Green mobility data models and services for smart ecosystems

D5.4 Whitepaper for the adoption of green mobility services by cities

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List of Acronyms

Abbreviation / acronym	Description
AI	Artificial Intelligence
ANN	Artificial Neural Network
API	Application Programming Interface
AQI	Air Quality Index
AQC	Air Quality Calculation
AQF	Air Quality Forecasting
AQ	Air Quality
CAGR	Compound annual growth rate
CB	Context Broker
DCAT-AP	Data CATalogue Application Profile
DPIA	Data Protection Impact Assessment
Dx.y	Deliverable number y belonging to Activity x
EC	European Commission
EEA	European Economic Area
EGM	Easy Global Market
EV	Electric Vehicle
EU	European Union
GHG	Green House Gaz
GDPR	General Data Protection Regulation
GPS	Global Positioning System
ICE	Internal Combustion Engine

Abbreviation / acronym	Description
IoT	Internet of Things
JSON	JavaScript Object Notation
KNN	K-Nearest Networks
LD	Linked Data
LDES	Linked Data Event Stream
LEZs	Low Emission Zone
LOM	Law of Orientation of Mobility
MaaS	Mobility as a Service
MAPE	Mean Average Percentage Error
MMT	Million Metric Tonnes of a gas
NGO	Non-Governmental Organizations
NGSI	Next Generation Service Interfaces
OSLO	Open Standards for Linked Organisations
RTO	Research and Technology Organisation
SME	Small and Medium-sized Enterprises
SNCF	Société Nationale des Chemins de Fer
SPARQL	SPARQL Protocol and RDF Query Language
UX	User Experience
PHV	Private Hire Vehicle
ZOU	Regional Transport Network of SUD region in France

Executive Summary

This document serves as a concise guide summarizing the key findings and recommendations of the GreenMov project. It is designed to assist cities in embracing sustainable transportation solutions. The document underscores the significance of transitioning towards environmentally friendly transportation systems to address urbanization and climate change challenges. It highlights practical use case examples, architectural considerations and digital solutions implemented in pilot cities. Key drivers for successful deployment, including infrastructure development, standardization efforts, open data access, privacy considerations, and the utilization of AI tools are emphasized. The document also addresses barriers to adoption such as regulation, infrastructure limitations, skills gaps, technology requirements and economic impact. Feedback from participating cities and end users enriches the insights provided, shedding light on implementation experiences and social acceptability. The document concludes by exploring emerging trends, technologies, and strategies that shape the future of sustainable transportation. Overall, it offers concise and practical guidance to empower cities in implementing green mobility services and fostering more sustainable and resilient communities.

1 Introduction

This public white paper represents a significant milestone in the GreenMov project—an initiative dedicated to fostering the adoption of green mobility services in cities. Its purpose is to provide a comprehensive summary of the project's key findings, recommendations and insights. Designed as a valuable resource for cities interested in embracing sustainable transportation solutions, this document encapsulates the project's research, pilot deployments and the invaluable feedback received from stakeholders.

Within these pages, readers will discover a wealth of knowledge and practical guidance to aid them in the adoption of green mobility services. The document highlights the importance of transitioning towards environmentally friendly and efficient transportation systems to address the pressing challenges of urbanization and climate change. It serves as a repository of lessons learned, showcasing successful use case examples, architectural considerations and digital solutions implemented in the three pilot cities.

The whitepaper outlines the drivers crucial for the successful deployment of green mobility services, including infrastructure development, standardization efforts, open data access, privacy considerations and the utilization of AI tools. By identifying these key drivers, cities can lay the foundation for effective implementation and operation of sustainable transportation solutions.

Moreover, the document sheds light on the barriers that hinder the widespread adoption of green mobility services. It examines challenges related to regulation, infrastructure limitations, skills gaps, technology requirements and the economic impact of transitioning to sustainable transportation. By understanding and addressing these barriers, cities can overcome obstacles and create an enabling environment for the implementation of green mobility services.

The insights gained from the GreenMov project are not limited to theoretical findings but are grounded in real-world experiences. The whitepaper incorporates feedback from the participating cities and end users, offering valuable perspectives on the implementation and social acceptability of green mobility services. This feedback serves as a valuable guide for cities, enabling them to fine-tune their strategies and improve their services to better meet the needs and expectations of their communities.

In conclusion, this white paper stands as a comprehensive compilation of knowledge and insights derived from the GreenMov project. It serves as a practical guide for cities seeking to adopt green mobility services, offering lessons learned, recommendations, and inspiration for the creation of sustainable transportation systems.

1.1 Purpose of the document

The purpose of this public whitepaper is to provide a comprehensive summary of the lessons learned and recommendations for cities aiming to adopt green mobility services. By synthesizing valuable insights and experiences, the document aims to guide cities in making informed decisions and implementing sustainable transportation solutions effectively.

1.2 Relation to other project work

This is the fourth deliverable of the Activity 5, it draws upon the insights gained from various previous deliverables and provides a comprehensive summary of all the activities undertaken throughout the project, with a specific emphasis on the accomplishments and outcomes of Activity 3, 4 and 5 and their direct relevance to the adoption of green mobility services.

1.3 Structure of the document

This document is structured in 8 major chapters.

Chapter 1 is an introduction to the document.

Chapter 2 and 3 presents the general and local context of the three use cases adopted in the project.

Chapter 4 presents implementation of digital solutions, user interfaces and the overall architecture deployed in the three pilot cities.

Chapter 5 highlights the key drivers for successful deployment of green mobility services. It covers infrastructure, standardization, data open access, privacy, AI tools, and explainable AI.

Chapter 6 focuses on the barriers that hinder the adoption of green mobility services. The chapter explores various challenges, including regulation, infrastructure limitations, skills gaps, technology requirements, and the economic impact of implementing sustainable transportation solutions.

Chapter 7 combines the lessons learned from the GreenMov project and the valuable feedback received from cities and end users.

Chapter 8 explores the future of green mobility services for cities, building upon the knowledge and experiences gained from the project.

2 Context

The concept of a Smart City has emerged as a transformative approach to urban development in response to the challenges faced by rapidly growing cities. A Smart City leverages digitalization and innovative technologies to optimize resource management, enhance quality of life, and promote sustainability. It embraces the integration of intelligent systems and data-driven solutions across various sectors, including transportation.

Digitalization plays a crucial role in reshaping transportation systems by enabling connectivity, automation, and real-time data analysis. It facilitates the development of intelligent transportation networks that seamlessly integrate different modes of mobility, such as public transport, cycling, walking, and shared mobility services. By leveraging data and technology, cities can optimize traffic flow, improve transportation efficiency, and enhance user experiences.

In the face of pressing environmental concerns, reducing greenhouse gas (GHG) emissions has become an imperative for cities worldwide. The transportation sector, a significant contributor to GHG emissions, requires a shift towards sustainable alternatives. Green mobility services offer a viable solution by promoting low-carbon and energy-efficient modes of transportation. Electric vehicles (EVs), sustainable infrastructure, and intelligent transportation systems are key components of green mobility services that help mitigate environmental impacts and pave the way for a greener future.

To achieve ambitious climate goals, cities are increasingly committed to the path towards net-zero emissions. This entails reducing overall GHG emissions and offsetting any remaining emissions through sustainable practices. By integrating green mobility services into their transportation frameworks, cities can significantly contribute to this objective. The adoption of EVs, the development of charging infrastructure and the implementation of intelligent transportation systems are instrumental in reducing emissions and moving towards a net-zero future.

In this context, the GreenMov project has played a pivotal role in advancing sustainable transportation solutions. Through research, pilot deployments, and stakeholder collaboration, the project has generated valuable insights and practical recommendations. It has explored the integration of Smart City principles, digitalization and a focus on reducing GHG emissions in promoting the adoption of green mobility services. The project's findings and recommendations presented in this whitepaper offer a comprehensive understanding of the challenges, opportunities, and best practices for cities aiming to embrace green mobility services on their path towards achieving net-zero emissions.

3 Local Context

3.1 Nice

The city of Nice is located southeast of France close to the Italian border, and benefits from access by air, by sea or by land.

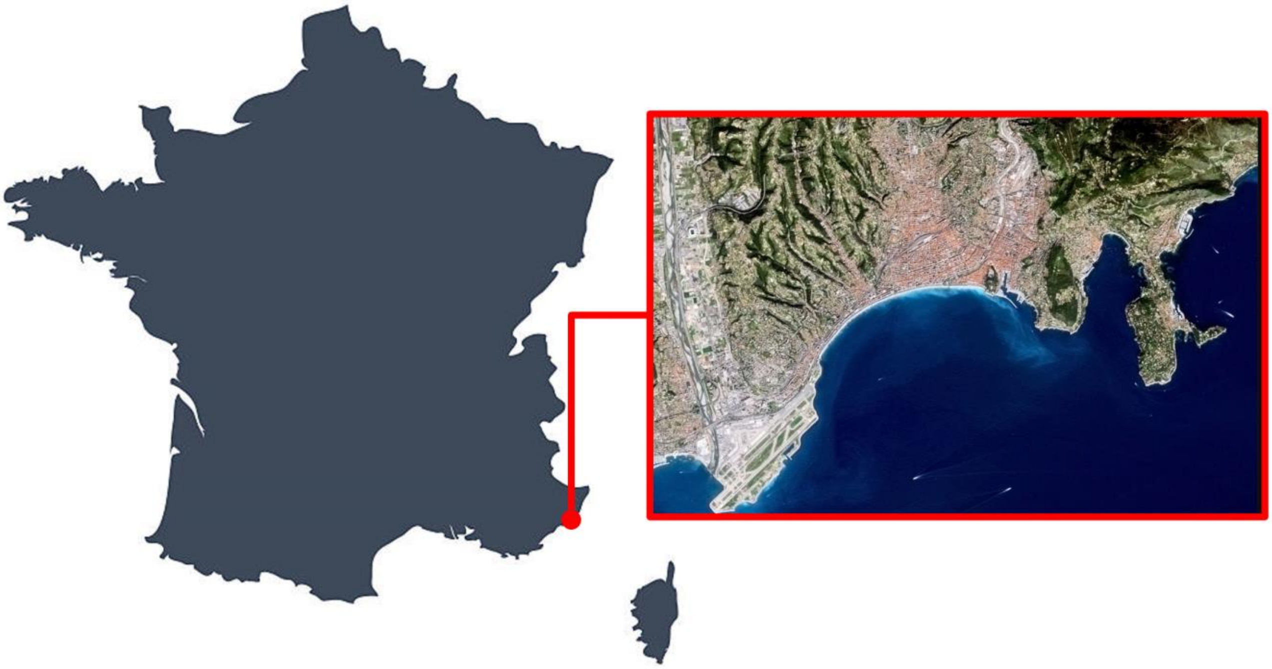

Figure 1. City of Nice: geographical representation

It has emerged as a frontrunner in integrating Smart City principles and sustainable urban development. The city's organizational structure, governance, regulations, technical readiness, and alignment with companies and community visions have laid the foundation for a successful adoption of green mobility services.

3.1.1 Legal context

In terms of regulation, Nice is a French city that must respond to several regulation that apply in the country. These regulations aim to increase the pace of the energy transition, and include several initiatives as listed below. First, the Law of Orientation of Mobility (LOM) aims to facilitate mobility and reduce the carbon impact of transport by allowing local authorities to experiment with alternative sustainable mobility solutions to the private car. The law was adopted on December 24, 2019, and represents a comprehensive framework for addressing various mobility challenges and transitioning towards greener transportation options. The LOM outlines ambitious objectives to enhance sustainable mobility and reduce greenhouse gas emissions in the transportation sector. It sets targets for the development of public transportation, active modes of transport (walking and cycling), and the promotion of clean vehicles. It empowers local authorities to create low-emission zones (LEZ) in urban areas to restrict access for high-polluting vehicles. These zones encourage the use of cleaner vehicles and reduce air pollution. It also includes provisions to prioritize and promote cycling and walking infrastructure. It aims to improve safety and convenience for pedestrians and cyclists, making these modes of transport more attractive options. The law emphasizes the development and modernization of public transportation networks. It encourages the integration of different modes of transport and the implementation of more efficient and interconnected systems. It also includes measures to promote the adoption of electric vehicles (EVs) and the development of charging infrastructure. It also encourages the use of alternative fuels to reduce dependence on traditional fossil fuels. It also supports the concept of Mobility as a Service, which aims to integrate various transport services and modes into a single platform, making it easier for users to plan and use multi-modal transportation. Finally, the LOM includes provisions for financial incentives, tax benefits, and regulatory measures to support the transition to cleaner and more sustainable mobility options.

As a result, following the framework proposed by the LOM, France has been actively promoting the adoption of electric vehicles to reduce emissions and combat climate change. Various measures have been implemented to incentivize the purchase of EVs, including subsidies, tax breaks, and reduced registration fees. In addition to this, the city of Nice proposes additional subsidies to fasten the adoption of electric mobility. This also requires strong investments in the development of charging infrastructure to support the growth of electric vehicle usage, which were mostly led by the French government. Initiatives include the installation of public charging stations in urban areas and along highways. Along with these incentives for electric mobility, the French government is also supporting various sustainable mobility initiatives, such as bike-sharing programs, pedestrian-friendly urban planning, and improved public transportation networks. Regulations also encourage companies to transition their corporate fleets to electric or low-emission vehicles. Proposed measures include financial incentives or stricter emissions standards for company-owned vehicles.

Also, France has incentivized the development of Low-Emission Zones (LEZs), which has led several cities in France to implement or plan low-emission zones, where only vehicles meeting specific emission standards, such as Euro 6 for diesel and Euro 4 for petrol, are allowed to enter. This measure aims to improve air quality and encourage the use of cleaner vehicles. Nice has planned the deployment of at least one LEZ in the city centre to improve the quality of life of its citizens.

In addition to these incentives for greener mobility solutions, France has planned to ban the sale of new internal combustion engine (ICE) vehicles in the future. The target year was set for 2040, although some cities might want to achieve their target earlier.

On top of these financial incentives, the French government has allowed concrete actions aiming to familiarize citizens with green mobility solutions. This includes the promotion of public transportation solutions through subsidized or discounted public transportation fares for certain groups, such as students, seniors, and low-income individuals, but also Free Public Transportation Days organized by some cities to encourage people to try out and experience the benefits of using public transit. Similarly, some cities in France propose integrated ticketing systems (MaaS) to allow passengers to use a single ticket or card for multiple modes of public transportation, such as buses, trams, and metro systems. This simplifies travel and makes public transportation more convenient. Then, many cities have implemented car-sharing and bike-sharing programs, providing access to electric cars and bicycles for short-term rentals. These programs offer a flexible and eco-friendly alternative to private car ownership. Finally, cities are increasingly implementing pedestrian-friendly initiatives, such as car-free zones and expanded sidewalks, to encourage walking and reduce reliance on cars.

3.1.2 Specificities of the metropole of Nice

The city administration of Nice has taken significant strides in promoting sustainable transportation solutions and digitalization.

First, the organization includes dedicated departments and committees responsible for sustainable mobility, actively driving the implementation of green mobility initiatives. For instance, the Department of Sustainable Development and Mobility oversees the planning and execution of sustainable transportation projects, ensuring their integration into the city's overall vision.

Some of the key initiatives undertaken by Nice to encourage eco-friendly transportation include the development of a modern and extensive tramway network that connects various parts of the city. Apart from the tramway network, Nice has been continuously working to improve its public transportation system, making it more efficient, reliable, and eco-friendly, by investing into electric buses for example. Indeed, public transportation providers such as "Lignes d'Azur" and "ZOU" have integrated electric buses into their fleets, reducing emissions and improving air quality. Private ride-sharing companies have also introduced electric and hybrid vehicles as part of their service offerings. The city also operates a bike-sharing system called "Vélo Bleu," providing residents and visitors with access to bicycles for short-term rentals. Along with this initiative, the city of Nice has improved its cycling infrastructure, including bike lanes and bike paths, to promote cycling as a viable alternative to motorized transport.

Following the LOM framework, Nice has established low-emission zones (LEZ) in certain areas to restrict access for high-polluting vehicles. Only vehicles meeting specific emissions standards are allowed to enter these zones, helping to improve air quality. For what concerns the promotion of Electric Vehicles (EVs), the city has been encouraging the use of electric vehicles by providing charging infrastructure across the urban area and offering additional incentives such as reduced parking fees for EVs, but also financial subsidies to buy EVs. Furthermore, the "Bonus-Malus" system, a national incentive program, provides financial incentives to residents who purchase electric or low-emission vehicles. Along with this deployment of EVs, the city has designated specific parking spaces for electric vehicles, making it more convenient for EV owners to find charging stations. Nice has implemented pedestrian-friendly zones in some parts of the city, creating car-free or car-restricted areas to prioritize pedestrian movement and make the city more walkable.

Finally, the city has conducted awareness campaigns to promote sustainable transportation options and educate the public about the benefits of using green mobility solutions.

In terms of governance, Nice has established strong partnerships and collaborations with both public and private stakeholders. The city works closely with transportation service providers, technology companies, and infrastructure developers to foster innovation and sustainable practices. Examples include partnerships with electric vehicle (EV) charging infrastructure provider Prise de Nice to expand the charging network across the city.

3.1.3 Digitization of Transport in Nice

Technical readiness is a key aspect of Nice's approach to green mobility services. The city has made significant investments in intelligent transportation systems, data analytics, and digital platforms. For example, the implementation of a comprehensive traffic management system enables real-time traffic monitoring and optimization, reducing congestion and improving overall transportation efficiency. Additionally, digital platforms and applications provide users with information on public transport schedules promoting sustainable mobility choices.

Additionally, technology companies are collaborating with the city administration to develop innovative solutions such as smart parking systems and mobility-as-a-service platforms such as “Moovit”, enhancing the overall transportation experience.

In the context of the GreenMov project, Nice leverages its organizational structure, governance, regulations, technical readiness, and alignment with company and community visions to accelerate the adoption of green mobility services. The project builds upon existing initiatives, sharing best practices and exploring innovative solutions. As an example, the city of Nice is one of the first European cities to implement a FIWARE based open-data infrastructure based on NGSI-v2 to enable the deployment of novel digital services to the city and to the end-users. By combining efforts from the city administration, private entities, and community stakeholders, Nice aims to create a sustainable and inclusive transportation system that meets the expectations of its residents, reduces emissions, and enhances the overall quality of life.

