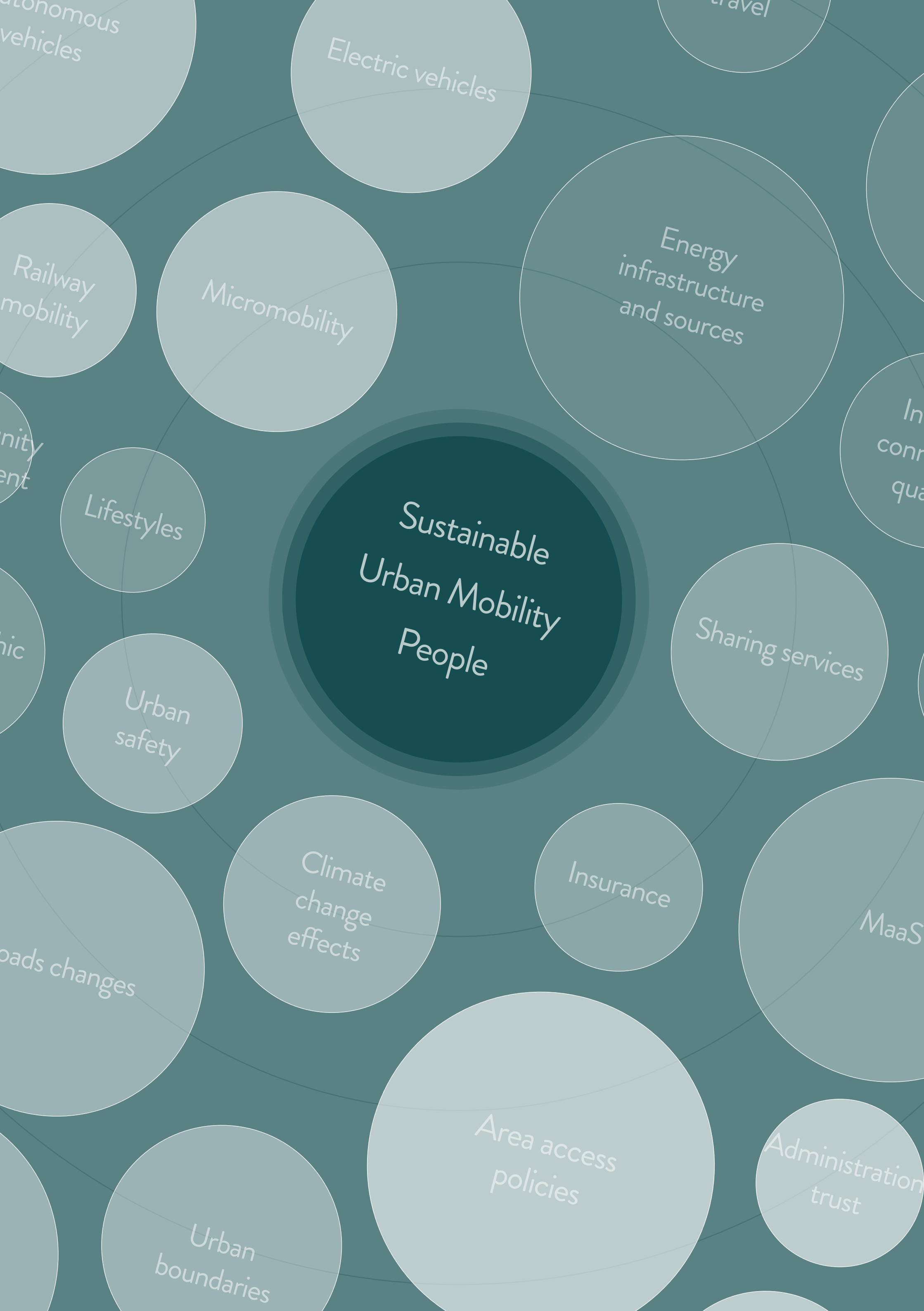
THE FUTURE OF SUSTAINABLE URBAN MOBILITY

How will we move in 2035?

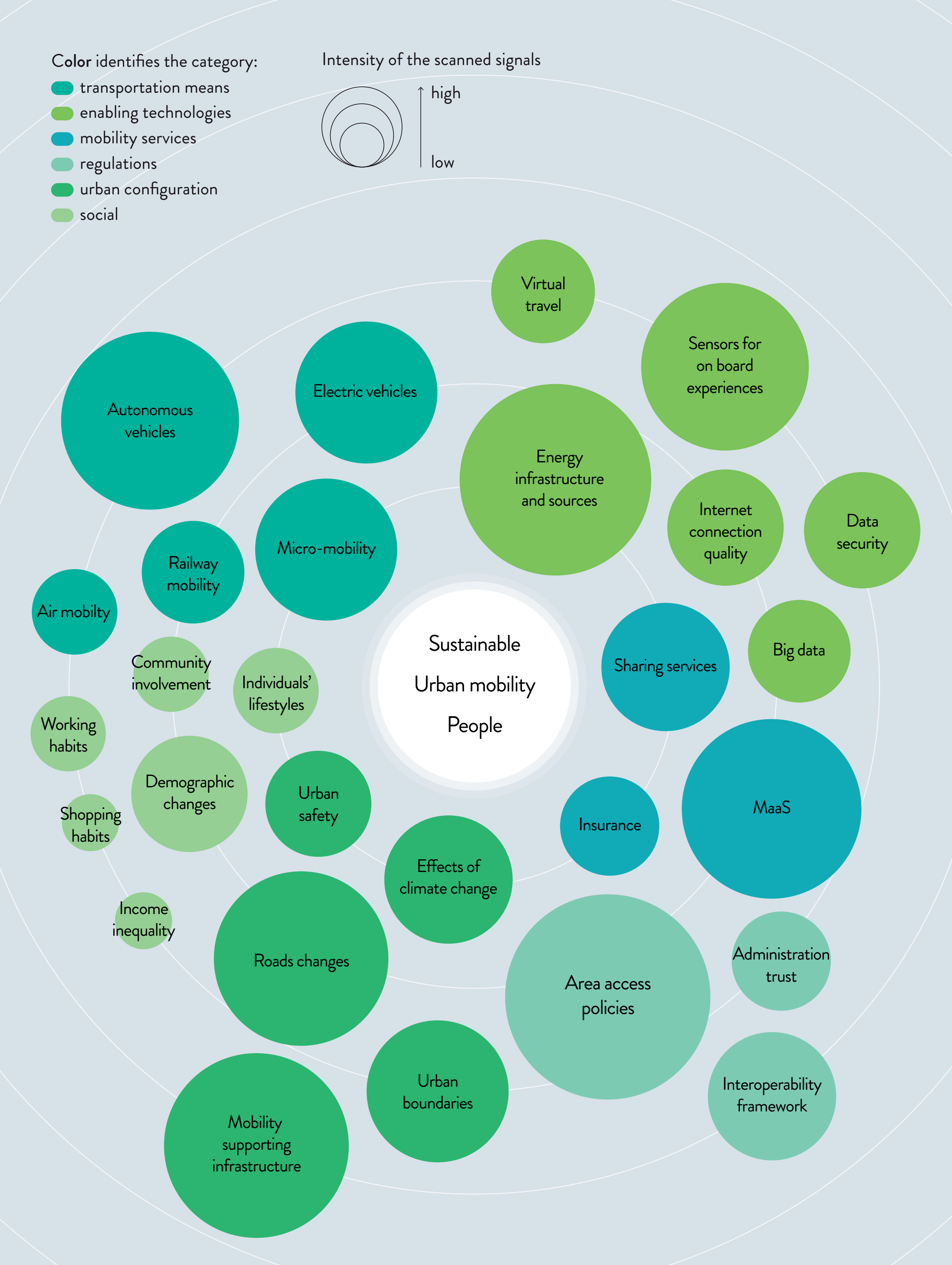
POLITECNICO
MILANO 1863

TECHNOLOGY FORESIGHT CENTER



Sustainable
Urban Mobility
People
Electric vehicles
Energy infrastructure and sources
Micromobility
Railway
Lifestyles
Sharing services
Urban safety
Climate change effects
Insurance
Area access policies
trust
Urban boundaries

