GUIDELINES FOR THE ECAVS TRANSITION ON THE REGIONAL LEVEL

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LIST OF ACRONYMS

EVs	Electric Vehicles
CAVs	Connected Autonomous Vehicles
ECAVs	Electric Connected Autonomous Vehicles
ESAVs	Electric Shared Autonomous Vehicles
ICE	Internal Combustion Engine
BEV	Battery Electric Vehicles
PHEV	Plug-in Hybrid Electric Vehicles
PEV	Plug-in Electric Vehicles (BEV more PHEV)
FCEV	Fuel Cell Electric Vehicles
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2V	Vehicle to Vehicle
LV	Low Voltage
MaaS	Mobility as a Service
SoC	State of Charge
DSOs	Distribution System Operators
TSOs	Transmission System Operators
BMs	Business Models
DER	Distributed Energy Resources
VRE	Variable Renewable Energy

TABLE OF CONTENT

1. INTRODUCTION **6**

2. FRAMEWORK AND PILOT SITES **6**

1.1 Issue description **6**

1.1.1 Evolution of European road mobility scenarios 8

1.1.2 Evolution of the global energy system and infrastructure 10

1.2 Pilot sites regional context focus **12**

1.2.1 Ticino (CH) 13

1.2.2 South Tyrol (IT) 14

2 TECHNICAL AND ECONOMICAL INSIGHTS **16**

2.1 Implications for the energy system and the charging infrastructure **16**

2.1.1 Smart charging 17

2.1.2 Sector coupling and bidirectional charging 19

2.2 Business models **21**

2.2.1 Distribution System Operator (DSO) 25

3 GUIDELINES FOR THE ECAVS/ESAVS TRANSITION **26**

3.1 Electric Grid **26**

3.2 Charging infrastructure **27**

3.3 ECAV's smart management **27**

3.4 Collect data and further research needed **28**

4 CONCLUSIONS **29**

BIBLIOGRAFY **30**

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1. INTRODUCTION

This report is intended to provide **guidelines to enable regional policymakers to deal with the current energy transition process**, involving the electrification of many sectors in the context of increasing decentralized renewable production.

Road mobility is already engaged in this process, and in the next years it will be so even more. The diffusion of new technologies such as **Electric Vehicles (EVs)** and **Connected and Autonomous Vehicles (CAVs)** is going to heavily impact **road mobility sector** and the **electricity system infrastructure**. While external dynamics, such as the energy cost or the passenger car market, cannot be managed locally, **regional policymakers still have a key role**, mainly acting on the electricity infrastructures.

The results of the European ERA-Net SES project "EVA" here reported can provide **reasoning tools regarding the evolution of local mobility and future electricity system infrastructure**, aiming to help regions better understand possible dynamics and be able to put in place **no regrets strategies**. This means that the knowledge of likely future scenarios allows policymakers to take a forward-looking approach, not running after daily needs, but planning today to reach a better positioning tomorrow.

2. FRAMEWORK AND PILOT SITES

In the last decades, occurring global phenomena are emphasizing the shortcoming of the actual state of the mobility sector, and opening at the same time new opportunities for development in this field. The fast population increase during the last half-century, driven by **urbanization**, has raised the need for more desirable cities. The growing **impact of digitalization** is already visible in our daily lives. The decline in numerical terms of the European middle class and the subsequent diminished purchasing power is raising more considerable attention to sustainability issues, lack of space in the city due to the growing urbanization, and a **propensity to share resources** rather than their possession. Decarbonisation has become not only a scientific commitment, but also a collective horizon supported by increased awareness of the limited resources of the Planet Heart.

In this context, we want to focus on emerging scenarios in mobility and energy sector, outline the issue and describe the main features project's pilot sites.

1.1 Issue description

To tackle the climate crisis and prevent further risks related to climate change, is coercive to manage the ongoing transformation of the road transport sector, and regional institutions must play a key role in this transition. In the medium to long term, they will be indeed **forced to address two emerging technologies in road mobility**, which are likely to happen in two separate consecutive phases (**Errore. L'origine riferimento non è stata trovata.**): a phase of decarbonization (A), characterized by a high level of adoption of **Electric Vehicles (EVs)**, and a phase of automation (B), characterized by a high level of adoption of **Connected and Autonomous Vehicles (CAVs)**. These two phases will take place in the context of **decentralized and increasingly renewable regional energy systems**.

According to authoritative observers, phase A is already ongoing and will probably peak around 2030. In particular, the IEA Global EV Outlook claims that supportive policies and cost reductions are likely to lead to significant growth in the market uptake of EVs by 2030 (from 7% to 12% stock share, depending on the scenario) (IEA, 2021). Similarly, McKinsey and Company predict that by 2025, the largest automotive markets (the EU, US and China) will be fully electric (McKinsey and Company, 2021)

On the other hand, phase B, characterized by the transition from human assisted to autonomous driving, is still uncertain. Nevertheless, many authors anticipate that **autonomous driving will increase safety and comfort, reduce traffic congestion, pollution and fuel consumption**, as well as improving mobility and accessibility opportunities for disabled and older people (Nacer, 2020) (Mora, 2020). The only certainty is that the transition to automated driving is underway and seems to be unstoppable. In fact, the enthusiasm of academia, media and manufacturers for this innovation is increasing.

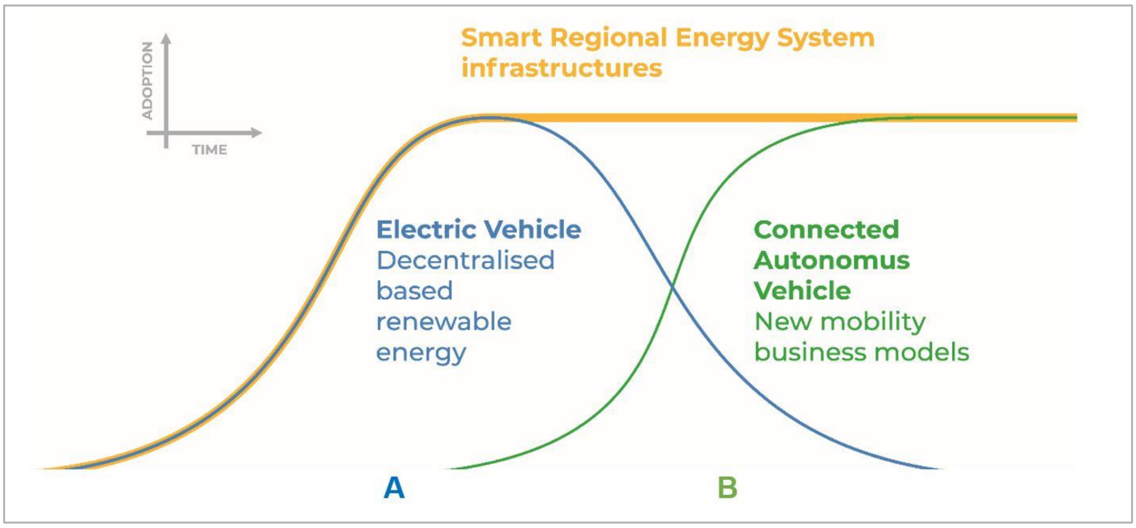

Figure 1 - The phases considered in this document, related at the two emerging technologies in road mobility.

To overcome negative impacts by the current individual car-based system, mobility might evolve towards **Electric Connected Autonomous Vehicles** (**ECAVs**) and **Electric Shared Autonomous Vehicles** (**ESAVs**), efficiently integrated with transit systems and with the electric grid. (Anwar, 2021).

