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Blockchain Applications in the Automotive Sector

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About this report

This is the twelfth thematic report prepared by the team leading the EU Blockchain Observatory and Forum. It aims to present upcoming trends, use cases, and blockchain applications in the automotive sector with a focus on the urban and smart city domains.

This is part of the series of reports that will be published addressing selected topics in accordance with the European Commission priorities.

Credits

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Note

While we have done our best to incorporate the comments and suggestions of our contributors where appropriate and feasible, all mistakes and omissions are the sole responsibility of the authors of this paper.

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Contents

CHAPTER 1. CHARACTERISTICS OF THE AUTOMOTIVE MARKET & POSITIONING OF BLOCKCHAIN APPLICATIONS **4**

CHAPTER 2. FUTURE BLOCKCHAIN APPLICATIONS IN THE AUTOMOTIVE SECTOR WITHIN THE SMART CITY DOMAIN **7**

2.1 PARKING MANAGEMENT 7

2.2 RIDE SHARING 9

2.3 PLATOONING 10

2.4 URBAN AIR QUALITY IMPROVEMENT 11

2.5 TRACKING AND MONITORING EMISSIONS 12

CHAPTER 3. EXPERT OPINION ON BLOCKCHAIN INITIATIVES DEVELOPMENT, NEEDS, AND FURTHER ACTIONS **15**

3.1 MOTIVATION BEHIND THE MOBILITY OPEN BLOCKCHAIN INITIATIVE 15

3.2 USE CASES, BARRIERS, AND SYNERGIES 16

3.3 RECOMMENDATIONS FOR EFFICIENT TRANSITIONING OF THE TECHNOLOGY TO A BROADER SCALE 19

CHAPTER 4. ASPECTS ARISING FROM THE USE OF BLOCKCHAIN ON THE INTERNET-OF-VEHICLES: LEGAL PERSPECTIVE AND ANALYSIS **20**

4.1 CONNECTED AND AUTONOMOUS VEHICLES 20

4.2 BLOCKCHAIN 25

4.3 APPLICATION OF BLOCKCHAIN IN THE CAVS ECOSYSTEM 28

CONCLUDING REMARKS 31

REFERENCES **32**

ANNEX **39**

Background on Gaia-X 39

Gaia-X 4 Mobility 40

CHAPTER 1. CHARACTERISTICS OF THE AUTOMOTIVE MARKET & POSITIONING OF BLOCKCHAIN APPLICATIONS

Beyond the world of cryptocurrency, blockchain is finding its way into the automotive sector. Blockchain might serve innovations in communication and data transaction security, component origin and location tracking, and opens up access to an entirely new world of products and services. However, its use in the automotive industry is still at an early stage, and there is a long journey towards where and how the technology can be used best. This section focuses on the preliminary research into the particular market characteristics and needs, the potential role of blockchain in the automotive industry, and the positioning of use cases.

As vehicles and other metrics are valuable measurements for the economy and social aspects in Europe, statistics are published by Eurostat to update the public. There is special attention paid to passenger cars and related statistics, as data tables on the age of passenger cars (European Commission. (n.d.)[d], the type of motor (European Commission. (n.d.)[e], and the type of engine (European Commission. (n.d.)[c] are available to the public. Eurostat provides an overview of the statistics in articles (European Commission, 2022)[f] along with a valuable explanation of the dataset. For example, the definition of passenger cars is fundamental for extracting insights from the data. Passenger cars expand from the conventional idea to include a range of vehicles like vans for passengers, taxis, hire cars, ambulances, and more.

A primary indicator for the automotive sector is the number of vehicles in total. Generally, the number of passenger cars has increased over the years, but the rate of increase varies due to events. For instance, the pandemic halted the increase in the total number, as there were uncertainties about the economic future and lockdown made commuting unnecessary. The updated figures for the years after the pandemic will show if the public prefers purchasing vehicles to meet their commuting needs. The statistics analysed on a country basis reveal an intriguing decline in registered passenger cars in some counties, for example, in Bulgaria (-9.3%) between 2015 and 2020. The figures for the rest of the countries increased.

Europe is undeniably aiming for greener policies, to build a sustainable future for its citizens. These policies can be incentives for desirable behaviours or prohibitions to unwanted ones, mandating different metrics to use as indicators of their success. The engine type of passenger cars is ideal as this correlates with the fuel type. Data on engine and fuel type provide a basis on which to consider their evolution up to the present and trends for the future. Europe reached a landmark in battery-only electric passenger cars in 2020, surpassing 1 million. The growth of battery-only cars has accelerated, as their market share is 20 times higher than in 2013.

The growth of alternatives to contemporary fuels can be attributed to the effect of the green movement on the automotive sector in Europe. On the other hand, petrol and diesel fuel vehicles remain the majority of passenger cars in circulation, despite the decline in new registrations over time.

As previously mentioned, the number of vehicles is only a primary indicator for the automotive sector. Sales of new vehicles are clearly depicted in the metric for the age of the fleet across Europe. Eurostat provides data on the age of national fleets of passenger cars by categorising cars depending on age: 2 years and less, from 2 to 5 years, from 5 to 10 years, from 10 to 20 years, and 20+ years old (European Commission, 2022)[f]. The impact of the pandemic on new cars is evident, as there were fewer cars under two years old between 2019 and 2020. On the contrary, the number of vehicles over 20 years old is steadily increasing, while the majority of the cars are between 10 and 20 years old. The age of the fleet is essential, as technology progresses over time, and newer cars are more efficient environmentally and economically.

Eurostat provides data on European imports and exports of cars, as provided in an article (European Commission, 2022)[e]. European export figures are more volatile than imports, but there is always a trade surplus between the reported periods. The trade surplus peaked in 2015, and a steep decline during the pandemic followed years where the surplus had a downward trend.

Similarly, the Bureau of Transportation Statistics[1] provides an overview of the automotive sector for the USA. In short, the data are divided into specified categories: financial, inventory, performance, and safety. The financial data indicate a decrease in gasoline and oil expenditure after the peak in 2018 and a sharp decline in 2020 due to the pandemic. The number of vehicles reports little volatility in the years 2018-2020, with motorcycle registration going into decline.

Electric vehicle (EV) adoption is an important part of the transition to a low-carbon future, but this adoption is already creating changes in the demand for electricity, which needs to be addressed, as even more vehicles are expected to be adopted in the coming years. More electric vehicles mean our electricity grid balance needs to be reviewed. Faster adoption of EVs will help to achieve lower vehicle CO_2 emission targets and slow down the impact of mobility on climate change, but it will also have a profound impact on the overall electricity demand in the grid and how we are able to balance it with the available sources, including the renewables from sun or wind. Creating smart grid ecosystems encompassing multiple components, which could see the energy for EVs being fed back into the system during peak hours as a sort of decentralised energy bank that helps to balance the grid, could be a promising solution or a new smart service. Dynamic real-time pricing, matching electricity demand with available supply from the wider smart grid and from different sources, could provide the balance that is needed.

To help us optimise EV battery usage in the new generation of electric vehicles, new AI models that will improve the EV battery life cycle will be highly valuable. Owners of EV vehicles will be incentivised to share their data and battery usage securely with data scientists, to help them build new AI efficiency models, which will then be shared back to EV drivers to help them optimise their journeys and extend their EV battery life span. This example takes us from particular a market characteristic, to needs identified, to a point at which blockchain could help. The change in vehicles preferred in terms of type and configuration (e.g., EVs) and in the needs of the infrastructure and industry needed to support urban development in the transition towards smart cities, create a significantly large series of requirements and use cases that blockchain can and was envisioned to support.

PwC has a report on the trends transforming the automotive sector, described by the abbreviation 'EASCY'. The acronym comes from the initial letters of the words detailing the trends within the sector: electrified, autonomous, shared, connected, and yearly updated. Regardless of individual trends, the outcome will be easier, safer, cheaper, and more comfortable driving for citizens, as the focus will be on users. There are different issues to take into account resulting from the general trends. For instance, artificial intelligence (AI) use will be extensive and result in greater usage of individual cars but a decrease in the total number of vehicles due to more efficient utilisation of the car services such as MaaS (mobility-as-a-service). On the other hand, the use of vehicles in the fleet will impact the lifespan of the vehicles as the frequency of use will increase. In other words, newly bought vehicles will replace older ones. Metrics to consider for the life expectancy of vehicles are estimates of personal mileage and vehicle mileage.

[1] Bureau of Transportation Statistics. Automobile Profile. Retrieved from: https://www.bts.gov/content/automobile-profile

Deloitte's analysis takes a consumer-based approach based on surveys carried out and detailed in the report. It should be noted that the region covered in the report is EMEA countries. In brief, the points can be summarised as follows:

- Consumers are unwilling to pay premiums for advanced technologies.
- Electrified vehicles, even hybrids, pique consumer interest as a lower cost and more environmentally friendly solution.
- Consumers are unwilling to execute transactions online compared to the in-person experience.
- Mobility shifted away from shared mobility to personal vehicles due to the pandemic.

An intriguing point from Deloitte's consumer report is the personal data exchange, as consumers are willing to share their data to access quality services. This trend raises questions for the future about data ownership and management, including permissioning, as tools for maintaining security should be in place. For this reason, blockchain can be a layer for data management and monetarisation. The initial use case for blockchains was the creation of digital tokens for a network of users, as described in Bitcoin's whitepaper. Essentially, fungible or non-fungible tokens (NFTs) facilitate the exchange of assets and values in a decentralised system. The use of blockchain for permissioning and to secure data ownership can be seen as a valuable option, as detailed in EUBOF's previous report on healthcare.

While the aforementioned applications of blockchain technology certainly make a strong case for changing many facets of the automotive industry, the community is just starting to explore the surface of blockchain applications in the automotive sector within the urban and smart city domain. The following sections are dedicated to the exploration of upcoming trends (see TRENDING BLOCKCHAIN APPLICATION IN AUTOMOTIVE WITHIN SMART CITY DOMAIN), an expert's opinion on blockchain initiatives in the sector (see EXPERT OPINION ON BLOCKCHAIN INITIATIVES DEVELOPMENT, NEEDS, AND FURTHER ACTIONS), and an analysis of existing legal grounds (see ASPECTS ARISING FROM THE USE OF BLOCKCHAIN ON THE INTERNET-OF-VEHICLES: LEGAL PERSPECTIVE AND ANALYSIS).

CHAPTER 2. FUTURE BLOCKCHAIN APPLICATIONS IN THE AUTOMOTIVE SECTOR WITHIN THE SMART CITY DOMAIN

While there are already many actively developing use cases, such as vehicle and component identities, there are numerous applications still to be explored. In this section, we aim to focus on the use cases at different levels of development within the urban and smart city domain, on the basis of our research. There are two main reasons for this: the urban use cases are more easily understood by the general public and hence have a high chance of being applied on a large scale; and second, the urban environment requires extra caution and support from the regulations and laws, and this section outlines the ongoing and future directions that government agencies and city administrators should look into.

2.1 PARKING MANAGEMENT

One of the applications to consider for smart cities and the automotive sector is parking management systems. These systems generally aid drivers to quickly navigating to park their vehicles. The application brings together the demand for parking, drivers, the supply of spots, and owners of the spots. It is, therefore, apparent that the application handles private data for both kinds of users and can incentivise owners to participate in solving an urban problem.

The value of parking management derives from the weaknesses created by different socioeconomic factors. Firstly, the competition between drivers in urban areas for the limited parking slots is immense. The results are traffic congestion caused by drivers seeking empty spots, and the increased pollution from the emissions as a result. Some trends can aggravate parking problems, like increased urbanisation and car sales. There are applications for parking management, such as Parkme[2], JustPark[3], and more, to make parking more accessible, less time-consuming, and more environmentally friendly.

Intelligent networking between vehicles and parking infrastructures in an open ecosystem without a lock-in platform effect would help to eliminate a lot of congestion and improve traffic flows in our cities. According to various studies, drivers looking for parking account for between 8 to 74 % of urban traffic (Hampshire & Shoup, 2018). These cars cruising the cities looking for a parking space create a lot of congestion and significant delays. From an environmental point of view, this translates into elevated CO_2 emissions and the resulting air pollution. The lack of parking spaces is not the only cause of traffic congestion. Drivers often spend extra time driving around looking for more economical parking or parking that is closer to their destination to save time. Providing real-time information about parking availability and enabling dynamic pricing incentivising low-demand parking spaces to improve occupancy distribution could solve some of the issues with allocating parking spaces and improve overall traffic flows.

In Deep parking, additional parking spaces can be provided to the parking market ecosystem by individuals or companies putting their own unoccupied parking spaces on the market and providing information about their availability, location and price. Availability and occupancy can be monitored with IoT sensors or cameras and updated in real-time.

