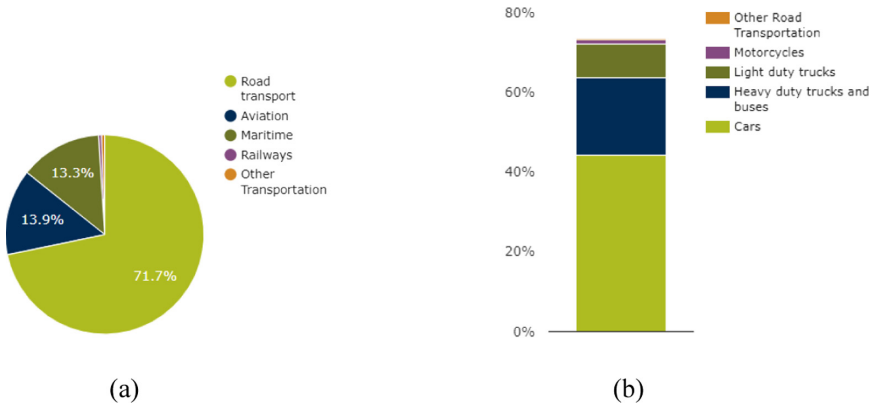

Fig. 2. (a) Transport GHG and (b) Road Transport GHG emission EU27 + UK (Source: [3])

An integrated way to plan the mobility system serving people in cities is through sustainable mobility planning [6, 7]. The SUMP not only focus on a coordinated transport system but also how the system impacts its users [8–11].

The European Green Deal published by the European Commission in December 2019, states that by 2025, will reinforce the CO2 targets for passenger cars and light-commercial vehicles to bring them in line with the EU's ambition to cut greenhouse gas emissions by at least 55% by 2030. Table 1 shows an overview of EV policies in EU 2018/2019.

Table 1. Overview of EV policies in the European Union (Source: Elaboration from [12])

Country	Policy type	Description
European Union	**Regulations** (Vehicles)	Tightened CO2 emissions standards for LDVs in 2025 and 2030 with credits for EV sales, following the 95 g Co2/km requirement for 2021; C02 emissions standards for trucks in 2025 and 2030; Clean vehicle Directive mandates public procurement for clean LDVs and HDVs; Increasing number of number states announcing ICE and diesel bans
	Incentive (Vehicles)	Incentives schemes for zero and low emission PDLVs in 33 European countries
	Industrial policy	European Battery Alliance to promote the development of a battery industry in Europe
	Regulation (Chargers)	Energy Performance of Buildings Directive approved in the EU mandates EV charges for new and renovated buildings
	Targets (Chargers)	Through the AFI Directive, EU member states have set EVSE deployment targets for 2020, 2025 and 2030

1.1 European Strategies for Sustainable Mobility in the Post-pandemic Phase

European decarbonisation policies have promoted several interventions in infrastructure and mobility services. Unfortunately, the transport sector has come to a standstill due to the recent pandemic and has faced new challenges in ensuring essential services and safe travel.

Since March 2020 with the advent of the pandemic in Europe and the first case in Italy, several mobility strategies have been put in place, trying to build sustainable and innovative models while promoting actions for resilient mobility [13].

On-board restrictions and the respect of social distancing have had a disruptive impact on people's travel habits with a particular effect on the public transport sector. In the short to medium term public transport has not been the primary choice of many citizens. This had repercussions on urban traffic in large cities, which was already at the limit of sustainability before the emergency [14–16].

In the coming years, the spread of digital platforms and MaaS (Mobility as a Service) will facilitate people's travel choices [17] and there will be an increasing use of electric vehicles as forms of private and shared mobility.

Several studies in Europe show that the private car has historically been the default mode of transport in many areas, affecting road capacity in a negative way [18, 19]. This has influenced the design of infrastructure and the surrounding working environment over the years [20, 21].

Reducing car traffic is indispensable to rapidly reduce pollution. Several European cities have invested in infrastructure measures such as new bicycle lanes and the creation of 30 zones. The European Commission has promoted the growth of shared mobility with the aim of reaching about 80% of the service with electric vehicles by 2040. In this sense, several European governments are incentivising electric mobility, through tax deductions, bureaucratic advantages or benefits related to traffic restrictions. However, while direct incentives create immediate benefits, tax credits are beneficial in the medium term, after three to four years on average.