3.2 Murcia/Molina

Located in south-eastern Spain, the Region of Murcia offers a unique blend of natural beauty, historical charm, and a vibrant urban environment. The mobility situation in Murcia has significantly improved in recent years, with the government implementing various initiatives to enhance transportation infrastructure and promote sustainable modes of mobility. This section explores the state of the current mobility situation in Murcia city and Molina de Segura city, highlighting the key transportation options available and the challenges to fostering a well-connected and eco-friendly transportation network. Figure 2 shows the location of Murcia in Spain, and the metropolitan area in the Region of Murcia.

Figure 2. Region of Murcia location.

Murcia boasts an efficient and well-integrated public transportation system, making it convenient for residents and visitors to navigate the region. Buses serve as the primary mode of public transportation, connecting the city centre with surrounding towns and villages. The bus network covers many routes, including urban, suburban, and intercity services, ensuring comprehensive connectivity within Murcia and beyond. Regarding the tram, the city has a unique line that connects the shopping centre with the Campus of Espinardo. This tram is not extended to the cities in the urban agglomerations, but there are plans to connect Murcia and Molina by tram.

On the other hand, Murcia City is investing in bicycles and pedestrian-friendly infrastructure. It is making commendable progress in promoting sustainable and active modes of transportation. The city has witnessed the implementation of extensive cycling infrastructure, including dedicated bicycle lanes and paths. These facilities allow residents and visitors to explore the city on two wheels safely. Introducing public bicycle-sharing systems has encouraged using bicycles as a viable transportation option. However, Molina of Segura does not have these infrastructures, but it is indeed a small city where people can move on foot.

Murcia has embraced smart mobility solutions to keep up with the evolving mobility landscape. The city has implemented intelligent transportation systems to manage traffic flow efficiently, optimise public transportation routes, and provide real-time information to commuters. These initiatives aim to reduce congestion, enhance safety, and improve the overall efficiency of the transportation network. Thus, the mobility situation in Murcia continues to evolve, with ongoing plans and initiatives to further improve transportation options and promote sustainable mobility. The government is investing in the expansion and modernisation of the public transportation infrastructure, including the development of new bus lines, the introduction of electric buses, and the integration of mobility services through smart platforms.

At this moment, they are two key challenges that the Region of Murcia - including Molina de Segura - address. The first one is traffic congestion, due to the growing population, increased vehicle ownership, and urban development have contributed to the proliferation of traffic jams in the region. Rush hours and peak travel times often witness severe congestion, resulting in delays, frustrated commuters, and environmental concerns. This is especially important in the Campus of Espinardo, an area that is shared by Murcia and Molina de Segura municipalities. The second one is the need of shared mobility strategies between both cities.

Thus, GreenMov plays a key role in addressing these challenges by placing the pilot in the Campus of Espinardo area. Our services will promote the use of bike-sharing services reducing the congestion as well as will allow municipalities to monitor the status of a conflictive area and will provide citizens with the information regarding air quality to take the bes decision regarding mobility. In addition, the participation in GreenMov has supposed the design of a common platform between both cities to share information.

In recent years, green mobility has gained significant momentum as the world strives to address the challenges of climate change and reduce carbon emissions. The region of Murcia is no exception to this global trend. With its beautiful landscapes, growing urban centres, and a strong sense of community, Murcia envisions a future where sustainable transportation is at the heart of its development.

Companies operating in Murcia recognise the need for a paradigm shift towards green mobility. They understand that adopting eco-friendly practices benefits the environment and contributes to their long-term success. This is especially important for SMEs working on digital solutions because of the wide range of opportunities that are opened. These companies envision sustainable impact assessment tools based on data, which allow public authorities to make decisions based on data. By implementing and providing these tools, companies in Murcia strive to create an economically viable and environmentally responsible green mobility ecosystem.

Cities in Murcia also play a crucial role in shaping the vision for green mobility. They aim to transform their urban landscapes into sustainable and liveable spaces. Murcia envisions cities with interconnected networks of pedestrian-friendly pathways, dedicated bicycle lanes, and efficient public transportation systems. Also, one of the key points in the Murcia metropolitan area is connecting different cities and taking common mobility policies.

However, the vision for green mobility in Murcia extends beyond the efforts of companies and cities. The communities within Murcia have high expectations and actively participate in shaping the future of transportation. Residents envision a region where most vehicles are electric or powered by renewable energy. They advocate for the availability of charging infrastructure, incentives for green vehicle adoption, and affordable access to public transportation. Communities also expect local governments and companies to prioritise sustainable transport initiatives that reduce their carbon footprint and promote a healthier environment for future generations.

To fulfil these expectations, a collaboration between companies, cities, and communities is paramount. Public-private partnerships can drive innovation, invest in green infrastructure, and create supportive policies. By fostering dialogue, engaging stakeholders, and involving citizens in decision-making, the vision for green mobility in Murcia can become a shared goal that strengthens the region's commitment to sustainability.

3.3 Flanders

Flanders, Belgium’s northern region, is located in the heart of Europe. Situated between France and the Netherlands and close to Germany, it benefits from access by air, by sea or by land.

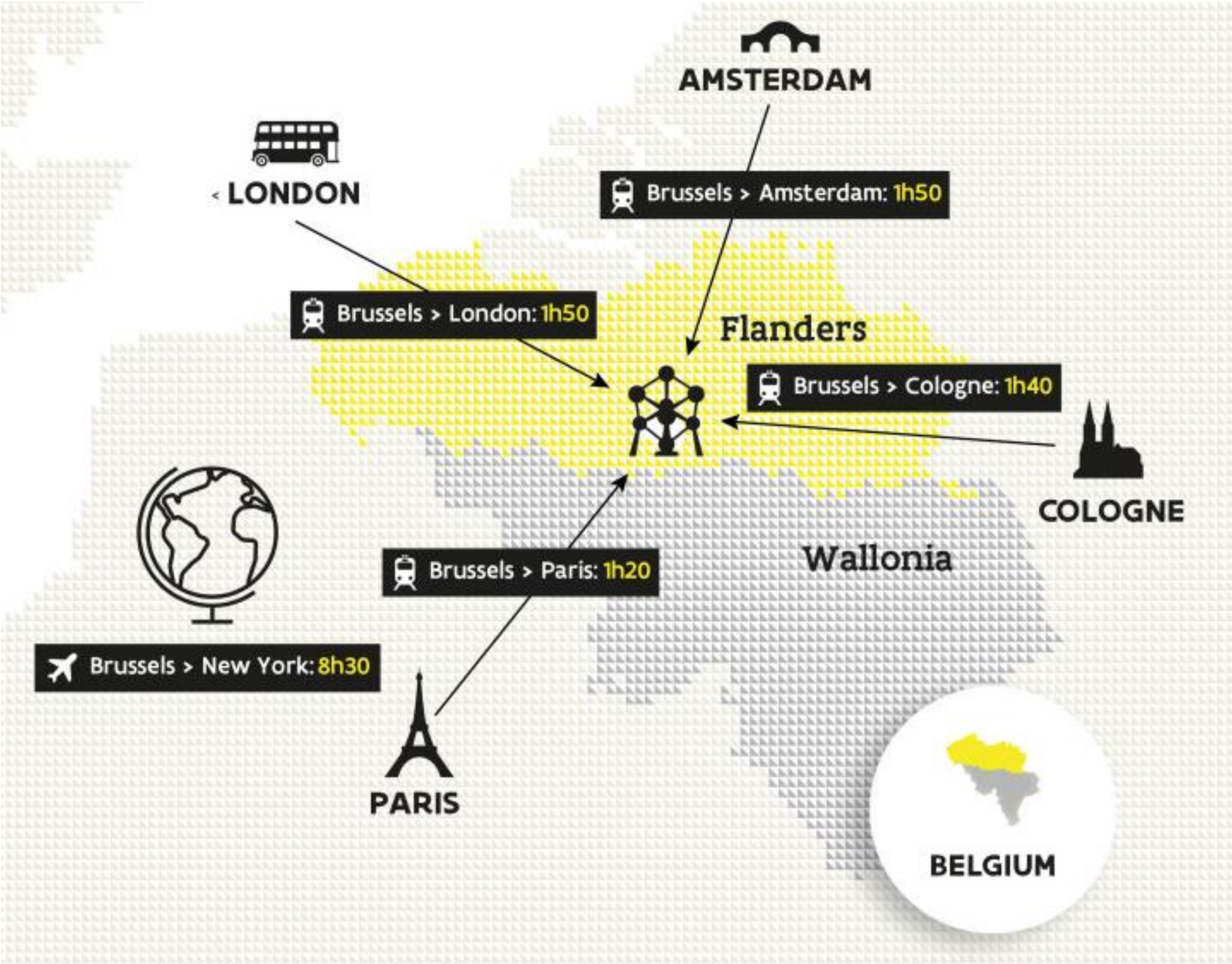

Figure 3. Region of Flanders: geographical location

Flanders is in the front group of digital regions in Europe and aiming to close the gap with the leaders. With Antwerp and Leuven, it contains two cities that been selected to join the EU Mission of being Climate-neutral and smart cities by 2030 [9]. Antwerp and Ghent have already introduced Low Emission Zones, as have the Capital Region of Brussels.

3.3.1 Policy context

As a region in Belgium, Flanders has almost full autonomy regarding mobility and environmental competencies (on land and in the air). Very densely populated with congested roads, the region takes on the challenge to make the modal shift towards green mobility.

The Flemish government developed the framework for the introduction of a low-emission zone on Flemish territory. All Flemish cities and municipalities that want to introduce an LEZ do so on the basis of the Flemish decree of 27/11/2015 and the decision of the Flemish Government on low-emission zones of 26/02/2016.

On 9 July 2021, the Flemish Government approved a vision for the future of Flemish mobility. The meaning of mobility can be summarized in one slogan: 'With smartly arranged traffic and transport to sustainably connected people and companies'. This slogan contains 3 crucial aspects of the future vision of mobility in Flanders. The Flemish government wants mobility and spatial organization to guarantee maximum connectivity and accessibility in a sustainable and safe manner and tailored to all people and companies.

The following perspectives are proposed by 2050:

- Elimination of severe road casualties.
- Eradication of transport emissions.
- Smooth and seamless mobility.
- Achieve a 60% reduction in the material footprint associated with mobility.

This mobility vision goes hand in hand with the principle of basic accessibility. With this, the Flemish government wants to make important social locations, such as business parks, schools, hospitals and shopping centres, optimally accessible for the traveller. Basic accessibility starts from the demand for mobility and therefore has a strong regional interpretation.

That is why Flanders has been split into 15 transport regions, which are currently drawing up their own regional mobility plans. The Flemish mobility vision serves as a framework for this.

3.3.2 Smart connected mobility system

To enable more people to travel in a sustainable and safe way, a smart connected mobility system is envisaged. That consists of a network of interchanges (so-called Hoppin points): travellers can go there get on, off or transfer to active, shared in a smooth and comfortable way or collective emission-free means of transport. These nodes are connected via different infrastructure networks and data and information systems, so that travellers are well informed about the available transport offer.

In the context of the GreenMov project, Flanders leverages its organizational structure, governance, regulations, technical readiness, and alignment with company and community visions to accelerate the adoption of green mobility services. The project builds upon existing initiatives, sharing best practices and exploring innovative solutions. As an example, the transport regions will implement the OSLO Hoppin points datamodel, which was further developed within GreenMov, to provide information about the nodes, the infrastructure network and the mobility solutions, in an interoperable way.

The mobility offer is very rich and complex:

Table 1. Mobility offers in Flanders

Area	Type	Brands	Public/Private
National	Train	NMBS	Public
Brussels	Bus, train & metro	MIVB	Public

Area	Type	Brands	Public/Private
Flanders	Bus and tram	De Lijn	Public
Wallonia	Bus and tram	TEC	Public
National	Shared bikes	Blue-bike	Public
Antwerp	Shared bikes	Villo	Public
Antwerp	Shared Scooters	Bird, Lime and Poppy	Private
National	Shared cars	Cambio	Private
Flanders	Shared cars	Cambio	Private

See also an overview for Antwerp https://www.slimnaarantwerpen.be/nl/deelmobiliteit.

This rich and diverse offer comes with a major challenge for citizens who want to plan their trip door to door. It leads also to a major challenge for all actors who want to publish or consume data:

- Data producers (e.g., a mobility provider) wants to publish its data while keeping control. The data is required for internal operational processes (service levels, forecasting), to service the customers directly in apps and websites and to feed route planners. The date producer wants to control the cost of publishing, control the access and eventually monetize the data.
- Route planners need data from different providers over regional and national borders.
- Cities or other public bodies that impose mobility providers to publish their data can be faced with major integration costs when this data is not standardized which is often the case today.

One of the key building blocks of Flemish Data strategy is the Flemish Smart Data Space. https://www.vlaanderen.be/digitaal-vlaanderen/onze-oplossingen/vlaamse-smart-data-space.

Several goals mentioned above are targeted in this major endeavour:

- Contribute to the digitalisation of Flanders and the Flemish administration.
- Contribute to efficient and green mobility with a mobility data space.
- Allow data producers and consumers to collaborate efficiently.
- Bring Flanders to leading pack of data technology.

Key components include interconnected, accessible, and standardized data.

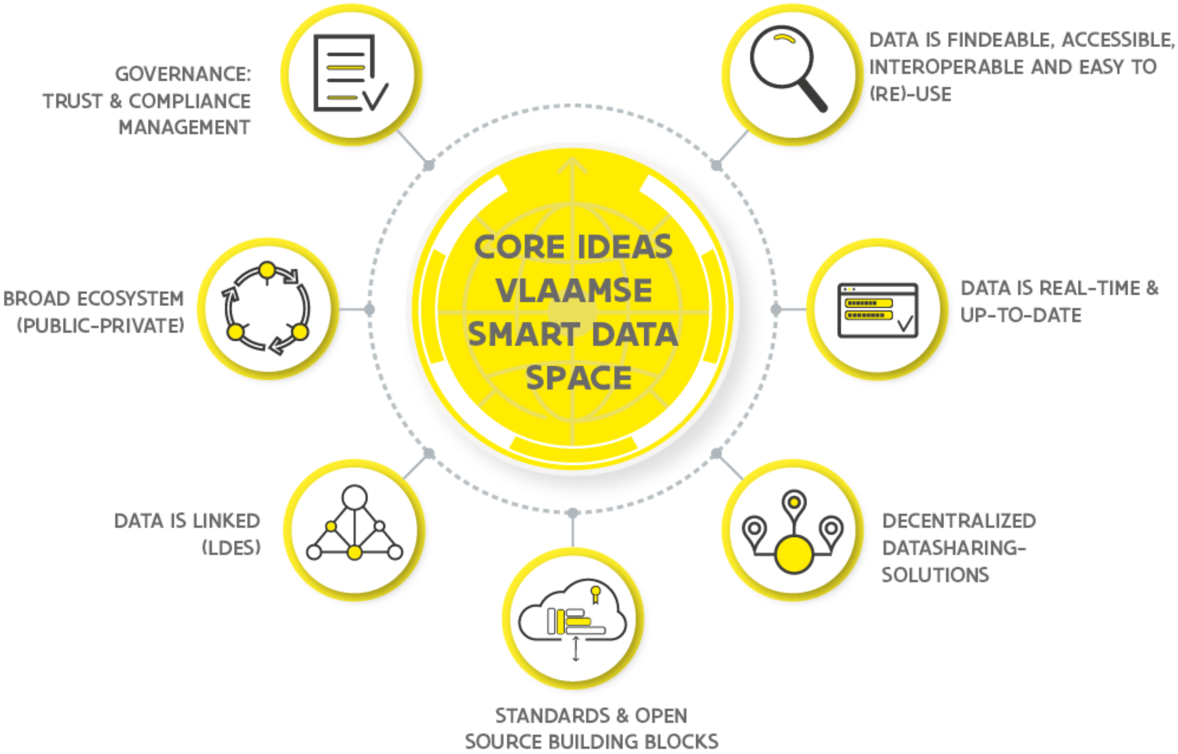

Figure 4. Key elements of the Flemish smart data space

4 Green Mobility Services Solutions

4.1 Overview of Green Mobility Services

Transportation is responsible for more than 22% of GreenHouse gases emissions worldwide [1]. Therefore, it is necessary to address these emissions in order to meet the objectives from the Paris Agreement in 2015. Among these 22%, 16% are due to road transport, which highlights the fact that countries and cities should work towards reduction of the use of carbon-based technologies such as individual petrol cars. To achieve this goal, several initiatives have been proposed by cities in order to incentivize citizens to use alternative low carbon mobility solutions, called “Green Mobility solutions”. These green mobility solutions rely on services that are enablers of these low carbon technologies by making it easier for the citizen to use them.

Green Mobility Services include “car-sharing services”, that allow users to rent vehicles for short periods, usually by the hour or minute, to use for specific trips or errands. Users can access cars through smartphone apps or membership cards and return them to designated parking spots within a service area. Similarly, bike-sharing programs provide bicycles for short-term use within a city or urban area. Users can rent bikes from docking stations, typically located at various points throughout the city, and return them to any other available docking station when finished. Also, electric scooter-sharing services offer electric scooters for short trips in urban areas. Users can locate and unlock scooters using mobile apps and pay for the time or distance travelled. Apart from bikes and scooters, micro-mobility services may include other small, lightweight vehicles like electric skateboards or small electric cars designed for short trips. However, these services rely on Real-Time availability indicators for bikes or car sharing: apps or services that provide real-time information on bike availability at bike-sharing docking stations or nearby car-sharing vehicles, helping users plan their trips and reserve their vehicle in advance.

Other services exist, such as ride-hailing platforms that connect passengers with drivers through mobile apps (Blablacar, etc). Users can request a ride from their location to a destination, and drivers, often using their private vehicles, provide the transportation service. Similarly, ride-pooling services enable multiple passengers with similar routes to share a single ride, reducing costs and environmental impact. Shared taxis operate similarly but with fixed routes and fares. Then, within cities, public transportation Apps provide real-time information on public transportation schedules, routes, and service disruptions, helping users plan their journeys efficiently and to use public transportation.

All these services could be integrated into Mobility as a Service platforms that integrate various transportation options, including public transit, ride-hailing, bike-sharing, and more, into a single app or service, allowing users to plan, book, and pay for multi-modal trips seamlessly.

Carpooling Services: Carpooling platforms connect drivers with spare seats in their vehicles with passengers heading in the same direction, promoting carpooling to reduce congestion and emissions.