[2] Parkme website. Retrieved from https://www.parkme.com/

[3] JustPark website. Retrieved from https://www.justpark.com/

Blockchain is a technology that can be added to other available technologies for deploying parking management systems, as contemporary solutions run different risks. An initial consideration for parking management is to preserve users' privacy, as personal data are necessary for the proper operation of the service. The service users are drivers and parking space owners, who provide data like their location, ID, and other personal information. This is where blockchain can be used to maintain privacy. Another possibility for the application is in infrastructure, as parking management systems usually operate on centralised structures. These centralised structures result in service availability issues, since centralised entities entail risks like a single point of failure, security breaches, or even the favouring of users. Moreover, the governance model of these systems relies upon a single authority that must be trustworthy and reliable. Blockchain can result in shifting the model to democratise participation in the application's governance. Applications using blockchain for parking management have been tested on the market. During the ICO craze in 2017, one such idea surfaced in Parkgene (2017), which aimed to create an ecosystem for rental contracts between drivers and owners of parking, based on Ethereum.

Complex applications mesh different technologies to deliver robustness. Moreover, different technologies create a stack to provide a range of functionalities to the application and address issues. For example, Singh et al. (2022) base their energy-efficient smart parking on encryption algorithms for securing communication, blockchain for data security, virtualisation for distributed storage, and deep learning for analysing data. This particular application uses blockchain on the RSU layer for authenticating and validating the data, as the RSUs act as miners for appending new blocks. Energy efficiency and intelligence are handled by virtualisation and deep learning.

As technologies increase for application development, consideration should be given to the system's architecture. While smart contracts can be tools for deploying business logic on the blockchain, developers have to design systems that make the most of the infrastructure and capabilities of the different technologies. Decentralised applications (DApps) should be considered to achieve granularity and system management. In an example from Zinonos et al. (2019), ParkChain uses the Ethereum blockchain, along with AI techniques, for license plate recognition to prevent unauthorised entrance to a parking space. The functionalities are offloaded to different hardware infrastructures and deliver other functionalities. Distributing the execution of functionality can use computational capabilities and augment the system's overall security.

The primary consideration in a centralised system is the users' privacy, especially in systems like those for parking, which handle personal information. Blockchain's layer two solutions address scalability issues like transaction throughput and user privacy by suggesting private channels or ZKP and optimistic rollups. An example comes from Hu et al. (2019) which has two separate blockchains for achieving privacy. While the consortium blockchain settles the negotiations, the amount is information that will be included in the public blockchain. A similar approach with multi-blockchains for privacy is in Kim & Kim's (2020) work, where a fine-grained view of the data stored on public and private blockchains is provided. Specifically, the private blockchain has data gathering and processing modules, while the public blockchain executes data provision and incentive management modules. There are different suggestions in the literature for achieving privacy for parking management systems with blockchain. Users must sign transactions to validate them, which are then available for audit on the distributed ledger. The literature suggests using short, randomised signatures to conceal the identity (Al Amiri et al., 2019, Badr et al., 2020). Short randomisable signatures seem appropriate for use in parking management, as the application requires repetitive transactions by users, who would like to maintain their privacy.

Blockchain can digitally represent physical objects with tokenisation methods. Tokens represent the physical objects on the blockchain, allowing the tracking of ownership. Non-fungible tokens became popular due to the fact that tokens can carry metadata for differentiating their features and are unique. NFTs use cases have been researched in EUBOF's earlier report and included: gaming collectables, art, supply chains, and more. Parking services can draw inspiration from blockchain's land registries since parking slots are a piece of land which can be tokenised. A research proposal from the literature has been published in Jennath et al. (2019), where ERC-721 tokens represent parking lots as unique identifiers stored in owner's wallets. The application involves governmental authorities to validate the available land.

Blockchain can impact parking management systems in different ways, like opening participation and constructing new economic models. The participation stems from the opportunity to decentralise the execution of tasks which consequently opens opportunities for devices with lower capabilities to partake in the system. Kim & Kim (2020) have pointed out the high cost of installing IoT sensors, and their suggestion for a crowdsensing-based system based on the blockchain can drive participation with more independently owned devices. Economic models require time to acquire data and predict how they will evolve. Most of the applications make use of the creation of crypto tokens for incentivising participation in the parking system. The idea requires digital wallets for storing authentication and digital tokens.

2.2 RIDE SHARING

Recent years have seen a trend for citizens to use digital applications to rent vehicles and their services as part of the MaaS (mobility-as-a-service) concept. The applications cover numerous vehicle types, from bicycles and taxi services to personal rides. Such services are called ridesharing or ride-hailing and have become popular in recent years with providers like Lyft, DiDi, Uber, and more.

The current applications are similar to a marketplace deployed by a software vendor to bridge the demand for lifts with available supply in urban areas. This context points to a centralised entity as the software vendor and separate individual entities as the ecosystem. There are concerns about the market operations as most power lies with the centralised entities. The first concern is the commission fees governed by the centralised entities, which take a percentage from the drivers. There are calls for artificially low rates to attract users to the platform and to raise the price once convincingly established (Smith, 2016). Moreover, the commission rate system is susceptible to change, as the software vendor imposes the policy on the network (Zhao & Su, 2019). The calculation of the fare and commission can be a black box for the platform's users, as they are calculated by an algorithm curated by the software vendor. This black-box paradigm lacks transparency for users, who can be left baffled by the mechanism. Finally, the governance of the ecosystem built around the platform is closed, as there is a centralised entity in the marketplace. The above considerations are mentioned in whitepapers for blockchain applications like Drife[4] and Dacsee as a means to appeal to potential investors.

With the aim of empowering drivers and passengers inside its ecosystem, Drife[4] was founded as a decentralised peer-to-peer ride-sharing platform. Built on the Aeternity blockchain, Drife only charges drivers an annual fee for accessing the platform. A feature of the Drife app enables the basic fare to be calculated in accordance with market conditions. This feature provides for fair pricing and gives the driver and passenger a chance to negotiate the rate. Additionally, Drife eliminates the problem of fares being unfairly increased while a ride is in progress, because it is a decentralised application on the blockchain without intermediaries.

There are other social and economic concerns about the ride-hailing service. Users can create side hustles to boost their income as part of the gig economy (Sundararajan, 2015), creating headaches for tax authorities. A

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[4] How Drife and blockchain are disrupting the ride-sharing industry. https://cointelegraph.com/press-releases/how-drife-and-blockchain-are-disrupting-the-ride-sharing-industry

social concern lies in an issue caused by the application of technology and new economic models. The deployment of such applications makes traditional jobs like taxis, which are considered direct competitors, obsolete (Jennath et al. 2019). Cases like Uber losing its license in London indicate the turmoil and shifts brought by the technology and its applications (Chee, 2018).

2.3 PLATOONING

Automated driving is one of the future trends that will disrupt the automotive industry and change drivers' behaviour. In envisioned scenarios, travellers could travel with minimal interaction with the vehicle, as the vehicle's decisions are based on information about the surrounding environment. Services for automated driving, like platooning, aim to increase efficiency and minimise costs. Platooning is the method where vehicles form clusters and operate homogeneously, sharing information between the vehicles as part of the internet-of-vehicles (IoV) ecosystem. A benefit of platooning is that the cost decreases as fuel consumption is minimised due to reduced air resistance and speed changes. Urban traffic management handles platoons of vehicles rather than individual ones, resulting in more road capacity. As a result, platooning reduces accidents, making driving safer, as vehicles will have information from multiple sources. Moreover, platooning reduces emissions and can serve as a bridge between our current state of mobility and a world in which all cars are autonomous with the wide use of V2V (vehicle-to-vehicle) and V2X (vehicle-to-everything) communications supported by the blockchain.

Blockchain applications in platooning have been reported, such as IOTA's Tangle network[5], a service where a human operates the platoon leader while the rest of the platoon operates automatically.

Blockchain can help in building trustless and fair platooning services in different ways. Firstly, the platoon's leader serves the rest of the vehicles and needs to be reimbursed for these services. A fundamental use of blockchain is the creation of a digital currency and the formulation of payment, as indicated by the use of Bitcoin since 2009. The literature suggests reimbursement systems based on blockchain for platoon leaders. Specifically, Chen et al. (2019) use smart contracts to automate the payment process and use road-side unit (RSUs) capabilities to offload their execution to let automated vehicles spend their computational capacities on decision making. Capgemini introduced the BEEPS platform[6], where innovative technologies like 5G, AI, and V2X, along with blockchain, are components for composing logistics capabilities for platooning services.

Another crucial aspect of the service for platooning is the election of the platoon leader. The platoon leader is the vehicle leading the rest of the platoon to a destination. The importance of the leader becomes even more crucial in a fully autonomous driving environment where the vehicles following are responsible only for keeping safe distances within the platoon. The election process can be complicated, as reputation can be a metric on which an election scheme for the platoon leader is based, as presented in Ying et al. (2021). In this work, a consortium blockchain on Hyperledger Fabric stores the reputation of each vehicle. There are intriguing ideas for including blockchain in the election process, like using leader-based consensus algorithms (Xiao et al., 2022). Essentially, Raft defines a clear process for electing a leader who can simultaneously act as the platoon leader. There are election processes for changing the leader and making the procedure fairer for everyone.

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[5] IOTA Foundation Blog. (December 16, 2020). Untangled Episode #13: Fraunhofer Platooning. Retrieved from https://blog.iota.org/untangled-episode-13-fraunhofer-platooning-a32731d5ccf6/

[6] Capgemini Engineering. (October 2020). Blockchain Enabled Enterprise Platooning Service (BEEPS). https://capgemini-engineering.com/us/en/brochure/blockchain-enabled-enterprise-platooning-service-beeps/

Privacy is a key aspect of every application, as identities and data have to be secure. Individuals traditionally carry identification documents to verify their identity to third parties. The case is similar in the digital era, where machines like cars can have their own identity. Moreover, the platooning service carries information like the vehicle's position, the companies cooperating, transactional data, and other data deemed too important to be publicly shared for safety reasons. Blockchain can enhance security and privacy for a reliable service.

Singh et al. (2020) propose a two-layer architecture with two blockchains for achieving trust and efficient platoon management. Essentially, the first blockchain is kept private between the vehicles and establishes trust between the parties. The private blockchain is linked with a second public blockchain curated by RSU devices, which stores the changes in the state of the private blockchain. The two-layer architecture aims to keep information private by having platoon vehicles, commonly under one company, operate the chain on the first layer.

While the aforementioned architecture is general and applicable to more blockchain services, zero-knowledge proof (ZKP) can have a role in concealing data like the location coordinates of vehicles. Li et al. implemented ZKP in a permissioned blockchain to preserve privacy within a location-aware system. The system conceals the identity of the vehicle, as this can be considered business crucial for organisations. The concept of ZKPs is used in other automotive cases, like concealing the identity of passengers in ridesharing services (Li et al., 2021). In all cases, a distributed ledger is used as a place for executing the transactions, and ZKPs are a tool to prove to third parties that the transaction is valid without revealing crucial information.

The deployment of a platooning service requires the establishment of communication channels for the vehicles. Typically, the information exchanged provides the current situation on the road network and the actions of the convoy. As a future trend for the automotive sector is the proliferation of autonomous vehicles, message exchange must be secure with little overhead. Communications have to be in real-time for autonomous vehicles to make decisions and transmit the decision to the rest of the convoy. Publish and subscribe channels are a candidate for using blockchain to maintain security for exchanging messages between vehicles in truck platooning, as in the work presented by Xing et al. (2020). Platoons operate as the brokers for the application, benefitting from the fact that they operate under the same organisation. Pub-sub channels based on blockchain exist in other sectors, such as IoT (Krejci et al., 2020) and the microservices marketplace for smart cities (Xu et al., 2019).

2.4 URBAN AIR QUALITY IMPROVEMENT

The growing environment-friendly consensus is larger than the climate change movement of previous years. EUBOF's supply chain report referred to the impact on that sector, and the automotive sector also has to consider environmental aspects. For example, air quality is an appropriate metric for the health and prosperity of a community, and air pollution is significantly correlated with public health and related public expenses. In brief, higher quality air will impact the public's longevity and quality of life, and there are initiatives to improve urban air quality around the globe.

There are different approaches in the literature for how to include blockchain for air quality. Most applications use a mixture of sensors in the city infrastructure or on vehicles to measure pollution and emissions. This section explores the use of blockchain in efforts to improve air quality through the automotive sector.