What implications will these two distinct phases have for investments in the charging infrastructure and the energy system? What opportunities for energy sector coupling might emerge from the possible increase in "batteries on wheels", first only as a replacement for internal combustion cars, then autonomous, considering two-way charging systems? Which actions could take regional policymakers to approach this transition with a forward-looking vision? How could different stakeholders aggregate their interests to create a new business model involving mobility, the energy sector and individual and collective users? There is a social and economic convenience in the shared use of these emerging technologies?

In this paper we try to answer these and more questions in the framework of the **European ERA-Net SES project EVA analysis (https://evaproject.eu)**.

1.1.1 Evolution of European road mobility scenarios

In 2017 the **road transport sector** was responsible for the emission of 895.8 Mtons of CO_2 equivalent in EU28, 19% of the total European CO_2 emissions (European Commission, 2019), and is **the only sector which did not record any important decline in greenhouse gas emissions in the last decades**. Before exposing the main strategic guidelines for the transition to ECAVs, we want to frame the current situation and the future scenarios of road mobility, considering both emerging technologies, such as EVs and CAVs, and the increasingly popular idea of more shared mobility.

Electric Vehicles

The electrification of transport appears as the best short- and medium-term solution not only to reduce CO_2 emissions, but also to cut particle and noise pollution in urban areas and steer away from dependence on foreign fossil-based energy. Despite the passenger car market is still dominated by internal combustion engines (ICEs), many different forms of electric engines were developed in the last years. This report will look with particular interest at the **Plug-in Electric Vehicles (PEVs), which can run with zero tank-to-wheel emissions and need electrical power from the grid to recharge the batteries**. PEVs comprehend:

- Battery Electric Vehicle (BEV);
- Plug-in Hybrid Electric Vehicle (PHEV).

Both BEV and PHEV store chemical energy in one or more rechargeable batteries that powers an electric motor. The batteries are recharged by plugging-in the vehicle to the electric grid. In addition, PHEV can switch to the ICE engine in case the batteries run out. The European Alternative Fuels Observatory (EAFO) has registered the penetration of PEVs in the European market: since 2012, the number of units sold has increased year by year, reaching almost **1.8 million units in the EU/EFTA/Turkey roads in 2019**, 31% of which just sold in 2019 (EAFO, 2020). Despite the continued growth in sales, BEVs and PHEVs represented only 3.7% of total newly registered cars in the EU/EFTA/Turkey in 2019. Figure 2 depicts in more detail the European evolution of the PEV market in the last decade.

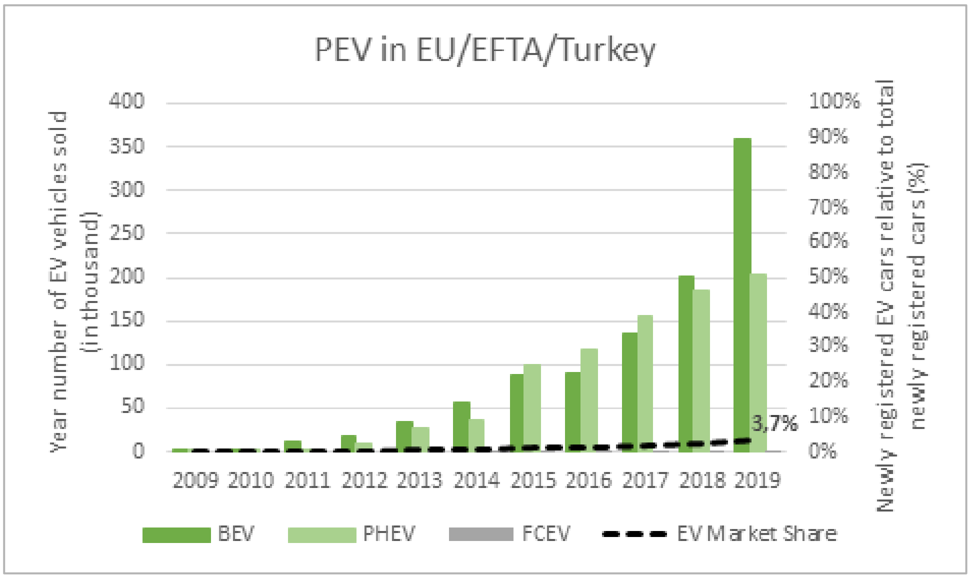

Figure 2 - Number of plug-in electric passenger cars sold in EU/EFTA/Turkey (EAFO, 2020)

The current market development of PEVs in the EU is heterogeneous and fragmented, also because of the correlation between the uptake of electric cars and GDP (ACEA, 2019). Moreover, the consumer purchase incentives, bonus payments and tax reductions or exemptions widely differ in each EU country.

The continued development of BEV technology leads to a predicted increase in BEV sales over the long term (EAFO, 2020). To **accomplish EU CO_2 emission targets**, at least 2.3 million PEVs would be sold in the EU in 2025 (1.4 million BEVs and 0.9 million PHEVs) and at least **5 million in 2030** (3.2 million BEVs and million PHEVs) (Transport & Environment, 2019). This means there should be roughly a 2-fold increase of PEVs in the EU28 roads within the next 5 years and roughly a 5-fold increase in the next 10 years. This will have a strong impact on electric networks, as discussed in the next subsection.

In particular, the IEA Global EV Outlook 2021 claims that supportive policies and cost reductions are likely to lead to significant **growth in the market uptake of EVs by 2030** (from 7% to 12% stock share, depending on the scenario) (IEA, 2021). Similarly, McKinsey and Company predict that by 2025, the largest automotive markets (the EU, US and China) will be fully electric (McKinsey and Company, 2021).

For sake of simplicity, in the following we use the term EVs (Electric Vehicles) only in reference to BEVs, which is the more impactful technology.

Connected Autonomous Vehicles

In the context of an increasing incidence of connectivity and automation of everyday objects (Internet of Things, IoT), t**he introduction of Artificial Intelligence in driving systems appears an almost certain scenario**. The diffusion of connected and autonomous vehicles will positively impact road safety for both drivers and weak road users and will contribute to improving traffic management (TA-Swiss, 2020).

Basically, the introduction of Artificial Intelligence in driving systems means that vehicles are becoming increasingly 'intelligent', capable of parking and changing the speed or direction of travel. The automation of vehicles varies according to technological progress, considering the role of the driver and the context in which the vehicle moves, and has been classified by SAE (Society of Automotive Engineers) in 6 different levels from 0 to 5, where 5 is the full autonomy[1]. To this day, only 1 or 2 automation level vehicles are on the market, and it is difficult to define a reasonable time horizon for the market penetration of the higher-level autonomous vehicles, for technological, regulatory and legal uncertainties. Anyway, there is no question that sooner or later there will be autonomous fleets on the European road (Scudellari, Staricco, Brovarone, 2021).

Car sharing and Mobility as a Service

Besides just described technology advancements, new ideas about the role of mobility are emerging. As reported in 2018 by the UN Intergovernmental Panel on Climate Change (IPCC), it will not be possible to sufficiently reduce the climate impact of transportation by simply changing the way vehicles are fuelled: we need to **move people out of cars into other forms of transport, and reconsider how trips are made**.

Car sharing is already a widespread reality, as reported by Hoerler et al. in their guidelines to accelerate the sustainable transformation of the Swiss mobility system. (Hoerler, 2021). The idea of **shifting mobility from individual and private to collective and shared** could find its fulfilment in the concept of **Mobility as a Service (MaaS)**, a “mobility distribution model in which a customer’s major transportation needs are met over one interface and are offered by a service provider” (Hietanen, 2014).