Most of these services rely on innovative digital services that enable an easy access to the services by the end-users. These digital services are mostly Apps (mobile or web-Apps) that leverage real-time data to provide valuable information, trip planning, and other useful features for public transit users. End-users currently have access to a few digital services that include Transit apps, which are designed to provide real-time information on public transportation schedules, routes, and service updates. These apps often include features like trip planning, live tracking of buses and trains, and alerts for service disruptions or delays, and require an interconnection with other mobility services such as public transportation services. As an example, Moovit is a popular public transit app that offers real-time public transportation information, including bus, train, subway, and tram schedules, trip planning, and live tracking of vehicles. Similarly, Citymapper is another widely used transit app that covers multiple cities worldwide. It offers real-time public transit data, step-by-step trip planning, and multimodal options, including walking, cycling, and ride-hailing services. Google Maps is another well-known digital service that incorporates public transportation information for many cities, providing schedules, routes, and estimated travel times. Users can easily switch between driving directions and public transit options. The main advantage of Google Maps is the fact that it works seamlessly in most of worldwide locations. As mentioned earlier, it relies on a deep connection to cities and their public transport offering. Indeed, Google Maps often compete with a certain success with many cities and public transportation authorities' official apps that provide real-time information, service alerts, and trip planning for their specific transit networks.

Then, digital services that are used for Green Mobility Services include secondary aspects such as ticketing and payment Apps that allow mobile ticketing and payment to purchase and store digital tickets for buses, trains, and other transit services directly on smartphones. Other secondary aspects include the calculation of the environmental impact of public transit use, such as CO2 emissions saved by choosing public transportation over driving.

Finally, we can also find some apps that are specific to some use cases such as accessibility Apps that are designed for people with disabilities to provide them with information about accessible routes, facilities, and services on public transportation. People cycling can also find bike routing Apps that offer bike routing and navigation, integrating bike lanes and cycling paths into trip planning.

In the rest of this section, we present specific Green Mobility solutions that were proposed within GreenMov to offer services that go beyond the state of the art, and that could help cities to decrease the environmental impact of transportation in their location.

4.2 Use Cases Examples from GreenMov Project

4.2.1 Nice

The GreenMov use case in Nice incorporates a range of green mobility services. Using IoT infrastructures and machine learning techniques, for example the AQI calculations service provides real-time and accurate forecasts of AQI levels within the city. It utilizes historical AQI data, weather parameters, and benchmarking techniques to select the most accurate forecasting model. The service is encapsulated into a Docker image for easy deployment and scalability, and it can be customized to integrate with the city's infrastructure. Other services offered by GreenMov in the Nice use case example include Traffic Environmental Impact Calculation and Forecasting, Bike's availability forecasting, Noise Annoyance Calculation and Forecasting, and Traffic Recommendations Generation.

Nice is the only use case that uses all the services developed within the project perimeters.

The use case general architecture is shown in the Figure 5 and the services are detailed in the Activity 3 deliverable GreenMov_D3.2 Green Mobility Services_v2.

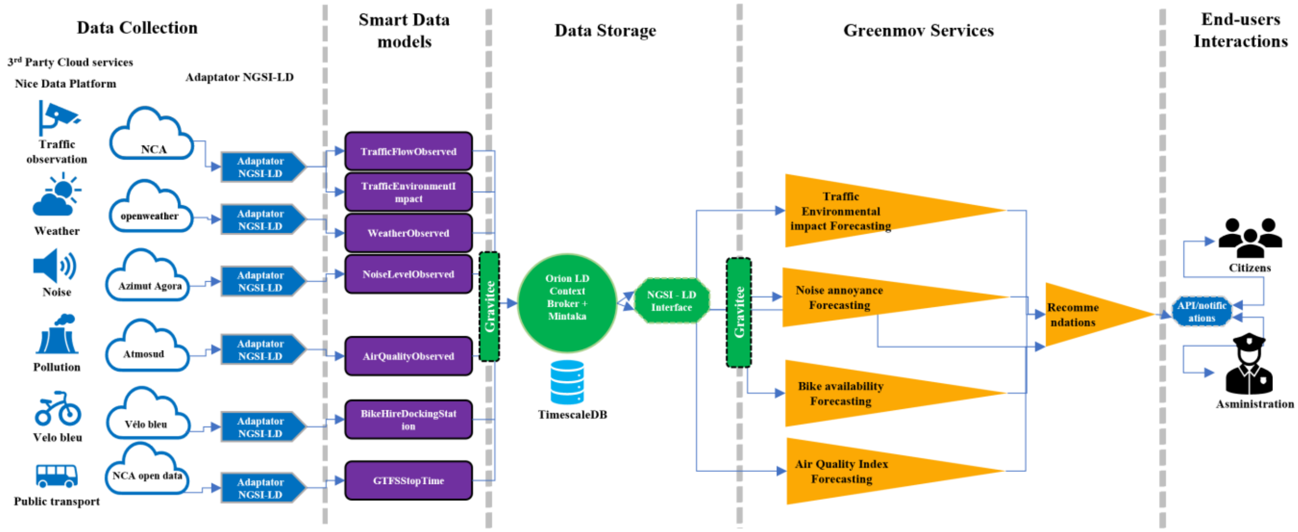

Figure 5. Nice green mobility services architecture.

The deployment of these services consists of many steps as shown in the Figure 6 below:

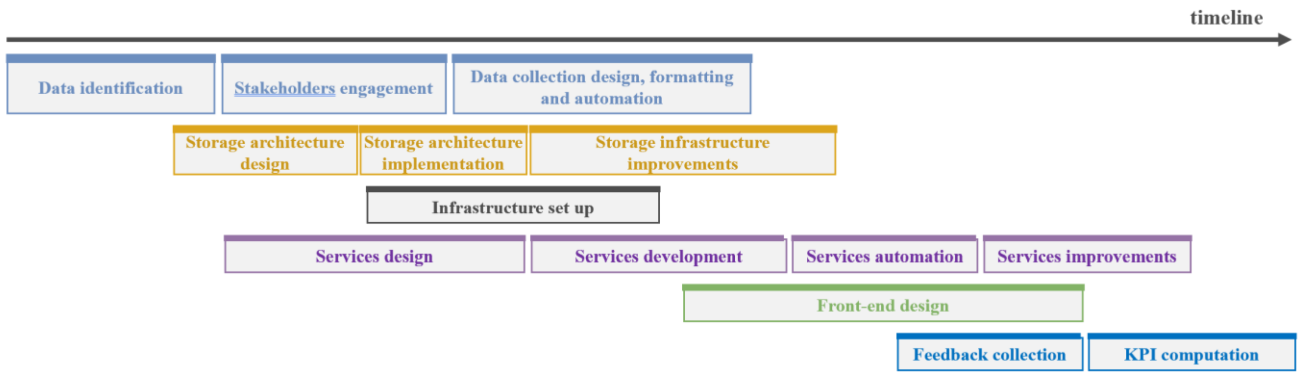

Figure 6. Green mobility services deployment steps.

4.2.2 Murcia/Molina

The municipalities of Murcia and Molina de Segura have similar goals in terms of mobility due to their proximity and common areas of work and expansion. As part of GreenMov, by pooling efforts and data sources, they are developing a use case based on AQI calculations, Traffic Environmental impact and shared bikes availability to assess and predict the impact of road traffic on urban air quality.

By providing a set of green services Murcia and Molina de Segura cities want to promote public transport and rent bike points to mitigate the impacts of traffic on air quality. To aim this objective, we will report the citizens the necessary information to decide to leave the car and search for green alternatives. We will also report to the public administration the knowledge to make intelligent mobility, a critical point for Molina de Segura and Murcia, two relevant cities in the south of Spain that share a lifestyle - companies, universities, shopping centres, etc.

So, in this context, GreenMov takes an essential role in the city necessities to obtain the green services for this use case. To delimit a bit, our pilot will focus on Espinardo, a shared university area that also hosts a lot of companies and commerce. Thus, the Campus of Espinardo is a hot spot in terms of mobility and a place with a good combination of public transport.

The architecture of Murcia/Molina follows the architecture proposed in Nice, with the particularity that take advantages context brokers federation to centralise data for both cities, and is detailed in Figure 7 below:

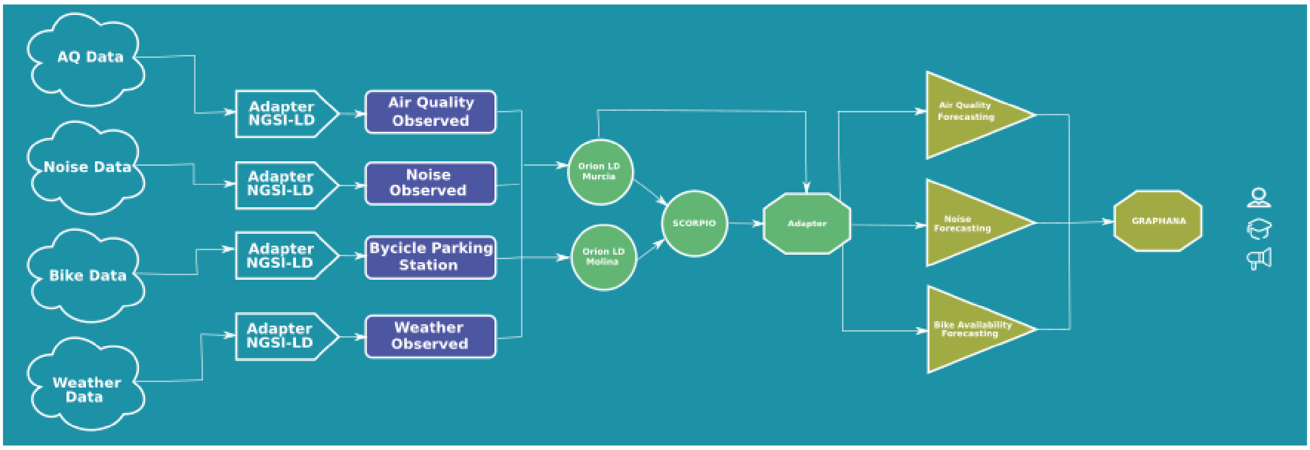

Figure 7. Murcia/Molina architecture.

4.2.3 Flanders

The use case consists at forecasting shared bike offered by Blue-bikes in combination with train timetables. Hence, 2 Flemish strategies are supported:

- The Hoppin-branded multi modal transport hubs.

Figure 8. Hoppin Logo.

- The dataspaces where actors in multiple domains are invited to shared Linked Data. Cf. https://www.vlaanderen.be/vlaamse-smart-data-space-portaal

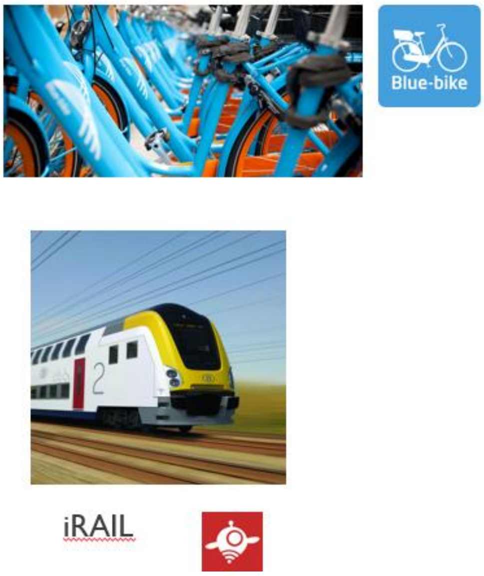

Figure 9. Mobility services used in GreenMov.

As described in the figure below this was achieved by creating Oslo semantics for a Hopping point and applying them to Blue-bike data. The latter are retrieved from the Blue-bike API and republished as LDES Linked Data with the proper OSLO-semantics.

In order to prove compatibility with the FIWARE NGSI-LD context brokers and smart data models the data are converted and made available in an Orion LD broker.

Figure 10. Homepage of the GreenMov Web app.

The GreenMov web-app allows the user to look-up real time train schedules and forecast the number of available Blue-bikes upon arrival. This is achieved by retrieving real time Bike data from the context broker to feed a machine learning-model. In GreenMov the machine learning model consists of the bike forecasting service.

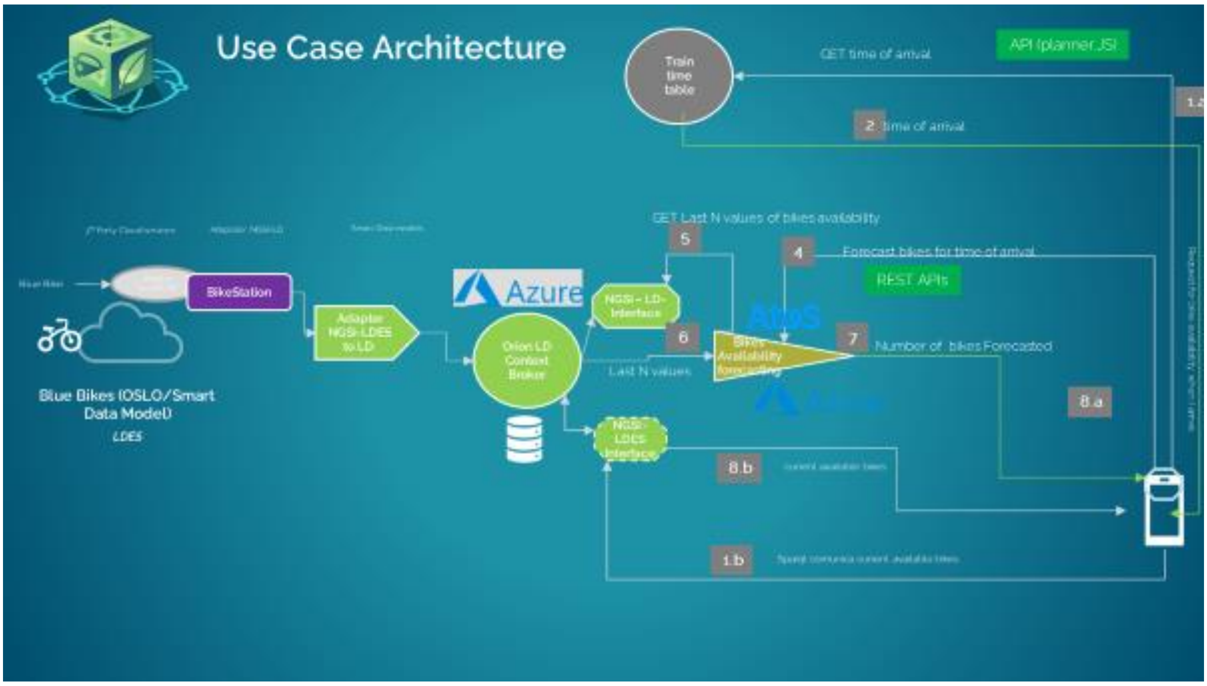

Figure 11. End 2 end flow for the forecasting of trainband Blue-bike combination.

4.3 Reference Architecture for Green Mobility Solutions

As most of Green Mobility solutions rely on real-time data, mobile apps and interfaces with end-users, it is necessary to implement a robust digital infrastructure. As it was highlighted above, the success of these solutions relies on the integration of local data and real time monitoring. From a city perspective, it is beneficial to enable access to data (static and real-time data) to any third-party service provider such as GoogleMap in order to provide better services to the citizens. This access to data from public transportation, shared vehicles, real-time traffic or environment data should be proposed in a standard format so any third party can directly integrate the data into their solution without requiring a custom middleware for each city. This will ensure replicability and better efficiency. For this reason, the GreenMov project recommends the use of a FIWARE based architecture solution to enable access to data in a standard and robust way.

Figure 12 shows such an architecture that adopts a multi-layer structure. First, at the bottom, we find the sensors that will provide the raw data from the cities. In parallel of the sensors, we can find as well third-party services, cloud services that provide relevant data for Green Mobility Solutions. Then, in the second layer, we find Aggregation platforms, such as proprietary platforms that directly gather data from the sensors, maybe using their own data models.

The third layer consists in the core solutions that will allow data routing and storage. Indeed, the third layer consists in the context broker, that will ensure consistency of the data received with existing data models, and that will then store the data in relevant databases. These databases can either be real-time databases, such as MongoDB based databases, or historical database, to store timeseries values, such as PostgreSQL databases.

APIs tools for such historical databases exist and include QuantumLeap (mostly for NGSI-v2), Cygnus, Draco, or Mintaka. The real-time brokers proposed in the generic architecture are OrionLD and Scorpio. The deployment can use container technology based on docker, or Kubernetes. At this level, all data is in its standard form to enable interoperability with the next layers. The application layer then includes all the data analysis aspects, as well as services that leverage analysed data. These application layer includes dashboards, data processing, etc...

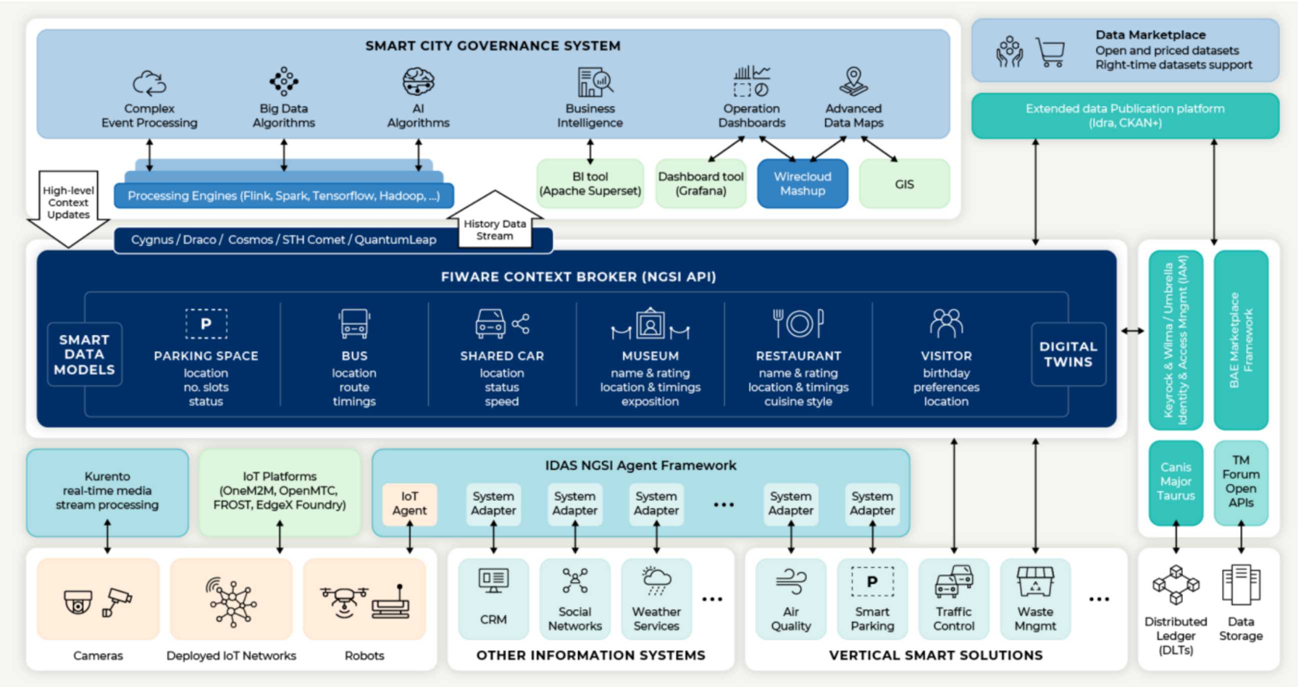

Figure 12. FIWARE's Smart City General Architecture

Finally, in parallel of these layers, we can find sub-services such as securing of access to data, using Keycloack and Keylock identity and access management.