A basic concept for using blockchain for air quality would be data validation from IoT devices (Benedict, 2019). In this application, blockchain is a layer for establishing data immutability so entities can build their applications around reliable data. The blockchain nodes can be deployed as virtual machines on cloud computing infrastructure to ensure data integrity. There is an application for streaming weather data from a station to

Ethereum (Sofia et al., 2020). The data include defined concentrations, gas concentrations, and organic compounds. Ethereum is used to solve the sensitive data's validation, timestamping the data packages from the weather station. The application's functionality was tested in Ganache, a component for evaluating smart contracts' behaviour once deployed on Ethereum. There are other innovative ideas for using blockchain in air quality measurement. For example, ArmChain (Yusuf et al., 2019) explores the creation of a blockchain-based communication layer for vehicles compared to MQTT.

Ford[7] did an intriguing pilot where hybrid electric vehicles were used to test the combination of geofencing and blockchain for air quality in urban areas. The effort expended on the pilot have been remarkable, as the data covers a three-year period and more than 400,000 kilometres in municipalities in London, Cologne, and Valencia. Dynamic geofencing is relevant to the trend for cities to define low-emission zones where environmental limits are set for certain road networks.

The Cologne pilot has taken bolder steps towards merging geofencing with blockchain. The use of blockchain here is no different from how it is used in other applications, as it enables trust in the data to be built in a trustless environment. As is the usual case, critical events and their underlying data are of interest and should be documented on the blockchain. The critical event in Ford's pilot is the entrance of a vehicle into the low-emission zone. For this reason, the application send data to the blockchain once the vehicle enters such a zone. The blockchain data are immutable and can be used to prove the switch to the low-emission mode.

2.5 TRACKING AND MONITORING EMISSIONS

Emissions and controlling them were initially part of the greenhouse effect movement, as environmental conscience was low among business practices, and the concerns for the future were piling up. Efforts to ameliorate health concerns and improve quality of life for citizens need to include the monitoring of emissions for forward planning. For this purpose, legislation and standards have been introduced to manage the vehicle emissions as they are the prevailing means of transportation for passengers and goods.

European legislation bears in mind the type of vehicle as it covers numerous vehicles transporting people and cargo, like buses and trucks. Additionally, the legislation includes emissions of nitrogen oxides, total hydrocarbons, non-methane hydrocarbons, carbon monoxide, and particulate matter as toxic emissions harmful to people. In particular, European standards for emissions were first published in 1992 and were updated to the current version named Euro 6. An update is imminent as Euro 7 has been postponed. Apart from the standard, the European Union introduced Directive No 443 in 2009 for a mandatory emissions target on the fleet's CO_2 emissions and Regulation 510 in 2011 for the emissions of vans. Both of these were replaced by Regulation 2019/631, which covers vehicle and van CO_2 emissions. The new legislation came into effect in 2020 and sets targets for 2020, 2025, and 2030 and mechanisms for incentivising low-emission vehicles.

A fundamental approach is to use blockchain to store valuable data without tampering with them. As standards and legislation are in place to govern emissions for individual vehicles and fleets, standardisation authorities have to be confident that the data have not been compromised. Blockchain is a technology that can ensure data immutability for emissions tracking. Specifically, a Joint Research Centre (JRC) report details emissions monitoring systems it has piloted. Hyperledger Fabric is used to create permissioned networks and guarantee

[7] Ford Media Center. (December 2020). *Ford study shows blockchain, dynamic geofencing and plug-in hybrid vans can help improve urban air quality.* Retrieved from https://media.ford.com/content/fordmedia/feu/en/news/2020/12/17/ford-study-shows-blockchain--dynamic-geofencing-and-plug-in-hybr.html

privacy through their channels. Another example of an emission monitoring system is suggested by Nußbaum et al. (2021), where blockchain merges with contemporary technologies to deliver a holistic system. As data from sensors are stored on the blockchain, the information is visualised for the public by dashboards using web libraries.

Another solution popular in the literature for applying blockchain is emission trading systems. The principal for basing such a platform on blockchain is to use blockchain as a trusted layer for storing data and deploying business logic on smart contracts. Smart contract execution automates procedures, and their immutability helps build trust between the stakeholders. Businesses can decrease costs and improve efficiency by minimising mistakes and omissions. Li et al. (2021) propose a system considering the whole downstream and upstream for emissions trading. The platform can facilitate the varying standards set by public authorities as the standards provide the numerical limitation for defining vehicles' efficiency. Similar systems built on blockchain can be found in the energy sector for trading electricity and were included in EUBOF's report.

Another intriguing application for blockchain and smart contracts is the automated enforcement of cap restrictions. While sensors can offer a stream of data documenting vehicle emissions, an ongoing and reliable evaluation is possible with smart contracts. As blockchain has multiple nodes and abolishes centralised authorities, the network can perform its operations as long as there is even a single available node. Moreover, reliability is achieved through the decentralisation of the execution. Lu et al. (2022) proposed STRICT authority with smart contracts handling functionalities like emission permission for purchase and emission violation.

As an output of a European project, Intelliot has suggested an emissions allowance trading system for vehicles as a decentralised platform based on a distributed ledger to achieve transparency and trust (Nguyen et al., 2021). The system is based on smart contracts adhering to requirements set by EU-ETS for the trading system. The operations are allocated in four distinct steps: publishing data, emission control, emission allowance trading, and settlement. Such an architecture can follow architecture proposals from the IoT sector for maximising resource usage. Vehicles can be handled as network edge nodes to execute tasks, while blockchain is a layer for storing data on a shared ledger and executing agreements with smart contracts. The benefits of such a platform can be monetising the unused emission limits and representing the value in digital tokens held in digital wallets.

Another European project on emissions was DIAS, where secure access and control over emissions data is accomplished via blockchain and self-sovereign identity (SSI) (Terzi et al., 2020). Emissions must be between values set by standards, and these data should be tamperproof. Blockchain offers a layer for secure data storage to store data permanently. The network is based hyperledger solutions to establish a permissioned network that operates zero-knowledge proof (ZKP) cryptography to minimse sensitive and private information. An issue in blockchain projects involving numerous stakeholders is the publication of data on the ledger available to the network's participants. The information is discrete from a cryptographic proof proving the statement to the network's participants.

Emission tracking and monitoring can expand in the future, as trends in the automotive sector may set requirements for others. A trend from the automotive sector that can impact emission traceability may have its root in the proliferation of electric vehicles (EVs). EV batteries leave a carbon footprint as they require mining and heavy processing. Such use cases indicate the need for applying traceability in the automotive industry's supply chain to achieve green goals.

Finally, identity is an issue in all the aforementioned systems. Vehicles require identities to operate in the network and to post their data. The necessity of identities is further evident in a paradigm for a new economy where devices can transact with each other without human intervention. Essentially, identities can aid in forming a path to trace and set accountability as a focal point.

CHAPTER 3. EXPERT OPINION ON BLOCKCHAIN INITIATIVES DEVELOPMENT, NEEDS, AND FURTHER ACTIONS

Expert profile: **Tram Vo** is the **CEO** & **Co-founder of MOBI**. A former art conservator with degrees in chemistry and studio arts, Tram spent many years consulting and working for organisations such as UNESCO and the J. Paul Getty Trust on cultural heritage conservation and preservation projects. In 2015, Tram began looking into smart contracts as a new way to preserve content producers' Intellectual Property Rights. This would lead her to co-found MOBI in 2017 with an aim to bring blockchain-enabled smart mobility and smart city applications to scale.

3.1 MOTIVATION BEHIND THE MOBILITY OPEN BLOCKCHAIN INITIATIVE

Q1: The vast majority of the players in the domain are familiar with MOBI, but what would be interesting to learn is how the initiative was started and what was the motivation or need. Could you tell us more about it?

A1: A little bit of background about MOBI and how we started back in 2016 and 2017. Many of our members were very excited about blockchain. They performed many proofs of concept and found that putting a vehicle, data or services onto a chain was easy. The technology was there, but they found out that the application couldn't scale, and it couldn't go anywhere. The reason being is that **we need standards** as an industry: criteria on how to identify the vehicle, trips, etc. When does a trip begin? When does it end? How do we share data, and how do we settle transactions? None of these things had been standardised yet. I think it's because many organisations were using blockchain, which is a Web3 technology, but they were still building and performing these proofs of concept on Web2 platforms. For example, one of the OEMs would build a multimodal platform and couldn't convince other OEMs to go onto it. Another OEM builds a supply chain platform but can't convince other OEMs to go onto it. In any case, it's difficult to bring multiple stakeholders to work together on a single proprietary platform. This is true for a few reasons. For one, these platforms are behind firewalls. And two is, there's also the antitrust policy. Recently, I talked to a logistics organisation in Europe that had spent $54 million on building a logistics platform. They got everybody in their vertical to onboard, but they ultimately couldn't convince other logistic providers to join the platform.

There are many stories like that, and I'm sure it's like that for many industries. And that's why MOBI started: so that stakeholders across the globe can work together to create standards. We can build a Web3 infrastructure together and map out identities for the ecosystem using a common framework. We call these identities Self-Sovereign Digital Twins™. MOBI is technology and vendor agnostic; therefore, we can have competitors sitting at the table working together for the good of the ecosystem.

Q2: MOBI actions seem to be actively transitioning from the US to the European market not only in terms of expertise but the pilots and particular use cases, such as the Citopia pilot. Could you give more details on that?

MOBI was launched on May 2nd of 2018, and from the beginning, we have been a **global organisation**. Approximately a third of our members are based in Europe, a third is based in the US, and a third is based in Asia. Our first working group — Vehicle Identity, or VID — was formed in 2018. Renault and Ford chaired that group. So, right from the beginning, we have had a **European presence**, and we have always had a diverse membership.

MOBI is a standards body, and so our standards, from the beginning, have been **intended for international adoption**. The first standard, released in 2019, was the MOBI VID on vehicle identity, which is a marriage between the ISO VIN standard and W3C's Decentralised Identifiers (DIDs) standard.

The European Commission, a MOBI member, has been involved with MOBI since 2019. One of the judges for the second phase of the MOBI Grand Challenge, Citopia, was employed by one of the agencies of the European Commission. This year we completed a pilot with the European Commission's Joint Research Centre, which focused on vehicle emissions self-reporting using Citopia and the Integrated Trust Network (ITN), the latter of which we are developing jointly with MEF, AAIS, and other consortia members from across the globe. In terms of regulations, including GDPR, MOBI standards and pilots always follow the strictest guidelines to **ensure scalability** across international and organisational lines.

3.2 USE CASES, BARRIERS, AND SYNERGIES

Q3: Are there any concerns in the industry that MOBI either already faces or envisions, and what does MOBI do about them?

A3: It doesn't matter what industry we are in. Right now, **two top concerns** seem to be discussed a lot by many industries. The first is **data privacy**, especially customer PII [Personal Identifiable Information]. So how do we safeguard the customer PII, and how do we safeguard our data? The number two concern is **interoperability**. How do we all do business with each other? How do we share data? How do we communicate and settle transactions without building new infrastructure? How do we do that without having to keep upgrading infrastructure every two years or so?

We are building out the ITN, which is the DIDs registry, and Citopia, a federated marketplace, to help address these concerns. I should talk a bit more about the architecture we built on a high level. Citopia and the ITN are both run by our members, and these members can be anywhere around the world. With the pilots, we aim to demonstrate what the technology is capable of and show that multi-party applications are possible.

So, there's no application we are building, but we are enabling services like **onboarding** and **service discovery**. Through MOBI solutions, we are implementing **zero-knowledge proof** technology and **enabling privacy-preserving transaction settlement** on Citopia. Citopia also enables the onboarding of Self-Sovereign Digital Twins, which acts as a self-sovereign identity that resides on the user/controller's smartphone or server.

I do have an aspiration that we can talk with European countries about joining our efforts because, ideally, these **networks are only as robust as the organisations running them**. So, if governments would like to come in and see how it works, we welcome them. I truly believe that no matter how much we advocate for what we are doing, it won't go very far if we don't have government buy-in.