In simple terms, MaaS proposes to integrate various transport options into a single mobility service through a digital interface, allowing for a **multi-modal approach to mobility** in which various trip options are available to the user, who can then make choices based on personal needs. A comprehensive overview of MaaS definitions is provided by Sochor et al. (2018). The core expectation of MaaS is to reduce private vehicle ownership (Hoerler, 2021) and the development and spreading of ECAVs could strongly enforce this vision.

1.1.2 Evolution of the global energy system and infrastructure

An increasing European fleet of EVs will require to be recharged. Nowadays, **the European public charging infrastructure network is undersized and fragmented**. Indeed, four countries covering 27% of the EU’s total surface area – the Netherlands, Germany, France and the UK – account for 76% of all charging points in the EU (ACEA, 2019). On the other side, almost all EU member states with

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1 A full description can be found at https://www.sae.org/blog/sae-j3016-update.

less than 1 charging point per 100 km of road have a PEV market share of under 1% (ACEA, 2019). This fact confirms the obvious intuition that **the penetration of EVs is related to the availability of recharging stations**, despite is not so easy to determine the causality nexus between them. In the next years, anyway, significant investments for charging points and renovations of the electric grid would be required to assist the expansion of EV market.

Nevertheless, is not enough to simply build more charging stations. Indeed, the peaks in energy demand for the growing EVs fleet rechargers could coincide with the peaks in demand for other appliances, and this could have a negative impact on the stability of the electricity grid. As reported by Anwar, M. B. et al. (Anwar, 2021) "A vast body of literature has examined the possible impact of adding new EV loads to existing power systems, showing that if unmanaged or uncoordinated (assuming each EV charges as soon as it is plugged in without any consideration of electricity supply and grid conditions), EV charging may exacerbate netload variability, impacting resource adequacy and attendant long-term planning, as well as contributing to bulk-level (generation and transmission) operational challenges". It is thus **impossible to consider EVs separately from the context**, since their **interaction with electric grid** will be stronger and stronger.

Electric infrastructures are mainly handled at the regional level, but they have a high dependence on the global energy system. Before exposing the results of project EVA in developing new interconnected regional electric infrastructures, it is, therefore, necessary to dwell on the actual situation and the future scenarios of the global energy systems. During 2022, the **energetic crisis** arising after the Covid-19 pandemic has been worsening because of the war, the shortage of raw materials, and the supply chain troubles. It is difficult to understand the complexity of today and even more to imagine how the situation will develop.

In this complex contest, some **structural transitions**, which have been underway for years, will go on despite the energy crisis. The IEA World Energy Outlook 2021 (WEO-2021) reports that "the new energy economy will be more electrified, efficient, interconnected and clean. Its emergence is the product of a virtuous circle of policy action and technology innovation, and its momentum is now sustained by lower costs. In most markets, solar PV or wind now represents the cheapest available source of new electricity generation. Clean energy technology is becoming a major new area for investment and employment – and a dynamic arena for international collaboration and competition" (IEA Energy Outlook 2021). This transition is driven by the **international pledges announced during COP-21** in Paris and more recently strengthened during COP-26 in Glasglow. Nevertheless, CO2 emissions are still increasing (at the global scale), thus requiring a deeper effort toward the IEA's landmark **Net Zero Emissions by 2050** Scenario.

From a historical perspective of the electrification process, it can be observed that at the present day "decentralized energy networks are rapidly spreading, based on super-efficient end-use appliances and low-cost photovoltaics" (Alstone, 2015). In particular, the share of variable renewables in electricity generation is supposed to rise and reach 40-70% (according to different scenarios) by 2050 (and even more in some regions), far above the global average of just under 10% today (IEA Energy Outlook 2021). One possible downside is that **wind and solar photovoltaic generation vary** with the weather as well as with the time of day and year, and this can cause sudden changes to generation patterns on a daily or weekly basis. Given this framework, the guidelines provided in this deliverable show that the diffusion of ECAVs should no longer represent a problem for the regional electric grid, but a part of the solution. The key concept is to **couple EVs with the regional electric grid**, thus bringing out many innovative solutions for future energy systems.

1.2 Pilot sites regional context focus

The EVA project was developed with reference to two pilot sites, which are **representative of medium-size and relatively sparsely populated regions**, apart from one bigger centre:

- Ticino, in Swiss;
- South Tyrol, in Italy.

In the following the relevant features of these territories are depicted to better describe the project's result. Both these sites present a heterogeneous territory which poses various constraints to the development of the transport network, the energetic systems and their complex interaction due to the increasing electric mobility. The mobility characteristics of the two pilot sites share many positive features, both regarding the actual situation and future scenarios, as in greater detail reported in the deliverable D 2.2. Specifically, both test sites have a **highly developed mobility infrastructure network and a good public transport interoperable service**; cycling paths are growing in length each year.

The major cities of the test sites (Bolzano and Lugano) attract and generate travel flows within and to/from them. Despite the growing use of public transport passes, the number of new driving licenses is still growing each year, in contexts which already present a high rate of car ownership. Residents heavily rely on private motorized vehicles for their trips, the purpose of which is mainly for leisure. The most critical mobility issues, however, are due to trips more concentrated in time and space, such as commuting trips, exacerbated in Ticino by cross-border workers. Sustainable mobility is promoted in both sites by several projects with a wide range of objectives, with the same intention to change mobility patterns in favour of public transport. Significant investments made in this direction will modify future mobility scenarios. Finally, both regions have **conducive features for the market uptake of EVs and give a favourable scenario for AVs introduction and smart grid planning**. In the following, we separately highlight the main issues related to EVs penetration in each pilot site.

1.2.1 Ticino (CH)

The canton of Ticino is the southernmost canton of Switzerland, bordering the Italian provinces of Lombardy and Piedmont. Its capital and largest city is Lugano. Whit a population of 353'343 permanent residents in 2018 (FSO, 2020), Ticino is considered a relatively small canton. In 2014, was elected the most ecologic canton of Switzerland (Isetti, Corradini, Gruber, Della Valle, & Zubaryeva, 2018).

Electric vehicles market trends in Swiss

In Switzerland, passenger cars are responsible for 75% of national transport sector emissions (VöV UTP, 2018), which amounts to 15 million tons of CO_2 each year. From the beginning of 2020, Switzerland introduced more restrictive legislation to decrease the climate impact of this sector, in compliance with EU targets. Electric propulsion engines will play a central role in achieving them, thanks to the significant share of Swiss electricity generated by hydroelectricity and nuclear energy (de Haan & Zah, 2013).

In a context of a passenger car market with a decreasing rate of growth, only 47'151 passenger cars (in 2019), corresponding to a 1.02% share, were PEV. Most cars still rely on fossil fuels. Nevertheless, the year selling of EVs have been growing in the last decade and in 2019 the market share of full-electrics and hybrids vehicles reached the maximum ever registered: BEV 4.2% and hybrids 8.4% (FSO, 2020). This result has been encouraged by the federal authorities, that in 2018, together with 50 e-mobility stakeholders, have drawn and published a roadmap with the aim of increasing the share of PEV in new car registrations to 15% by 2022 (DATEC, 2018). This goal has been achieved: **in the first semester of 2022, PEVs reach the 16% market share**, with a particular increase of +36% in BEV registered (FSO, 2022).