In this deliverable, we propose a simplified version of this architecture that allow quick implementation of green mobility solutions. Figure 13 shows this architecture. On the left side, we can find sensors that belong to the cities or to third parties such as weather monitoring stations, or bikes sharing suppliers for example. Their data is then aggregated by the city and stored locally in a standard format, such as NGSI-LD in order to allow any third party to easily integrate this data into their solution. The third stage consists in services that leverage data proposed by the city. This includes forecasting services, clustering, or route planner services. Figure 13 shows a non-exhaustive list of digital services that could be used as green mobility solutions enablers, as it was the case for the GreenMov project. Finally, user interfaces enable citizens to have access to these services in an ergonomic way.

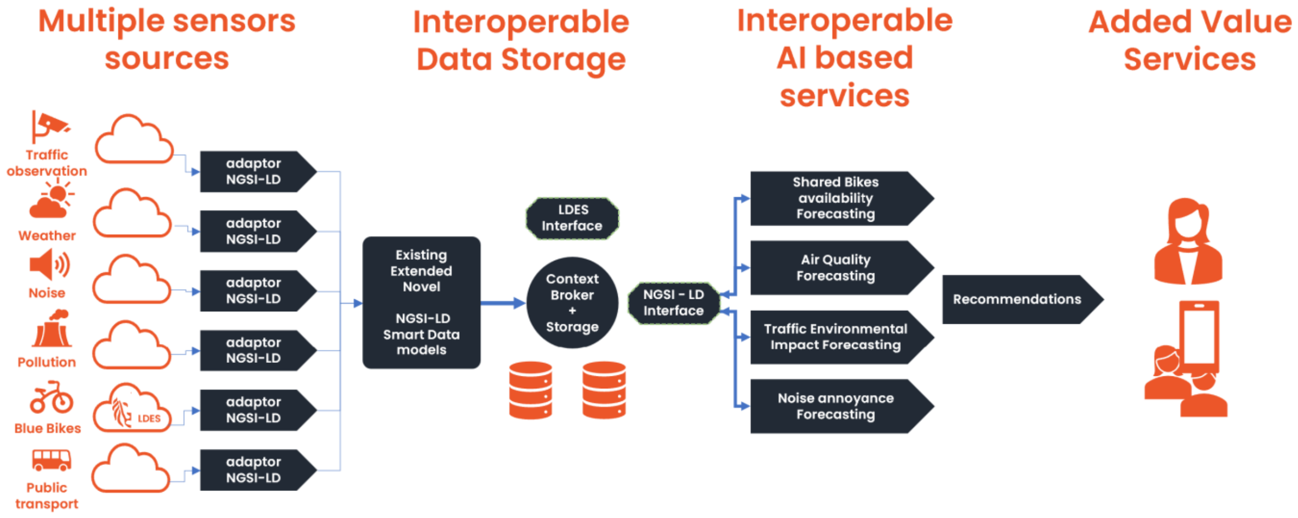

Figure 13. Reference Architecture for Green Mobility Services

Each of the use cases of GreenMov project has adopted a similar architecture, which demonstrate the replicability and robustness of such approach. In the next section, we will discuss an important part of green mobility solution, i.e., the end-users' interface.

4.4 User Interface

Green mobility solutions play a vital role in promoting eco-friendly alternatives to traditional fossil fuel-powered vehicles. However, for these green mobility initiatives to succeed, the role of user interfaces, especially through mobile or web applications, cannot be underestimated. Indeed, user interfaces are the critical link between users and green mobility services, acting as the gateway to access and utilize these sustainable transportation options. A well-designed and intuitive user interface is essential for several reasons. In the fast-paced world we live in, convenience is key. A user-friendly interface simplifies the process of finding, booking, and using green mobility services. Clear and intuitive navigation ensures a smooth user experience, encouraging more people to adopt these sustainable alternatives to traditional transportation. Furthermore, mobile or web apps provide real-time data on vehicle availability, transit schedules, and traffic conditions. With up-to-date information at their fingertips, users can make informed decisions about their travel plans, reducing waiting times and optimizing their routes. Also, green mobility solutions such as MaaS often involve a combination of modes, such as bike-sharing, electric scooters, and public transportation. A well-designed interface can seamlessly integrate these services into a single app, allowing users to plan multi-modal trips effortlessly, as it was done in the Flanders use case in GreenMov project.

Interfaces should also encourage users to choose sustainable transportation options over private cars. An engaging and visually appealing interface can motivate users to make environmentally conscious choices. They can also incorporate personalized features, such as tailored recommendations and loyalty programs, to incentivize users to use green mobility services more frequently. This can help create a loyal user base and increase the overall adoption of sustainable transportation. Finally, a well-designed user interface should take into account the needs of all users, including those with disabilities. Accessibility features such as voice commands and easy-to-read text can make green mobility services more inclusive and accessible to a broader audience.

In conclusion, user interfaces play a pivotal role in the success and adoption of green mobility solutions. By providing an enjoyable, efficient, and convenient user experience, mobile or web apps can drive positive behavioural changes, reduce reliance on fossil fuel-powered vehicles, and contribute to a more sustainable and eco-friendly transportation ecosystem. As we move towards a greener future, the thoughtful design of user interfaces will be instrumental in shaping how we embrace and integrate sustainable transportation options into our daily lives. The rest of this section presents examples of user interfaces from the GreenMov project.

4.4.1 Nice

In the case of Nice, an interface is made available to the city and end-users to get recommendations on their mobility within the next hours. Users are able to access and utilize the traffic recommendation services directly through the interface. Additionally, individual services outputs have been provided. In the Nice use case, the front-end component consists of both the interface for end-users and the API component. The interface for end-users consists in a WebApp that is displayed in Figure 14. End users can use the slide in the middle of the interface in order to select the time for which they want a traffic recommendation. Figure 15 shows an example of interface when there is an event of high air quality pollution and high noise annoyance. In this case, a recommendation follows a logic provided by a traffic recommendation service.

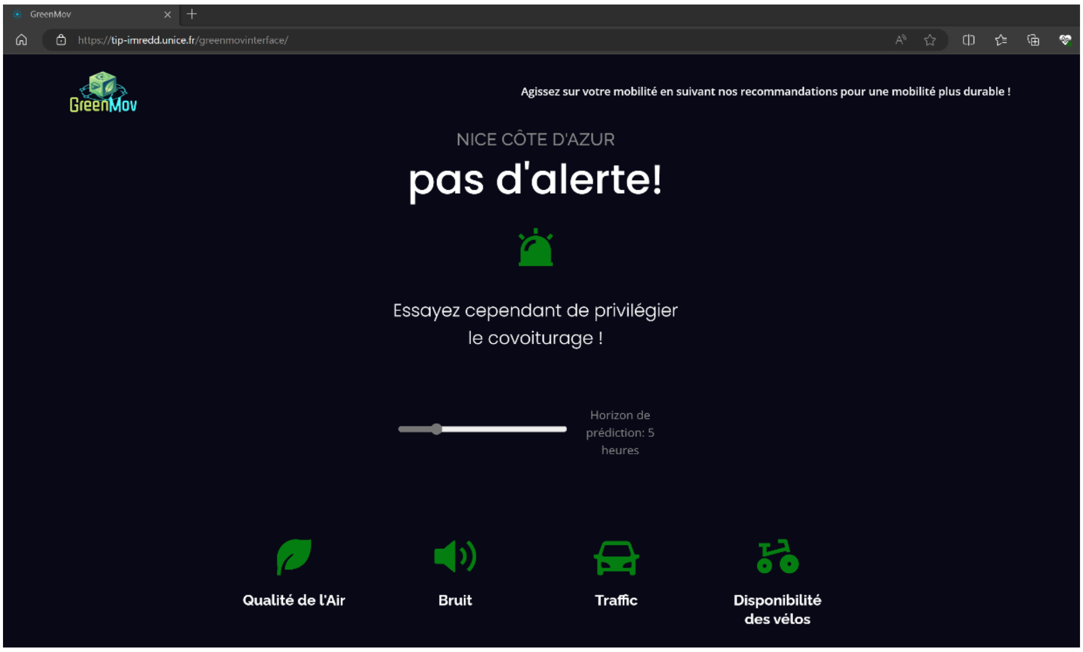

Figure 14. Nice Use case front end

Figure 15. Nice use case front end with an alert due to air quality and noise annoyance

Then, the rest of the interface is constituted of graphs showing the accuracy of the forecasts along with the shape of future noise annoyance or traffic evolutions. Figure 16 shows these different visualisations proposed to the end-users, along with a map on which users can find where the bikes are available.

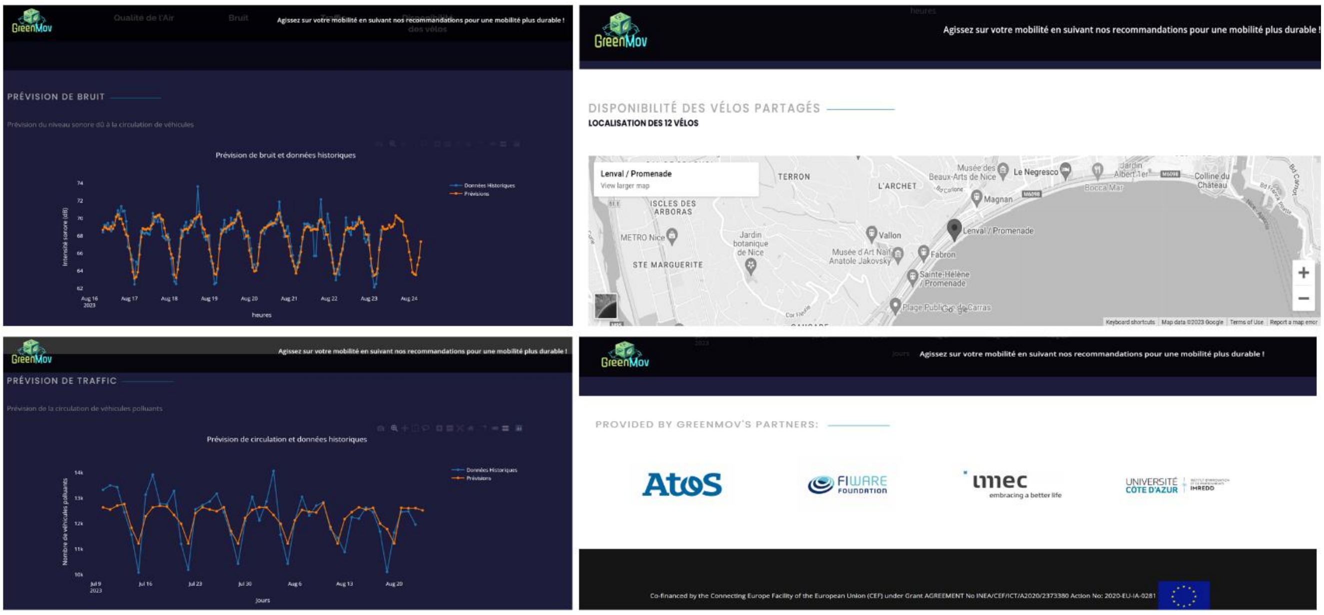

Figure 16. Rest of Front End for Nice use case

4.4.2 Flanders

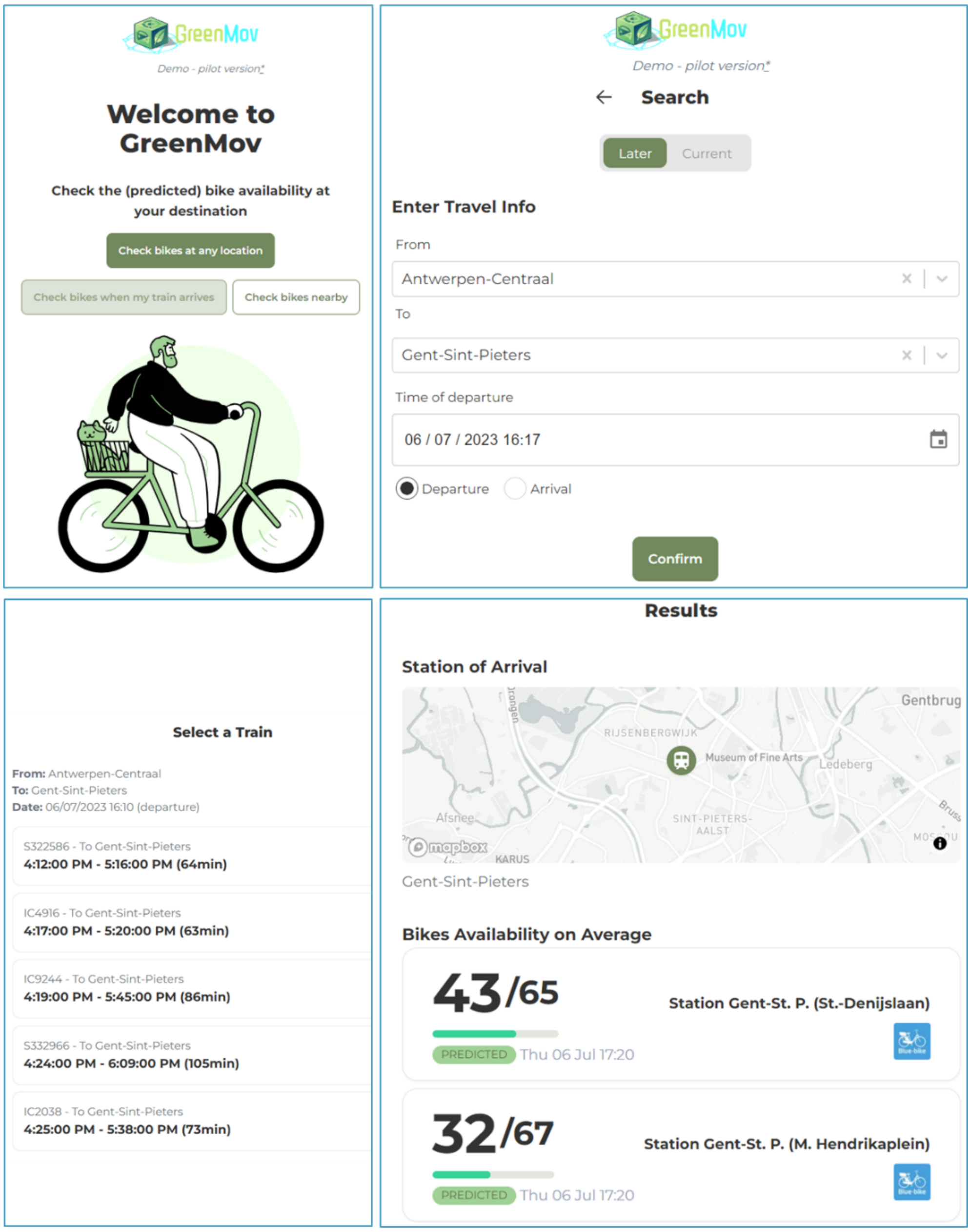

Figure 17. Screenshots of the GreenMov app.

The Figure 17 above illustrates how to plan your journey from Antwerp to Ghent using both the train and a Blue-bike. According to the application, 43 and 32 bikes will be available upon arrival in Gent-Sint-Pieters.

The web-app can be used in any browser and will adapt to the screen size. The screens have been optimized so they can be used on the move on a regular mobile device.

4.4.3 Murcia/Molina

The end user interface in Murcia/Molina case uses Grafana as driver. This is a powerful and open-source front-end tool for data visualisation and monitoring. With its intuitive and user-friendly interface, Grafana allows users to create dynamic dashboards, charts, and graphs to represent complex data in a visually appealing manner. Its extensive library of plugins and integrations with various data sources enables seamless data retrieval and analysis. Grafana empowers developers and data analysts to effortlessly explore and present data-driven insights and provide friendly interfaces for end users.

The first dashboard shows the location of the different sensors over the use case perimeter.

Figure 18. Location of the Air Quality sensors in Murcia/Molina.

Then, it is possible to inspect each sensor and the different pollutants. The colour of the sensor is selected as a function of the AQI calculated by the corresponding service.

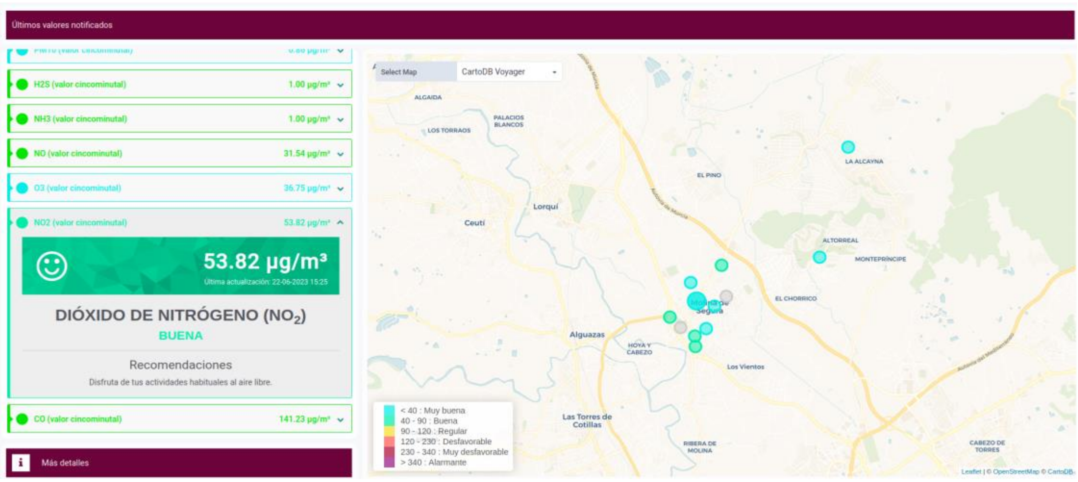

Figure 19. Example of the AQI service user interface in Murcia/Molina.