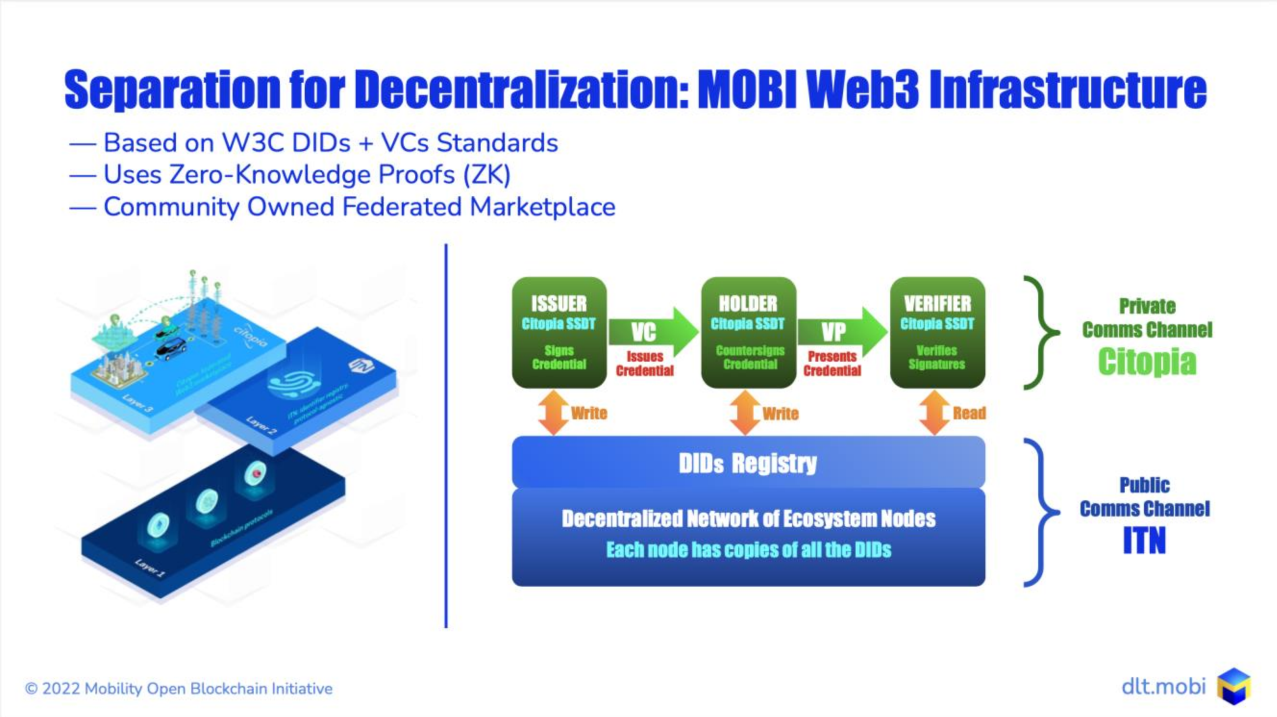

Figure 1: MOBI Web3 infrastructure

Q4: Is there a difference between EU and US market needs, and do you have any ongoing collaborations with European initiatives?

A4: Many of the applications we are demonstrating on Citopia are valid for global markets and deal with international concerns and use cases. I've spoken with representatives from many government agencies in Europe and the US and found that they have similar needs. For example, as electric vehicles grow in popularity, the **gas tax** is going to bring in less and less revenue. As such, governments are seeking new ways to fund road infrastructure. One of the most popular alternatives to the gas tax is road usage charging, which many government agencies and toll road operators have explored heavily in recent years. However, this requires the ability to collect usage data and facilitate these transactions in a tamper-evident, privacy-preserving manner. This is a pain point that many governments around the world are looking at. Another similar case is **usage-based insurance**.

Regarding interesting potential synergies, we've been talking with **Gaia-X** (see ANNEX) as we are doing essentially the same thing and hoping to work together to build out a more robust connected ecosystem. Catena-X mainly focuses on the supply chain, similar to MOBI's Supply Chain Working Group. MoveID is similar to Citopia, and IDunion is similar to ITN. We all are trying to solve the same problems.

I believe we [as a community] don't have enough resources or time to do everything that we want, and I don't believe in reinventing the wheel. If all you do is reinvent the wheel, sooner or later, you'll have a garage full of wheels and nothing else. So, we hope to sit down with other initiatives like GaiaX so that we can support each other. And if we can share the work, we don't duplicate efforts. To our knowledge, many MOBI members are also Gaia-X members. One of our members, who is also a Gaia-X member, has implemented MOBI VID as a POC [Proof of Concept]. So, I hope we can all **work together to improve the space**.

Q5: Based on the analysis of the use cases' popularity, we noticed that vehicle identity and CO_2 emission are the trendiest. Yet, when we try to talk to the general public, such use cases might not always be understood in depth. Are there any urban/smart city use cases within the automotive sector that you believe the general public would easily engage with?

A5: I think the use case that the general public would relate towards is **seamless transportation** because we all know the pain points when we travel. Many governments are looking for ways to enable more **seamless multimodal travel**, and that's because their end users are asking for it. From the end-user perspective, for example, I would like to plan it all from one gateway instead of having multiple apps and comparing prices and modes. So, I think, in the end, the general public is looking for that solution. End-users don't know how we [technology providers] are going to solve it and might not care. It is like the internet, 99.9% of the general public doesn't know how the internet works and might not think of that as long as they're getting a smooth experience. So seamless multimodal is the "number one" use case for the end-user and public to easily understand in terms of blockchain applications in automotive because the trust would be essential in such applications. And based on this use case, we can gradually explore more use cases.

Another use case we're working on that will enable other use cases to build on it is the Dealer Floorplan Audit. To us, this is somewhat of a simple use case because there are not many stakeholders: you have the bank, the dealership, and the car. And despite the simplicity of the process, the value of the solution is clear and high.

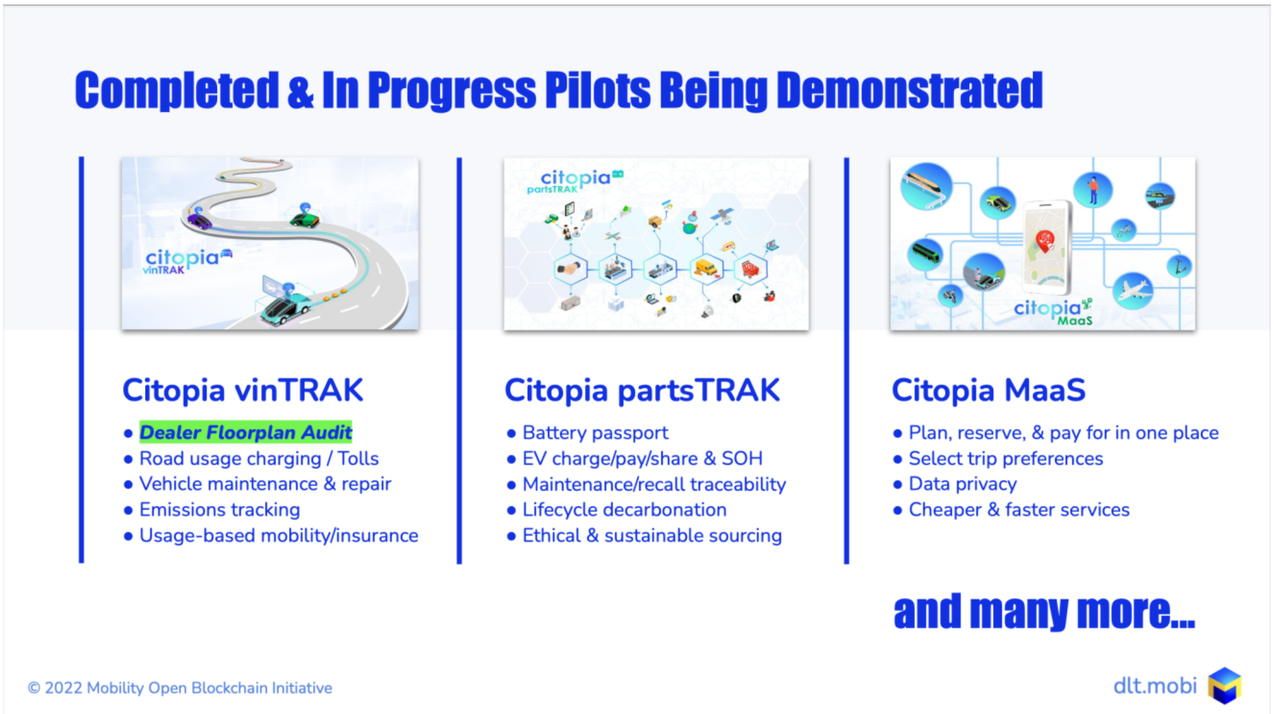

Figure 2: MOBI pilots

We're close to completing a pilot for this use case. The pilot leverages Citopia vinTRAK, which links a vehicle's self-sovereign identity with its time-stamped location and pertinent metadata into a verifiable trip. We showed our progress in a demonstration last week — we haven't arrived at the finished product yet, but our members, including BMW, Ford, GM Financial, Honda, Toyota Industries, and Mazda, were very excited about it. Currently, the pilot is based in the US, but we would love to do it with one or more partners in Europe. We use zero-knowledge proof implementation, which ensures that no sensitive or confidential information is transmitted during the pilot

3.3 RECOMMENDATIONS FOR EFFICIENT TRANSITIONING OF THE TECHNOLOGY TO A BROADER SCALE

Q6: Would you like to share any insights based on your/MOBI experience that would be important for the formation of future regulations or easier/more efficient transitioning of the technologies across multiple countries (an ecosystem approach)?

A6: I strongly believe in the **public and private sectors working together**. Throughout my whole life, it hasn't mattered which career I'm in; it's always about facilitating public and private collaboration. And so this is not any different. No matter how excited we are and how cool we think the technology we are working on is, we need government agencies to be involved. And if we can sit down with such entities and be able to talk about the capabilities of the technology and what it can solve or what kind of issues we could help with, this would enable us to work together on policies that serve everyone.

Enterprises want to be able to comply with regulations. Likewise, regulators want to create regulations with which enterprises can comply. Otherwise, there is no point in having such regulations. To sum up, it would be wonderful if we all [public and private] could sit down together and talk about the potential of the technology and what solutions we're looking for. At the end of the day, the government needs to be involved.

As I mentioned earlier, many governments are looking for a solution to road usage charging [as the adoption of electric vehicles is increasing]. Still, governments haven't mandated that the vehicle itself needs to pay for road use. If they do, then the OEMs would have to implement a solution. For example, we could think of an asset wallet in the vehicle so that it can pay for all these needs or consumptions.

CHAPTER 4. ASPECTS ARISING FROM THE USE OF BLOCKCHAIN ON THE INTERNET-OF-VEHICLES: LEGAL PERSPECTIVE AND ANALYSIS

Emerging and disruptive technologies (EDTs),[8] including, blockchain and autonomous systems such as connected and autonomous vehicles (CAVs), but also big data analytics, the internet of things (IoT), and artificial intelligence (AI), present a multitude of societal and economic opportunities (Manyika et al., 2013; Burri, 2017, p. 2; European Investment Bank et al., 2021).[9] At the same time, however, they present significant legal, regulatory, and ethical challenges, which must be adequately dealt with for their benefits to be reaped in a way that is sustainable. Such disruptive technological innovations can often be combined with the goal of exponentially increasing their potential benefits. An example is the use of blockchain-based systems in the context of CAVs and, more generally, in smart city[10] environments (European Commission, 2022)[d].

In an effort to maintain and improve competitiveness in a sector where '80% of the growth [in the automotive industry] is expected to occur outside the EU' (European Commission, n.d)[a], the European Commission is investing heavily in automotive research and development (R&D) (Ecorys, 2021; European Commission, 2018; European Commission, n.d.)[a].[11] At the same time, investments are being made to explore how blockchain can potentiate technological progress in the mobility sector, among others (European Commission, 2021). Within the context of the highly innovative European automotive industry, recent research shows that blockchain has multiple potentially transformative applications which may contribute to Europe's continued position as an industry leader (European Automobile Manufacturers' Association [ACEA], 2022). [12]

For the purposes of this report, we will commence by introducing and exploring the concepts of 'CAVs' and 'blockchain', to serve as a foundation for the subsequent sections. Three relevant use cases, namely, the application of blockchain to facilitate data collection in the CAV, blockchain for trusted supply chain management, and the use of blockchain for easy electric vehicle charging and decentralised energy management, will be explored. Additionally, the added value that blockchain can bring to CAV development and functioning will be dealt with.

4.1 CONNECTED AND AUTONOMOUS VEHICLES

Hailed as one of the 'next big trends in the automotive industry' (European Commission, n.d.)[b], connected and automated mobility (CAM), or CAVs, are connected, autonomous or self-driving vehicles (European

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[8] While there is no established definition for EDTs, such technologies are understood to be technologies that 'have the potential to disrupt the status quo, alter the way people live and work, rearrange value pools, and lead to entirely new products and services'. Burri (2017, p. 2) provides further details, as does Manyika et al. (2013), as also seen in Burri.

[9] Opportunities include sustainability, cost-effectiveness, enhanced safety and security, as suggested by European Investment Bank et al. (2021).

[10] According to the European Commission (2022)[d], a smart city is 'a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business. A smart city goes beyond the use of digital technologies for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.'

[11] Note that, according to the European Commission (n.d.)[a], '2.6 million people work in direct manufacturing of motor vehicles, representing 8.5 % of EU employment in manufacturing. The EU is among the world's biggest producers of motor vehicles, and the sector represents the largest private investor in research and development (R&D). To strengthen the competitiveness of the EU automotive industry and preserve its global technological leadership, the European Commission supports global technological harmonisation and provides funding for R&D.'