Table of contents



Color identifies the category:
transportation means
enabling technologies
mobility services
regulations
urban configuration
social
Intensity of the scanned signals
high
low
Virtual travel
Sensors for on board experiences
Autonomous vehicles
Electric vehicles
Energy infrastructure and sources
Internet connection quality
Data security
Micro-mobility
Railway mobility
Air mobilty
Sustainable
Urban mobility
People
Sharing services
Big data
Community involvement
Individuals' lifestyles
Working habits
Demographic changes
Urban safety
Shopping habits
MaaS
Insurance
Effects of climate change
Income inequality
Roads changes
Area access policies
Administration trust
Urban boundaries
Mobility supporting infrastructure
Interoperability framework

Foreword

2035 marks a significant milestone. Following the European Committee calendar, this date is, for many, the moment when mobility, as we know it, will come to an end: new technological perspectives and new habits suggest a significant change of pace that is making smart mobility a turning point for the future and sustainability of our cities.

This approach clearly emerged from the first activity led by the Center of Technology Foresight at Politecnico di Milano. The study considered the impact of a selected set of fifty technologies and innovations toward the achievement of the United Nations Sustainable Development Goals. Among the various findings, technologies related to mobility showed divergent tendencies requiring a more in-depth investigation.

As a result, this publication explores the future of the mobility of people in urban areas as one of the main challenges that the society is tackling in the transition towards more sustainable models and lifestyles. The context is particularly complex because of the many interactions between social, economic, political, and environmental issues related to urban landscapes, where the vast majority of the worldwide population is expected to be concentrated in the mid-21st century.

Indeed, everywhere around the globe, big economies are investing public and private funds in what they refer to as "the seventh transport revolution", a revolution that will be possible by evolving mobility along with some ongoing trends: urbanization, globalization, new ecology, connectivity, safety/security, and

FIGURE A

Macro areas of interest identified through signals analysis.

—

health. A crosswise approach that makes technology the enabling key.

Our ability to create innovation within complex ecosystems is therefore of primary importance. Our objective is to present an analysis of the potentials offered by emerging technologies and innovations towards the definition of upcoming scenarios that are not only preferred but also feasible, highlighting both empowering as well as preventing factors.

This document summarizes the work done by a group of researchers at Politecnico di Milano together with experts and other stakeholders with the intent of broadening our perspective and share, as much as possible, different points of view, thus improving the foresight process itself. As a matter of fact, this report is meant not only to inform but also to suggest actions: to highlight new opportunities to seize and give advice on possible risks to avoid. We need to be aware and ready to face one of the biggest challenges of our times.

Sustainable mobility starts today.

Ferruccio Resta
Rector

Milano, May 2022

5 key insights on the future of urban mobility

The current situation of urban mobility is widely considered unsustainable. Scenario analysis and technology road mapping have made it possible to identify mobility needs in 2035 and highlighted supporting evidences for drivers of change guiding the transition towards a more sustainable future. Within this context, a set of enabling technologies and innovations emerged in association with the relevant policies and strategic actions to be put in place to address the most desirable scenarios.

The following five takeaway messages are set forth to summarize the many elements that resulted from the foresight study.

→ To work towards more sustainable mobility in 2035, the technologies and strategic actions identified by the study move in two main directions: transitioning from private cars to services and making public transportation smarter and multimodal. The study also highlighted what are the key enabling technologies, innovations, policies, and strategies, as reported in the following graphs.

PRIVATE MOBILITY

From ownership to service

a Connected and autonomous vehicles

- → Level 4 and 5 autonomous vehicles
- → Incremental upgrade kit for vehicles
- → Connectivity and data infrastructures

b Personal transportation vehicles

c Engines with new generation fuels

- → E-Fuels
- → Bio-Fuels
- → Green/Blue hydrogen

d Electric vehicles

- → Batteries
- → Charging infrastructure
- → Electric roads

e Multimodal mobility platform

f Personalized services

- → Augmented reality

g Policies and strategies

- → Vehicle ownership restrictions
- → Pollution-related fees
- → Restricted access areas
- → Reclaim of street parking areas

PUBLIC TRANSPORTATION

Smart, flexible, and multimodal

a Public connected and autonomous vehicles

- → Level 4 and 5 autonomous vehicles
- → Incremental upgrade kit for vehicles
- → Connectivity and data infrastructures
- → Flying taxi

b AI for mobility planning and orchestration

- → On-demand services
- → Data protection and privacy

c Engines with new generation fuels

- → E-Fuels
- → Bio-Fuels
- → Green/Blue hydrogen

d Electric vehicles

- → Batteries
- → Charging infrastructure
- → Electric roads

e Multimodal mobility platform

f Multimodal hubs for urban-peripheral connections

g Policies and strategies

- → Private-public mobility partnerships
- → Flexible demand-response services
- → Private car use restrictions
- → Sustainable journeys incentives and rewards
- → 15-minutes neighborhoods
- → Work from anywhere

FIGURE B

Enabling technologies, policies and strategies that will accompany urban mobility in 2035.

—

→ The speed of the transition towards more sustainable mobility strongly depends on different combinations of political and strategic choices that need to be supported by the development of technologies and actions integrated into the existing, consolidated urban reality.

→ The prerequisites for sustainable mobility in 2035 are already visible today where travel habits are gradually changing: owning a car is no longer a status symbol, walking or cycling is considered not as a necessity but for its health benefits. The choice of the means of transport is also determined by the growing awareness of the contribution to the environmental impact.

→ Greater attention is required to adopt means of transport and policies capable of meeting, on the one hand, the growing demand for mobility of an aging society and, on the other, the travel needs of citizens who, because of an expected increase in migration flows, will be living on the outskirts of urban centers.

→ The future of mobility is strongly affected by the evolution of choices related to the energy domain and the consequent infrastructural renewal and upgrade. Its implementation could be longer than the time horizon considered. Therefore, we expect 2035 to be an intermediate transition phase, with the coexistence of several technological alternatives regarding the type of energy vector for means of transport and autonomous driving.

Methodological note

This is the result of five-months activities that, starting from research and analysis of industry literature and data, has involved a set of experts through interviews, workshops, and a survey. All of these aimed at collecting their opinions and encourage discussions on different visions of the future, debating assumptions, ideas and concerns, and allowing to jointly elaborate plausible trends of evolution. We engaged 19 professors from various departments of Politecnico di Milano, whose expertise falls in multiple areas related to mobility, and 8 experts from companies and public administrations with interests in multiple areas of urban mobility.

Desk research activities gathered evidence and drivers of change associated with STEEP forces (Social, Technological, Economic, Environmental e Political) to prepare the field and complement expert's evidence, serving as a guide to expand the area of research and reframing the landscape under analysis. A technology scanning activity allowed us to collect an overview of prominent technologies and innovations of interest for the mobility context.