Last, when the user inspects the data, selecting the period it will be shown is possible. This allows us to select past and future data, and the forecasting services allow us to perform this.

4.5 Digital Solutions

GreenMobility solutions will have a better impact and acceptability if they propose services that will improve our quality of life as well as decarbonising transportation. As it was discussed in the previous section, their acceptability will require the use of ergonomic interfaces to propose optimal route planning using low carbon-based transportation solutions. Such services will strongly rely on digital tools that monitor physical signals, such as traffic density or buses' locations, that send data to a storage facility, and digital tools that analyse the data, process it before displaying it to the end-users. Therefore, digital solutions for green mobility solutions involve a range of hardware and software components such as sensors and storage technologies, but also data processing and visualization.

Data collection involves extracting and processing data from multiple sources. For example, in GreenMov project, traffic data is retrieved from the Nice city database on a regular basis, weather data is obtained through public APIs, and noise and air quality data are collected from respective sensors installed in the Nice and Murcia/Molina cities. Bike availability data is extracted from the Velo Bleu website in Nice and from the Blue Bikes database in Flanders, and public transport data is retrieved from public sources. All collected data is converted into a standardized NGSI-LD format and sent to the context broker for storage.

Digital solutions also include data storage infrastructure that can implement technologies such as Context Brokers to propose an API to access data, databases such as PostGreSQL based database as TimescaleDB and Mintaka. Additional digital components can be incorporated to enhance functionality, including API managers to propose a catalogue of all the data available, proxys for routing, and secure access mechanisms through API keys. These components work together to facilitate efficient data storage and retrieval.

Then, Digital solutions for data processing employ AI models for various forecasting and analysis tasks. Regular model training and monitoring using tools like MLFlow ensure the operation and maintenance of the services through monitoring of accuracy and performance of the forecasts.

Finally, digital solutions include front-end implementations (user interface), providing user interfaces to interact with the services. These interfaces facilitate easy access to the services and enable users to request specific outputs or interact with the system directly.

4.5.1 GreenMov's digital services

In the use case of Nice, GreenMov project has deployed several digital services as listed below:

- Traffic density and environmental impact forecasting. Such service was used to identify the times at which there was a need to request end-users to reduce their use of private car. Similar to other route planner services that forecast the density of traffic, this service aimed to reduce the environmental pollution from transportation instead of reducing the transportation time.
- Bikes availability forecasting is another service that aimed to propose a low carbon alternative for travelers who would be willing to use a bike to reach their destination.
- Air Quality forecast is an important digital service developed within GreenMov project to assess the impact of cars on air quality.

- Noise annoyance forecasting. This service was deployed to assess the impact of traffic on the noise annoyance for citizen and thus to propose alternatives to car owners so they minimise their impact on the environment.

In the case of Murcia/Molina implementation, the GreenMov project proposed several services:

- IoT Hyperlocal Sensors: This use case is based on a strong network of IoT devices that are deployed in Molina de Segura and Molina City. Regarding air quality, electrochemical methods are used for inorganic compounds and optical sensors for particle matter. For noise monitoring, class 2 sonometers are used. The strength of the IoT approach used is that all these sensors are integrated into the Smart Spot solutions manufactured by HOPU Ubiquitous S.L (Libelium Murcia), which can perform real-time monitoring of all these parameters. On the other hand, bike stations from the Murcia municipality are used, providing quasi-real-time bike availability. In total, 11 Smart Spot devices are deployed and 59 bike stations.
- Data Storage: For data storage, Murcia/Molina proposes a federated approach, but the data of the local brokers (Molina/Murcia) are centralised into a Scorpio hosted by HOPU. To guarantee the persistence of the data, a QuantumLeap component has been included, which is connected to a CrateDB database. A docker image was used to replicate the architecture in other use cases.
- Services: the services integrated in the architecture of this use case include all the green services that has been deployed, namely Air Quality Index Calculation, Air Quality Forecasting, Bike Availability Forecasting and Noise Annoyance Forecasting. In addition, the software includes the NGSI adaptors, and a service used to check and correct the missing values from Air Quality Sensors.

In the case of Flanders' use case in GreenMov:

- Storing the Blue-bike as LDES https://semiceu.github.io/LinkedDataEventStreams/ balances the cost between data publisher and data consumer and allows rapid querying by fragmenting the data stream.
- Transforming LDES into NGSI-LD allows using tools from the FIWARE-family such as the Orion-LD context broker. As many cities and other organizations have legacy NGSI-V2 context brokers: adopting to Linked Data by upgrading to NGSI-LD can be a natural way forward.
- As semantics are fundamental for Linked Data a vocabulary and application profile for passenger transport hubs have been created using the OSLO/purl.eu standards. https://purl.eu/ . And in GreenMov they have been mapped on the FIWARE smart data model.
- A very strong argument in favour of Linked Data is making data machine readable. In the Flemish GreenMov use case this has been demonstrated by feeding the Bike Forecasting service with data from the NGSI-LD orion.ld context broker.
- All of this is presented as a digital web app where a user can look up forecasts for bike availability at any location and time, optionally in combination with train schedules.

5 Drivers for Successful Green Mobility Services Deployment

In this section, we present some of the drivers that can lead to successful Green Mobility solutions.

5.1 Local context awareness

Knowing the local context is crucial in the development of local green mobility solutions. Indeed, it first allows a better understanding of specific transportation challenges, which is of prime interest as each locality has its unique transportation challenges, such as traffic congestion, air quality issues, specific geographical features, and population density. Knowing the local context allows decision makers and green mobility solutions providers to identify and address these challenges effectively. This will allow them to provide solutions tailored to local needs. Indeed, green mobility solutions must align with the preferences and needs of the local population.

Factors like cultural norms, preferred modes of transport, and commuting patterns vary between regions, and a tailored approach ensures that the solutions resonate with the target users. Similarly, local contexts influence the availability of infrastructure, energy resources, and technologies. Understanding these factors helps in designing solutions that make the best use of existing resources while adapting to local conditions.

Also, different regions have varying regulations and policies related to transportation and sustainability. Developing solutions that comply with local regulations and align with the region's sustainability goals is vital for their long-term viability and success. It will also help developers to integrate green mobility solutions seamlessly with existing transportation infrastructure and public transit systems, promoting connectivity and reducing travel friction for users.

The economic conditions and income levels in a region can also influence the affordability and viability of green mobility solutions. Therefore, knowing the local context enables solution providers to create solutions that are economically accessible and sustainable in the long run. Cultural norms and behaviours play a significant role in transportation choices. Knowing the local context helps in developing solutions that align with the cultural preferences and encourage positive changes in behaviours towards sustainable transportation.

Finally, it is also important to consider the expectations from the end-users. Therefore, local surveys on expectations and needs should be carried out locally in order to understand and adapt the proposed green mobility solution to the population needs. The next subsection explains this in more details.

By taking into account the local context in the development of green mobility solutions, developers can create more effective, user-centric, and sustainable transportation options that address the specific needs and challenges of the community. This approach enhances the likelihood of successful implementation and greater adoption of eco-friendly transportation solutions tailored to the region's unique circumstances.

5.2 User centric solutions and future users' surveys

In order for the mobility solution to be used and to achieve the expected environmental impact, it must be focused on the needs and expectations of the customer. In addition to strong communication during the launch of the application, customer support and a real understanding of how the customer uses his personal vehicle and mobility systems are priorities.

5.2.1 A survey of workers and households in the study area?

The deployment of a mobility solution responding to specific environmental issues can be accompanied by a collection of data and information necessary to understand the functioning of the Metropolitan area in terms of intermodality practices.

Thus, a survey campaign could be carried out on the territory of the Metropolis and would include, for example, the following elements:

- A survey of workers using public transport on their homework journey.
- A survey of workers using their personal vehicles on their homework journey.
- A survey of households in the study area.

Indeed, in order to better understand the current practices and expectations concerning travel in the territory, we need to understand the following determining and complementary elements:

- The how many: the volume of trips made either by private vehicle or by public transport combining more than one mode (including at least one by public transport), the places of intermodality...
- The how: the conditions under which these practices are currently carried out, the constraints encountered on home-work trips (tariffs, physical, temporal, use of digital tools, intermodality, etc.).
- The prospects: in order to measure the extent to which a better public transport offer, better fare and ticketing integration, better access to traveler information, and the implementation of incentives with ecological objectives could encourage users to make greater use of public transport for their trips.

Some of these aspects are already being studied by the city. The survey campaign could focus on complementary aspects, in particular perspectives that would allow a good understanding of the elements that could motivate workers to limit the use of their personal vehicle.

This survey would also be an opportunity to communicate, in one minute, about the future green project of the Metropolis.

5.2.1.1 Conducting the survey

The survey on the practices of workers and households using public transport or their personal vehicle would consist of short interviews with a defined sample of users at a given stop/exchange point or parking lot.

5.2.1.2 Survey locations

This would ensure that the interviewers are not in the middle of a crowd and are able to survey at any time. A choice will have to be made about the most important and significant stops. The survey could also be opened online to reach the largest number of people.

5.2.1.3 A pilot survey

Before starting the survey campaign, a pilot survey could be carried out with about 15 users in order to test the questionnaire in terms of its length, the understanding of the questions by the users...

The survey questionnaire would then be adapted according to the feedback from this pilot survey.

5.2.1.4 A varied and sufficient sample

In order to guarantee a better representativeness of the results, the sample of users to be interviewed should be chosen randomly while respecting, as far as possible, the following principles:

- Gender target: 50 men/50 women.
- Different age groups.
- Different activities (study, employment, other).
- Riders who use public transport vs. those who use their own vehicles.
- Users who currently make 50% multi-modal trips vs. those who do not make 50% multi-modal trips.

5.2.1.5 Collection Period

Surveys could be administered during one to two weeks on weekdays, excluding weekends, holidays and school breaks.

5.2.1.6 Survey management and follow-up

A short training session could be provided to the teams of interviewers to familiarize them with the questionnaires and to practice conducting the interviews.

Feedback on the progress of the survey would be shared with the Metropolis and the various parties involved in the project.

5.2.2 How to enroll and retain users of personal vehicles and occasional public transport?

In addition to communication at strategic points (via companies, EMPs, commercial agencies, existing mobility solutions, etc.), it is essential to create the largest and most comprehensive customer base possible so that workers and households are aware of the new solution. The latter will then have access to the solution via a customer account that can offer them ecological incentives in exchange or as a motivation for a change in mobility use.

The implementation of such a solution could be done in phases or only partially according to the wishes and expectations of the Metropolis.

5.2.2.1 Mobility services customer bases and the solution's customer account

A single registration portal allows users to register once and for all when creating their user account, and then to have access to a multitude of mobility offers and services existing in the study area:

- Traveler information (congestion, pollution peaks, alternative solutions to a trip by personal vehicle).
- A single registration for all or part of the proposed services: public transport, bicycle, scooter and short- and long-term rental, cabs, PHV (Uber, …), parking.
- A single invoice for all the services used (invoicing can be instantaneous, per use, post-payment, in the form of a subscription to a mobility pack).
- Save and manage favorites (accessibility, modes of transport, bicycle and car preferences, lines, directions, itineraries, places and stops frequented, in order to quickly find schedules and related information and to be alerted in case of disruption).
- A management of the use supports and validation.

- An evaluation of the mobility offers and passenger information services.

The customer account that could be set up could be of the MaaS type, making it possible to group together all the elements that could be shared between several mobility services:

- The customer base.
- The identifiers for accessing the services and the media used.
- The customer's contact information (address, email, telephone, etc.).
- The subscribed services.
- Usage data for billing purposes.
- Preferences and general parameters (beneficiaries of social services or people with reduced mobility).

When the new solution system is created, the customer base could be created from the customer databases of the various existing mobility services. An account aggregation procedure would then have to be put in place to avoid duplication. Within the framework of the regulations, and the GDPR, this data transfer will be conditional on prior acceptance by each of the mobility operators for each customer.

5.2.2.2 Green incentives

In order to motivate and retain users of the solution, incentives can be offered. Algorithms that highlight certain modes of mobility, certain services and certain financial bonuses linked to usage are essential. These algorithms can be used to accentuate the policy objectified through the deployed solution by reducing the use of certain mobilities such as the private car while facilitating the modal shift often targeted in order to reduce the environmental impact of mobility solutions.

The available options encompass:

- Neutral: an application can address all modes without highlighting a more beneficial or ecological service.
- Oriented: the application can encourage the use of public transport rather than private cars for example or smooth out usage during peak hours.

Access to mobility data is synonymous with control and protection of this data in order to avoid predation of personal data or unfair competition between public and private transport partners. Historical usage data of the various modes of transport can be shared following their anonymization. However, the personal data of passengers, financial transactions of ticketing systems and revenues of private transport partners must remain confidential.

5.2.2.3 User rewards

In order to encourage users of personal vehicles to switch to existing mobility services or to use bicycles (personal or self-service), rewards can be introduced for changes in behaviour:

- For every kilometer not driven in a personal vehicle on a usual trip.
- For the frequency of not using one's own vehicle on a usual trip.

Some mobility services, such as cycling or walking (zero carbon footprint), can be considered as more important rewards than others in order to encourage people to improve their health through sport for example.

In order to record the number of ecological actions carried out by users, an ecological portfolio allowing the accumulation of "green points" could be set up. Thus, these points could be exchanged by users for rewards:

- Discounts (on mobility services, vouchers (cinemas, sports events...). These discounts can be used to advertise the ecological commitments of the partners.
- Access to places in the city (museums, shows, events...).
- Free access to services (scooters, parking...).
- The achievement of an ecological level classified on 5 levels, for example by accumulating ecological points. In exchange for reaching each level, a behavioral guide of ecological know-how could be transmitted with an ecological diploma. This guide could inform, for example, that 20% less traffic representing one car less out of 5 (i.e., on an individual scale, not using one's own car every 5 trips) would practically eliminate traffic jams in a given area.
- A transfer of loyalty points to ecological causes (planting a tree, cleaning beaches or to associations involved in sustainable development).
- An exchange of a point accumulation against money financed by partner companies that want to be ecological.

For any portfolio, the number of green points can be associated with the carbon footprint saved. A concrete example can be associated with the number of points accumulated by the individual user and by all the accumulated users using the solution (saving of 3 hours of personal vehicle for a low threshold to saving the carbon footprint of the annual electricity consumption of a village of 50 inhabitants for example).

5.2.2.4 A panel of green users?

In order to boost the use of the application, a panel of green users could be recruited. These users could commit to a minimum modal shift frequency (to be defined) in exchange of greater incentives, for example.

This panel of users could act as ambassadors for the solution by committing to promote the solution and the ecological objectives that the city is seeking to achieve, but also by providing critical feedback to improve the solution.

5.3 Involvement of Citizens

As explained in the previous sub-section on end-users' surveys, involving the local community in the development process fosters a sense of ownership and ensures that the solutions are accepted and embraced by the people who will use them. Understanding the local context enables better communication and engagement with community stakeholders which is necessary to ensure success of green mobility solutions. Therefore, ensuring the involvement of citizens when designing mobility solutions is crucial for creating services that align with their needs, preferences, and aspirations. Strategies to promote citizen involvement in the design process include surveys and feedback sessions to gather insights into citizens' transportation preferences, pain points, and suggestions. Cities can also solicit feedback through online platforms, community meetings, or mobile apps to reach a diverse audience. Then, it is important to collaborate with local community groups, NGOs, and advocacy organizations that represent different demographics and interests. These groups can provide valuable input on specific mobility needs of their communities. Organizing workshops where citizens actively participate in brainstorming and co-designing mobility solutions is also very fruitful. Design thinking methodologies can help to involve citizens in problem-solving and solution ideation. Also, leveraging digital platforms and social media for crowdsourcing ideas and feedback. Citizens can submit suggestions, vote on proposed solutions, and comment on the ideas of others. More expensive but also very interesting is the implementation of small-scale demonstration projects or pilot tests of mobility solutions in collaboration with citizens. Citizens' real-world feedback and experiences can inform refinements and improvements. Cities can also organize public consultations and open forums to discuss proposed mobility solutions. This provides citizens with an opportunity to voice their opinions, ask questions, and express concerns. Also, the use visual aids and clear communication to present complex mobility concepts in an understandable manner can be instrumental. Finally, sharing the outcomes of citizen involvement efforts and how their input influenced the design process is also very useful to get citizens involved. Transparently communicating on how their feedback was considered and incorporated into the final solutions. Cities can also educate citizens about the benefits of sustainable mobility and the impact of their choices on the environment and community.

By incorporating these strategies, transportation planners and policymakers can create mobility solutions that genuinely address the needs and aspirations of citizens, while also fostering a sense of collective ownership and support for sustainable transportation initiatives. Citizen involvement ensures that mobility solutions are user-centric, inclusive, and contribute to the well-being of the communities they serve.

5.4 Understanding local and national policies

Similar to the local context, knowing the national and local regulations is vital in the development of local green mobility solutions. Indeed, Green mobility solutions often aim to complement existing public transit systems. Knowing the regulations governing public transportation integration helps developers design solutions that seamlessly fit into the larger transportation ecosystem. More specifically, solutions involving new technologies or infrastructure, must adhere to relevant national and local laws, regulations, and standards. Understanding these requirements ensures that the solutions are legally compliant and can be implemented without facing legal hurdles. Also, developing green mobility solutions often involves obtaining permits and licenses from local and national authorities. Knowing the regulatory process streamlines the permitting and licensing procedures, avoiding delays and potential project setbacks. Cities can propose guidelines on this to favour the development of novel green mobility solutions. In terms of safety and security, regulations often encompass safety standards for vehicles, infrastructure, and operations. Complying with these regulations is essential to ensure the safety and security of users and the public at large. Similar to safety, understanding environmental, accessibility and inclusivity regulations helps in conducting proper impact assessments and that the solutions are accessible to all users. Finally, complying with data privacy and security regulations will ensure the protection of user data and can help maintaining users' trust in the solutions.

In terms of funding, many green mobility projects may be eligible for public funding or support through grants, subsidies, or incentives. Understanding the regulatory criteria and application process is crucial to secure such funding opportunities. This can be facilitated by cities which can provide guidelines on how to apply.