[12] It is interesting to note that according to ACEA (2022), Europe is the second largest producer of vehicles (China is the first) followed by North America.

Commission, 2022)[c]. 'Connected, autonomous or self-driving' means that the vehicle, whether a car, bus or any other form of vehicular transport, can be driven without the continuous intervention of a human being (European Commission, 2022)[c]. Because of the removal of important causes of delays in traffic flow (i.e., human error and reaction time), CAVs have the potential to reduce road congestion by as much as 50 per cent when compared to 'traditional' vehicles (US Department of Transportation Intelligent Transportation Systems Joint Program Office, 2019; Medina-Tapia & Robusté, 2019).[13] This increased operational efficiency may further help to reduce pollution and usage costs,[14] (US Department of Transportation Intelligent Transportation Systems Joint Program Office, 2019; Medina-Tapia & Robusté, 2019) as well as increase road safety by reducing car accidents. CAVs may also permit individuals with mobility challenges to enjoy the luxury of private transportation (Alonso Raposo et al., 2019). Though this is not without its counterarguments[15] (Alonso Raposo et al., 2019, p. 1), it is reasonable to suggest that the development and adoption of CAVs present relevant potential benefits to European society, which merit careful consideration.

In the current CAV landscape, vehicles are being developed with different levels of autonomy (European Union Agency for Cybersecurity [ENISA], 2019[a], p. 13).[16] These levels have been taxonomised by SAE International – a global standardisation body in the area of mobility – in the SAE J3016™ 'Recommended Practice: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles' standard (SAE International, n.d.). Autonomy levels considered in this standard range from CAVs which still require a human driver (supported by specific features, such as automated emergency braking, steering/acceleration/brake support, adaptive cruise control, etc.) (SAE International, 2021), to CAVs in which a human does not continuously drive the vehicle when automated driving features are in use (including CAVs which prompt human driving under specific circumstances but ranging up to CAVs which are able to effectively drive themselves without any human assistance at all).[17]

[13] For example, 'CAVs are expected to decrease congestion up to 50 per cent, increasing the effective capacity of urban networks leading to a new equilibrium with more users but with negligibly less congestion than the current system', as reported by the US Department of Transportation Intelligent Transportation Systems Joint Program Office (2019).

[14] 'CAVs were projected to decrease operation cost by about 30 per cent compared to manually operated vehicles,' as reported by the US Department of Transportation Intelligent Transportation Systems Joint Program Office (2019).

[15] For example, in the short term, this could lead to more emissions and, therefore, health and environmental consequences. The proliferation of CAVs would also likely lead to the loss of employment for individuals working in the transportation sector and would furthermore necessitate that the actors in the automotive sector value chain (i.e., consisting of mobility service providers, the secondary automotive aftermarket, dealers, and of course, original equipment manufacturers (OEMs), vehicle producers and suppliers) develop new business models, etc. (Alonso Raposo, 2022, p. 1).

[16] The SAE J3016™ Recommended Practice: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, frequently referred to as the SAE Levels of Driving Automation™, were launched in 2014 and are the most widely used source for autonomous driving. SAE's taxonomy present six levels of driving automation 'from Level 0 (no driving automation) to Level 5 (full driving automation) in the context of motor vehicles and their operation on roadways.' More information is available at: https://www.sae.org/blog/sae-j3016-update.

[17] It is relevant to note that currently levels 0, 1 and 2 CAVs, which contain driver support features are present on the European market, 'but the conditional, high and full automation levels (when a vehicle becomes self-driving) are expected to become available only in 2020-2030, and whereas driver assistance systems are therefore important as an enabling technology on the path towards full automation' (European Parliament, 2019).

CAVs are embedded in a complex system of communications where multiple actors (Canada Group Limited & Ontario Centres of Excellence, 2019, p. 4; Balboni et al., 2020),[18] including drivers, passengers, pedestrians, manufacturers, infotainment service providers (European Data Protection Supervisor [EDPS], 2019),[19] smart city infrastructure managers (Michelucci et al., 2016),[20] and law enforcement agencies, engage in the collection, sharing and further use of personal data, understood as information which can reasonably be linked to an individual (European Data Protection Board [EDPB], 2021[b]; Balboni et al., 2020).[21] No longer the vehicles of the past, CAVs constantly process and transmit data about the vehicle, its passengers, and the surrounding environment by way of in-vehicle applications/systems, sensors and connected devices (EDPS, 2019). In 2019, it was estimated that CAVs may be capable of generating up to 4,000 gigabytes of data per day (Roll Call, 2019; EDPS, 2019, p. 2), including data which can directly or indirectly be linked to the vehicle and/or its human occupants (such as details on driver behaviour or activity on in-vehicle infotainment systems, but also more sensitive information, notably health, biometric, location and communication data) (EDPS, 2019, p. 2). Figure 1 below shows examples of ways in which personal data processing takes place in a CAV context (considering semi-autonomous and fully autonomous vehicles) (ENISA, 2019a, p. 14).

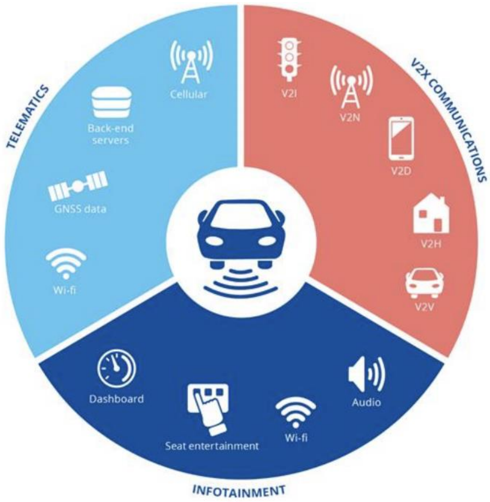

Figure 3: ENISA's 'Smart Car Ecosystem' (ENISA, 2019, p. 14)[a]

As a result, core European legal acts applicable to CAV regulation are the General Data Protection Regulation (GDPR)[22] – which regulates the processing of personal data[23] – and the ePrivacy Directive (Directive

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[18] Interactions between these stakeholders which involve a CAV, can be categorised as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2E or V2X).

[19] Consider 'hands-free phone calls, WLAN hot spots, music, video, social media, mobile office or smart home services', as suggested by the European Data Protection Supervisor.

[20] According to Michelucci et al. (2016), Smart City Managers are 'responsible for leading SC projects indifferent vertical domains, even if SC Managers have a limited budget for investments.' The Main competencies necessary to fulfil the role include: 'city planning capabilities, legal competencies, soft skills, financial resource management, and basic requirements.'

[21] Note that the GDPR, in Art. 4(1) defines personal data as 'any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person'.

[22] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).

[23] Article 4(1) GDPR defines personal data as 'any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an

2002/58/EC) (European Data Protection Board [EDPB], 2021, p. 6)[b][24] – which establishes more specific rules on the storage and access to information which is stored in the terminal equipment of users (EDPB, 2021[b], p. 7).[25] Aside from these, given the high relevance of data and cybersecurity in the mobility sector, the EU Network and Information Security directive, also known as the NIS Directive or Directive EU 2016/1148,[26] comes into play as well in the CAV and smart city context (Balboni et al., 2020; ENISA, 2019[b], p. 32).

Possibly the main challenge presented to CAV stakeholders by this legal framework is the need to allocate responsibility for compliance with privacy and data protection obligations effectively (e.g., through appropriate contracts) and in line with GDPR principles (e.g., correctly identifying controllers[27] and processors[28] in complex, multi-stakeholder data management activities. In the CAV context, the data controller may be, e.g., a service provider, equipment manufacturer, or vehicle manufacturer (EDPB, 2021[b], p. 21). Processors may instead be, e.g., 'equipment manufacturers and automotive suppliers [which] may process data on behalf of vehicle manufacturers' (EDPB, 2021[b], p. 12).[29] Without this, privacy/data protection compliance becomes diffuse and difficult to enforce, undermining the goals aimed at by the GDPR's principle of accountability (see, e.g., Art. 5(2) GDPR) – i.e., ensuring effective and demonstrable compliance with the GDPR's data protection principles.

Having said this, various other relevant challenges can be highlighted. For example, it is often the case that individuals are not aware that their personal data is being processed by a CAV (EDPS, 2019), which suggests deficiencies in compliance with GDPR transparency obligations. There may not be an easy fix to this problem in a CAV context, particularly considering that it is not enough to dump the minimum legally-required information on data subjects by any means possible – instead, because such information must be provided 'in a concise, transparent, intelligible and easily accessible form, using clear and plain language',[30] creative solutions must be devised. In particular, information-provision interface design and formatting (EDPS, 2019,

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identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person'.

[24] Note that as underlined by the EDPB at para. 11, 'most of the ePrivacy directive provisions (art. 6, art. 9, etc.) only apply to providers of publicly available electronic communication services and providers of public communication networks, art. 5(3) ePrivacy directive is a general provision. It does not only apply to electronic communication services but also to every entity, private or public, that places on or reads information from terminal equipment without regard to the nature of the data being stored or accessed.'

[25] Note that according to the EDPB in para. 13, 'the connected vehicle and device connected to it should be considered as a 'terminal equipment' (just like a computer, a smartphone or a smart TV)' when specific criteria are met.

[26] Directive (EU) 2016/1148 of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union, available at: https://eur-lex.europa.eu/eli/dir/2016/1148/oj.

[27] Article 4(7) GDPR defines a data controller as 'the natural or legal person, public authority, agency or other body which, alone or jointly with others, determines the purposes and means of the processing of personal data; where the purposes and means of such processing are determined by Union or Member State law, the controller or the specific criteria for its nomination may be provided for by Union or Member State law'. In the context of CAVs, 'Data controllers can include service providers that process vehicle data to send the driver traffic-information, eco-driving messages or alerts regarding the functioning of the vehicle, insurance companies offering 'Pay As You Drive' contracts, or vehicle manufacturers gathering data on the wear and tear affecting the vehicle's parts to improve its quality. Pursuant to art. 26 GDPR, two or more controllers can jointly determine the purposes and means of the processing and thus be considered joint controllers. In this case, they have to clearly define their respective obligations, especially as regards the exercising of the rights of data subjects and the provision of information as referred to in art. 13 and 14 GDPR.' (EDPB, 2021, pp. 11-12)[b].

[28] Note that Art. 4(8) GDPR defines a processor as 'a natural or legal person, public authority, agency or other body which processes personal data on behalf of the controller'.

[29] In the CAV context, 'in a number of cases, equipment manufacturers and automotive suppliers may process data on behalf of vehicle manufacturers (which does not imply they cannot be a data controller for other purposes). In addition to requiring data processors to implement appropriate technical and organisational measures in order to guarantee a security level that is adapted to risk, art. 28 GDPR sets out data processors' obligations.'

[30] See Art. 12(1) GDPR.

p. 2; EDPB, 2021b),[31] as well as data protection icons (Balboni & Francis, 2022; *Commission nationale de l'informatique et des libertés* [CNIL], 2017, p. 13),[32] should be considered to ensure the effectiveness of communication to individuals (without which the essence of the principle of transparency is not respected, and without which consent – which is arguably mandatory for many cases of CAV data collection, given the restrictive rules imposed in this respect by the ePrivacy Directive – cannot truly be validly collected). It should also be pointed out that CAV's leveraging of artificial intelligence to collect, analyse and infer information from personal data may be in conflict with the GDPR's principle of purpose limitation[33] in that the effectiveness of CAV-relevant AI use cases is at least partially reliant on the possibility to, over time, reinterpret, or shift focus from, the original purposes for which data were collected (European Commission, 2020, pp. 16-17; Balboni et al., 2020). Other examples (while many more could be provided) include the tension between the perceived benefits of expanded data collection[34] and the GDPR's principle of data minimisation,[35] the heightened sensitivity of IoT-related security concerns in the CAV context (connected to the potential applicability of NISD rules to CAV manufacturers [Balboni et al., 2020; ENISA, 2019b, p. 32],[36] among other CAV stakeholders) (Benjamin et al., 2019, pp. 2-4)[37] and the possibility of misuse of driver-related data for covert and potentially abusive profiling activities (Horizon 2020 Commission Expert Group, 2020).[38]

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[31] For example, the European Data Protection Supervisor has suggested that providing a lengthy privacy policy on the vehicle's screen may not be efficient. Also see the Article 29 Working Party, Guidelines on Transparency under Regulation 2016/679 (wp260rev.01), endorsed by the EDPB.