The e-mobility scenarios drawn by EBP for Switzerland (EBP, 2018) forecast that only with coordinated development of charging infrastructure, incentive instruments and Connected Mobility vision the market penetration of PEV will significantly increase.

Autonomous vehicles framework

Since 2015, some tests of AVs were authorized and run on the federal territory, mainly concerning shuttles buses in densely populated areas as a first/last mile solution. Nonetheless, to date, "vehicles tested are still far from being able to move independently from a point A to a point B: they are like students in the first driving lessons and still have a hard time juggling traffic and managing a whole series of complex situations" (FEDRO, 2019, pp. 16).

Electric charging infrastructure development

The development of the public charging infrastructure in Switzerland is mostly operated by the private sector (HEV TCP, 2019), amounting to 25 diverse public charging network operators. The federal government is taking in last years a coordinating role, launching some projects aimed at providing information and consulting services for the installation of charging stations at the workplace, harmonizing and aggregating information to give an overall picture of the network of charging stations in Switzerland, and creating a fast-charging network along national roads.

Since 2012, 6’200 public charging points were installed in Switzerland up to 2019. Most of them, as in the rest of EU/EFTA/Turkey, are normal charging points (5’414), and a small portion are fast charging points (786). Moreover, in the last 5 years, the number of PEVs per public charging point has increased up to 8 units, still lower than the reference value indicated by the EU directive (10 electric vehicles per charging infrastructure).

Focus on Canton Ticino

The same federal trend in the passenger car market is heightened in canton Ticino: since 2014 the yearly rate of growth is decreasing, even registering negative growth for 2018 and 2019. Nevertheless, this canton has the third higher ratio of cars per inhabitant in Switzerland (632 passenger cars per 1000 inhabitants) (FSO, 2020), but only 0.48% of the total (about 1’060 units) are registered as BEV, quite less than the federal percentage of 0.62%. Based on the current rate of growth of PEV sales, the objective of the Swiss roadmap (15% market share for 2022) is likely to be achieved and even surpassed.

Despite the cantonal incentive program specifically dedicated to electric mobility approved in 2019, buying a new ICE model today in Ticino tends to be cheaper than buying a similar BEV model. The allocated 3’000’000 Swiss francs, if fully spent, will result in 1’250 new EVs, which represents less than 1% of the total passenger cars sold in Ticino in 2019. Moreover, **many local municipalities have their own incentive programs** that can be accumulated with the **cantonal incentive**.

The actual network of public charging stations, managed by several different providers, has a widespread diffusion over the territory, which is not the result of cantonal planning, but the result of the individual actions of the municipalities or some private individuals (MOBSTER, 2020).

During the period 1995-2015, the program VEL has tried to create the right conditions for the penetration of EVs in the local car market (Isetti, Corradini, Gruber, Della Valle, & Zubaryeva, 2018), while today initiatives are led by private companies or associations, such as Enerti (with Emotì project https://www.emoti.swiss/), and Protoscar, flanking Canton Ticino Government’s policies.

1.2.2 South Tyrol (IT)

South Tyrol is an autonomous province, the northernmost of Italy, and has a total population of about 534,000 inhabitants as of 2021. Its capital and largest city is Bolzano. It is known as the "Green Region" of Italy for its being at the forefront in its sustainable approach to multiple sectors, ranging from that of renewable energies to the context of mobility. The provincial strategy, approved in 2015, aims to transform South Tyrol into a model region for sustainable Alpine mobility by 2030, through the development, with the participation of politics, of the economy, science and the entire population, of public transport and inter-mode electric mobility.

Electric vehicles in Italy

From its appearance in the Italian passenger car market in 2008, EVs have increased constantly their sales, markedly between 2015 and 2020. In last two years, while ICEs sales have fallen because of the Covid-19 pandemic, legislation on CO2 emissions push EVs to a 420% increment from 2019 (ACI, 2022). Last available annual data (2021) report a EVs market share of 4.6%. If compared with the 0.04% in 2012, this margin represents **one of the biggest market growths in Europe**.

In the context of investments for the Green New Deal envisaged in the Budget Law 2020, the Italian State provided that regional authorities in areas with high pollution of PM10 particles must replace the respective fleet of cars, buses and public utility vehicles, including those for the collection of municipal waste, at least 30% by 2022, 50% by 2025 and 85% by 2030 with electric and hybrid vehicles. This measure should push the road transport market towards EVs.

Autonomous vehicles framework

In Italy, no AVs tests were conducted so far. Many arguments arose about the civil liability of the driver, since an intelligent vehicle are supposed to make decisions, and the quick information processing gives to AV a higher decision spectrum than a human mind. On the other hand, priority objectives for the dissemination and use of intelligent transport systems on the national territory have been already identified in 2014 by the Ministry of Transport. In addition, some insurance models were developed to be applied also to the world of autonomous driving.

Electric charging infrastructure development

The national infrastructure plan for recharging vehicles powered by electricity (PNire) was updated in 2015 by the Italian government and aims for the installation of 4,500 charging points no later than 2020. At the end of 2017, 2298 normal current columns (< 22 kW) were installed while the rapids (> 22 kW) were 443.

A Legislative Decree in 2016 introduced obligations for newly constructed residential buildings to facilitate domestic charging.

Besides the public sector strategies, led by the Ministry of Infrastructure and Transport and the Authority of Regulation for Energy Networks and Environment (ARERA), many private stakeholders are engaged in the development of electric mobility such as the operators of the charging stations and charging station suppliers.

Focus on South Tyrol

South Tyrol has activated at regional level incentive measures for both the purchase of EVs and charging stations. The Autonomous Province grants contributions to its resident in terms of individual charging systems, which are used exclusively for charging electric vehicles. South Tyrol also provides for the granting of incentives to private companies for the development of electric mobility.

The number of EVs circulating in South Tyrol in 2019 cannot be said to be significant, amounting to a few hundred. Nevertheless, **the provincial strategy, together with a well-structured mobility governance system**, made it possible to double EV registrations in 2017 (compared to 2016) and to plan the installation of about 5,000 columns on the territory by 2021. According to a study carried out by Eurac and following a BAU (business as usual) model, 20% of the vehicles will be BEV in 2030.

2 TECHNICAL AND ECONOMICAL INSIGHTS

The framework depicted so far has been the starting point of the EVA project. In this section, we deepen the technical and economic implication of ECAVs/ESAVs transition, and we give some interesting insights for **planning the electric grid development and ECAVs/ESAVs fleet management**. An essential explanation of charging technology is required to understand the guidelines provided in the next chapter.

The investigated scenarios take **the perspective of an integrated grid operator or a charging station operator**, interacting with ECAVs coupled to the electric grid. The objective of the problem was to identify a better charging strategy, and the number of chargers in the grid to satisfy the charging demand of a given population of EVs while respecting the distribution grid's constraints.

Technical details regarding the algorithm's architecture or the concrete implementation are reported in deliverables D4.1 and D4.2; in the following, the main insights resulting from the research work are exposed to point the way toward regional recommended policies.

2.1 Implications for the energy system and the charging infrastructure

Projections show that EV charging will require careful planning, caused by the additional regional electricity demand (BNEF 2022). **Uncontrolled charging could increase peak stress on the grid** and require grid reinforcement investments: EVs charging management and infrastructure should therefore be planned while cognizant of the capability and limitations of the underlying power grid. (IRENA, 2019)

The planning of the power grid development must consider smart charging, the likely autonomy of EVs in future and the power exchange with the electric grid, which could be crucial in stabilizing the available power in the context of growing shares of variable renewable energy.