By being well-informed about national and local regulations, developers of green mobility solutions can ensure legal compliance, safety, and public acceptance. Knowledge of the regulatory landscape allows for smoother project implementation, enhanced partnerships with public entities, and the creation of solutions that align with broader sustainability and transportation objectives. Ultimately, understanding and adhering to the regulations play a crucial role in the successful development and adoption of local green mobility solutions.

5.5 Benchmark of existing solutions

Benchmarking other mobility solutions when developing a green mobility solution is also crucial to the success of the solution proposed, in order to avoid redundancy or misalignment with what end-users are willing to use. Indeed, through benchmarking mobility solutions providers can avoid reinventing the wheel and duplicating efforts by leveraging existing knowledge and experiences. Benchmarking also allows mobility solutions providers to study and learn from successful green mobility solutions that have been implemented elsewhere. By understanding the best practices and success factors of similar projects, solutions providers can avoid potential pitfalls and adopt effective strategies in their own solutions and specific to the cities. Benchmarking also provides insights into the latest innovations and technologies used in other green mobility solutions. This knowledge enables developers to integrate cutting-edge features and advancements into their own solutions, enhancing their competitiveness and appeal, providing up-to-date services to the end-users. Similarly, understanding user expectations from the analysis of other mobility solutions helps solution providers gain a deeper understanding of user expectations, preferences, and pain points. This user-centric approach ensures that the green mobility solution is designed to meet the specific needs of the target audience.

When developing a green mobility solution, gaining support from stakeholders, including government authorities, investors, and the public, is essential. Benchmarking helps provide evidence of the solution's feasibility and success in other settings, increasing confidence in its potential.

Finally, benchmarking encourages collaboration between different stakeholders and organizations involved in green mobility. By sharing insights and experiences, the collective effort towards sustainable transportation solutions can be strengthened.

In conclusion, benchmarking other mobility solutions when developing a green mobility solution provides valuable insights, knowledge, and inspiration. It enables developers to make informed decisions, improve their solution's effectiveness, and enhance its chances of success. By building on the experiences of others, developers can create more robust and impactful green mobility solutions that contribute to a more sustainable and eco-friendly transportation ecosystem.

5.6 External communication

In order for the solution to be used, communication during its launch is essential. Users must know about this new system, receive descriptions during communication campaigns (mail, email...), see posters, demonstrations, web pages, associate their need for mobility with an ecological impact with an easily identifiable brand...

The other mobility actors present must also know the solution in order to be able to communicate and answer possible user questions.

5.7 A sustainable business model

The economic business model must be thought out and adapted to the territory, the uses and the services proposed. This is of main importance as cities aim to have strong partnerships and strong solution providers that will be established for a long time. In order to reach a viable economic model, scenarios can be considered and even tested.

For any type of solution, the search for the economic model to be implemented remains one of the main reflections during the design phase. When studying the different mobility solutions that have been implemented, we see that each one has its own economic model, adapted to the services available and to the different actors. Nevertheless, some business models tend to be replicable and adaptable to the services available.

These business models are closely linked to the "type" of solution implemented:

- A "public" solution financed and organized by an authority.
- A "private" solution with operators and aggregators (without authorization from the authority, such as UBER, SNCF assistant).
- A "private employer" solution that finances home-work trips via a sustainable mobility package (this is required by law).

5.7.1 A "public" solution

A "public" solution, providing services to users, can have a positive impact on the use of these services in relation to public policy. This generally increases the number of users and therefore the related revenues.

Nevertheless, some costs remain unavoidable, such as the creation and management of a multimodal repository for operation, management, planning and multimodal information.

On the other hand, the digitization of distribution will reduce the costs associated with sales at ticket offices or distributors. In addition, the saturation of certain routes can be reduced (e.g., by proposing less congested alternate routes during peak hours or by offering lower fares during off-peak hours).

5.7.2 A "private" solution

5.7.2.1 Resale of mobility services

This solution can offer services to users through monthly subscriptions to mobility packages. The advantage of this model is to predict future usage of mobility services based on the number of subscriptions.

However, this business model must remain attractive to users, meaning, in addition to simplicity of use, to offer attractive discounts, i.e., the monthly subscription must be cheaper than the sum of the services included in the pack. The players in the solutions involved must therefore reduce certain margins in order to increase the volume of usage.

5.7.2.2 Reselling mobility data

When a company aiming to deploy a mobility solution uses a large amount of data available on the Open Data platform, financial compensation may be requested, as stipulated in the LOM law. However, significant revenues should not be expected, as Article R1115-4 of the Transport Code stipulates that the total amount of financial compensation may not exceed the investment and operating costs resulting directly from the provision of data necessary for passenger information.

In addition, care must be taken to ensure that the provision of data does not allow a private operator to compete unfairly with the solution provided by the public authority.

5.7.2.3 Commissions

In this model, mobility services are generally available on a platform. Users pay per use "pay as you go". The operator of the solution is remunerated through commissions on the transactions.

Depending on the services and partners, commissions are often between 4 and 15% of the transaction.

This model requires a critical mass of users in order to pay the operator.

5.7.2.4 Increasing the customer base by increasing the services available

In this model, the operator of the solution invests in the solution in order to increase the services available to users, in order to improve user satisfaction and therefore increase usage. The goal is to integrate new mobility services so that the solution is multimodal. This type of solution is often enriched by first/last mile services.

Only large mobility operators have the means to invest in this model. The SNCF, wishing to offer a door-to-door service by offering other services such as PHV, is an example.

5.7.2.5 The travel agency

In this model, the user pays more in order to have a more complete, simpler service with certain advantages.

The main difficulty is to identify the premium services to be included in the offer and for which users are willing to pay more.

Currently, rail and air operators are interested in this model.

5.7.2.6 The advertising model

The solution operator could sell some non-GPR data, such as search data to improve advertising targeting or by directly displaying sponsored offers as Waze currently does.

5.7.2.7 Monetization of mobility traces

Mobility traces (information about geographic movement as well as the temporal dynamics of users' movements) can be sold:

- Web logs (queries, offers, competition, etc.).
- GPS tracks: Moovit or Upstream Mobility use this model.
- Wi-Fi or Bluetooth tracks.
- Mobile tracks via mobile operators.
- Road data. TomTom and Google sell them for example.

5.7.2.8 A "private" employer solution

This model is centralized on a service platform designed to improve employees' urban and interurban commuting.

The objective of this model is not to generate a profit but to offer a service to employees by managing their mobility services and saving them time and money, as budgets/services are allocated to them. This could correspond to a "mobility package" via the company.

In 2019, the French spend more than 4h17 per week in commuting to and from work, which is 39% of their weekly travel time. In addition, in order to comply with current regulations, companies often contribute to their employees' transport costs. Mobility plans are indeed mandatory under the LOM law for companies with more than 50 employees. Companies can thus encourage their employees to use public transport to get to work and achieve a more ecological model.

The main challenge of this model is to have enough data on the mobility services around the company. This solution is only suitable for very large companies. It could also be proposed to business clubs that bring together companies in the same city or business cluster.

5.7.3 A viable business model

To date, the economic models for mobility solutions have struggled to be viable: public transport is rarely, if ever, profitable and users underestimate the real cost of their personal car and therefore the savings that can be made by using the mobility systems available to them.

In order to achieve a viable solution, different sources of revenue, as detailed in this study, can be combined. In addition, another source of revenue depends on the registration of users to the mobility solution.

5.7.3.1 "Pay as you go"

The "pay as you go" model allows users to pay according to their usage, generally in post-payment, although some solutions require a pre-payment at the beginning of the month (a subscription basis) and a usage-based billing at the end of the month.

In this model, the platform can:

- Decrease prices by negotiating the margin with operators to offer an attractive price to users, which may impact the budget balance if it is reached.
- Increase prices by applying its margin on the public prices of tickets, but thereby reducing the attractiveness of the solution.

5.7.3.2 The package system

When subscribing to the mobility solution of a territory, the user subscribes to a package corresponding to his needs. These packages can include services and the costs are therefore more or less important.

Nevertheless, at first sight, these packages remain quite expensive, even if they offer an alternative to the personal vehicle. Users who tend to underestimate the budget for their own vehicle are not likely to use these expensive packages.

5.7.3.3 Alternative models

The commercial value of a mobility platform can be monetized, as the platform brings users to mobility operators, via:

- A subscription offered to operators.
- A commission on new customers.
- A commission on the volume of business generated.

5.7.3.4 Indirect economic contributions

Finally, it is possible to consider that this solution can be a tool for steering mobility policy within a conurbation or a territory, and that it contributes to improving the modal shift from the car to public transport, but also from the most saturated public transport to the available ad hoc solutions.

This would enable local authorities to optimize the use of these services by reducing the need for reinforcement or substitution services and therefore the need to invest in vehicles for occasional reinforcement. But this requires real-time management of the resources that enable users to respond to their travel needs, which would be directly dependent on the current context. This would involve the creation of a service regulator function, which, relying on artificial intelligence, could adapt the parameters of the mobility solution implemented in real time.

5.8 Data Management

It was shown in earlier sections that data and real-time data are key to a successful deployment of green mobility solutions that provide actual value to the citizens. However, for cities providing access to data to third parties (green mobility solutions providers), it is necessary to consider the following considerations to ensure a successful operation.

5.8.1 Standardization

Standardization plays a crucial role in ensuring the effective functioning of services provided to citizens and used internally within public administrations, such as cities and regional governments. For mobility-related services, there is an additional requirement for near real-time data that must be rapidly shared and utilized. This necessitates a seamless data interchange between city sensors, legacy applications, and the generation of expected services, leaving no room for information translation or manual processing. Furthermore, standardization of data enables scalability and quick deployment of third-party solutions that can then be proposed in any other city that use the same standard.

The standardization efforts as experienced within GreenMov encompass two levels: the communication level, which involves the mechanisms for requesting information between systems, and the semantic level, which deals with the structure and meaning of the exchanged data.

At the communication level, the project has implemented NGSI-LD, along with its integration into LDES, which has facilitated the connection between different systems, especially in Flanders. NGSI-LD, being a general-purpose API specification, allows for a wide range of operations, including sending, retrieving, and updating information.

However, the semantic level presented more challenges due to some innovative elements not adequately covered by existing standardization. Consequently, as outlined in deliverable GreenMov_D2.2 Core Vocabulary, new data models had to be defined to effectively process the data. If the project should rely on existing approach to standardization, mediated by national or sectoral standardization bodies, no real standardization had been achieved during project time span. To address this dynamic nature, the GreenMov project adopted an Agile standardization approach based on the seven principles.

1. Don't just standardize, be agile and standardize.
2. Do not reinvent the wheel.

3. Normalize real cases.
4. Be open.
5. Don't be overly specific.
6. Flat not Deep.
7. Sustainability is key.

These principles have been coined at the Smart Data Models initiative, and further information can be found in the “Agile Standardization Manifesto “.

Additionally, due to the changing nature in the requirements of the mobility systems agile standardization can help to cover new standardization needs.

5.8.2 Data Open Access

Cities or Third parties need to access data (form sensors or applications), and some of it could be made publicly available, either as value-added services or as raw data sources for reuse. GreenMov project has built 3 services based on the gathered data providing an added value for their users. It is also true that the raw publication of data opens the door to the creation of other added value services provided by the data reuses community. To achieve effective publication, it is essential not only to release raw data but also to provide documentation and support for data reuses. This information, known as metadata, follows the standardization set by DCAT-AP 2.1.1 in the EU. This standard defines a dataset and its distributions, which refers to different exports of the original datasets in various technical formats or serializations. The three data portals participating in the GreenMov project includes this metadata.

Additionally, there is a concept of data federation, wherein some open data portals publish data while others gather the main information (metadata) and republish it, pointing back to the original source. The participants in the GreenMov project demonstrate this approach, as their published data has been harvested by national or European data portals.

5.8.3 Governance

Cities could make the political choice to exert a decisive impetus on the coordination and management of green mobility solutions.

Cities could therefore provide their own data, supplemented by the data made available by third parties, available to one or more operators, that would fulfil the missions of mobility integrator, without cities themselves seeking to play an active role in linking the supply and demand of travel.

If the data used are only Open Data, the governance of the different actors remains relatively light.

If the solution implements mobility solutions with contracts linked to the different services and actors, then the governance will have to be very precise. These public and private actors will have to be contractually bound to the project owner and/or the operator of the solution. For example, each mobility operator or service integrated in the solution will sign an agreement with the operator.

In all cases, as the cities are the initiator of the pollution reduction project and has a large part of the skills necessary for its practical implementation, the organization of governance will be designed to give it a central role.

5.9 Stakeholders' engagement

The success of green mobility solutions mostly relies on the fruitful interaction with the right stakeholders. This requires a strong engagement between the city and these stakeholders, and of course a preliminary identification of the main stakeholders.

5.9.1 Engagement with stakeholders

Engaging with stakeholders is a proactive and ongoing process that requires effective communication, collaboration, and relationship-building. Here are some strategies for engaging with various stakeholders for green mobility solutions: a good start is to identify key stakeholders (see next subsection) and understand their interests, concerns, and potential contributions.

A stakeholder analysis helps prioritize engagement efforts based on their influence and importance. Then, cities can establish open lines of communication with the identified stakeholders through various channels, such as meetings, workshops, forums, and online platforms. Regularly update stakeholders on project progress and seek their input and feedback. It has a cost, but it is also necessary for a successful implementation of green mobility services.

Therefore, engagement approaches should be tailored to the preferences and needs of each stakeholder group, and cities should clearly communicate the value and benefits of green mobility solutions to each stakeholder. Emphasize how the solutions address their specific needs, align with their goals, and contribute to the overall well-being of the community.

Similarly, cities could also engage with public advocacy groups and NGOs to create awareness about the benefits of sustainable transportation and mobilize support from the broader community. They could offer incentives, such as discounts or recognition programs, to stakeholders who actively support and promote green mobility solutions. Acknowledging their efforts can actually foster loyalty and commitment. to achieve that, cities can actively work with local media outlets to highlight the significance of green mobility solutions and showcase successful implementation examples. Positive media coverage can generate public interest and support.

Finally, data-sharing agreements show be established as soon as possible in the project with relevant stakeholders to exchange information and research findings. Collaboration on data analysis can provide valuable insights for decision-making.

As it was experienced within the GreenMov project, stakeholder engagement is an iterative process, and it is necessary to continuously assess and adapt our engagement strategies based on feedback and changing stakeholder dynamics. Building strong relationships with stakeholders fosters a sense of ownership and collective responsibility for the success of green mobility solutions, leading to greater acceptance, adoption, and sustainability over the long term.

5.9.2 Identification of relevant stakeholders

Identifying the right stakeholders is crucial for the successful implementation and adoption of green mobility solutions in a city. Different stakeholders play specific roles in influencing, supporting, and contributing to the development of sustainable transportation options. Here are the types of stakeholders a city should identify for green mobility solutions, based on the experience from the GreenMov project:

- Regional or local transportation authorities are essential stakeholders in planning and integrating green mobility solutions with existing public transportation networks. Their support is crucial for smooth coordination and seamless integration.
- Urban planners are instrumental in incorporating green mobility solutions into city planning and infrastructure development. Their input ensures that the solutions align with urban development goals and promote sustainable urban design.
- Environmental agencies and organizations are important stakeholders as green mobility solutions aim to reduce carbon emissions and improve air quality. Their expertise and data can help measure the environmental impact of the solutions.
- Engaging with community groups and residents is essential to understand their transportation needs and preferences. Their feedback and involvement are crucial for garnering public support and ensuring the solutions address local challenges.
- Existing transportation service providers, such as public transit operators and private mobility companies, are stakeholders that may collaborate or compete with green mobility solutions. Partnerships with these entities can enhance service coverage and accessibility.
- Private companies, employers, and businesses are stakeholders in green mobility solutions, particularly if they provide transportation options for their employees or customers. Incentives or partnerships with businesses can drive adoption.
- Companies and organizations specializing in green mobility technologies, electric vehicles, bike-sharing platforms, and other relevant solutions are crucial stakeholders for providing the necessary tools and expertise.
- Universities and research institutions can contribute valuable expertise, data, and research on sustainable transportation practices and their impacts.
- Non-governmental organizations (NGOs) and advocacy groups that focus on sustainable transportation and environmental causes are stakeholders that can advocate for and support green mobility initiatives.
- Investors, venture capitalists, and funding agencies are essential stakeholders in providing financial support and resources for the development and expansion of green mobility solutions.
- Stakeholders advocating for accessibility and equity in transportation ensure that green mobility solutions cater to the needs of all citizens, including those with disabilities and underserved communities.

Identifying and engaging with these stakeholders from the outset of planning and development is critical for garnering support, building partnerships, and creating sustainable, inclusive, and effective green mobility solutions that align with the needs and aspirations of the city and its residents.

5.10 Digital solutions

Digital solutions are essential in the implementation of green mobility services. They include monitoring solutions, data conversion, data storage, data analysis, data processing, services such as forecasting, planning, routing, and front-end visualisations. Each one of these steps should be carefully implemented in order to achieve successful, sustainable and scalable green mobility solutions.

5.10.1 Infrastructure

A strong infrastructure for digital solutions is key to achieve successful green mobility solutions. It should be robust, flexible, scalable, and secure to support the seamless and efficient operation of digital services. Figure 20 displays the key elements of a distributed infrastructure.