[32] Balboni & Francis (2022) have developed a comprehensive set of data protection developed in order to improve transparency in various contexts. Furthermore, note that the *Commission nationale de l'informatique et des libertés* (2017, p. 13) Compliance Package states that 'concise and easily understandable clauses in the contract of sale of the vehicle and/or in the contract for the provision of services; and by using distinct documents (e.g., the vehicle's maintenance record book or manual) or the onboard computer; and using standardised icons in vehicles. The Commission strongly encourages the implementation of those icons to inform the data subjects in a clear, summarised, and easily understandable manner of the processing of their data. In addition, the Commission emphasises the importance of standardising those icons so that the user finds the same symbols regardless of the make or model of the vehicle.'

[33] Article 5(1)(b) GDPR, establishing the principle of purpose limitation, states that information should be 'collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes; further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall, in accordance with Article 89(1), not be considered to be incompatible with the initial purposes'.

[34] Note that more data from more sensors means 'better diagnosis of vehicles, maintenance, and other car services' (Mohammad et al., 2022, p. 257).

[35] Art. 5(1)(c) GDPR calls for personal data to be 'adequate, relevant and limited to what is necessary for relation to the purposes for which they are processed'.

[36] The NISD has established obligations for intelligent transport systems (ITS), which are classified as Essential Service Operators (ESOs). Under the Directive, ESOs are obliged to ensure the security of information systems and networks for services which include, e.g., road transport and telecommunications. Such entities, including Original Equipment Manufacturers (OEMs), may therefore be subject to the rules established by the EU under the NISD so long as they run ITSs, see footnote 46 in Balboni et al. (2020). It is also relevant to observe that the forthcoming NIS2 Directive, which establishes a high common level of cybersecurity in the EU, is applicable to operators of essential services and digital service providers and will replace the current NISD (European Parliament, 2022b). The Proposed NIS2 Directive, which distinguishes between 'essential' and 'important' entities, classifies OEMs as belonging to the 'important' category (European Parliament, 2022a). As with NISD, OEMs acting as ITSs will continue to qualify as ESOs.

[37] Note that 'Technology advancements in the IoT field through distributed intelligence and data fusion (edge and fog computing) at the roadside, can lead to improved awareness of impending events over a broad geographical area. It can include real-time notifications and alerts by reducing delays in data transmission [sic]. Ultimately, it can accelerate road safety improvements without needing to wait for CAVs to be adopted en masse.' And that 'CAVs are closely aligned with the Internet of Things (IoT) concept. Traditionally, the network was responsible for transporting data from the roadside systems back to the applications in the cloud. As part of the IoT's evolution, the Data Fabric has been realised – a highly distributed virtual layer residing on top of the IoT Network Fabric (Connectivity) responsible for managing the flow of data from devices.'

[38] Note that 'Data-driven CAV technology can technically be used to identify and monitor vehicle passengers through sensors and video monitoring inside the vehicle. It can also be used for personal identification requirements (facial recognition, biometric data, etc.). This data can technically be collected and associated with users, developing their profiles over time in conjunction with background information. With these technical possibilities, concerns arise about uncritical or improper fine-grained [sic]profiling and its potentially illegal applications, including manipulation and misuse. CAV users should have control over their personal data. This data should only be

As with AI more generally, CAVs should be developed according to the principles of data protection by design and by default enshrined in Article 25 of the GDPR,[39] so as to take privacy and data protection concerns into consideration from the very start of design and development (ENISA, 2020; Balboni & Francis, 2022).[40]

In short, while potentially a harbinger of significant improvements to relevant societal facets, such as quality-of-life, the environment and the economy, lawful and compliant CAV technology implementation is not without its obstacles – many of which continue to be discussed to date.

4.2 BLOCKCHAIN

Most famous thanks to its application in the context of cryptocurrencies, blockchain is defined by the National Institute of Standards and Technology (NIST) as 'a collaborative, tamper-resistant ledger that maintains transactional records' (NIST, 2021).[41] Blockchain is a type of distributed ledger technology (DLT) (World Bank, 2018)[42] – it is, in essence, technology which allows for the setting-up of databases on decentralised ledgers, where data is 'stored and distributed to a large number of computers and in which all entries, called 'transactions', are visible to all users' (CNIL, 2018)[b]. Using such blockchain-based ledgers allows the tracking of, for example, commercial exchanges and tangible/intangible assets (e.g., vehicles, intellectual property) (IBM, n.d.).[43] in a manner which provides greater assurances of transparency, authenticity, and security (Meijers et al., 2022; ENISA, 2018), given that a relevant amount of ledger users validates each and every transaction recorded on the ledger (Chiang et al., 2018).[44] Multiple identical copies of this ledger are, in turn, hosted on different computers and made visible to all participants (which, in the case of public blockchain systems, means data is made visible to everybody) (CNIL, 2018)[b].

disclosed, forwarded and used on a voluntary basis to the point that all terms and conditions for data provision to second and third parties have to adhere to the highest standards of free, informed and explicit consent.'

[39] Article 25(1) GDPR calls for controllers to take 'into account the state of the art, the cost of implementation and the nature, scope, context and purposes of processing as well as the risks of varying likelihood and severity for rights and freedoms of natural persons posed by the processing, the controller shall, both at the time of the determination of the means for processing and at the time of the processing itself, implement appropriate technical and organisational measures, such as pseudonymisation, which are designed to implement data-protection principles, such as data minimisation, in an effective manner and to integrate the necessary safeguards into the processing in order to meet the requirements of this Regulation and protect the rights of data subjects.' Furthermore, Article 25(2) GDPR calls for the controller to 'implement appropriate technical and organisational measures for ensuring that, by default, only personal data which are necessary for each specific purpose of the processing are processed. That obligation applies to the amount of personal data collected, the extent of their processing, the period of their storage and their accessibility. In particular, such measures shall ensure that by default personal data are not made accessible without the individual's intervention to an indefinite number of natural persons.'

[40] Data security should also be considered by design. Data security by design, as ENISA (2020) suggests, 'recalls the fundamental importance of data security as an enabler of both technological advancements and consumer trust'.

[41] Note that ENISA (n.d.) defines blockchain in its glossary as 'an authoritative record that everyone trusts within the network without the existence of a central authority. Every node in the network can arrive at the same consensus by sharing information and assembling a shared, global and public ledger trusted by everyone.' It is also important to point out that distributed ledger technology or DLT, is often referred to as 'blockchain' (Finck, 2019, p. I). Blockchain is a specific type, of DLT, for more information, see CNIL (2018)[b].

[42] Note that 'Distributed ledgers use independent computers (referred to as nodes) to record, share and synchronise transactions in their respective electronic ledgers (instead of keeping data centralised as in a traditional ledger). Blockchain organises data into blocks, which are chained together in an append only mode.'

[43] As IBM suggests, 'Virtually anything of value can be tracked and traded on a blockchain network, reducing risk and cutting costs for all involved.'

[44] As suggested by Chiang et al. (2018), blockchain is understood to be a 'trusted' or 'trustful technology'. This is largely because such trust is based on specific processes, which include 1) verifying transactions when received by nodes and before propagation to other nodes of the network and 2) validating transactions into 'blocks' by way of mining and validating new blocks and by adding new blocks to the chain 'with the highest computational effort demonstrated through proof-of-work'. In the blockchain, all network nodes are therefore capable of reaching consensus and contributing to the 'shared, global and public ledger trusted by everyone' (ENISA, n.d.). Also, observe that blockchain is characterised by disintermediation, as stated by the CNIL (2018)[b].

While blockchain has been around for some time already, and some argue it is yet to prove its worth to a significant extent (Barber, 2019), it is also reasonable to state – given the possibility to apply blockchain to different technologies, scenarios and purposes – that important potential may remain unexplored; it is worth noting, on this point, that the European Union is currently aiming for global 'leadership' in blockchain development, notably by promoting a 'gold standard' for blockchain in Europe (European Commission, 2022)[a], and the European Commission continues its regulatory efforts around blockchain, with the objective of allowing for innovation within a much-desired framework of greater legal certainty (European Commission, 2022)[b].

Multiple types of blockchains exist, which can be characterised by their diverse user permission levels (CNIL, 2018)[b]. These are, namely, public blockchains – which are publicly available and in which anyone can participate in the transaction recording process – permissioned blockchains – in which eligibility criteria are established for participation in transaction validation and/or recording – and private blockchains – which are managed by 'a unique actor who alone oversees participation and validation' (CNIL, 2018)[b]. Actors in the blockchain environment can, in turn, be divided into assessors – who are allowed to both read and hold a copy of the blockchain ledger – participants – who can submit transactions to be validated – and miners – who actually validate transactions and add new validated 'blocks' to the 'chain' by 'applying blockchain rules for 'acceptance' by the community' (which may involve executing complex computational operations to ensure the authenticity of each submitted transaction and its compliance with such rules) (CNIL, 2018)[b].

Because of the possibility to record practically any type of information on a blockchain ledger in an immutable form, the compliance of this technology with the GDPR (to the extent that personal data – particularly on ledger users, but also any other information on individuals which may be recorded in connection with a given transaction – is stored) is a subject of great debate. It has been suggested that blockchain 'may, by its very nature, be unable to comply with European data protection law, which in turn risks stifling its own development to the detriment of the European digital single market project' (Finck, 2019, p. 1).

Blockchain presents challenges with respect to specific GDPR obligations, notably compliance with its principles of storage limitation and data minimisation (CNIL, 2018, p. 8)[a].[45] The GDPR requires the definition of specific storage periods for personal data, taking into consideration the purpose for which data is processed, such that personal data should not be held onto for any longer than needed,[46] and the principle of data minimisation requires a filtering of personal data, such that only the minimum amount of personal data needed to meet a given purpose is processed at any given time; however, by its very nature, blockchain makes it impossible to delete and/or rectify data stored within a blockchain ledger (CNIL, 2018[a], p. 6),[47] creating an inherent conflict. The French data protection supervisory authority[48] has provided some potential technical solutions to these challenges, such as refraining from the storage of cleartext data on the blockchain (storing

[45] Articles 15 to 22 of GDPR provide data subjects with specific rights which include the right to access (article 15 GDPR), the right to rectify (article 16 GDPR), the right to erase data, also known as the 'right to be forgotten' (article 17) GDPR, the right to restrict data processing (article 18) GDPR, the right to data portability (article 20 GDPR), the right to object (article 21 GDPR), and the 'right to not be subject to a decision based solely on automated processing, including profiling, which produces legal effects' or similar (article 22 GDPR). According to the CNIL (2018, p. 8)[a], the rights of access and data portability are considered to be compatible with blockchain.

[46] Art. 5(1)(e) GDPR. Note that 'personal data may be stored for longer periods insofar as the personal data will be processed solely for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1) subject to the implementation of the appropriate technical and organisational measures required by this Regulation in order to safeguard the rights and freedoms of the data subject'.

[47] As the CNIL (2018, p. 6)[a] points out, 'once a block in which a transaction is recorded has been accepted by the majority of the participants, that transaction can no longer be altered in practice.'

[48] The *Commission nationale d' l'informatique et des libertés*, or CNIL.

only proof of such data in the form of a commitment or hash [CNIL, 2018, p. 6][a] [49] on the blockchain itself), which may nonetheless fall short of full GDPR compliance (CNIL, 2018, p. 9)[a].[50]

The tendential immutability of blockchain logs also calls into question the exercise of the right to rectification regarding any personal data stored within them. On this point, the French supervisory authority has recommended relying on overriding older logs (holding inaccurate or incomplete data) with newer logs correcting and completing as needed (CNIL, 2018)[a].[51] Also relevant to mention are the issues posed to appropriate data processing role allocation, arising largely because distributed databases are decentralised and frequently 'replac[e] a unitary actor with many different players', which represents a problem with respect to accountability (Finck, 2019, p. ii).[52] Within the blockchain, 'anyone that chooses a particular technical infrastructure, such as DLT, to process data, can be a joint controller of that system even though they may only have limited control over the purposes and no meaningful control about the means of processing' (Finck, 2019, p. 40). It should, however, be noted that joint controllership[53] should be determined on a case-by-case basis (Finck, 2019, p. 42) and that it is also possible for, e.g., multiple blockchain participants to establish a new legal person to be identified as a single data controller (CNIL, 2018, p. 2)[a]. The European Data Protection Supervisor has also noted particular challenges with the GDPR and blockchain in the area of extra-EEA data transfers (Wiewiórowski, 2021), a topic which is of particular relevance at this time. The European Data Protection Board is expected to provide additional guidance on the lawful use of blockchain in the near future (EDPB, 2020[a]; EDPB, 2021[a]),[54] which may help better understand how to deal with these points of tension.

As mentioned, blockchain is a type of technology which can be applied in a multitude of contexts. The trust and transparency mechanisms inherent to a blockchain make the CAV context (particularly where integrated into a smart city environment), for one, an interesting scenario in which potentially transformative solutions may be unlocked.