In the literature, several studies focus on evaluating the benefits of a higher percentage of electric vehicles in the fleet and present the results obtained by comparing scenarios using traffic micro-simulation tools [22] or multicriteria analysis [23] or by administering questionnaires and interviews to gain information on the travel habits of different types of users [24, 25]. These studies show a lower CO2 emission into the environment including the e-in the daily vehicle fleet and a greater tendency among young people to rent or use shared mobility services including electric vehicles such as scooters or vehicles.

To improve infrastructures and the location of recharging areas, it is necessary also to spread the digital representation of physical and functional characteristics through I-BIM (infrastructures Building information modelling) in order to be able to evaluate in an integrated way the different steps of construction and maintenance of infrastructures, also considering the aspects of safety and service level [26, 27].

The present work, following an accurate examination of the correlation between transport demand and the growth of the offer of electric mobility services, focuses on the statistical evaluation of the benefits produced by the diffusion of electric mobility in the different European countries and in the UK, focusing on policies and strategies for the promotion of sustainable mobility.

2 Materials and Methods

2.1 Correlation Analysis for Electric Vehicles Demand Growth

On a global scale, there are some good practices adopted by various countries to encourage the purchase or use of EVs. China is the largest market in the world for the sale of electric cars thanks to low-cost supply and a wider choice, as well as a strong incentive policy. Moreover, electric vehicles are not subject to registration restrictions (although the number of new license plates in China is limited) or driving bans on certain days. Purchase incentives vary according to battery capacity and lasted until 2020. The US encourages the purchase of electric cars by cancelling federal taxes that depend on fuel consumption. In Europe, in particular Norway represents a forerunner in the introduction of e-mobility and it is currently a leader in the production of renewable energy that powers its energy grid. Electric cars are not subject to the 25 percent VAT on motor vehicles, and other benefits include limited use of bus lanes in select areas and savings on ferry crossings, tolls and parking. In the Netherlands, there are no registration taxes for pure electric cars, which are based on the CO2 emissions of a vehicle. As in Germany, there are tax benefits for company car drivers who also privately use the vehicles. Plug-in vehicle grants of up to £ 3,500 are available to all consumers purchasing a pure electric vehicle in the UK. Surprisingly, Romania is one of the countries offering the most significant government subsidies for electric cars and is currently the strongest incentive policy in the whole of the EU (Fig. 3).

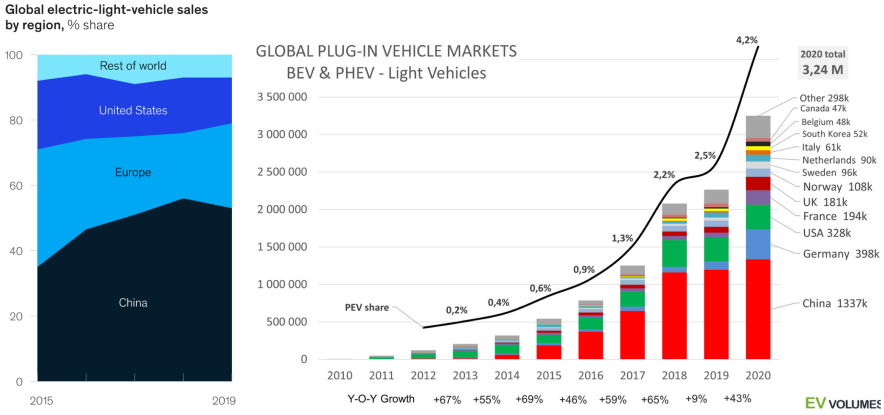

Fig. 3. (a) Market in the world for the sale of electric cars; (b) Statistical trend of Plug-in vehicle sales in the world. (Source: [28])

Based on this short premise, the paper will focus on private electric vehicles total costs and investigates the European and United Kingdom tax benefits and purchase incentives in order to understand how the demand growth is related with the policies of the European countries (see Fig. 4).