Politecnico experts have been engaged initially in individual interviews to gather their expertise and personal vision of mobility today and in 2035, followed by two workshops (the first in-person and the second online), as well as a survey. The group workshops led to the construction of multiple collective and integrated mobility scenarios, starting with the analysis of four alternative futures, identifying their foundations, and then converging into recommendations and opportunities for stakeholders. The survey of technologies, innovations, and policies that emerged from previous activities provided feedback on their expected impact and role in achieving the envisioned sustainable mobility conditions.

Finally, the interviews with external experts broadened the analysis to the different challenges in the field of mobility, with a perspective not directly related to technology but extended to the entire ecosystem by presenting the social, economic, political, and environmental factors that influence it.

References:

https://www.foresight.polimi.it/mobility/references.html

Why care about the future of urban mobility?

Mobility is a key element of our lives. Its evolution, in modes and means of transportation, has been shaped by various factors - needs, expectations, and constraints - embedded in our social, economic, technological, political, and environmental spheres, the so-called STEEP forces (Social, Technological, Economic, Environmental e Political).

In a rapidly urbanizing world, the quality of life experienced by the people living in the cities will determine the quality and sustainability of our future. In this respect, technological advances and innovative approaches addressing the sustainability of urban mobility are of outmost importance for resource use, public health, environmental protection, and economic growth, in line with the Sustainable Development Goals (SDGs).

The introduction of the mass-produced car represented a revolution in mobility. However, this has led to many of the causes of the current condition of the poor quality of life in many cities such as high rates of pollution, traffic, and mental stress.

In Italy, almost all urban centers exceed the EU thresholds on air pollution indicators, with levels of PM2.5 and NO_2 that negatively impact citizens' health.

As far as public transportation is concerned, affordability, accessibility, safety, and reliability are essential aspects that challenge many local administrations.

To move toward a more sustainable urban transportation in the future, we need to look at mobility as a complex system, starting by identifying the social and individual factors that will guide people's travel motivations and choices.

Therefore, it is essential to understand the direction of the changes in the paradigms and elements that influence mobility, because this can determine the quality of citizens' lives as they adapt their habits to better spend time and resources.

Social changes, such as the growing and aging of the population, overlay and interact with mobility. For example, active travel (walking and cycling) tends to decrease with age, while car use increases. This combines with the challenge of keeping the older population healthy and living independently for longer times. Today, 25% of the EU population is aged 60+ and in 2050 this figure is expected to increase to almost 35%. Therefore, changes in the transportation system need to account for the elderly population with limited moving capabilities.

The Covid-19 pandemic made people reflect on the importance of healthy living, achieved through more physical movement and less polluted air. Active mobility is spreading around the urban areas and is being adopted by all social classes, becoming an occasion for daily trips.

Currently, shopping is the most common reason for personal travel, with commuting coming second. The rise of e-commerce has led to a decline in offline shopping, as more people shop online, which has led to an increase in home deliveries. Internet and digitization have disrupted the way people work, shop, socialize and learn by eliminating the need to be physically present, creating more agile work schedules and flexibility in movements. This has given public transportation companies the need to manage demand more flexibly and plan optimized routes.

FIGURE C

Relation between STEEP forces and SDG areas.
(continued on next page)

STEEP categories

Social · Technological · Economic · Environmental · Political

SDG areas of impact

ENP: Essential needs for the person
SEG: Socio-economic growth
SRU: Sustainable resources usage
PPR: Planet preservation
UVP: Universal values protection
GOV: Governance

Relationship between STEEP categories and macro-drivers

related · unrelated

STEEP categories	STEEP forces	ENP	SEG	SRU	PPR	UVP	GOV
Social	Working habits	related	unrelated	unrelated	unrelated	related	related
Social	Demographic patterns	related	unrelated	unrelated	unrelated	related	related
Social	Community belonging	related	related	unrelated	unrelated	related	unrelated
Social, Political	Rise of activism	unrelated	related	related	unrelated	unrelated	related
Social, Technological	Digital dependency	unrelated	related	unrelated	unrelated	related	related
Social	Social divide	unrelated	unrelated	unrelated	unrelated	related	unrelated
Social, Environmental	Sustainability concern	unrelated	unrelated	related	related	unrelated	related
Social, Technological	Technology fear	unrelated	related	unrelated	unrelated	related	unrelated
Social, Technological	Car ownership	related	related	unrelated	unrelated	related	unrelated
Social	Opposing lifestyles	related	unrelated	unrelated	related	related	unrelated
Social	Urban stress	related	unrelated	unrelated	unrelated	unrelated	related
Technological	Big data	unrelated	related	unrelated	unrelated	related	related
Technological	Faster internet connectivity	unrelated	related	unrelated	unrelated	unrelated	unrelated
Technological, Environmental	Energy sources	unrelated	unrelated	related	related	unrelated	related
Technological, Social	Digital identity	unrelated	unrelated	unrelated	unrelated	related	related
Technological, Political	Smart grid infrastructure	unrelated	related	related	related	unrelated	related
Technological	Powered micro-mobility	related	related	unrelated	unrelated	unrelated	unrelated
Technological	Experience booster	related	unrelated	unrelated	unrelated	unrelated	unrelated
Technological	Air mobility	unrelated	related	related	unrelated	unrelated	related
Technological	Mobility as a service	related	unrelated	related	related	unrelated	unrelated
Technological	Sensors everywhere	unrelated	unrelated	related	unrelated	related	related
Technological	Security and cyber attack	related	related	unrelated	unrelated	related	related
Technological	Autonomous vehicles	related	related	unrelated	unrelated	unrelated	related
Technological	Virtual travel	unrelated	unrelated	unrelated	related	related	unrelated
Economica, Political	Coopetition	unrelated	related	related	unrelated	unrelated	related
Economic	Post scarcity economy	unrelated	related	related	related	unrelated	unrelated

STEEP categories

Social · Technological · Economic · Environmental · Political

SDG areas of impact

- **ENP:** Essential needs for the person
- **SEG:** Socio-economic growth
- **SRU:** Sustainable resources usage
- **PPR:** Planet preservation
- **UVP:** Universal values protection
- **GOV:** Governance

Relationship between STEEP categories and macro-drivers

related · unrelated

STEEP categories	STEEP forces	ENP	SEG	SRU	PPR	UVP	GOV
Economic, Technological	Digital experience	unrelated	related	unrelated	unrelated	related	unrelated
Economic, Environmental	Sustainable infrastructures	unrelated	related	related	related	unrelated	unrelated
Economic, Political	Regional connectivity	related	related	unrelated	unrelated	related	unrelated
Economic	Freight mobility	unrelated	related	related	unrelated	unrelated	related
Economic, Social	Multiresidentiality	related	related	unrelated	unrelated	unrelated	unrelated
Economic	Value re-distribution	related	related	related	unrelated	unrelated	unrelated
Economic, Technological	Sharing economy	related	related	related	unrelated	unrelated	related
Economic, Political	Transparency	unrelated	related	unrelated	unrelated	related	related
Environmental	Climate change	unrelated	related	related	unrelated	unrelated	related
Environmental, Political	Decarbonisation	unrelated	unrelated	related	related	unrelated	related
Environmental, Technological	Harmless energy	unrelated	unrelated	related	related	unrelated	unrelated
Environmental, Political	Urban sprawl	unrelated	related	unrelated	related	related	unrelated
Environmental, Economic	Health impact	related	unrelated	unrelated	unrelated	unrelated	related
Environmental	Air pollution	related	unrelated	unrelated	unrelated	unrelated	related
Environmental, Economic	Active mobility	related	unrelated	related	related	unrelated	unrelated
Environmental, Social	Urban rewilding	unrelated	unrelated	related	related	unrelated	related
Environmental	Traffic related noise	related	unrelated	unrelated	unrelated	unrelated	related
Political, Economic	Stakeholder engagement	unrelated	related	unrelated	related	unrelated	related
Political, Social	Citizen collaboration	unrelated	related	unrelated	unrelated	related	related
Political	Statistical skills	unrelated	related	unrelated	unrelated	related	related
Political	Urban configuration	unrelated	related	unrelated	unrelated	related	unrelated
Political, Technological	Standards definition	related	unrelated	related	unrelated	unrelated	related
Political, Social	Social inclusivity	unrelated	related	unrelated	unrelated	related	related
Political, Environmental	Post-carbon regulation	related	unrelated	related	unrelated	unrelated	related
Political, Technological	Interoperability regulations	unrelated	related	related	unrelated	unrelated	related
Political	Local support	related	related	unrelated	related	unrelated	unrelated