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[49] See specifically footnote 1 and note that 'A "commitment" is a cryptographic mechanism that allows one to "freeze" data in such a way that it is both possible - with additional information - to prove what has been frozen and impossible to find or recognise such data by using this sole "commit".'

[50] As stated by the CNIL, 'when the data recorded on the blockchain is a commitment, a hash generated by a keyed- hash function or a ciphertext obtained through "state of the art" algorithms and keys, the data controller can make the data practically inaccessible, and therefore move closer to the effects of data erasure. Excluding the specific case of some commitment schemes, these solutions do not, strictly speaking, result in an erasure of the data insofar as the data would still exist in the blockchain. However, the CNIL observes that it does allow data subjects to get closer to an effective exercise of their right of erasure. Their equivalence for what concerns the requirements of the GDPR should be evaluated.'

[51] Also note that 'Indeed, a subsequent transaction can cancel an initial transaction, even though the first transaction will still appear in the chain. The same solutions as those applied following a request for deletion of personal data could be applied to erroneous data when such data requires deletion. Although this approach is somewhat different, it requires, similarly to other rights, careful consideration in advance regarding the right to a restriction (introduced by Article 18 of the GDPR) and to human intervention in the context of entirely automated decision-making (Article 22 Paragraph 3).'

[52] Furthermore, 'This makes the allocation of responsibility and accountability burdensome, particularly in light of the uncertain contours of the notion of (joint)-controllership under the regulation. A further complicating factor in this respect is that in the light of recent case law developments, defining which entities qualify as (joint-) controllers can be fraught with a lack of legal certainty.'

[53] See Art. 26(1) GDPR: 'Where two or more controllers jointly determine the purposes and means of processing, they shall be joint controllers. They shall in a transparent manner determine their respective responsibilities for compliance with the obligations under this Regulation, in particular as regards the exercising of the rights of the data subject and their respective duties to provide the information referred to in Articles 13 and 14, by means of an arrangement between them unless, and in so far as, the respective responsibilities of the controllers are determined by Union or Member State law to which the controllers are subject. The arrangement may designate a contact point for data subjects'. Also see Case C-210/16 Wirtschafsakademie Schleswig-Holstein [2018] EU:C:2017:796, 1 Case C-25/17 Jehovan todistajat [2018] EU:C:2018:551, and Case C-40/17 Fashion ID [2018] EU:C:2018:1039.

[54] It is relevant to note that the European Data Protection Board's Strategy for 2021-2023 and the EDPB work programme 2021/2022 include the assessment of new and existing technologies such as blockchain and the development of Guidelines on the blockchain. Such guidelines will provide fundamental information on the compatibility of blockchain with the GDPR.

4.3 APPLICATION OF BLOCKCHAIN IN THE CAVS ECOSYSTEM

Within the context of the highly innovative automotive sector, blockchain has multiple potentially transformative applications. Action is being taken to leverage blockchain by several large industry members, such as General Motors, which has filed a patent for a system that updates a distributed navigation map for vehicles with embedded sensors by comparing sensor-detected differences to a known navigation map and transmitting such differences to a blockchain-based map network (Pollock, 2020).[55] Furthermore, in the context of the Mobility Open Blockchain Initiative (MOBI), a group of leading industry members is developing blockchain standards (MOBI, 2022)[56] with the aim of rendering transportation '**more efficient, equitable, decentralised, and sustainable**, all while preserving the data privacy of users and providers alike'(MOBI, n.d.). This section of the report will deal with three specific use cases which have been selected due to their ability to highlight the potential benefits blockchain may bring to the CAV and, more generally, the mobility sector – namely, the facilitation of CAV data collection, the increase of trust in supply chain management, and the increase of efficiency in electric vehicle charging through decentralised energy management.

The first salient example of blockchain in the CAV context concerns blockchain as a data collection technique in the internet-of-vehicles (IoV) (Asia-Pacific Economic Cooperation, 2014).[57] Given that blockchain is a technology which is, in simple terms, used to record transactions, it is particularly suited for data collection (Roiter, 2021). This is highly relevant to the CAV context, given that data 'enable[s] better diagnosis of vehicles, maintenance, and other car services' (Mohammad et al., 2022, p. 257), and that connected vehicles are 'equipped with more than 200 smart sensors, an on-board computer and a cloud-based information base' (Narbayeva et al., 2020, p. 169). In this respect, blockchain is capable of providing 'an immutable and secure solution to support data collection in the automotive industry' (Mohammad et al., 2022, p. 257). Shun-Yuan Wang et al. (2018) have, for example, developed an innovative implementation that integrates blockchain technology for the purpose of data collection and analysis in wireless sensor networks.[58] There are, however, as also suggested earlier, a number of challenges inherent to the use of blockchain for the purpose of data collection. For example, challenges have been identified in terms of cost, scalability, security, privacy, etc. (Mohammad et al., 2022, p. 263). Additionally, blockchain could be used to support data collection and

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[55] In other words, as stated by Pollock (2020), General Motors has developed 'a process by which self-driving cars would be able to store all their data on a distributed ledger'.

[56] 'MOBI defines a trusted trip as a trip whose attributes are certified by ecosystem stakeholders in a federated network. The trusted trip combines identity and ubiety to enable a multitude of mobility applications in Web3. An important function of blockchain/DLT consortia is to establish trust primitives which serve as public shared infrastructure for decentralised business networks. For MOBI and its members, the key primitive is the trusted trip. MTT enables marginal cost pricing for decentralised services and ensures trip data can be trusted (tamper-evident) when using Web3 applications. Combining secure decentralised identity with trusted time-stamped location will enable the creation of trusted multiparty track-and-trace applications and scale use cases such as battery passport, supply chain track and trace, urban road tolling, meter-free parking, congestion management, carbon and pollution taxing, usage-based insurance, and many other usage-based mobility as a service (MaaS) applications.'

[57] As suggested by the Asia-Pacific Economic Cooperation (2014, p. 2), 'The internet of vehicles (IoV) is an integration of three networks: an inter-vehicle network, an intra-vehicle network, and vehicular mobile Internet.'

[58] Wang et al.'s study 'integrates blockchain technology which treats each mobile database as a block. Each block will first detect its own range of sensor data. The system then concatenates the sensor data for each block through the blockchain technology. In addition to their own measurement data, these concatenated sensor data also contain all the sensor data of the previous block. Therefore, when the system completes the connection of each block, each block node stores the sensor data of the entire wireless network. Mobile database is placed in an embedded hardware module like the Raspberry Pi. This module also establishes web server at the same time. The setting of this mobile web server is based on the web of things (WoT) structure. The advantage of this mobile database is easy information collection, while maintaining confidentiality and security. This mobile web server can draw figures with multiple chart types on the web page whilst delivering these web pages of charts to the cloud. The mobile web server is also built on the same embedded hardware module, and even the system can be a private cloud data centre. The proposed system will visualise the data uploaded by these sensors and draw the relevant chart after performing big data analysis. This web page server of the system is built on an embedded operating system so that it is easy for the system to model and visualise the corresponding graphics using the Python or JavaScript programming language.'

transmission inherent to the provision of CAV-related telematics services, such as those 'can provide insurance companies with information on the driver's location, duration of the trip, acceleration and braking modes, vehicle speed, cornering behaviour and other information', in a 'secure unchanged state' (Narbayeva et al., 2020, p. 170), this would notably bring with it important privacy and data protection challenges where, for example, location data (EDPB, 2020, p. 13)[b] [59] is considered to be highly sensitive and 'preference should always be given to the processing of anonymised data rather than personal data' (EDPB, 2020, p. 5)[b].

On the matter of automotive insurance, it has been said that CAVs themselves will act as a disruptive force (Oham et al., 2018). It is clear that present liability models, which are connected to the driver, must necessarily differ in the case of autonomous vehicles, where multiple actors, including original equipment manufacturers (OEMs), service technicians, etc., are part of the ecosystem and where, thanks to numerous sensors and embedded technologies, the vehicle may 'gather sufficient data for liability attribution' which may also be shared (Oham et al., 2018). To this end, Oham et al. (2018, p. 1) have proposed a framework based on blockchain which 'integrates the concerned entities in the liability model and provides untampered evidence for liability attribution and adjudication.' [60] It is also very interesting to note that OEMs may become automotive insurers in the future, as already evidenced by Elon Musk (Motion-S, n.d.).

On the matter of supply chain management, blockchain can be used to develop more trusted and transparent processes for the management of vehicle parts, raw materials, fuelling, and, of course, payments (Turpitka, 2021). For example, BMW has found that applications such as VerifyCar (BMW, 2021)[61] would allow buyers to be certain of given facts about a vehicle, such as whether or not it has been maintained properly or has ever been in an accident. Another example is for supply chain verification of, e.g., cobalt, which is a fundamental component of electric cars largely found in developing countries, where oversight is very complex (BMW, 2021) – using blockchain could allow for better monitoring of the supply chain, rendering it 'forgery proof' insofar as a refinery would be capable of proving the source of its raw materials by linking it to a specific mine; the same could apply to the spare parts market (BMW, 2021).[62]

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[59] As the EDPB writes, location data 'refers to all data processed in an electronic communications network or by an electronic communications service indicating the geographical position of the terminal equipment of a user of a publicly available electronic communications service (as defined in the e-Privacy Directive), as well as data from potential other sources, relating to: • the latitude, longitude or altitude of the terminal equipment; • the direction of travel of the user; or • the time the location information was recorded.' Also see p. 5 and furthermore, note that 'location data collected from electronic communication providers may only be processed within the remits of articles 6 and 9 of the ePrivacy Directive. This means that these data can only be transmitted to authorities or other third parties if they have been anonymised by the provider or for data indicating the geographic position of the terminal equipment of a user, which is not traffic data, with the prior consent of the users. Regarding information, including location data, collected directly from the terminal equipment, Art. 5(3) of the 'ePrivacy' directive applies. Hence, the storing of information on the user's device or gaining access to the information already stored is allowed only if (i) the user has given consent or (ii) the storage and/or access is strictly necessary for the information society service explicitly requested by the user.' And that 'when data have been collected in compliance with Art. 5(3) of the ePrivacy Directive, they can only be further processed with the additional consent of the data subject or on the basis of a Union or Member State law which constitutes a necessary and proportionate measure in a democratic society to safeguard the objectives referred to in Art. 23 (1) GDPR'.

[60] Oham et al. 'present a detailed description of data contributing to evidence. Our framework uses permissioned BC and partitions the BC to tailor data access to relevant BC participants. Finally, we conduct a security analysis to verify that the identified requirements are met and resilience of our proposed framework to identified attacks.'

[61] This app 'could enable users to track and verify the complete vehicle history and share data – like the mileage – with third parties. It could even be used in conversation with the seller. A green check mark then tells me that the used vehicle's data is plausible and has been verified. However, the blockchain doesn't only facilitate data transfer between private individuals. Car owners could, for example, also send verified data on the mileage of their car to a car insurance company in order to receive a discount for infrequent drivers. For security reasons, this has so far only been possible by accessing an isolated database. The decentralised blockchain could facilitate access to this information without compromising security.'

[62] Note that according to BMW, 'The blockchain-based method offers many advantages to everyday business, such as easier certification and shorter customs procedures. For end users, the advantages of a blockchain-verified supply chain are obvious: better protection against counterfeit spare parts, for example, or a clear conscience regarding the raw materials used in a car.' Also note that in cases

One further use case for blockchain in the CAV field concerns electric vehicle charging, considering that most CAVs are (and, in the future, will be) electric (Jiang et al., 2022, p. 22; NAVYA, n.d.). In this area, BMW has developed a pilot project for a decentralised network for charging which embeds smart contracts (European Law Institute, n.d.)[63] with electricity providers, allowing users to make use of any charging station without needing to provide any identification (BMW, 2021).[64] While smart contracts do not necessarily need to use blockchain (Maugeri, 2022),[65] its use may provide greater assurances to all involved stakeholders (not just users, but also service and grid providers) of lawful, secure and adequate exchange within the realm of e-charging services. In the future, autonomous vehicles may be capable of navigating on their own to charging stations, completely eliminating the need for a human to use a charging card or plug the vehicle in; in such a case, the vehicle itself could 'trigger' transactions via the charging stations, executed and recorded on blockchain technology (BMW, 2021). MOBI has also worked to develop '[a] global standard on blockchain for electric vehicle grid integration (EVGI)', which has been said to potentially 'lay the foundation for a worldwide decentralised vehicle charging network, according to the international working group developing what it says is the first such standard' (Gresham, 2020). The standard contains design specifications and data schemes to use blockchain in the areas of vehicle-to-grid integration,[66] tokenised carbon credits,[67] and peer-to-peer applications (Gresham, 2020). Naturally, similar concerns around data processing apply to this use case (notably, the possibility for e-grid users to be tracked and profiled by service providers based on electricity consumption habits), which may be made more salient due to the practical impossibility of pulling information off a blockchain once it is logged – great care will need to be taken in designing blockchain-reliant data collection systems to ensure the principle of data minimisation is respected, and technical solutions for data erasure (potentially involving workarounds, such as the French supervisory authority's commitment/hash suggestion) will need to be considered and, potentially, developed to ensure this technology can be used in compliance with EU privacy/data protection laws.