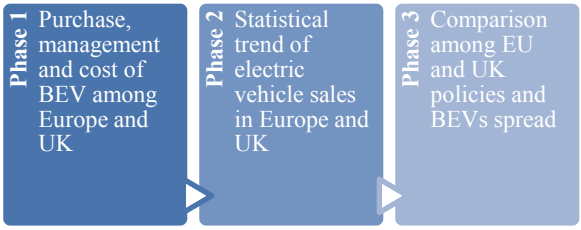

Fig. 4. Methodological framework (source: Authors elaboration)

2.2 BEVs Purchase, Management and Maintenance Costs Analysis

To investigate about the purchase, management and maintenance cost of Battery Electric Vehicle (BEV) among Europe and UK a research has been carried out on the 10 best sellers BEV. The ranking in Fig. 5 shows the top 10 best sellers BEV in EU countries and UK.

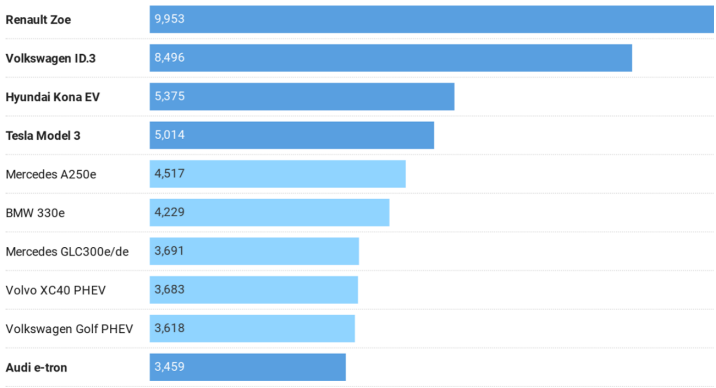

Fig. 5. Top 10 best sellers BEV in EU and UK (November 2020). (Source: [29])

In the electric car ranking, Renault Zoe holds on to its top spot. In November 2020, the main market was Germany (4,287 units), followed by France (2,944), with Italy (555 units) and the UK (450 units) also helping along [28].

Considering the first BEV in ranking (Renault Zoe) it has been carried out an investigation about the price list among the main EU countries and UK, the purchase cost after deducting e-mobility subsidies (if provided), the management cost with particular reference to battery charge cost (both with public and private charge stations), the maintenance cost (during 6 years) and last but not least the cost for battery replacement (necessary after 8 years or 160.000/200.000 km) (Table 2).

First, what immediately show up is the battery replacement cost which is equal to approximately 90% of the total cost of the vehicle (necessary after only 8 years).

Also, another interesting data concerns the battery charge cost. As regard charging with public energy, the cost differs from one country to another (min value 0,21 €/kWh

Table 2. Investigation about BEV (Renault Zoe) purchase, management and maintenance cost. (Sources: [30]).

Renault Zoe						
Countries	Price list	Purchase cost (after deductig all e-mobility subsidies)	Management cost (battery charge 41kWh - Autonomy 300 KM) - Public charge	Management cost (battery charge 41kWh - Autonomy 300 KM) - Private charge	Mantainance cost (total for 6 years)	Battery replacement (after 8 years or 160.000/200.0
Austria	30.590 €	25.190 €	0,21 €/kWh	0,15 €/kWh	700 €	
Belgium	28.990 €	-	0,35 €/kWh	0,20 €/kWh	-	
Denmark	30.800 €	-	0,50 €/kWh	0,30 €/kWh	-	
Estonia	33.000 €	28.000 €	0,21 €/kWh	-	-	
Finland	33.500 €	31.500 €	0,28 €/kWh	0,09 €/kWh	-	
France	28.000 €	23.000 €	0,30 €/kWh	0,18 €/kWh	580 €	
Germany	32.550 €	25.300 €	0,53 €/kWh	0,27 €/kWh	680 €	
Grecee	34.000 €	-	0,42 €/kWh	-	-	
Hungary	33.500 €	29.075 €	0,37 €/kWh	-	-	
Ireland	32.200 €	27.200 €	0,39 €/kWh	-	-	
Italy	33.880 €	27.380 €	0,45€/KWh	0,23€/kWh or (0,07€/kWh with solar power system)	675 €	20.000/22.000 €
Netherlands	29000 €	-	0,30 €/kWh	0,14 €/kWh	-	
Norway	33.000 €	-	0,21 €/kWh	0,10 €/kWh	750 €	
Poland	33.800 €	25.300 €	0,29 €/kWh	-	-	
Portugal	31.800 €	28.800 €	0,46 €/kWh	-	-	
Romania	32.200 €	22.200 €	0,24 €/kWh	-	-	
Slovakia	28.800 €	20.800 €	0,33 €/kWh	-	-	
Slovenia	30.000 €	22.500 €	0,55 €/kWh	-	-	
Spain	33.880 €	29.380 €	0,54 €/kWh	0,35 €/kWh	700 €	
Sweden	32.200 €	26.300 €	0,22 €/kWh	-	-	
UK	28.670£ (33.280€)	25.670£ (29.798€)	0,20£/KWh (0,23€/kWh)	0,09 €/kWh	750£ (870€)	