In the next subsections, both smart-charging strategies and the bi-directional charging technology are described, followed by the possible business model in which these technologies will play an important aggregating role.

2.1.1 Smart charging

Smart charging means "adapting the charging cycle of EVs to both the conditions of the power system and the needs of vehicle users. This facilitates the integration of EVs while meeting mobility needs" (IRENA Innovation Outlook, 2019). We can thus understand smart charging as a broad term to describe technical, economic and social aspirations related to EV charging. Indeed, smart charging aims to concurrently ensure reliability of the power system, improve the economic efficiency, such as increasing the infrastructure use, providing maximum mobility service, maximizing the service per unit cost paid.

We afford the management of simultaneous charging demand of large populations of EVs from distribution network point of view. One of the main problems is the violation of grid constraints. The need is to **shift away the charging periods from the morning and evening peaks in energy consumption**, as shown in the figure:

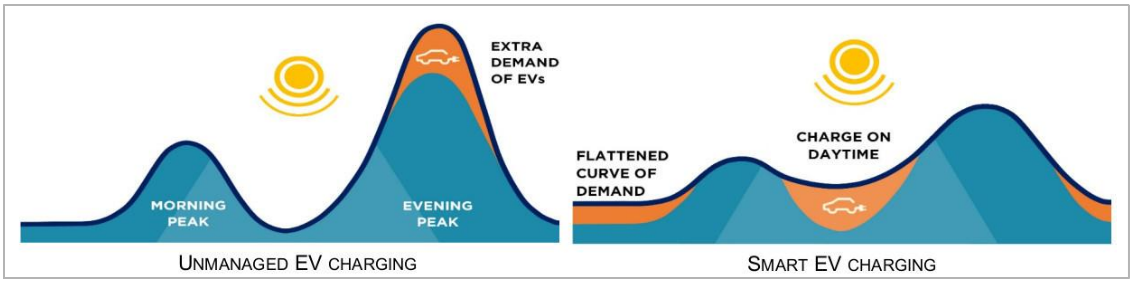

Figure 3 - Unmanaged EV charging and smart EV charging scheme (Corchero Garcia, 2022).

This goal could be achieved by scheduling algorithms which try to meet EV's owners demand and grid constraints. To this day, it is only possible suggest to EV's owners the better time to charge their non-autonomous private EV. While waiting to ECAV's penetration, regional policymakers could act on the grid management side, developing a smart one.

In deliverable D4.1 and D4.2 we investigate the optimal charging strategy by simulating some scenarios. While it is possible to retrieve information about local road infrastructure, traffic and possible commuting trips, we cannot avail data about the charging process because most charging providers are private ones. The timing of this process is simulated based on the technical information about EVs and charging stations. The algorithms developed in the context of the EVA project aim to evaluates the performance of smart charging in the context of autonomous EVs:

indeed, if future mobility is autonomous, **grid reinforcements and technological developments planned today for non-autonomous EVs might become obsolete tomorrow.**

Given all the constraints about the electric grid, the ECAV's fleet and the required mobility demand in a day (a concrete list of scheduled trips), some of the smart charging algorithm developed during the project can provide a strategy to serve all the trips in the given day without delays, while minimizing the voltage violations during ECAV's charging and giving priority to more depleted vehicles when assigning the charging power. Some other developed smart charging algorithms can provide a planning method to site and size chargers of EVs in distribution grids, accounting for grid constraints, EV owners' flexibility in plugging and unplugging their EVs, and multiple charger typologies.

Charging stations classification

An essential description of **different types of charging stations** is needed to understand subsequent results of the developed smart charging algorithms. For the current purposes, it is possible to classify charge infrastructures type in UE-CH regional territory into 4 categories, as shown in the figure 4:

- AC Private (from 7.2 to 22 kW), installed in:
  - → single-family houses [AC-Pr-H];
  - → multi-family [AC-Pr-B];
- AC Public standard (from 7.2 to 22 kW) [AC-Pu];
- DC Public fast (from 50 to 300 kW) [DC-Pu].

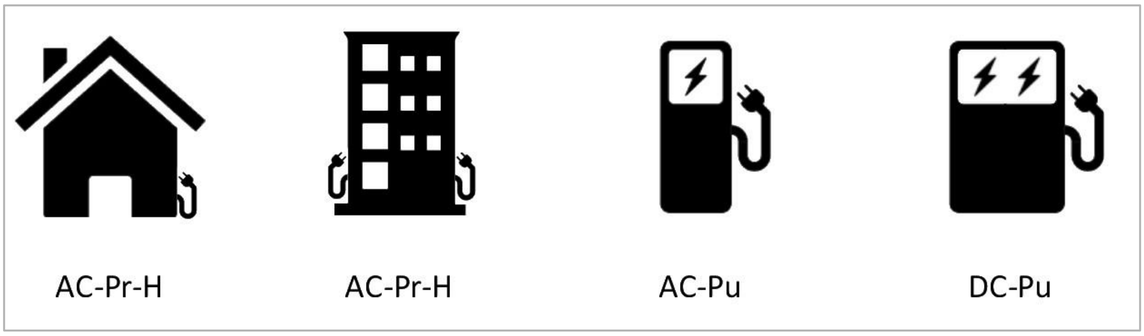

Figure 4 – Types of charging stations (Authors, 2022).

The main technical difference is **between AC and DC chargers**. Since the current stored in a typical EV battery is the direct current (DC) and the current that comes from the grid is the alternating current (AC), a conversion must occur to reconcile these two distinct currents. When charging with an AC station, the conversion occurs inside the EV, bounding the AC power to 22 kW. An AC station will take about 40 minutes to give the power needed to travel 100 km.

DC charging, on the other hand, employs the service of a charge point that can convert AC to DC before transmitting the current into the EV. This operation lowers the recharging time up to the same time or even faster than ICE vehicles. Generally, AC charge stations are installed in both private and public contexts, while DC fast charge stations are intended to serve highways or similar public situations.

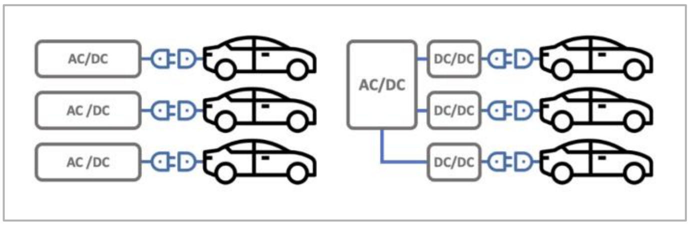

Figure 5 – Single- and multi-port chargers (Mukherjee B., 2021).

Moreover, in this project were considered **single- and multi-port chargers (SPCs and MPCs, respectively)**. The main distinction between these two charger typologies is that SPCs have a plug for each charging column, whereas MPCs have a centralized AC/DC power conversion stage and multiple ports to enable the connection of multiple EVs, as shown in the figure. From an operational perspective, MPC can be cheaper to purchase and install and enable arbitraging the charge among multiple vehicles, offering increased flexibility for congestion management.

2.1.2 Sector coupling and bidirectional charging

Each EV have a **significant battery storage capacity, that remains unutilised during parking time, about 95% of the whole EV lifetime** (IRENA Innovation Outlook, 2019). Has been already developed technical solutions that enable EVs to send the power that they are not using to the grid. This possibility have consequences not only for the charging algorithm but also for the grid itself, increasing its flexibility.