Less harmful and sustainable energy sources will replace fossil fuels. Environmental protection goals will favor electric vehicles and energy vectors like clean hydrogen and bio-fuels, which are crucial to break dependence of the European transportation sector on fossil fuels and reduce greenhouse gas emissions. The urgency of mitigating climate change supports the adoption of micro-mobility infrastructures as well.

Coping with a changing ecosystem demands requires the collaboration of all. Citizen-led innovations grow exponentially to shape a city aligned with real users' needs. Policymakers should embrace them while engaging with businesses to collaborate on mobility solutions that induce people to support the transition from private cars to public transportation solutions.

All these elements will play an essential role in changing the future, leading to different possible scenarios that have been explored to identify impact requirements and opportunities for technologies and innovations addressing sustainable urban mobility in 2035.

Macro-category

TECHNOLOGY

Macro-driver

1. Alternative fuel vehicles & advanced technology vehicles
2. Energy infrastructures & mobility infrastructures
3. Automation
4. Data and connectivity infrastructure

POLICY

5. Data privacy
6. Vehicle ownership: private vs shared
7. Flexible demand-response mobility

URBAN CONFIGURATION

8. City landscape reconfiguration
9. User-system interaction & interfaces

SOCIAL

10. Inclusivity
11. Motivation to move
12. Travel as an experience

Emerging macro-drivers

The future of sustainable urban mobility is a complex ecosystem that goes beyond the mere definition of the main transportation means that citizens will experience when commuting in the urban area. It considers what might remain almost immutable, such as the urban infrastructure, and is under radical and rapid transformation, regardless of the source that propels it, as well as the broad digital world that supports mobility, and of course the complex human sphere concerning behaviors, expectations, and needs of individuals.

Politecnico di Milano and indipendent experts have highlighted 12 main macro-drivers as crucial aspects to take into account when considering the future of sustainable urban mobility.

1 **Alternative fuel vehicles & advanced technology vehicles**. Electric vehicles are envisioned to become the *status quo*. Driven by restrictions posed by laws, new fuels will also be commercialized to enable different typologies of vehicles to circulate.

FIGURE D

Macro-drivers to promote sustainable urban mobility.

—

2 **Energy infrastructures & mobility infrastructures.** The diffusion of e-mobility calls for a new generation ofelectricity infrastructure and smart grids, where charging stations and e-vehicles for temporary energy storage are fully supported. Soft mobility, such as bicycles and other micro-mobility solutions, requires dedicated infrastructure and spaces in a renewed city landscape.

3 **Automation.** Despite the great potential that autonomous vehicles can provide for urban mobility and people's lives, their future is quite controversial. Due to the high unpredictability of the city environment, maintaining the contemporary city structure will prevent having a safe circulation of autonomous vehicles (AVs) by 2035. Autonomous driving will most likely be used for public transport, while private vehicles will be reserved for highways.

4 **Data and connectivity infrastructure.** Future mobility is envisioned as a solution shaped on daily users' needs, without forcing individuals to adjust their daily schedule according to it. This means generalized and unified data management coming from different sources to deliver the right service at the right time and in the right place.
Investing in the proper level of connectivity infrastructure (5G and 6G) is important to deploy on-demand mobility in areas outside the city center.

5 **Data privacy.** The vast amount of collected data will impact numerous aspects of citizen's future life, mobility included. As urban mobility will strictly depend on data exploitation and usage, data privacy and security will be critical to guarantee willingness and trust in sharing personal data with city authorities.

6 **Vehicle ownership: private vs. shared.**

The need to own a private car will gradually decrease, and the destiny of cars will be a shared one. By building a network of services (sharing both two- and four-wheel vehicles and public transportation), people will obtain the same freedom of moving as with an owned car.

Abandoning a private vehicle will be driven not only by economical savings but mainly by the aim of being more sustainable while moving.

7 **Flexible demand-response mobility.**

A more flexible mobility offer will become a reality by leveraging available data to predict mobility needs to build an on-demand public transportation service.

Mobility-as-a-Service (MaaS) implies the possibility of dynamically adjusting timetables to actual demand, lowering costs without lowering users' satisfaction and quality of service.

8 **City landscape reconfiguration.** The change in urban mobility and the reduced number of vehicles commuting within the city will change the urban structure, not only in the configuration of street lanes but also in freeing up areas dedicated to new purposes. The definition of 15-min neighborhoods spread around the urban area guarantees a city at a human scale, even in large metropolitan cities in which social relations and active mobility are preserved.

9 **User-system interaction & interfaces.** Sustainable mobility is also based on widespread accessibility to the service, considering both the geographical diffusion of service delivery points and their user-friendly interfaces. The first aspect requires livable multimodal and connecting stations; the second aspect regards the touchpoints within vehicles

and in the stations. Moreover, a widespread network of sensors will be used to enhance travelers' experience.

10 **Inclusivity.** The envisioned implementation of public transportation in 2035 will allow many more people to move within the urban area. The accessibility of public transportation services without depending on others' driving skills or physical capabilities will enable the elderly, disabled, or children to reach their destinations under safe conditions autonomously.

11 **Motivation to move.** The endless possibilities given by digital tools and connectivity have induced a radical change in people's lifestyles. Traditional shopping habits and the daily commute to the workplace will no longer be taken for granted, since everything can be done remotely with a seamless experience. A radical change in motivations to move will turn into different expectations regarding quality, safety, and mobility costs.

12 **Travel as an experience.** Two emerging aspects are the personalization of the travel experience and the opportunity to use the time while moving from one place to another for other purposes. Indeed, users expect to be able to do other activities during the trip, to enjoy the time spent in mobility through reserved space for working or entertaining with friends. The future of work characterized by a "work-from-everywhere" scenario impacts the motivation to move (#11) and the expectations related to the journey itself, which will offer the user a personalized, customizable, and programmable experience.

Key technologies and innovations

During the interviews and workshops, a rich set of technologies and technological innovations emerged as key elements for the future of mobility, independently of the alternative future scenarios that can possibly come true.

These were clustered into three groups: transportation system, urban infrastructure, and policies.