in Austria, Estonia and Norway – max value 0,55 €/kWh in Slovenia). In each country charging the car battery with private charge energy is much cheaper than the public ones. The difference can be up to 50% if the private plant is solar powered (photovoltaic plant). Finally, maintenance costs (for those countries where data are available) are homogeneous and not particularly expensive.

2.3 The Spread of Electric Vehicles in Europe and UK: Statistical Data

The spread of BEV in Europe is increasing, in line with the EU objectives of emissions reduction derived by transport sector. Figure 6 shows the electric cars registered in the EU-27 and UK from 2010 to 2019. An increase in the number of electric vehicles is evident. However, the market penetration ok BEV remains relatively low. In 2019, it is possible to observe that the electric vehicle registrations have been close to 550.000 cars (i.e. 3.5% of the total), compared to 300.000 in 2018 (i.e. 2% of the total). Moreover, comparing the plug-in hybrid vehicles (PHEVs) and BEV, the latter represent the majority in terms of registrations in 2019.

The notable increase in BEV new registrations between 2018 and 2019 can be associated with the high increase of electric vehicles recorded in Norway, where around 60.000 BEVs have been registered. Considering the various countries of Europe, the

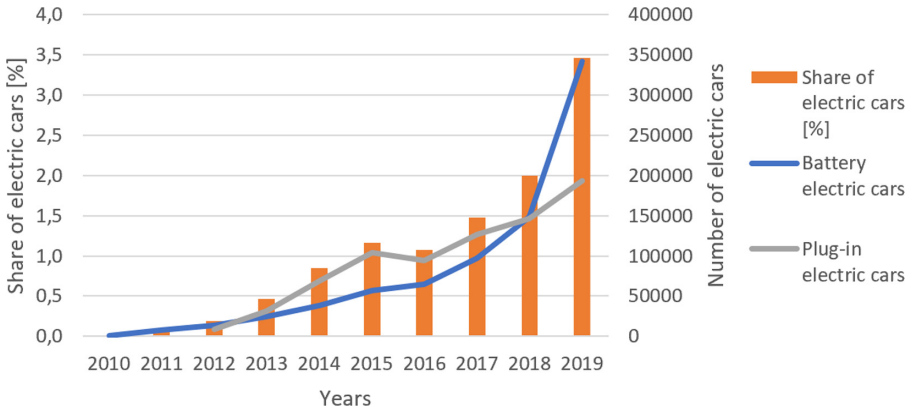

Fig. 6. Electric cars registered in the EU-27 and UK from 2010 to 2019. (Authors elaboration, Data Source: [31])

highest shares of BEVs have been found after Norway (i.e. 56%), in Netherlands (i.e. 16%) followed by Sweden (i.e. 12%), while in Italy and Spain the percentage of BEVs remained less than 1% of the total fleet.

According to the report "Making the Transition to Zero-Emission Mobility", sales of electric-charging cars in the EU have benne increased by 110% over the past three years. However, during the same period, the number of charging points only grew by 58%, demonstrating that investments in infrastructure are not at the same level with the increase in sales of electric vehicles.

Despite the pandemic's effect on the economy and restrictions on people's travel habits, global adoption of electric vehicles increased in 2020. According to data from EV Volumes, global sales of electric vehicles have been increased, marking a + 43% for a total of 3.24 million vehicles placed on the market.

But the real evidence of the year 2020 is that Europe has overtaken China as the engine of electric vehicle growth, with Norway's record. Europe is ahead in terms of the share of electric vehicles: BEV and PHEVs increased from 3.5% in 2019 to 10.2% of the fleet in 2020, counting the EU countries including the United Kingdom. The share in China increased from 5.1% to 5.5% during the same period (see Fig. 7).