It thus seems convenient to couple the electric mobility sector with the local power grid, so that **each EV becomes a grid-connected storage unit with the potential to provide a broad range of services to the system**. The charge released from the EV's batteries, for proper reward, could allow for **stabilising the electric system** not only during peaks of energy consumption, but also in dealing with the introduction of much **higher shares of variable renewable energy** into the overall power generation mix, allowing a **higher flexibility** for the system. We refer to the framework which allows an EV to share energy with the grid as **Vehicle to Grid (V2G)** system.

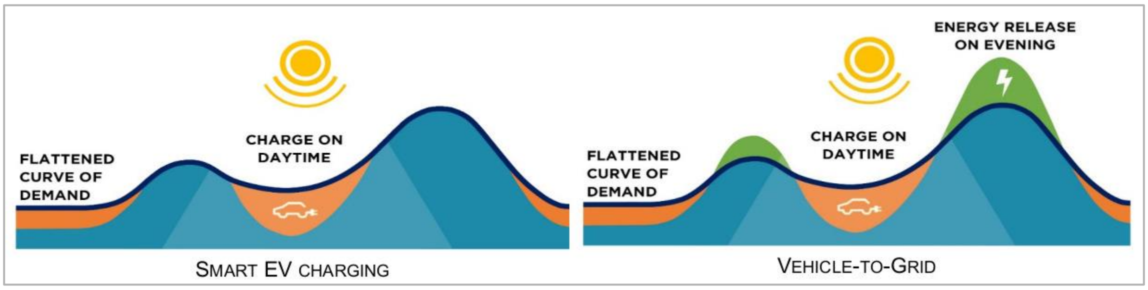

Figure 6 - Smart EV charging and V2G scheme (Corchero Garcia, 2022).

To this day, mainly Japanese manufacturers produce bi-directional charge EVs, but Tesla already has hundreds of thousands of Model 3 vehicles bidirectional-ready on the road and Volkswagen has just announced that it will produce them too (Electroteck, 2020). The charge station as well must be bi-directional to allow coupling: the Swiss start-up “Sun2Wheel” has already developed this technology. Moreover, the car-sharing cooperative “Mobility” recently launched the project "V2X Suisse", in which 50 EVs will power the grid when parked. It will be a unique occasion to collect data, both technological and regulatory.

EVs coupled to a power grid become components of the power system and thus can be modelled as such in charging algorithms. In the context of the regional parallel project MERA[2], a simulation was conducted based on the real electric grid of a local company (AMS Stabio) and the employees' EV fleet which could be interconnected. Results confirm that **peaks of energy consumption could be shaved by properly rewarding the power that an EV put back to the grid**.

[2] MERA is a Ticino regional project funded by the renewable energy fund (*Fondo Energie Rinnovabili - FER).* No official documentation is available for citation at the time of writing this deliverable.

2.2 Business models

In this section, are reported the main results of the investigation conducted on the integration of ECAVs/ESAVs into the electric grid, and on business models (BM) tailored to new forms of mobility, exploring how these dimensions may interact. in general, this transition produces the need for a process of integration among actors and stakeholders (Figure 7).

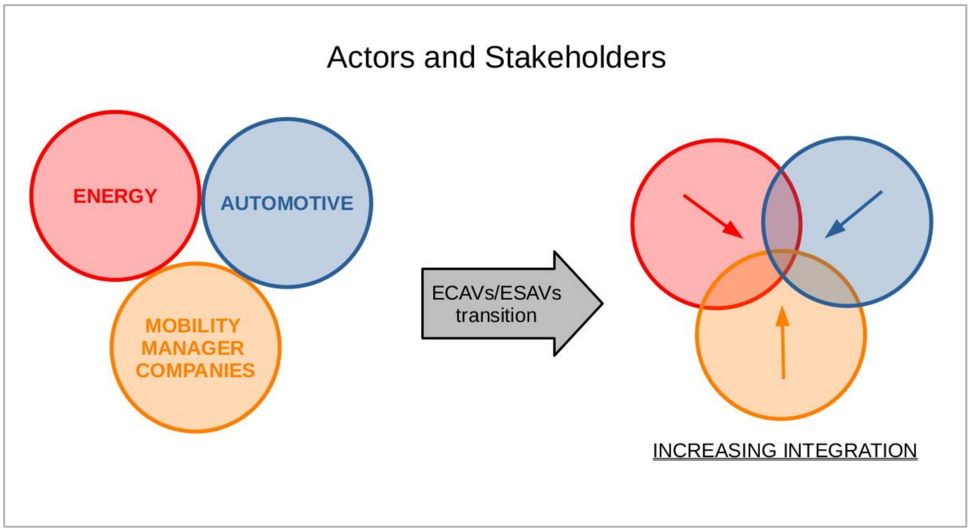

Figure 7 Actors and stakeholders interaction dynamic (Authors (2022) inspired by Corchero Garcia (2022).

In particular, besides economic scenarios related to the transition to ECAVs/ESAVs, deliverable 5.1 in parallel addressed the business models that lend themselves effectively to evolving aspects of the mobility sector (Gavrilescu, 2017). The analysis was carried out beginning with a review of the scientific literature aiming at identifying how BMs are presented and described.

One the concept most commonly used in literature to describe Business model (BM) is the BM canvas introduced in year 2005 by Alexander Osterwalder[3]. He defines BM as "the way business enterprises create, capture and transfer value". The canvas is a representation in table format of the 9 elements which characterize BM. According to Osterwalder these are:

1. *Key partners*
2. *Key activities*
3. *Key resources*
4. *Value propositions*
5. *Customer relationships*
6. *Channels*
7. *Customer segments*
8. *Cost structure*
9. *Revenue streams*

[3] Official website: www.alexosterwalder.com

Upstream of these elements are the choices and strategic decisions with which companies outlines, manages and organises those elements.

Defining a business model requires the analysis (or the definition, for a new one) of the specific characteristics of a company and the way it operates on the market. It cannot be separated from the context. Furthermore a BM cannot be disentangled from the company to which it belongs.

Analysing BMs would require the involvement of interested companies. As ECAV are not yet available, in the frame of this project it is has not been possible to analyse existing BMs in the strict sense.

The focus has been on addressing those elements of the BM canvas that might be influenced by ECAV and to highlight where change could occur and in what form. These insights might be relevant for future BMs developments.

The future changing context might lead to two reasons for which new BM will have to be introduced:

- Delivering of existing services and products with innovative approaches.
- Creation of an innovative corporate organization due to new products and services required.

In this work the focus has been on existing services and products with also two mayor area of interest:

- Energy companies (retailers and DSO in Switzerland).
- Transport companies.

Furthermore, Impacts on BMs are mainly scenario and context dependent. In particular these elements have been considered:

1. Total numbers of vehicle circulating.
2. Situation of the relevant energy system context (grid and demand/supply profiles).
3. Share of EV and AV over the total of vehicles in circulation and ownership redistribution.

Since the context lacks specific data on the impacts of autonomous driving on existing energy and mobility systems, interviews with the most relevant players (in accord with the scientific literature) in the two sectors were conducted to investigate new perspectives on developing business models that will manage electric and autonomous mobility. By conducting interviews, BMs can be contextualised in a broader context and feedback can be gathered.