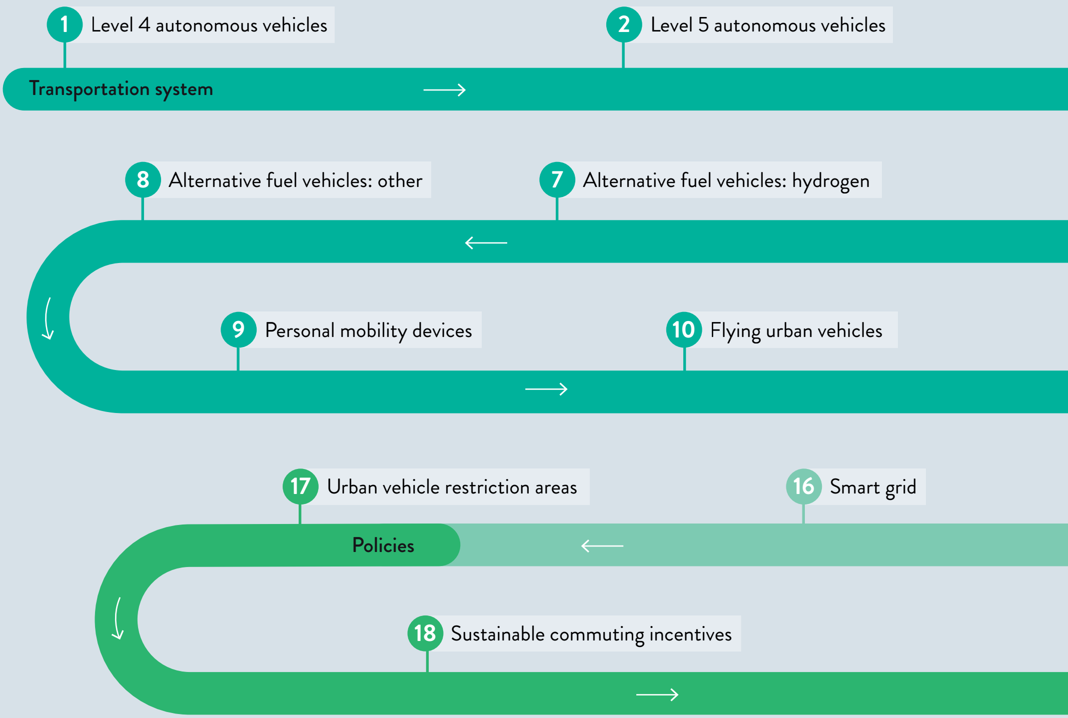
TRANSPORTATION SYSTEM

1. **Level 4 autonomous vehicles.** It refers to highly self-driving automated vehicles (without human control) within a well-defined operational design domain. Outside of these specific situations, the control of the car switches back to human driving, except for emergency steps triggered in case the human driver does not respond appropriately to a request for action.

2. **Level 5 autonomous vehicles.** It refers to a fully self-driving vehicle (without human control) in all driving environments and environmental conditions, including privately-owned

shared cars and buses/shuttles for public transport. Therefore, it is not constrained by geofencing or affected by weather conditions, and humans are transported comfortably and efficiently without requiring a driver. The only human involvement will be to set the destination.

3 **Public demand-responsive transportation.** It refers to an alternative to personal vehicles or taxis; it aims to supplement public transportation in areas with reduced access and manage late night or off-peak hour trips. The objective is to efficiently provide streamlined transportation solutions to match supply with demand based on real-time data.



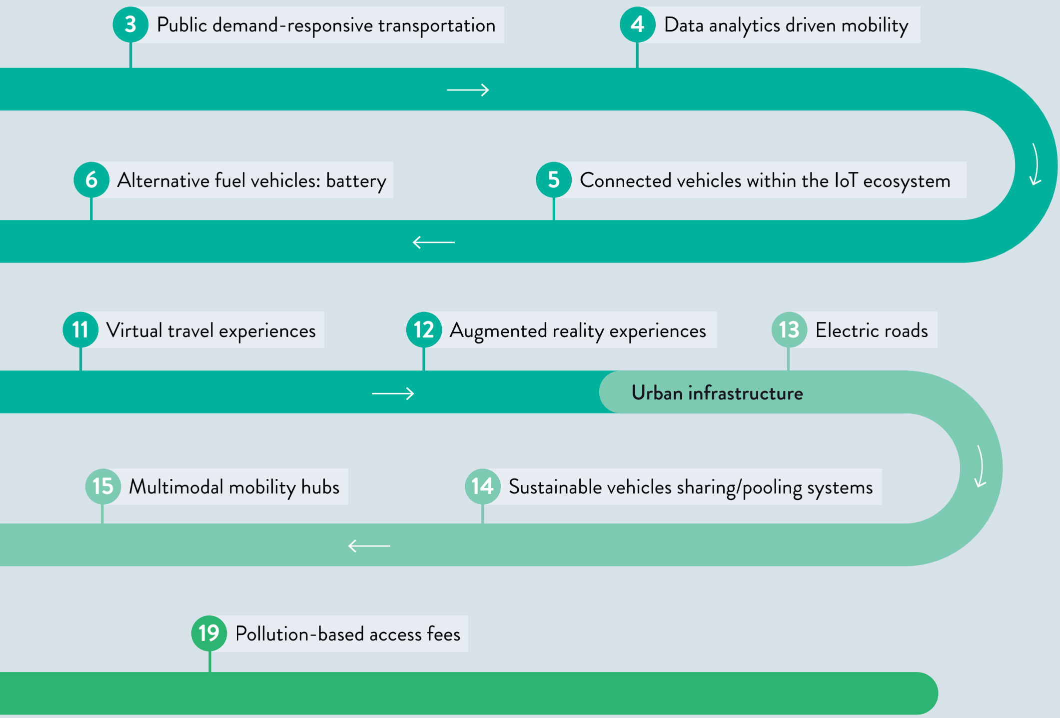
4 **Data analytics driven mobility.** Nowadays, transportation means generate a large amount of data. Processing this unstructured data and gaining insights is key to success in the frenetic mobility sector. Data analytics and AI will enable the development of real-time platforms for increased safety, reduced environmental impact, and improved efficiency.

5 **Connected vehicles within the IoT ecosystem.** It refers to a vehicle connecting over wireless networks to nearby vehicles, infrastructure, and mobile devices. The cases of use range from vehicle-to-vehicle to vehicle-to-infrastructure communications (also known as vehicle-to-everything). Vehicles already have sensors and enabling technology on board (e.g., GPS and on board diagnostics). Of utmost

FIGURE E

Key technologies and innovations for urban mobility in 2035.

—



importance are investments in developing 5G communication technologies to ensure speed and reliability in data transfer between connected vehicles while minimizing latency. Legislation is also needed to regulate connected vehicle operations and privacy aspects.

6 **Alternative fuel vehicles: battery.** A battery-electric vehicle is a vehicle that uses only energy stored in rechargeable batteries, without any secondary source of propulsion. The use of these vehicles in an urban context can reduce air and noise pollution, improving urban comfort.

7 **Alternative fuel vehicles: hydrogen.** It refers to a motor vehicle that runs on hydrogen. Once consumed in a fuel cell, only water is produced. Today, hydrogen is produced through the process of reforming of natural gas (a thermo-catalytic process) with significant CO_2 emissions ("gray hydrogen"). The prospect of being able to produce it without CO_2 through electrolysis with renewable energy ("green hydrogen"), reforming processes with CO_2 capture ("blue hydrogen"), or methane pyrolysis ("turquoise hydrogen") makes hydrogen a promising candidate for a sustainable energy vector.
Hydrogen fuel cells are very attractive for vehicle propulsion, and most of the large automotive companies are trying to adapt to this new technology.
The production, storage, transportation, and utilization of hydrogen as a fuel are essential steps in exploiting this alternative energy vector.

8 **Alternative fuel vehicles: other.** These are vehicles that use non-fossil fuels (for example, gasoline or diesel). This technology refers to engine solutions that create zero net carbon dioxide emissions. Bio-fuels and e-fuels are among the most promising solutions. Around the world, the development

of cleaner alternatives has become a priority for many governments due to the environmental impact generated by fossil fuels in relation to CO_2 emissions.
It is essential to pay attention to the possible impacts these alternative fuels may have in the long-term and assess the impact of emissions for the entire production cycle, especially when a technology is used on a large scale.