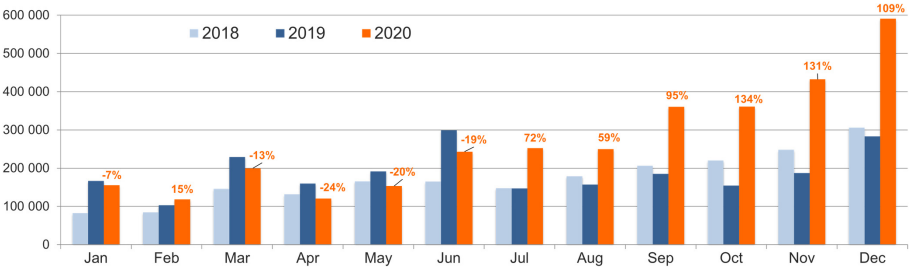

Fig. 7. Monthly Plug-in vehicle sales in the world. (Source: [28])

3 Results and Discussions

3.1 Comparison Among EU and UK Policies and BEVs Spread

Electric cars — battery electric vehicles (BEVs) are gradually penetrating the EU market. However, despite a steady increase in the number of new electric car registrations annually, from 700 units in 2010 to about 550 000 units in 2020, they still account for a market share of only 3.5% of newly registered passenger vehicles [33]. According to Schmidt Automotive Research it will accelerate again in 2025 to a market share of 13%. The analysis carried out in paragraph 2.1 showed that the higher purchase costs for electric vehicles compared to combustion-powered vehicles remain a barrier. Therefore, the policies adopted by the different countries should be crucial to encourage BEV purchase uptakes [33]. In Figs. 8 are shown the purchase incentive for BEV among the main EU countries and UK.

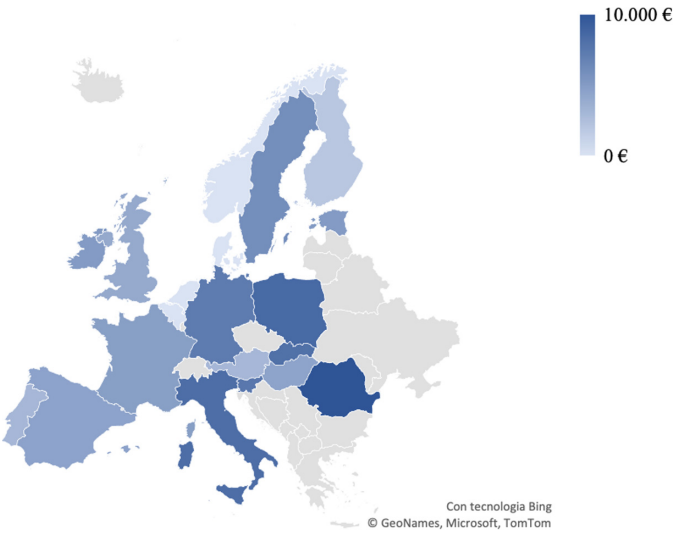

Fig. 8. Purchase incentive for BEV among EU countries and UK. (Authors elaboration, Data Source [34])

Comparing Figs. 8 and 9 it is interesting to note that the ratio between GDP and purchase incentives for BEV is quite proportional except in Italy and Germany (low GDP – high incentives).

In Table 3 is shown a comparison between policies (focusing on restrictions and tax exemptions) and the percentage of BEVs registration on the total automotive registration among main EU countries and UK.

Purchase incentive and annual national tax breaks on vehicle registration and operation are common where electric shares are high—for example in Austria, Finland, France, Germany, Ireland, Portugal, Sweden and UK.