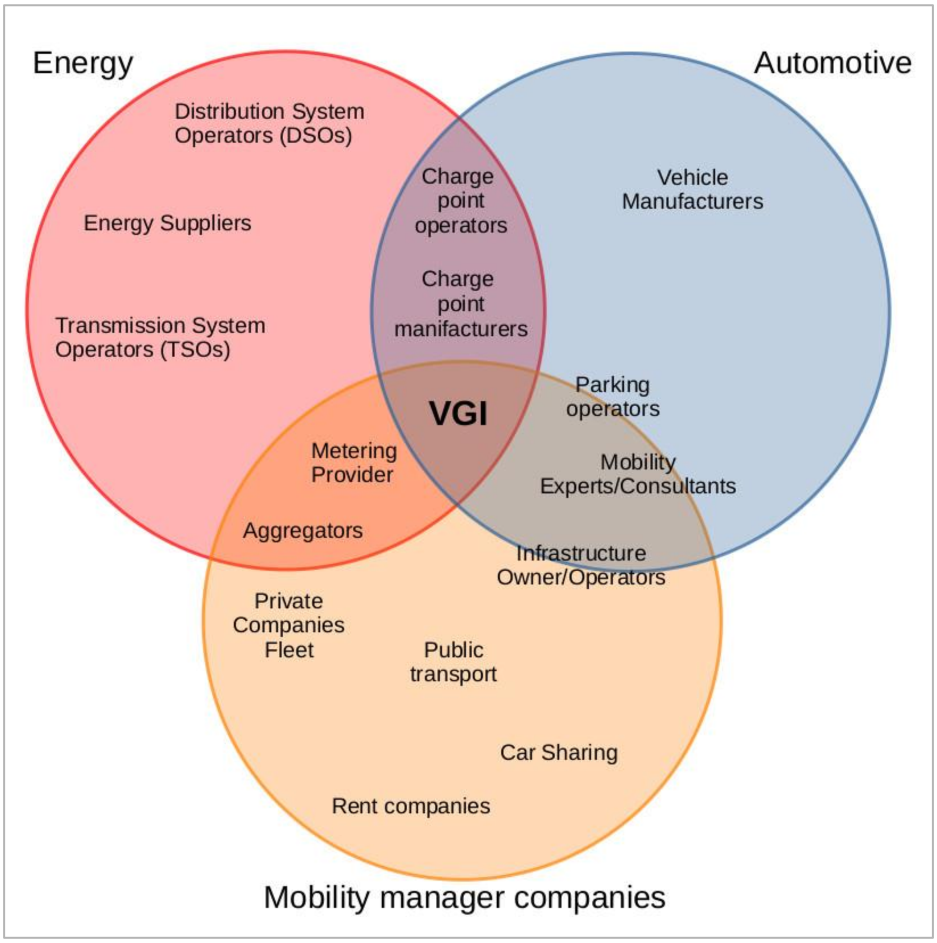

Figure 8 Actors and stakeholders (Corchero Garcia (2022)).

The methodology chosen was the semi structured interviews in anonymous form, a data collection method which relies on asking questions within a predetermined thematic framework (George, 2022). In this way was effectively collected valuable qualitative information, to be subsequently applied to the development of innovative business models.

Comparison between pilot areas

Assuming that regulations and business models will not be significantly affected by local specifications and considering the geographic and economic similarities between South Tyrol and Ticino (Grotto, Cellina, et al., 2020), interviewees and subsequent analyses have been carried out in the same way for the two pilot areas. Thus, in the pool of experts and stakeholders identified and involved in the analysis we can find indiscriminately South Tyrol and Ticino ones. The results and insights obtained from stakeholder involvement are therefore applicable to both the project areas.

The only difference highlighted between Italy and Switzerland is the regulatory framing of the DSO's role, as discussed in the dedicated section. However, it can be assumed that in the time horizon in which autonomous driving will be available and widespread, Switzerland will apply the same unbundling principles valid in the EU for the energy sector.

Main findings

Overall, the interviews revealed that the role of local governments will be crucial in designing the context in which autonomous mobility will be employed. For this purpose, local governance must have vision and be capable of setting ambitious goals to lead the ecological transition and contribute substantially to the climate change mitigation through a careful management of the increasingly integrated mobility and energy sectors. Many of the views expressed in the individual interviews, even the more futuristic ones, are broadly shared by almost all interviewees from different sectors and with different expertise, expressing a need for more ambitious and environmentally conscious policies.

We can summarize the main insights emerging from the interview, their relevance for BMs and the output of the main findings with regard to the key elements of the BM canvas affected by ECAVs:

1. The AVs will have high utilization factors and therefore limited flexibility: they must always be ready for use, thus reducing the impact on grid stabilization;

2. As more players (aggregators of individual EVs) participate in power exchanges through V2G, the more the price differential will decrease due to the inherent behaviour of electricity markets, thereby reducing revenue opportunities;

3. For small economic returns that are difficult to appreciate, it is difficult to see in the future that the average private user would be incentivized to make his or her car available to an aggregator (changing his or her charging behaviour and increasing wear and tear). Different might be the case for owners of large fleets of cars;

4. Fleet decisions are always based on cost logic, and thus react to current trends. With EVs, companies have learned that exposing themselves to technologies with very strong growth and development carries the inherent risk of having vehicles that become obsolete very quickly. This risk factor is considered and often mitigated through long-term leasing;

5. It is important to place fast charging at strategic locations;

6. AVs could add the most value on the last mile, thus complementing the public transportation that already covers the rest.

7. Current investments on electric charging infrastructure play an important role on the diffusion of electric mobility. As set out in the previous points, these infrastructures must be positioned at the most strategic points in the territory, considering technical, social and economic variables. Investments for new charging facilities for ECAVs should be aimed at having infrastructures that will necessarily actuate smart-charging techniques and if possible also bi-directional flows with the grid (V2G).

8. ECAVs could offer flexibility services (batteries on wheels) which could integrate the flexibility services offered by simple EVs. It is therefore important to distinguish them.

The relevance and potential exploitation of such additional services will depend on:

- General context about the transport sector:
  - Availability, cost and diffusion of AVs.
  - Share of AV in respect to other vehicles.

- General situation with regard to future energy system:
  - Diffusion of other form of storage.
  - Diffusion of demand side management measures.^

- Specific characteristics of the network and of the supply/demand situation in the area of interest (the context in which the company would operate)

9. AVs' flexible services appear to have the potential to be exploited, but their future implementation will be heavily influenced by context.

10. Ownership could be rendered irrelevant by AV (and related BMs) transport services.

Finally with regard to the components of the BM canvas potentially affected the most relevant ones are:

- Key activities
- Key resources
- Customer segments
- Value creation

A table summarising the results for the entire set of key elements is available in the 5.1 project deliverable “New business models to cope with ECAVs/ESAVs diffusion”.

2.2.1 Distribution System Operator (DSO)

Distribution System Operators (DSO) are the entities responsible for distributing and managing energy, carrying it from the transmission grid (responsibility of the TSOs) to the final consumers. Thir growing importance in the energy sector and their local nature places DSOs at the centre of the ongoing transition to ECAVs/ESAVs investigated in this context. Regional policymakers must interface with DSOs, since they are directly involved in the physical maintenance of the network and can provide the investment necessary to guarantee the safety and quality of the service. The transition to ECAVs/ESAVs will bring many opportunities for DSOs, thereby requiring them to be prepared in handling the technological developments and adapting the network to accommodate them (DSO Role, 2017) (DSO Future, 2015).

In Europe, the DSO's activities are strictly limited by the authority that issues the distribution service by concession, thus reducing the possibilities in exploiting the business opportunities related to autonomous driving. However, its role will be crucial in other aspects: it will certainly have to react to signals coming from electric mobility operators and support change by adapting the local electric grid. In addition, we already see DSOs being present in associations that guide choices in electric mobility, fostering an exchange of information and practices that is certainly beneficial to all.