9 **Personal mobility devices.** These are compact, motorized micro-mobility vehicles aimed at personal transportation. They include kick-scooters, electric scooters, electric unicycles, electric hoverboards, skateboards, roller skates, and similar devices. In recent years, with the spread of these devices in the sharing mobility market, it has been shown that it is increasingly necessary to regulate personal mobility devices: many countries have already introduced a series of regulations to ensure minimum safety conditions.

10 **Flying urban vehicles.** The idea of flying vehicles has been appealing to humans even before automobiles existed.
As the means of transportation evolved and congestion became an issue, the dream evolved. Today, advances in the miniaturization of sensors, power storage, electric motors, and artificial intelligence seemingly align to finally bring the flying car close to reality, even if the engineering challenges are manifold. The flying vehicle prototypes under development attempt to combine the best features of airplanes and helicopters and are here envisioned for the transport of a limited number of people, e.g., flying taxis. The imagined scenario will require dramatic upgrades to air traffic control systems and procedures.

11 **Virtual travel experience.** It refers to commuting experiences in a virtual world, recreating real-life situations using immersive artificial experiences supported by virtual reality and wearable

devices, equalizing the value of a virtual commute to a real one.

12 **Augmented reality experience.** It refers to digital tools that overlay reality with virtual enhancements to empower drivers and travelers during their commute. Augmented reality technology can play an important role in the interaction between drivers/passengers and automated vehicles.

URBAN INFRASTRUCTURE

13 **Electric roads.** These are roads that provide electrical power to vehicles traveling on it. Typical implementations are ground-level power supply through conductive rails or inductive coils embedded in the road and overhead power lines above the road. They represent an advantage when they provide a cleaner alternative to the combustion engine, especially if the energy comes from renewable sources (wind or solar). The efficiency of electric roads is highest in the case of conductive charging technology.

14 **Sustainable vehicle sharing/pooling systems.** It is a membership-based service that enables sharing vehicles within a dispersed network, available 24-hours a day. This technology refers to both four-wheel vehicles and micro-mobility ones. Specifically, the areas of analysis are medium towns, small cities, and a context different from the metropolitan area. One of the main challenges is to ensure fast access to on-demand ride-hailing and car-sharing services. Vehicle connectivity will bring the critical benefit of improving traffic conditions by promoting the perceived loss of convenience that consumers expect when they abandon car ownership.

FIGURE F

Most cited concepts that emerged during conversations with experts.

—

Community Proximity Freedom
Purpose
New competences Incentives Hydrogen Safety
Digitalization No cars city
Big Data Collaboration Social aggregation
Electrified streets
Electric cars Green spaces Elderly Sharing
Regulation Sensors
Decarbonization Public transportation Activism
No traffic Consciousness
Stress reduction Multimodal system
Urban
Flexibility Comfort Autonomous cars
Relax Digital identity Energy sources
Pedestrian
Mobility Silent roads
Charging stations Climate changes
Cybersecurity E-fuels Smart working Education
Energy communities Smart Grid Multiresidentiality Micro-mobility
Augmented reality Connectivity Sharing
Restrictions Car ownership
Air pollution Megacity
Sustainability Inclusivity Urban planning
Capillarity Infrastructures Temperature CO_2 Train
Health concern Urban sprawl
Renewable energy Fluid mobility E-Bike
Air mobility Energy production
Reconfiguration Virtual mobility
Maas

15 **Multimodal mobility hubs.** It is a mobility service infrastructure positioned in a crucial access point of the city center to switch seamlessly between two different transportation means. Potentially, this facility addresses the diverse needs of commuters while shaping a car-free city center. The multimodal mobility hub has the advantage of combining various public and private modes, facilitating connections and changes, and improving access to sustainable transit by combining and structuring networks to meet the needs of more users.

16 **Smart grid.** It is an electricity network enabling a two-way flow of electricity and data with digital communication technology allowing the detection, reaction, and pro-action to changes in usage and multiple issues. Smart grids have self-healing capabilities and enable electricity customers to become active participants.

POLICIES

17 **Urban vehicle restriction areas.** It refers to implementing car and parking restrictions in a particular city area. These solutions are typically applied in the city center to protect public transportation from traffic congestion, thus enhancing its competitiveness and increasing the public space attractiveness. To successfully implement this policy, the city must provide a public transportation offer tailored to the demand and sharing mobility offers. The presence of dedicated routes for alternative and non-polluting means of transportation, such as bicycle lanes, is essential.

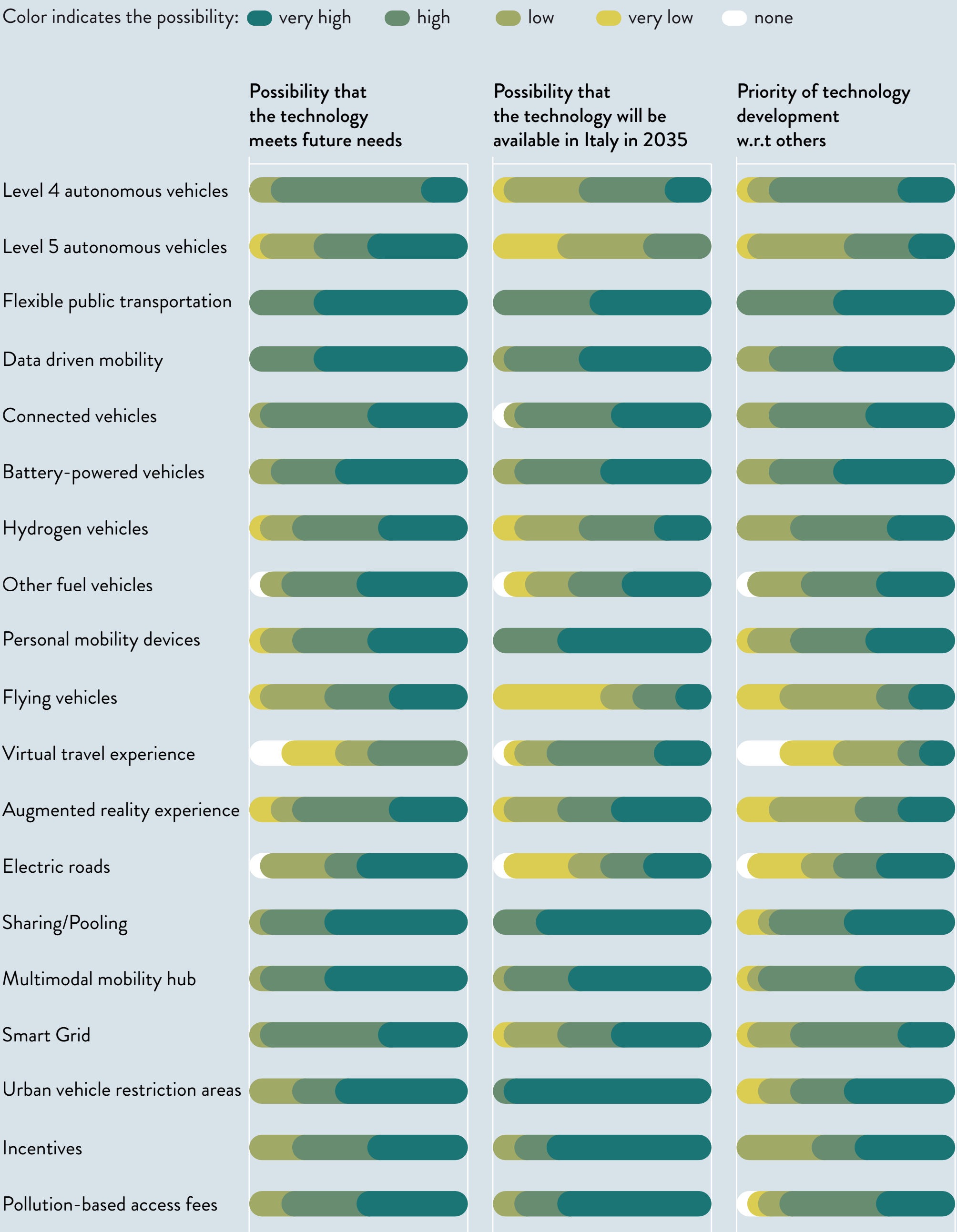
18 **Sustainable commuting (tax) incentives.** It refers to all public incentives introduced to induce the abandonment of polluting vehicles in favor of more sustainable means of transportation. Many alternatives are currently implemented