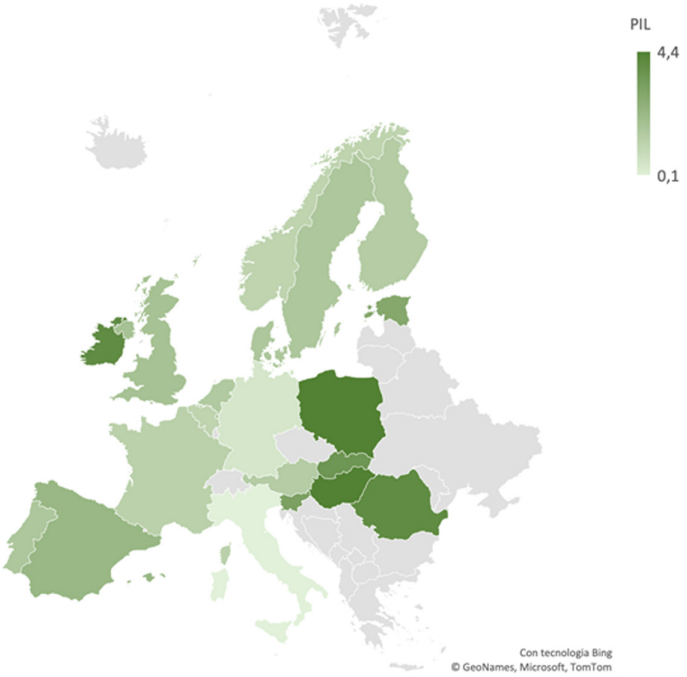

Fig. 9. GDP (2019) among EU Countries and UK. (Authors elaboration, Data Source [35])

Yet, even though many countries like Italy, Spain, Greece, Hungary, Poland, Romania, Slovakia and Slovenia provides both purchase and tax incentives, the registration percentage is still set on low levels. (Fig. 8).

Analyzing Fig. 8 it shows up that Norway, Netherlands, Denmark do not provide any incentive or scrapping bonus, yet the percentage of BEV registrations reached the highest level (Table 3). This is probably due to the general attention of the population towards environmental sustainability issues. Regardless of the number of incentives available, the purchase of an electric vehicle contributes to environmental respect.

3.2 Policies and Educational Strategies to Promote Sustainability

From the analysis of the data obtained in Sect. 3.1, by comparing Figs. 8 and 9 and Table 3, the following remarks can be made:

- In most Eastern European Countries (Romania, Slovakia, Poland, Slovenia), although both GDP and incentives for purchasing electric vehicles are set on high levels, the registration rate of BEV is among the lowest percentage in Europe.
- In Italy, where GDP in 2019 has been among the lowest levels within European Union and incentives for the purchase of electric vehicles are high, still the registration rate for BEV is set on low percentage.

Table 3. Comparison between policies and uptake of private electric vehicles among main EU countries and UK. (Source [36]).

Country	Restrictions	Exemption ownership tax	Exemption registration tax	% of BEV registrations on the total automotive registrations in each country 2019
Austria	Gross list price of ⩽ €60.000	Yes		3,3
Belgium		Flanders: Yes Brussels and Wallonia: minimum rate (€76.32 + 10% municipal tax).		2,8
Denmark	-	Yes	Reductions of 40.000 DDK and payment in instalments	3,6
Estonia	Gross list price of ⩽ €50.000	-	-	0,3
Finland	Gross list price of ⩽ €50.000	Minimum rate	Minimum rate	5,6
France	-	-	Yes	2,5
Germany	-	Temporary VAT reduction 16% to 19%	10 years	2,6
Grecee	-	Yes	Yes	0,3
Hungary	Gross list price of ⩽ €44.000	Yes	Yes	1,7
Ireland	-	Reduction up to 5.500€	Minimum rate	3,5
Italy	Gross list price of ⩽ €50.000	for 5 years then 75% reduction	-	0,7
Netherlands	-	Yes	Yes	10,1
Norway	-	Yes	Yes	56,2
Poland	Gross list price of ⩽ 150.000PLN (32.000€)	Yes	-	0,5
Portugal	-	VAT deduction	Yes	4,7
Romania	-	Yes	-	0,6
Slovakia	-	Yes	-	0,4
Slovenia	-	-	Minimum rate (0,5%)	0,8
Spain	Gross list price of ⩽ €35.000	Reduction of 75% in the main cities (eg. Madrid, Barcelona, Zaragoza, Valencia)	Yes	1,3
Sweden	-	Reduction on annual road tax (360 SEK - 35€)	-	11,3
UK	Gross list price of ⩽ £50.000 (58.000€)	Yes	Yes	2,1

– In northern European countries such as the Netherlands, Norway and Sweden, whose GDP is set on average level and the BEV's purchase incentives are low or non-existent the registration rate for electric vehicles is among the highest percentage in Europe (Norway 56.2%, Sweden 11.3%, Netherlands 10.1%). As mentioned above, this trend is probably due to the culture of these populations perceiving environmental sustainability aspects as paramount.