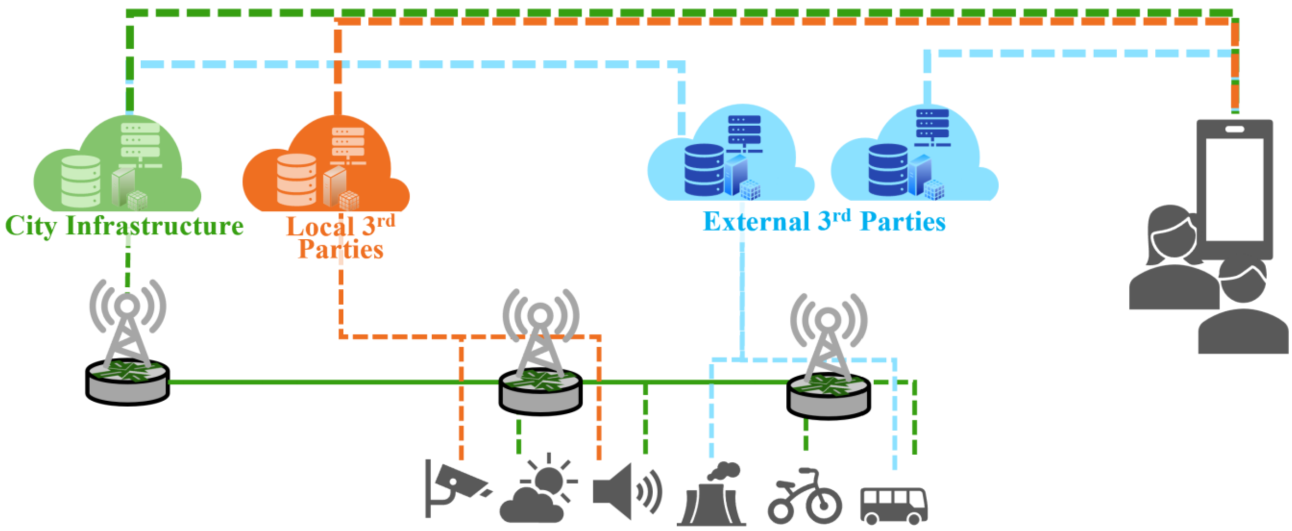

Figure 20. Digital Infrastructure for Green Mobility digital Services

The main components include the following:

- Internet of Things (IoT) and Internet Connectivity, at the bottom of Figure 20, aim at integrating IoT devices that capture data from vehicles, transportation infrastructure, air quality, noise, weather, but also from user devices. This layer enables real-time data collection, monitoring, and communication. Data can be collected directly by the city itself, or by third parties which will then make this data available through APIs, as discussed below. Remote control can also be achieved through IoT connectivity to enable traffic lights management system for example. IoT connectivity rely on fast and stable internet connectivity that is fundamental for real-time data exchange, communication with connected vehicles, and providing uninterrupted service to users.
- Application Programming Interfaces (APIs) are required to allow real-time access to data from third parties. APIs facilitate seamless integration between different mobility services and third-party applications. They enable data sharing and interoperability, supporting a comprehensive mobility ecosystem.
- Data storage is achieved at several locations. Usually, data storage happens at the premises of the data collector. If the city owns sensors, it will most likely store data at its premises, or on a cloud provider's server.
- Data Management and Analytics: Robust data management systems are essential for storing, processing, and analyzing the vast amounts of data generated by mobility services. Advanced analytics can provide valuable insights into user behavior, service performance, and predictive maintenance. This

stage usually happens at the third parties' level, in their servers, or at the city level if the city provides specific value and services to the citizens or other third parties.

- Cloud Computing: Leveraging cloud-based services allows for scalable and on-demand resources to handle varying traffic loads. Cloud computing enables cost-effective data storage, processing, and real-time data exchange across different mobility applications. However, given the large amount of data, it can be noted that cloud-based solutions with central management of data might leave the space for federated decentralized computing.
- Cybersecurity solutions are necessary at each location of the digital infrastructure. Robust security protocols and encryption mechanisms are critical to protect user data, prevent cyberattacks, and ensure the integrity of digital services. Security measures must cover data transmission, storage, and user authentication.
- Mobile and Web Applications are necessary to propose user-friendly and intuitive mobile and web applications at the forefront of digital mobility services. These applications will provide real-time information, booking capabilities, and personalized user experiences.
- Payment Gateways: Depending on the business model that was selected, secure and reliable payment gateways might be essential for processing transactions related to mobility services, including fares, subscriptions, and additional charges.
- Redundancy and Disaster Recovery: A strong infrastructure should have redundant systems and disaster recovery mechanisms in place to ensure continuity and minimal downtime during unforeseen events. This is associated with a certain cost but ensures continuous operations even in case of cyber-attack.

Then, several services (from data base and context broker to machine learning and geospatial services) can be implemented as docker images in each server displayed in Figure 19 in order to ensure an easy deployment and maintenance. This also ensures a high level of interoperability in the case of change of hardware.

As an example for GreenMov project, APIs were used to retrieve data, NodeRED based software achieved data conversion. Storage was using Context Brokers, MongoDB for real time database and PostgreSQL for temporal storage. Finally, specific dockers were deployed with python codes for Machine Learning based services integrating API interface.

5.10.2 Privacy concerns

Privacy requirements for digital services in green mobility solutions are of paramount importance, as such solutions involve the collection, processing, and sharing of sensitive user data. The first step towards privacy requires to stay updated on relevant data privacy laws and regulations in the regions where the digital mobility service operates. For example, European cities should comply with privacy regulations such as GDPR (General Data Protection Regulation). Also, design methodology should adopt the privacy and security by design. This requires incorporating privacy considerations from the early stages of service development. Privacy by design principles involve building privacy protections into the core architecture of the service.

Digital mobility services often collect various types of data, including location, travel patterns, and personal information. Cities should ensure that clear and explicit consent must be obtained from users before collecting their data, and they should be informed about the purpose of data collection and any third-party sharing, as explicated by GDPR. Therefore, services should collect and retain only the minimum necessary data for the functioning of the service. They should also implement techniques like anonymization or pseudonymization to protect user identities when possible. They should ensure that personally identifiable information (PII) is not stored unnecessarily. Additionally, sensitive data, especially during transmission and storage, should be encrypted using strong encryption algorithms and strong keys (at least 12 characters long) to prevent unauthorized access. This will protect user data from unauthorized access, data breaches, and cyberattacks. GDPR also requires that users have access to their data and are allowed to control how their data is used, shared, and deleted. Users should be able to withdraw consent and request data deletion easily.

Although it was mentioned that cities should foster partnerships with third parties, this should not prevent them from ensuring that third parties adhere to privacy and security standards and establish clear agreements for data handling and protection.

Building on the need for a user centric approach, a key driver for successful green mobility solutions consists in transparency with end-users. Cities should promote transparency with users about the service's data practices, privacy policy, and any changes made. This will, they will provide clear and easy-to-understand information about data usage and privacy measures.

Finally, every privacy preserving approaches should also include regularly conduct privacy audits and assessments for the cities and their third parties to evaluate compliance with privacy requirements and identify areas for improvement.

By prioritizing user privacy and adhering to these privacy requirements, digital services for green mobility solutions can earn users' trust, ensure regulatory compliance, and foster a positive user experience. Protecting user privacy is essential for the sustainable growth and long-term success of digital mobility services in an increasingly connected and data-driven transportation landscape.

In GreenMov use cases, privacy was ensured with respect to GDPR. The following Privacy Notice is included in the end-users' interfaces:

"*This application can make use of your location when you want to see the nearest train/blue bike station.*

We will not store your location or any other personal data at any time.

For questions/complaints or more information on how the development team processes personal data, please read our privacy statement here."

In Europe, data privacy is governed primarily by the General Data Protection Regulation (GDPR), which became enforceable on May 25, 2018. The GDPR is a comprehensive data protection law that applies to all European Union (EU) member states and the European Economic Area (EEA). It sets stringent requirements for the processing of personal data and aims to strengthen the privacy rights of individuals. Among others, GDPR require that data processing must have a preliminary consent, contract performance, compliance with legal obligations, protection of vital interests, or should consist in tasks carried out in the public interest, or legitimate interests pursued by the data controller or a third party.

Consent is very important in GDPR and require the obtaining of clear and explicit consent from individuals to process their personal data. Data controllers should collect and retain only the minimum amount of personal data necessary for the stated purposes of processing, and personal data should be processed for specific and legitimate purposes and not be further processed in a manner incompatible with those purposes. Data controllers must provide individuals with clear and easily accessible information about how their data will be processed, including purposes, legal basis, data recipients, and rights. Among these rights, end-users have the right to access their data, rectify inaccuracies, erase data (right to be forgotten), restrict processing, object to processing, data portability, and not be subject to automated decision-making.

Therefore, cities willing to enable green mobility solutions should ensure that third parties perform Data Protection Impact Assessments (DPIAs) for processing activities that are likely to result in high risks to individuals' rights and freedoms. This should be supervised by a Data Protection Officer (DPO), who aims to oversee GDPR compliance and to act as a point of contact for data subjects and supervisory authorities.

In addition to this, it is important to note that personal data can only be transferred to countries or organizations outside the EU/EEA that provide an adequate level of data protection or under specific safeguards.

Non-compliance with the GDPR can result in significant fines, so cities and organizations processing personal data of EU residents need to ensure strict adherence to these privacy requirements. The GDPR's focus on individual rights, transparency, and accountability and aims to promote a high level of data protection and privacy across Europe.

5.10.3 Scalability

The behaviour of the solution must not be fixed; it is designed to evolve and provide the necessary openness over the coming years. The system must be able to support changes in hardware and software, including the sizing of servers, or in terms of volume. Thus, the deployed solution must be scalable and modular in order to allow a constant evolution of the solution:

- The services offered (addition, for example, of new mobility services present in the territory concerned).
- The actors.

The functional administration must be able to make the systems evolve by simply modifying the operating parameters for: modifications of the fare range, network extensions (addition of stops, extension and addition of lines...) or the addition of unit prices to the market (new functions, new equipment...).

5.10.4 Interfaces and simplicity of use

Ease of use for the different actors of the solution is essential to its proper functioning.

5.10.4.1 For mobility solutions, operators and cities

The mobility solutions, the different operators or actors of the solution, cities will simply have to have access to the statistics of the latter in order to analyse the real users and observed impacts.

5.10.4.2 For users

The visuals, customer pathways and fare structure must be simple and understandable for users. The slightest complexity or momentary malfunction has a strong impact on usage.

Indeed, the user experience is the way the user will live his interaction with the product, the site, the brand. The user experience is essential to take into account so that the media meet the expectations of users. For example, between 40% and 80% of users will not return to a site or application after a bad user experience.

5.10.5 Artificial Intelligence Tools

Most of efficient and popular green mobility services rely on AI technology (for forecasting and optimising mostly). AI technologies are generally defined as smart software and hardware solutions that have knowledge of their environment and take actions that maximise their chance of successfully achieving their goals. AI solutions can be classified into three main categories of functions, which are regressions, mostly used for forecasting, classification, used to identify hazardous situations or to classify patterns, and optimisation solutions, used for example to control appliances.

To achieve these three main functions, different techniques exist, such as Artificial Neural Networks (ANN), deep neural networks, support vector machines, k-means algorithms, etc. These techniques are usually classified by types (machine learning, deep learning, bio-inspired algorithms, etc), as shown in Figure 21.

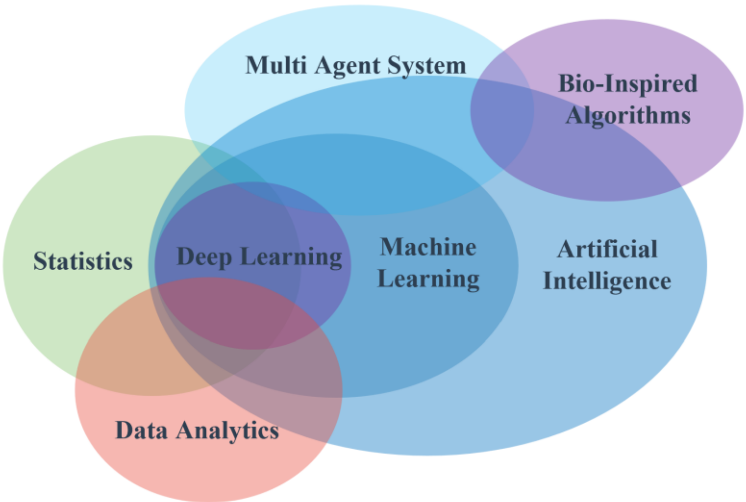

Figure 21. Artificial Intelligence Landscape

These AI technologies allow engineers to leverage vast amounts of historical data, implement robust preprocessing techniques, develop accurate models, and deploy efficient forecasts or clustering solutions. In this section, we will detail the technical aspects of AI tools techniques that were used within GreenMov, providing insights into the key components that drive successful green mobility services.

- Historical Data:
    - The AI models powering green mobility services should be trained on a diverse range of historical data that should be augmented with various additional characteristics beyond primary mobility data such as the type of day (weekend or weekday), the hour of the day, the value at specific lagged time intervals (t-1, t-2, t-3, t-1 hour, t-1 day, t-7 days, and some other data such as weather, when relevant.
- Data Pre-processing:
    - Data pre-processing played a crucial role in ensuring the quality and reliability of input data for the AI models, key preprocessing steps included:
        - Time alignment to ensure synchronicity between datasets.
        - Cleaning of the time array by filling small gaps using extrapolation methods. In some cases, it can be relevant to use pre-existing forecasting models to achieve interpolation on large shortfall of data.
        - Removal of outliers based on the Z-score or other standard deviation based.

These pre-processing steps aimed to enhance data balance and representativeness, accounting for various conditions and events impacting green mobility services.

- Model Development: The development of AI models involved essential steps such as data preparation, model selection, and model training. Multiple AI models were benchmarked for their performance in handling complex data and diverse factors influencing green mobility services. Models benchmarked within GreenMov included, k-Nearest Neighbors (KNN), Decision Trees, Random Forest, XGBoost and Artificial Neural Networks. Evaluation of models utilized various historical datasets to determine the most accurate predictions. On a general basis, KNN models are a good compromise between accuracy and time of training and inference, although XGBoost often give the most accurate results.
- Training: Training the AI models involved a train/test split of the data, typically utilizing 75% for training and 25% for cross-validation. This approach allowed efficient storage and processing of historical data for the green mobility services.
- Results: Evaluation metrics, such as R^2 or MAPE values, are usually considered to assess accuracy of short-term to day-ahead forecasting.
- Model Deployment: Once the AI models were designed, they were deployed in the infrastructure supporting the green mobility services. The deployment process involved data gathering, preprocessing, augmentation, and model creation. The deployment architecture utilized dockerization techniques, leveraging tools like docker-compose for replication, monitoring, and maintenance. Then, some useful tools exist, such as MLflow, which is an open-source platform designed to manage the entire machine learning lifecycle. It was developed by Databricks and is now maintained by the Linux Foundation's Center for Open Data in AI. MLflow provides tools and functionalities to track, organize, and deploy machine learning experiments, models, and associated data. MLflow allows data scientists and machine learning engineers to log and track experiments, model parameters, metrics, and artifacts. It provides a unified API for logging results from different machine learning libraries, making it easy to compare and reproduce experiment. It facilitates the management and deployment of machine learning models, and provides tools to save models in a standard format, enabling easy sharing and integration with various deployment frameworks. MLFlow's Model Registry component allows versioning, organizing, and managing machine learning models throughout their lifecycle. It provides collaboration features for multiple team members working on different versions of a model. MLflow also supports model deployment to various deployment platforms like Docker containers, cloud platforms, and on-premises infrastructure. It simplifies the process of deploying models to production environments. Finally, MLflow provides a web-based user interface that allows users to visualize and compare experiment results, including metrics, parameters, and artifacts. In terms of compatibility with AI models, MLflow integrates seamlessly with popular machine learning libraries, such as TensorFlow, PyTorch, Scikit-learn, and XGBoost, making it easy to incorporate MLflow into existing workflows. MLflow promotes collaboration and reproducibility in the machine learning development process by providing a structured framework for managing experiments and models. It simplifies the process of tracking, organizing, and deploying machine learning projects, making it a valuable tool for data science teams and machine learning practitioners. If MLflow is not used, engineer can still develop their own API using tools such as Kserve or FastAPI, which was employed within GreenMov to provide an API interface for users to access the green mobility services. In case MLFlow is not used, joblib library can facilitate model parameter retrieval and storage.

5.10.6 Explainable AI

In the context of Green Mobility Services, Explainable AI plays a crucial role in building trust, enhancing transparency, and ensuring the successful adoption of AI-driven solutions. As these services rely on AI models to provide accurate predictions and optimize various aspects of transportation, it becomes essential to understand the decisions made by these models. Explainable AI refers to the ability of AI systems to provide clear and interpretable explanations for their predictions or recommendations.

In the case of Green Mobility Services, explainable AI helps stakeholders, including city authorities, service providers, and end-users, to comprehend the factors influencing transportation decisions. For instance, when utilizing AI models for traffic flow prediction or route optimization, explainable AI can provide insights into the specific data points and features that influence the model's output. This transparency empowers stakeholders to validate the model's accuracy, identify potential biases, and assess the reliability of predictions.

Explainable AI is also vital in addressing regulatory and ethical considerations associated with AI-driven decision-making in the transportation sector. By offering interpretable explanations, stakeholders can ensure compliance with privacy regulations, understand how sensitive data is utilized, and confirm that AI models align with legal frameworks.

Furthermore, the explainability of AI models enhances end-user trust and user experience. When individuals have insights into how AI recommendations are generated, they are more likely to embrace and rely on green mobility services. This trust fosters greater user engagement, leading to increased adoption rates and the broader acceptance of sustainable transportation options.

To achieve explainable AI in Green Mobility Services, various techniques and methodologies were employed. These includes using interpretable machine learning models like decision trees, rule-based systems, or leveraging techniques. Additionally, visualizations and interactive interfaces developed for the services can be employed to present AI-driven insights in an intuitive and understandable manner to end users.

6 Barriers to Green Mobility Services Adoption

6.1 Regulation

The adoption of green mobility solutions is often hindered by barriers, and one significant obstacle is the complex regulatory landscape. Regulations and policies related to transportation, urban planning, and sustainability can pose substantial challenges for implementing green mobility initiatives. These regulations encompass a wide range of areas, including vehicle standards, charging infrastructure, operational requirements, data sharing, and safety regulations.

For example, when implementing a green mobility project that requires access to city data for planning and optimization, stakeholders must navigate the procedures of obtaining relevant data from city authorities. This process may involve formal data-sharing agreements, compliance with data privacy and security regulations, and adherence to specific protocols for data access and usage. The complexity of these procedures, including negotiations, legal considerations, and technical requirements, can significantly delay the implementation of green mobility solutions.

In addition, the distribution of green mobility services often requires obtaining licenses or permits from regulatory authorities. For instance, electric scooter sharing services may need to comply with regulations governing permits for operating in public spaces, ensuring safety standards, and managing user data privacy. The licensing process typically involves submitting comprehensive applications, providing proof of insurance, demonstrating compliance with operational requirements, and paying associated fees. The time and effort required to obtain these licenses can pose significant barriers for service providers, especially in jurisdictions with complex and lengthy approval processes.

The lack of standardization and consistency in regulations across different jurisdictions further adds to the complexity. Each city or region may have its own set of rules, making it challenging for green mobility service providers to navigate the diverse regulatory environments they operate in. For example, e-bike sharing companies may need to comply with different speed limits, parking regulations, and insurance requirements depending on the city they operate in. The need to navigate multiple regulatory frameworks, interpret varying requirements, and maintain compliance across different locations can be a daunting task for service providers and hinder the scalability and expansion of green mobility services.