Photo by Kindel Media on Pexels

around the world, such as incentives for traveling during off-peak demand hours or for medium-long distance daily trips by public transport. Other economic incentives include flexible pricing on public transport, economic support for the purchase of sustainable transport, or the adaptation of taxation to stimulate sustainable behavior of the individual.

19 **Pollution-based access fees.** It refers to a payment of a fee based on the amount of pollutants released into the environment (e.g., air and wastewater emissions or solid waste). A regulated party pays a fixed amount for each unit of pollution emitted or disposed of, having the choice to pollute and pay tax or install systems to prevent or reduce the level of pollution. To implement this kind of policy, infrastructure is needed to process data on who accesses the various areas. This infrastructure is mainly composed of in-field sensors and data processing servers.

Percentage distribution of experts' opinions.



Expected impact and readiness level by 2035

FIGURE G

Percentage distribution of impact for each technology and area.

—

FIGURE H

Experts' opinions on the possibility of key technologies and innovations being ready by 2035.
(On the following page)

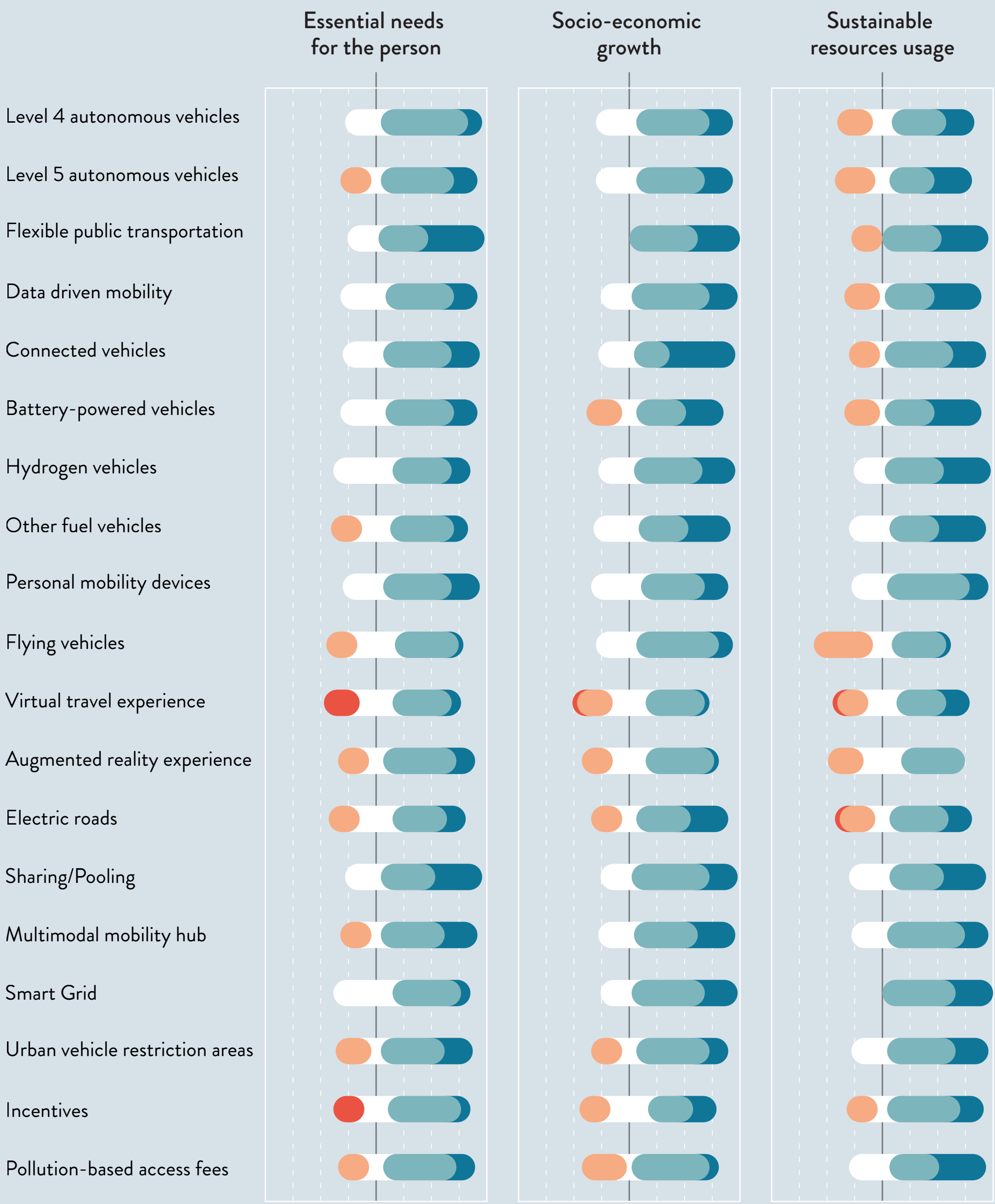
—

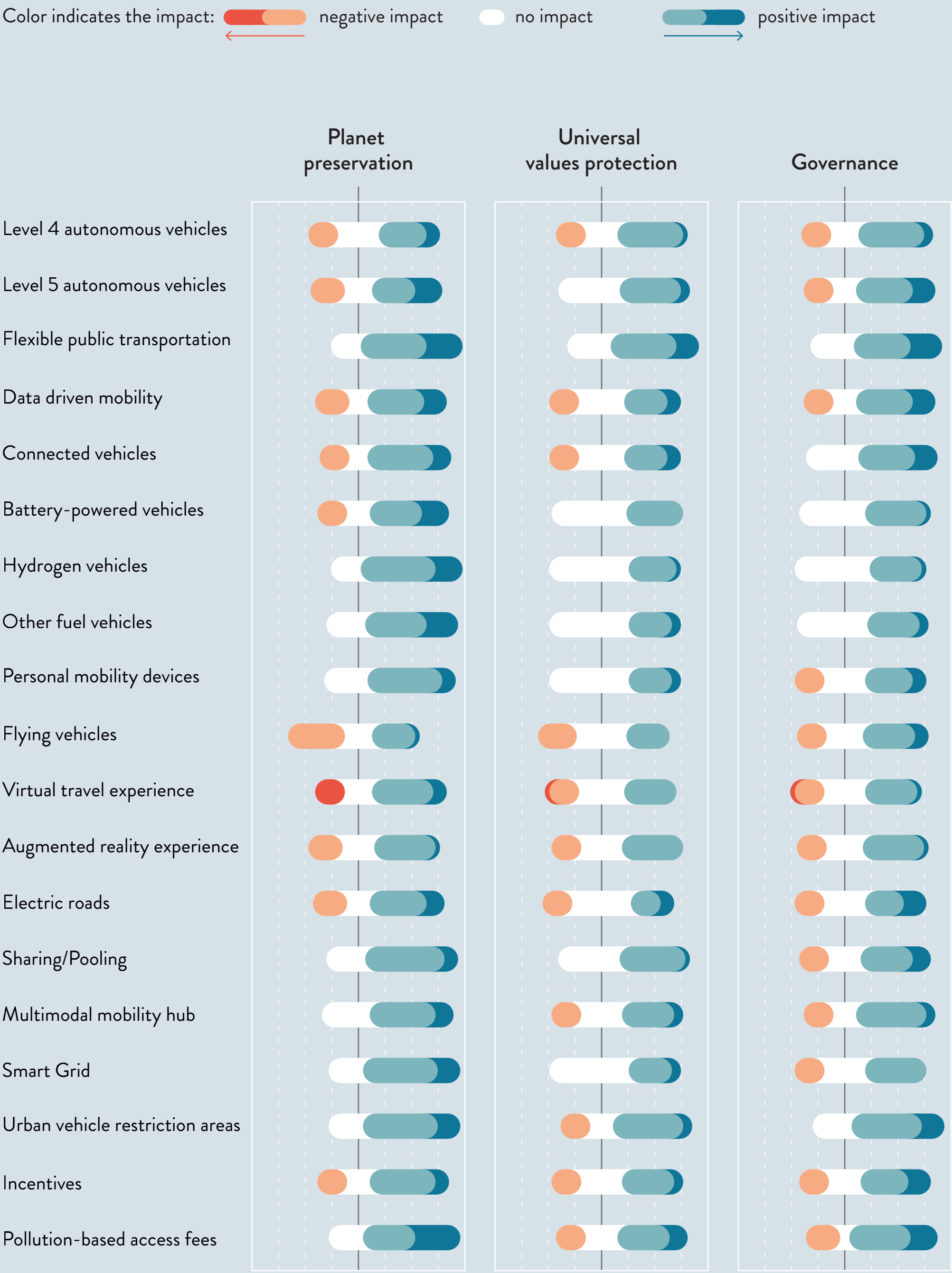
The technologies and innovations that emerged from the individual and group activities were also analyzed in order to understand their potential contribution to the realization of sustainable urban mobility scenarios. The level of maturity and the likelihood of being available within the identified time window was also taken into account.

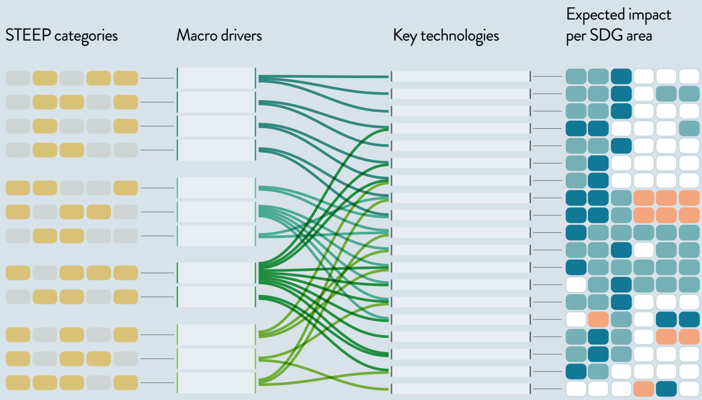
Overall, according to experts, there is a medium to high probability of having all the considered technologies fully developed and ready for implementation in Italy by 2035. The only exceptions are autonomous vehicles at level 5 and flying urban vehicles, for which more years will likely be needed to reach the required level of maturity. As for public demand-responsive transportation, sustainable vehicles sharing/pooling systems, and urban vehicle restriction areas, experts largely agree on a high/very high probability of implementation and social acceptance.

Experts have also shown a good level of agreement on the impact that the key mobility technologies and innovations will have in achieving the sustainable development goals. The SDGs that receive the greatest support are in the "Social-economic growth" and "Essential needs for the person" areas. Still, a non-negative impact is also envisioned on SDGs in the "Sustainable

Percentage distribution of impact for each technology and SDG area.




Color indicates the impact:
negative impact
no impact
positive impact
Planet preservation
Universal values protection
Governance
Level 4 autonomous vehicles
Level 5 autonomous vehicles
Flexible public transportation
Data driven mobility
Connected vehicles
Battery-powered vehicles
Hydrogen vehicles
Other fuel vehicles
Personal mobility devices
Flying vehicles