Whether subsidies policies prove insufficient to achieve the set objectives, it will be appropriate to plan educational strategies to promote environmentally sustainable habits for citizens. To tackle the crisis, a structural approach is needed: it is a multi-year incentive plan, with a much longer horizon than the current one, which must be characterized by favoring low-impact cars, to lead towards the reduction of emissions.

Structural policies in this direction would also contribute to modernizing the vehicle fleet which has a strong negative impact not only on the environment but also on traffic safety, as shown by the death rates due to road accidents:

– Incentives for the purchase of new zero-emission cars;
– Scrapping of old vehicles and dealer bonus;
– Incentives for sharing and rental services;
– Integration of charging infrastructures.

With reference to these last two points, even in a highly critical economic phase, the rental confirms the innovative charge and the role of driving force for the diffusion of electrified cars in our countries. The electric turnaround can only pass from a wider spread of "pay-per-use" mobility. Indeed, rental is a strategic element of the circular economy, thanks to a fleet of latest generation cars and the ability to put on the second-hand market every year safe and low-emission vehicles (at the end of the rental more polluting. Furthermore, the role of charging infrastructures is an essential factor for the transition towards zero-emission mobility. Equally fundamental is the capillarity of the territorial distribution of infrastructures, both in terms of accessibility (public / private) and in terms of number of charging stations. This technological adaptation is necessary to keep up with the growth in the diffusion of the electric car. But that's still not enough: the user must be able to quickly and easily identify the location of the infrastructures in order to make the most of them. Integration is the key word: research and use of public charging stations through a few apps able to offer standardized services ranging from booking to unblocking the charging up to payment (often online), interfacing with charging networks spread globally.

Finally, to be able to raise awareness with a bottom-up approach, the issue of sustainability must be strengthened through constant training activities, correct dissemination information, communication campaigns, sharing and promotion of good practices in the area, in addition to university and scientific research that allow the development of new knowledge and technologies and the identification of intelligent and more efficient mobility systems.

4 Conclusions

In the coming years, mobility will be one of the biggest environmental challenges, especially in terms of emissions. It is hoped that increasingly sustainable solutions and new technologies can be proposed and promoted by investing in electric mobility.

The current European e-mobility market has connected to the Green Economy in all European countries. Several strategies will have to be implemented by the automotive industry to reduce high production costs, low range and non-zero environmental impacts from vehicle production, circulation and recycling. However, "local emissions" are zero, making this technology useful for urban mobility, where there is often a high population density. Furthermore, e-mobility is useful within the new forms of mobility stimulated by the deployment of MaaS, which could emphasize the strengths of e-mobility and reduce its weaknesses.

The shift towards more sustainable transport modes will also be encouraged through incentives and reward mechanisms (i.e. incentives for the purchase of low-impact vehicles or for the installation of devices capable of reducing pollutant emissions; incentives for public transport passes; provision of minimum requirements and reward criteria referring to sustainable mobility). In addition, several actions may be adopted to encourage users to use e-mobility. Considering a short-medium time horizon, the awareness-raising campaigns addressed to different age population groups, focused on the theme of sustainability and green mobility, can encourage the propensity of transport demand to use electric vehicles.

However, in the medium-long term,, the implementation of an improved recharging infrastructure and the exemplification of the procedures (i.e. waiting times and types of charging stations) can be a strategy to support the spread of e-mobility.

There is certainly still a long way to go. But the year 2021 can truly be the "driving force" to ensure that the trends recorded for electric vehicles in 2020 become structural. In this direction, this study lays the foundations for in-depth research aimed at analyzing the measures put in place for 2021 by the State and Regions to encourage the use of e-mobility. The comparison between the spread of shared and private e-mobility will highlight the critical points in both mobility sectors. At the same time, a more in-depth analysis of recharging infrastructures will increase the study of the electric mobility sector in terms of both transport demand and supply, promoting new strategies for the spread of sustainable mobility in different time horizons.

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