A recent trend in South Tyrol (Italy) is the increase in requests for a connection type different from the standard used in Italy for the domestic end user, which is opposed to the rest of Europe. This innovation is being hindered by the Italian authorities who want to preserve a historical situation, despite the advantages that the change would bring (ensuring more power and more control) and that it is evidently very much pushed by the users themselves.

In Switzerland, the responsibility for supply lies with energy supply companies, the majority of which (nearly 90 percent) are owned by public entities, namely cantons and municipalities. After the opening of the market for large consumers, DSOs can also purchase electricity on the free market and supply it to their customers, that cannot purchase electricity by themselves and are thus tied to the local electricity supply company.

3 GUIDELINES FOR THE ECAVS/ESAVS TRANSITION

The results of the simulated charging scenarios allow a wide discussion about cost-optimal planning of EV charging infrastructure in power distribution grids. Regional policymakers' scope for action is mainly about decisions and planning of charging infrastructures. The key evidence is that **smart charging is needed to afford this complex phase of transition toward an ESAV's regional fleet**. A smart charging approach will affect both the electric grid development, with special regard to charging infrastructure, and the EV's management. Regional policymakers should also act in aggregating stakeholders and promoting research and data collection.

3.1 Electric Grid

First, the simulated scenarios lead to the conclusion that **smart charging can postpone the reinforcement of power distribution** grids by controlling the peak charging demand, as expected. Most notably, developing smart charging represents an **alternative to indiscriminate infrastructural reinforcement of the power grid**. There are in addition opportunities to capitalize on the benefits of smart charging by coordinating with the embedded intelligence of the ECAVs. The main strategic aims when developing the electric grid are to:

- promote the **shaving of peak charging demand**, by rewarding the energy returned to the grid;
- encourage **coupling between EVs and the electric grid**, by implementing V2G infrastructures.

The extension of the electric grid to ECAVs, which should be considered as a part of it, will increase the flexibility of the electric grid itself. It means that **it will be easier to cope with the variability of energy from renewable sources**, and possibly increase the share of energy produced from these sources.

3.2 Charging infrastructure

In a home-to-work commute setting, the optimal EV charging infrastructure in terms of investment costs is sensitive to various factors, including mobility demand, operational limitations of distribution grids, chargers' typology, timely plugging or unplugging EVs into and from chargers, and size of the EV batteries. Urban planners should then consider all these factors when designing the charging infrastructure. The simulations conducted allow us to conclude that **smart charging can improve the infrastructure utilization efficiency and thus reduce the number of charging points required at a given charging location**. Nevertheless, it may not significantly reduce the number of charging stations required in a city or a region. This result could be obtained only with the progressive introduction of a shared fleet of ESAVs.

Regarding the charging type, **MPCs (multi-port chargers with AC-to-DC conversion stage serving multiple recharging plugs)** can be considered an initial degree of automation of the recharging process of EVs. These allow arbitrage of the power among multiple locally connected EVs without requiring the EV owners to plug and unplug the vehicles manually; moreover, MPCs can lead to better utilization of the charging infrastructure thanks to improved turnover of chargers. However, this improvement decreases with larger EV batteries. Future studies are needed to investigate interactions between the charging infrastructure at different spatial scales, such as in urban and highway contexts.

The key actions that regional policymakers could take in this context are to:

- invest in **bi-directional smart charge infrastructures;**
- invest in **MPCs**.

3.3 ECAV's smart management

To improve charging infrastructure utilization, it is imperative to properly manage the available ECAVs fleet. Simulations show that **smart charging can maximize ECAV's turnover rates at charging stations, and thus reduce empty rides**, given fixed grid constraints.

The more EVs will become autonomous, the better flexibility of smart charging will be reached, thanks to the autonomous choice of the recharging location of the vehicles. Also, from the economic point of view, **a better optimization is possible if EVs were autonomous** since the model acquires more degree of freedom.

At the same time, it should be considered that increasing the vehicle turnover rate at a charging station may have a negative impact on the V2G potential of ECAVs. A trade-off between these two aspects can be found and dynamically adapted as autonomous driving technologies will penetrate the market.

The key actions that regional policymakers could take in this context are to:

- increase the **availability of shared ECAVs** for the customers, thus allowing to **reduce the size of the ECAVs fleet** required to meet the mobility demand in a community;
- promote the **use of ECAVs as aggregated and distributed storage units to maximize reintegration and self-consumption**, thus giving the electric system the required flexibility to afford the transition to higher shares of variable renewable energy.

Moreover, a smaller number of vehicles in a given region would also **reduce the need for new expensive transport infrastructures** and car parks.

3.4 Collect data and further research needed

To concretely implement smart charging, it is necessary to rely on a large amount of data, which most of the time is incomplete and sparse and must be processed to retrieve proper information. There is specifically a need for data about the charging process, in terms of time, power supplied, and eventual power returned to the grid. It is, therefore, crucial to **encourage the fast growth of data-driven and hybrid smart-charging controllers**, because they are more suitable under the uncertainties, partial observability, and data corruption associated with smart-charging environments. National and regional policies must **push for open datasets and data sharing between industry and academia** to accelerate the development, testing, and prototyping of data-driven and hybrid smart-charging controllers. It will be required to fund future studies to deepen understanding of technical, social, and economic trade-offs of smart charging via future research grants.

4 CONCLUSIONS

The increasing penetration of EVs has prompted many questions about how to properly charge them. Most regional electric grids seem to be not prepared for such a significant increase in power demand. At the same time, **the world is facing an energetic transition toward renewable-based energy**, characterized by a **highly variable availability**.

Regional authorities must cope with these global phenomena, by acting on electric infrastructures. A passive approach suggests simply running after EVs spreading by a structural reinforcement of the local electric grid, to allow the usage of more and more charging stations at a time. Nevertheless, we know that autonomous driving technologies are rapidly emerging, and will sooner or later lead to Electric Connected Autonomous Vehicles (ECAVs). Simulations have shown that **autonomous EVs will impact the electric grid far less than non-autonomous ones**, precisely because of the interconnection between themselves and the electric grid, which allows a deep optimization of both routing and smart charging. It spontaneously arises a question: **is it necessary a huge investment to reinforce the electric grid, if incoming ECAV's technology will leave a significant part of them unused?**

The main result of the European ERA-Net SES project "EVA" suggests that the solution is not to create many new infrastructures, but to smart manage the charging stations. Indeed, **allowing EVs to serve the electric grid (V2G) contributes to stabilizing the electric system shaving peaks in energy demand**. This would help to charge an increasing number of EVs without structural intervention to improve available power. Moreover, EVs coupling with the electric grid guarantees the latter high flexibility, essential in the **energetic transitions towards variable renewable-based energy**. The further crucial element in this transition is the **social and economic convenience of the shared use** of technology in general, of an EV in our case. This affordability increases when moving towards fleets of electric and autonomous vehicles, shared and interconnected (ESAVs). Emerging technologies and sharing propensity could reciprocally influence, speeding each other up.

This transition will not occur alone: must be pushed with **specific intervention by regional and local governments, mainly in the energy infrastructure sector**. The planning of their development must be projected in the light of forward-looking reflections on future mobility developments, which we tried to provide in this report.

According to the accomplished project work, electric and autonomous driving technology might develop until the creation of **regional fleets of ESAVs**. As this transition moves forward, it might be less and less necessary to serve the grid through V2G, since ESAVs themselves have a lower impact on the electric system. We could therefore reach this **radical renewal of road mobility without having undertaken in the meantime useless investments in the long run**.

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