Virtual travel experience
Augmented reality experience
Electric roads
Sharing/Pooling
Multimodal mobility hub
Smart Grid
Urban vehicle restriction areas
Incentives
Pollution-based access fees



resource usage" and "Planet preservation" areas. The only SDG area marginally affected by the considered technologies is the "Universal values protection" area, where a predominantly neutral impact is expected. Indeed, despite inclusivity being highlighted as a relevant driver from all the voices and during the entire activity it seemed to be a goal to be pursued by designing mobility as the whole ecosystem rather than a feature brought by technologies and innovations as such.

An integrated view of the study's findings highlights the relationships between macro-drivers and key technologies and innovations, decoding the former in relation to STEEP forces and the latter concerning their potential impact on the achievement of sustainable development goals. The map reports the average impact values based on what was expressed by the experts through the opinion survey.

The set of relations between different factors underlines the complexity of the urban mobility ecosystem, in which technologies undoubtedly play an essential role only through the mediation of policies and strategies that will foster their further development and effective adoption.

FIGURE I

Comprehensive and integrated view of the study, represented with full details in the attached poster.

—

Electric cars
Electrified streets
Decarbonization
Public transportation
Spazi v
ess reduction
Regulatio
ility
Comfort
No tra
lax
Multimodal system
Autonomous cars
Pedestrian
Digital identity
harging stations
Ener
Mobility
Cybersecurity
E-fuels
ommunities
Smart Grid
Smart workin
ented reality
Multiresidential
Car ownership
Connectivity
ainability
Megacity
Infrastructures
Inclusivity
Air pollution
Urb

Participants to interviews and workshops are listed below.
We thank them for their unvaluable contributions and insights.

At Politecnico di Milano: Marika Arena, Benedetto Bozzini, Fausto Brevi, Stefano Bruni, Andrea Casalegno, Federico Cheli, Grazia Concilio, Pierluigi Coppola, Francesco Grimaccia, Gianpiero Mastinu, Matteo Matteucci, Angelo Onorati, Paola Pucci, Giuseppe Sala, Sergio Savaresi, Luca Studer, Emanuele Toraldo, Simone Vantini, Dario Zaninelli.

External Experts: Roberta Bonacossa, Arianna Censi, Stephane Cretel, Giulio Del Balzo, Fabio Fossa, Giovanni Romano, Fabrizio Gatti, Giorgio Gori.

This activity has been carried out in collaboration with the Institute For The Future and Leadin' Lab of the School of Management at Politecnico di Milano.

Technology Foresight Center – Scientific Board:
Cristiana Bolchini, Francesco Braghin, Giuliana Iannaccone, Matteo Maestri, Paolo Trucco.

Technology Foresight Center - Researcher: Habiba Abdelfattah, Silvia Gadola, Riccardo Medana, Alberto Speroni.
Leadin' Lab - School of Management, Politecnico di Milano:
Tommaso Buganza, Claudio Dell'Era, Daniel Trabucchi.
Institute For The Future: Jacques Barcia,
Susanne Forchheimer, Joseph Press, Leah Zaidi.

Design and layout: Accurat