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where blockchain is used for supply chain management, such processing could find its legal basis in the performance of the contract (Article 6(1)(b) GDPR) (Finck, 2019, p. 62).

[63] Smart contract can be defined as 'a computer programme that, upon the occurrence of pre-defined conditions, runs automatically and executes pre-defined actions according to the terms of a contract or an agreement. By one account, the global smart contracts market size is projected to reach EUR 1,5 billion by 2028, from EUR 308 million in 2021.' It should also be noted that calls have been made to provide certainty with respect to consumer rights in the context of blockchain and smart contract translations and that 'European Union law already strengthens the position of consumers, as they lack both bargaining power as well as knowledge and expertise in their dealings with businesses. For consumers, the functioning of blockchains and smart contracts is like a black box, which makes their position even more precarious'. Also, see European Law Institute (2022).

[64] BMW's goal is for 'Customers [to] simply plug their vehicle into a charging station and don't need to worry about anything else – not the provider, not identification (which currently requires a customer card), not the cheapest available charging tariff at that particular station. All of this is taken care of behind the scenes by a blockchain.'

[65] As Maugeri (2022, p. 902) explains, 'Smart contracts were originally just thought of as algorithms that would prevent the parties from choosing whether or not to perform. In other words, as algorithms that entrusted machines with the task of assuring performance'.

[66] This would permit eVehicles to share stored electricity with the power grid.

[67] This would permit the sale and purchase of digital tokens, which represent carbon offset credits.

CONCLUDING REMARKS

The automotive industry is looking for new tools in existing business processes to gain a competitive edge. One such promising technology that could advance the automotive industry is blockchain. Several use cases for blockchain in the automotive industry have been proposed and are currently in various stages of testing or real-world implementation. Blockchain uses in the automotive industry include parts authentication, marketing interactions, financial applications, connected car and vehicle tracking, autonomous driving, car sharing, marketing, CO_2 emission tracking, and many others. While the aforementioned applications of blockchain technology certainly make a strong case for changing many facets of the automotive industry, the community is just starting to explore the surface of blockchain applications in the automotive sector within the urban and smart city domain. In this report, we mainly focused on upcoming trends of urban application blockchain in the automotive sector, what benefits it can bring in general, and what bottlenecks exist for its successful implementation from the regulatory standpoint.

One of the fundamental issues discovered during report preparation is that the ecosystem of the use cases within the automotive sector, where blockchain could support the development and solve some of the existing concerns, is rapidly growing. However, it is crucial to consider the applications from multiple perspectives (e.g., environmental, economic, social, etc.), focusing on **better leveraging these applications to the general public**, introducing simple use cases serving high value and gradually expanding the link between services.

Another aspect to be considered when developing blockchain solutions in the automotive sector is **synergies with other concepts and technologies**. For example, **telematics** provides a combination of vehicle data generated by the vehicle and received from other vehicles and infrastructure. In the connected automotive space, telematics includes navigation based on software, **V2V** (vehicle-to-vehicle) and **V2X** (vehicle-to-everything) communications and a large number of services that can impact vehicle and driver and passenger safety. To fulfil an essential level of safety and security, data sent and received by telematics systems must be kept secure and unaltered, and blockchain is vital for just such applications. Moreover, the **IoT** concept and applications have become a part of the environment we are surrounded by and operate within, and the automotive sector is no exception. Smart sensors are increasingly being used to monitor traffic and communicate with it (V2X), and the need for data speed and security has become apparent. Finally, comprehensive analyses and predictions based on the data powered by **AI** would be critical for advancing services and supporting new needs as the data will grow along with insights and new use cases.

This report has dealt with the opportunities and legal challenges created by blockchain and connected and autonomous vehicles as prime examples of EDTs. Fundamental questions of compliance raised by CAVs and blockchain, when individually considered, can be observed, and these are only exacerbated when applying the latter to the former. Legal challenges inherent to both EDTs, such as difficulties in assigning data processing roles to stakeholders and ensuring compliance with GDPR principles (e.g., accountability, transparency, data minimisation, storage limitation) arose, as well as others specific to each one separately. Adding to these challenges – while the legal and regulatory framework for CAVs is clear – there are still many open questions about the compatibility of blockchain with the current European legal framework. Moreover, regulations and frameworks need to be developed with the input of government agencies, industry representatives, and technical experts to ensure the guidelines support and protect all parties involved as active and passive users.

Further research and **official guidance are very much needed** for legal certainty to be obtained regarding how blockchain can be implemented in the context of the IoV. To this end, the upcoming EDPB guidelines on blockchain (EDPB, 2021)[a] will prove fundamental for the EU to adopt such EDTs on a mass scale and for Europe to reach its objective as a competitive market player.

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ANNEX

BACKGROUND ON GAIA-X

Gaia-X 'is a project initiated by Europe for Europe and beyond. Representatives from business, politics, and science from Europe and around the globe are working together, hand in hand, to create a federated and secure data infrastructure. Companies and citizens will collate and share data – in such a way that they keep control over them. They should decide what happens to their data, where it is stored, and always retain data sovereignty.

The architecture of Gaia-X is based on the principle of decentralisation. Gaia-X is the result of a multitude of individual platforms that all follow a common standard – the Gaia-X standard. Together, we are developing a data infrastructure based on the values of openness, transparency, and trust. So, what emerges is not a cloud, but a networked system that links many cloud services providers together.' [68]

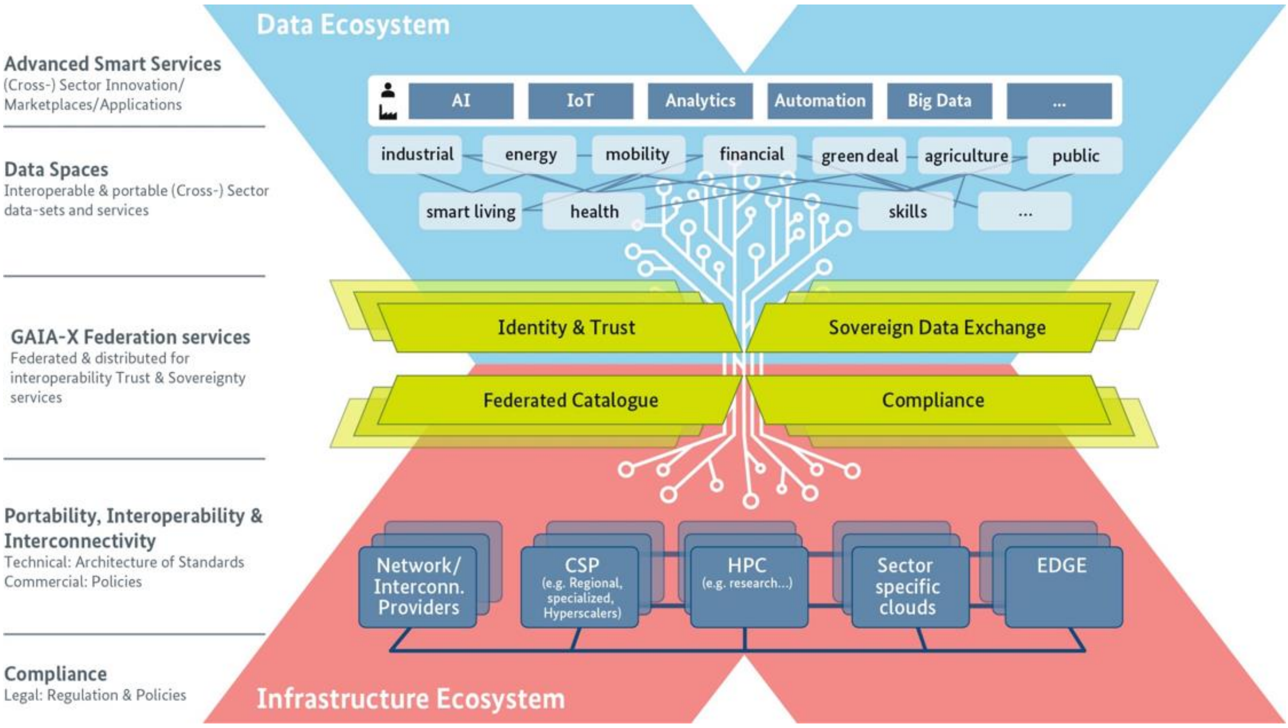

Figure 4: Gaia-X ecosystem

- Guiding principles of GX - based on European Values
  - Openness
  - Transparency
  - Trust
  - Sovereignty
  - Data privacy protection
  - Unrestricted market access

[68] https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html

- Usability

- Ensured by a set of policy rules, it is built on existing standards
- Creates transparency over the entire data and federated services portfolio
- Secures unique identification of the participants

GAIA-X 4 MOBILITY

The project family **GAIA-X 4 Future Mobility**[69] is in the mobility domain of the German Gaia-X Hub. The common focus of the family's projects 'is on the Gaia-X-based implementation of future mobility applications with high product proximity, in which data-based networking with manufacturers, suppliers, service providers and users is essential. Accordingly, a wide variety of actors from all application, research and subject areas of mobility and, in particular, information and communication technologies are involved'.[70] A total of around 80 participants from business and science come together in this joint initiative.

Gaia-X 4 Future Mobility currently includes five projects funded by the BMWK: GAIA-X 4 KI (AI), GAIA-X 4 AMS (Advanced Mobility Services), GAIA-X 4 ROMS (Remote-Operation for Automated and Connected Mobility Services), GAIA-X 4 PLC-AAD (Product Life Cycle – Across Automated Driving) and GAIA-X 4 moveID; Another project is planned for autumn 2022.

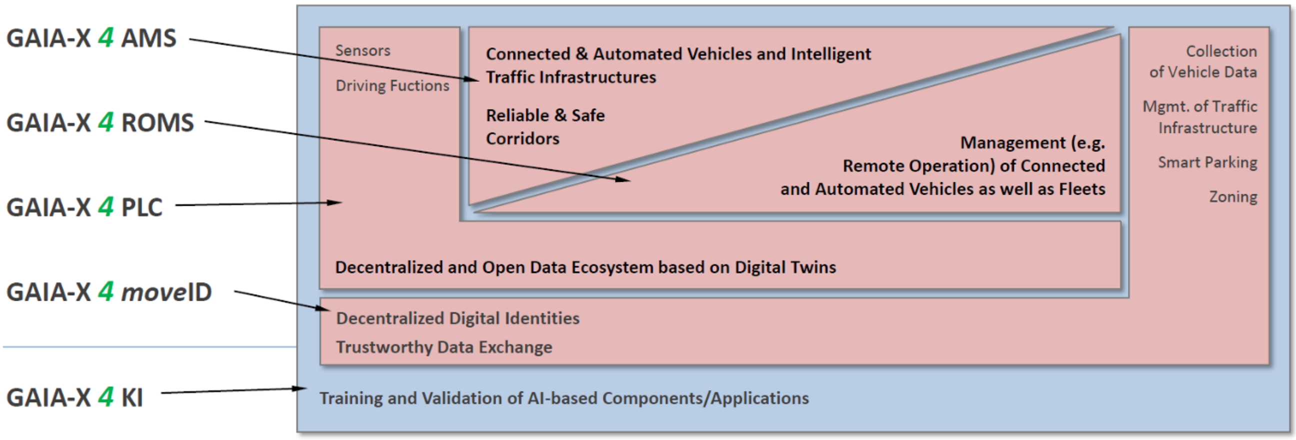

Figure 5: Gaia-X 4 future mobility

The projects focus on various topics from the field of distributed data and service infrastructures based on Gaia-X and thus make an effective contribution to the development of correspondingly shaped applications for the field of mobility. This is the case, for example, with data supply for automated vehicles and the development of cooperative system networks made up of vehicles and intelligent traffic infrastructures; the remote operation of automated vehicles and vehicle fleets; secure decentralised digital identities; Product life cycle and digital twin with a focus on the area of automated driving.

[69] https://www.gaia-x4futuremobility.dlr.de/

[70] moveID - moveID. https://moveid.org/

With the above-mentioned main areas of work, the GAIA-X 4 Future Mobility project family will provide important product-related impulses for answering questions in the mobility sector, which is currently undergoing transformation. The project family stimulates the emergence of new product ideas and innovative business models, which focus on digital assets or products in addition to established products in the mobility sector through the respective specification of concepts based on concrete use cases or application situations.