Overcoming these regulatory barriers requires close collaboration between stakeholders and policy-makers to streamline regulations, establish clear guidelines, and create a supportive environment that fosters the adoption of green mobility solutions. It is crucial for city authorities to develop standardized procedures and guidelines for data sharing, ensuring transparency, privacy protection, and a streamlined process for accessing city data. Likewise, regulatory authorities can work towards harmonizing licensing requirements and simplifying approval processes to facilitate the deployment of green mobility services across different jurisdictions.

6.2 Investment, operational costs and economic viability

The set-up of Green Mobility services requires high investment in terms of infrastructure (servers, sensors, etc) and human resources. Based on the GreenMov project, it was assessed that the setup of a use case such as the one that was deployed in Flanders, with only one type of sensors to which the stakeholders already had access, took more than 9 months of 2 Full Time engineers. This represents considerable costs if several use cases/services are requested in a city. Furthermore, on top of these investment cost, we should add the operational costs, that are required in order to maintain the servers, especially when considering security issues. It also requires full time maintenance and monitoring to ensure that if the service is down, it can be re-established in less than a few hours. As a result, it is difficult to set up a viable economic business model. Furthermore, the adoption of GreenMov services in cities around Europe may face various economic barriers that could hinder the economic viability of the green mobility services provider's business model. Factors that can prevent economic agents to invest in Green Mobility services include the current inflation rates, that make it difficult to find money to invest. Indeed, as it was stated Vice-President of the ECB speech "a succession of unprecedented shocks over the past three years has pushed inflation far above target in the Euro area and around much of the world." [2] As the technology proposed by GreenMov has associated considerable upfront costs, this may cause that some cities should refrain from their adoption plans. Another aspect to consider is that investments from cities are mostly reducing due to the financial situation in most European countries, which will then reduce the investments for green mobility solutions. Similarly, the increasing cost of energy during the last year [1] and its associated market instability has affected the adoption of high energy demand technologies such as AI training algorithms. Finally, as Green Mobility services use digital service that require a skilled workforce with expertise in AI technologies and data analysis, the development of green mobility services can quickly because expensive.

6.3 Infrastructure Needs

Currently the mobility and environmental data is scattered over a multitude of platforms with poor semantics and standardisation.

In GreenMov state of the art platforms and technologies were tested that can manage Linked Data in at scale and with the right speed. We tested linked data context brokers in the labs and deployed them in our pilots. We have also tested federation of context brokers for use case that require multiple context brokers (e.g., different data domains or different geographical regions for the same domain). In GreenMov we have also developed a prototype for source selection by source pruning for huge data sets with high performance requirements.

Serving Linked Data can be a headache if the cost and effort must be acceptable for the data publisher and the consumer or the app builder. For the publisher raw a SPARQL endpoint is very costly and for the consumer data dumps are not usable. With LDES the cost is balanced between both, and high performance is enabled including for rapidly changing data https://tree.linkeddatafragments.org/linked-data-event-streams/.

6.4 Requirements for specific skills

When it comes to adopting green mobility solutions, several barriers can hinder their implementation. One prominent barrier is the lack of necessary skills and knowledge among stakeholders involved in the process. This barrier encompasses various aspects related to the understanding and expertise required to effectively deploy and manage green mobility solutions:

- Technical Skills: Implementing green mobility solutions often involves complex technologies, data analytics, and integration of various systems. A lack of technical skills among stakeholders, such as city planners, transportation authorities, and service providers, can impede the successful adoption of these solutions. Skills in areas like data analysis, programming, IoT integration, and system optimization are crucial for effectively leveraging green mobility technologies. Furthermore, there is a shortage of qualified software professionals across Europe [3], leading to a talent gap. As a result, cities may struggle to attract and retain skilled software specialists, further impeding adoption.

- Policy and Regulatory Knowledge: Green mobility solutions operate within a framework of policies, regulations, and standards set by local and national authorities. Stakeholders involved in adopting these solutions need a comprehensive understanding of the existing policies and regulations governing transportation, urban planning, and sustainability. Without this knowledge, it can be challenging to navigate legal requirements and ensure compliance, hindering the adoption process.
- Strategic Planning and Project Management: Developing and implementing green mobility solutions requires strategic planning and effective project management. Stakeholders need skills in areas such as project scoping, resource allocation, risk management, and stakeholder engagement to ensure successful deployment. Insufficient skills in these areas can lead to delays, budget overruns, and suboptimal outcomes.
- Data Literacy and Analytics: Green mobility solutions rely on data collection, analysis, and interpretation to optimize operations, make informed decisions, and assess the impact of interventions. Stakeholders must possess skills in data literacy, including the ability to collect, process, analyze, and derive insights from large datasets. Without adequate data skills, stakeholders may struggle to harness the full potential of green mobility solutions and miss opportunities for improvement.
- Change Management and User Engagement: Implementing green mobility solutions often requires behaviour change among users and stakeholders. Effective change management skills, including communication, training, and engagement strategies, are crucial for promoting acceptance and adoption. Stakeholders need to understand how to engage with communities, address concerns, and effectively communicate the benefits and value propositions of green mobility solutions.

Overcoming the skills barrier requires targeted capacity building initiatives, training programs, knowledge sharing, and collaboration between academia, industry experts, and public institutions. By investing in skill development and knowledge transfer, stakeholders can enhance their capabilities and effectively adopt and manage green mobility solutions, leading to a more sustainable and efficient transportation ecosystem.

6.5 Technology Readiness

The adoption of green mobility services, aimed at promoting sustainable transportation options, is crucial for addressing environmental concerns and reducing carbon emissions. However, several barriers hinder the widespread adoption of these services, particularly in terms of technology needs.

One significant barrier is the limited infrastructure to support green mobility services. The absence of bike-sharing stations, and smart transportation systems impedes the convenient use of these services. To encourage adoption, it is essential to invest in developing an extensive and accessible infrastructure that accommodates and facilitates the use of electric vehicles, shared bicycles, and other sustainable transportation options.

Another barrier is the need for accurate data collection and integration. Green mobility services heavily rely on real-time data on air quality, traffic patterns, and bicycle availability. However, acquiring and integrating such data can be challenging due to factors like the establishment of sensor networks, data sharing agreements, and data privacy concerns.

User-friendly mobile applications and platforms play a vital role in promoting the adoption of green mobility services. These applications should provide accurate and real-time information on bike availability, electric vehicle charging locations, public transportation routes, and air quality conditions. Developing intuitive and user-centric applications that cater to the specific needs and preferences of the users can significantly contribute to increasing the adoption of green mobility services.

In conclusion, overcoming the barriers to the adoption of green mobility services requires addressing the technology needs associated with infrastructure development, data collection and integration, and user-friendly applications.

7 Lessons Learnt from GreenMov and End Users/Cities Feedback

7.1 Lessons Learnt

7.1.1 Nice

Although GreenMov was a successful project, many learnings were raised from issues that had to be solved. First, it was experienced that documentations are lacking to replicate the deployment of NGSI-LD compliant storage facility. This resulted in great delays until engineers from the FIWARE Foundation taught the consortium the right way to install an NGSI-LD infrastructure. However, we should always request for written tutorials on the best practices to replicate solutions, and we should insist that such tutorials are done by the entities that provided the services and have been tested by third parties. If we cannot impose such formalisation and guidance, then, most of these tools will be replicated in a wrong way, which might lead to large delays in the whole system or to functional issues and waste of time for engineers.

Second, it is necessary to ensure all concerned stakeholders are aware of any decision made. In the case of GreenMov, some smart data models had to be modified afterwards because some attributes were missing to meet the use cases requirements.

Third, access to qualitative data happened to be a real challenge, as it was complicated to obtain available air quality, noise and traffic data at the same location. As a result, GreenMov team had to limit the scope of the Nice use case to only one location. This challenge might be encountered by similar cities that do not have a full open data strategy.

Fourth, engagement of stakeholders happened to be harder than expected, as people in Nice were not ready for the proposed use case. They were not exactly willing to reduce their carbon footprint by subscribing to the proposed web service. This has limited the number of end-users participating to the initiative.

Fifth, although it was important to achieve interoperability of data storage, it happened that some use case AI based services were using a local database in addition to the NGSI-LD compliant database in order to store augmented data in a very simplified way. Future work could include the creation of lighter data storage approaches.

Sixth, despite the numerous gains from Linked Data, it was experienced that Linked Data stored at a very high frequency rate (e.g., one data per minute) can lead to excessive requirements in terms of data storage space, which is one of the main drawbacks from LD technology.

7.1.2 IMEC/FLANDERS

Both Flanders and IMEC consider GreenMov as a successful project as the project goals were reached. Assets that will survive the project have been developed and positive feedback was shared by the stakeholders.

- The value of the Blue-bike data was augmented by publishing them as Linked Data with OSLO semantics in the LDES-format.

- The project confirmed that good semantics and linked data as such are more important than the format: LDES was transformed into NGSI-LD and OSLO was mapped on Smart Data models.
- The project delivered an OSLO vocabulary application profile for passenger transport hubs.
- The test users confirmed that combination of real time train schedules and shared bike availability make sense. However, they would prefer the integration of the data in existing mobility and route planner apps over a dedicated app.
- The Blue-bike organization is interested in the results of GreenMov and suggested some new use cases as future work.

In terms of challenges:

- Users expect very fast response, and this is not obvious in a research context. The desired response time, but we faced some glitches in the e2e chain. Flanders is mitigating this by developing industrial component in the VSDS-project.
- Already today blue-bikes points have several variants and that makes a clean user experience difficult:
  - 1 or more Blue-bike stations at one train station.
  - Connected bike that can be unlocked with a smartphone and legacy bikes that are unlocked with a key retrieved from a vending machine.

This will be even harder when other services with different business logic are included. Just think of the difference between free floating and non-free floating or return at same location and return anywhere.

7.1.3 Murcia

The GreenMov project, focused on implementing digital green services for cities, has provided valuable lessons and insights into the realm of sustainable mobility in the Murcia/Molina use case. One significant lesson learned is the importance of collaboration and partnerships between cities to achieve goals and promote common policies. GreenMov has demonstrated in Murcia that successful implementation of digital green services requires close cooperation between municipalities, technology providers, and other relevant stakeholders. By fostering collaborative relationships, sharing expertise, and leveraging the strengths of each partner, the project has developed effective and innovative solutions that address the specific mobility challenges cities face.

In addition, this use case has received strong feedback in implementing these green solutions that will be considered in future iterations. The following are the lessons learned regarding technical points.

- Importance of Assuring Air Quality Data: One of the challenges we have observed during the implementation of the services is that air quality sensors present gaps in the time series. This is a challenge when implementing and training artificial intelligence models, and it is necessary to act on this problem. To deal with this in GreenMov, the Murcia Molina use case implements a micro-service that reconstructs missing values with information about the closest sensors. However, it is critical to work more on this and develop data enhancement methodologies to assess that the collected data has the proper quality to feed the services and generate valuable insights that can be used for decision making.
- Federation of Context Brokers: One of the particularities of the Murcia/Molina use case is the federation of the brokers of Murcia and Molina in a centralized one hosted by HOPU. This is aligned with one of the goals of this use case, which promotes unifying the information of both cities in a single platform.

However, this process highlights challenges, especially in the case of data models that include a timestamp attribute generating a new entity or subscription for each data sent and increasing the number of subscriptions inside the broker exponentially, increase the time of reply of the federated brokers accordingly.

- Need to define forecasting data models: during GreenMov, a set of Smart Data Models were created to complain with the use cases requirements. Among these new models, the forecasting ones stand out over the rest. It is quite important to differentiate between observed values and the forecasting ones, not only because of the origin of the data but also because forecasted values are valid only for some time - until a measurement corresponding to the forecasted timestamp is done. This supposes a mind change in the IoT context that is increasing with the development of artificial intelligence techniques and should be considered in the data models and semantic definitions.

Assess scalability in services architecture: one of the issues noticed during the development of the services is that the air quality forecasting service is necessary to deploy an instance for this sensor. This is feasible for the use case as we work with 6-7 sensors. Still, it is unrealistic for a production environment where the number of devices increases exponentially, and more complex air quality networks are being implemented. For this reason, it is necessary to continue working on the scalability of the green solutions provided.

7.2 Cities and End Users Feedback

7.2.1 Cities Feedback (Murcia - Molina)

GreenMov has received positive feedback from cities across the Murcia/Molina use case. One of the primary reasons why these cities have participated GreenMov is its commitment to sustainability. By green services for sustainability needs, GreenMov has significantly contributed to transform Murcia and Molina in greeener cities. By providing shared bike mobility options that complement buses, trains, and other forms of public transit, GreenMov helps to improve the mobility situation in the use case. Also, the monitoring of air quality and noise encourage citizens to opt for eco-friendly transport options over personal vehicles, thus further reducing traffic congestion and emissions.

GreenMov's commitment to smart technology has also played a significant role in earning positive reviews from cities. In addition to the environmental benefits, cities have lauded GreenMov for its positive impact on the local economy. By partnering with local businesses as HOP Ubiquitous S.L for IoT devices and sustainability impact assessment solutions, GreenMov has strengthened the synergies between both cities. Cities have also appreciated GreenMov's proactive approach to addressing any potential challenges.

From the technical point of view, Murcia and Molina are satisfied with the results of GreenMov, but more efforts in the scalability of the solutions are also being developed. NGSI-LD interfaces are still under research, and it is difficult to deploy solutions in this interface that scales. The same occurs with green services, which should be productized in order to be compatible with more devices and more complex collecting layers in the future. However, the results are satisfactory and Molina and Murcia have gained strong experience being pioneering in implementing this kind of innovative solution.

7.2.2 End users feedback and social acceptability (Flanders example)

In Flanders we have been working with Flanders region and not the individual cities. The Flanders region represented by Digitaal Vlaanderen (formerly known as AIV) communicated that they appreciate the outcome of GreenMov that is perfectly aligned with and contributes to the Flemish data strategy.

During the qualitative validation phase of the study, 10 Blue-bike users were engaged to evaluate the app and express their interest in integrating a forecasting service within different mobility apps. Out of these users, 9 found the application easy to use. As for the prediction information provided, 4 out of 9 users found it useful, while 3 users remained undecided due to concerns about the prediction's reliability being limited to the next 48 hours, app instability, and a restricted search range of 500 meters to find nearby stations. It was acknowledged that these issues exceeded the scope of the GreenMov project and could be addressed in a production version. The primary objective was to assess whether shared bike availability prediction information could be beneficial. The subsequent questions confirmed that users expressed interest in such predictions being integrated into various platforms: 6 users preferred it within the Blue-bike information ecosystem (app or website), 4 users favoured integration with Google Maps, and another 4 users wanted the prediction information available through National railway information services. These insights provide valuable feedback for future implementations of the service.

This study is detailed in the Deliverable GreenMov_D5.3 Pilot deployment and validation_v2 section 7.3.1.

7.2.3 Feedback from the city of Nice

The city of Nice has always been a precursor in the use of digital technologies. As a result, Nice has quickly adopted the NGSIv2 standard to store our data and the data from our partners. Now, with the demonstration from GreenMov's team that NGSI-LD can also be used with more interoperability to propose green Mobility services to the citizens, the city is considering migrating parts of our data storage solution towards NGSI-LD standard. Furthermore, the use case that was implemented in Nice was a perfect fit for our local context with the current deployment of hundreds of sensors to monitor the streets traffic intensity, air quality and noise. Therefore, the city of Nice would like to thank all the stakeholders and funding partners of the GreenMov project who created the framework, tools, and standards to replicate green mobility services that provide actual value to the citizens.

8 Future of Green Mobility Services for Cities

Green mobility services have captured significant attention as cities worldwide strive to solve environmental challenges and enhance sustainable transportation options.

Cities play a crucial role in realizing the objective of achieving climate neutrality by 2050, which is a target aim of the European Green Deal [4]. Cities occupy only 4% of the EU's land area, nevertheless 72% of EU citizens lives in urban areas [4]. Additionally, according to UN Habitat, "cities consume 78 per cent of the world's energy and produce more than 60 per cent of greenhouse gas emissions" [5].

Taking into account that efficient climate mitigation actions should be developed by cities, it is essential to provide comprehensive support to cities in accelerating their environmentally friendly and technologically advanced transformation. European cities have the potential to significantly contribute towards the Green Deal's target of reducing emissions by 55% by 2030.

As it is demonstrated in GreenMov AI intelligence services can provide benefits in several areas, such as improve air quality, smooth transportation, and reduce congestion and noise pollution. Juniper research predicted [6] that "The Carbon [7] emissions saved by smart city deployments in Europe are forecast to reach 247 MMT by 2028, from 161 MMT in 2023." These predictions are encouraged cities to adopt Intelligence services. According to Guide house Insights report, the global smart city technology market is expected to grow "from approximately $121.1 billion in annual revenue in 2023 to $301.2 billion by 2032 at a compound annual growth rate (CAGR) of 10.7%.".

In light of cities across Europe (and indeed, the world) intensifying their efforts to curtail emissions, enhance air quality, minimize noise pollution, and promote efficient transportation systems, it is apparent that the future of Green Mobility Services in Cities is indeed favourable. Artificial Intelligence (AI) is showcasing its capability to surmount these pressing challenges, thereby solidifying this optimistic outlook.

9 Conclusions

This document is the final deliverable of Activity 5 (Pilot deployment) and serves as a comprehensive guide for cities aiming to adopt green mobility services. It highlights all the Activities 3 (Smart services for a green mobility), 4 (Architecture for Context Broker enhancement in concurrent data intensive scenarios and mobility) and 5 stages and showcases the lessons learned and recommendations from the GreenMov project.

The document emphasizes the key drivers for successful deployment, including infrastructure development, standardization, open data access, privacy considerations, and the utilization of AI tools. It also addresses the barriers that hinder the adoption of green mobility services, such as regulation, infrastructure limitations, skills gaps, technology needs, and economic impact.

Through the project's research, pilot deployments, and stakeholder feedback, valuable insights have been gathered, providing a solid foundation for cities to make informed decisions and implement sustainable transportation solutions effectively.

Overall, this document serves as a valuable resource, offering practical guidance and recommendations for cities to embrace green mobility services, reduce emissions, and enhance the quality of urban transportation. It is a crucial steppingstone towards building a greener and more sustainable future for cities and communities all over Europe.

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