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Integrating Autonomous Mobility into the Transport System: A Saudi Arabian Case Study

WHITE PAPER

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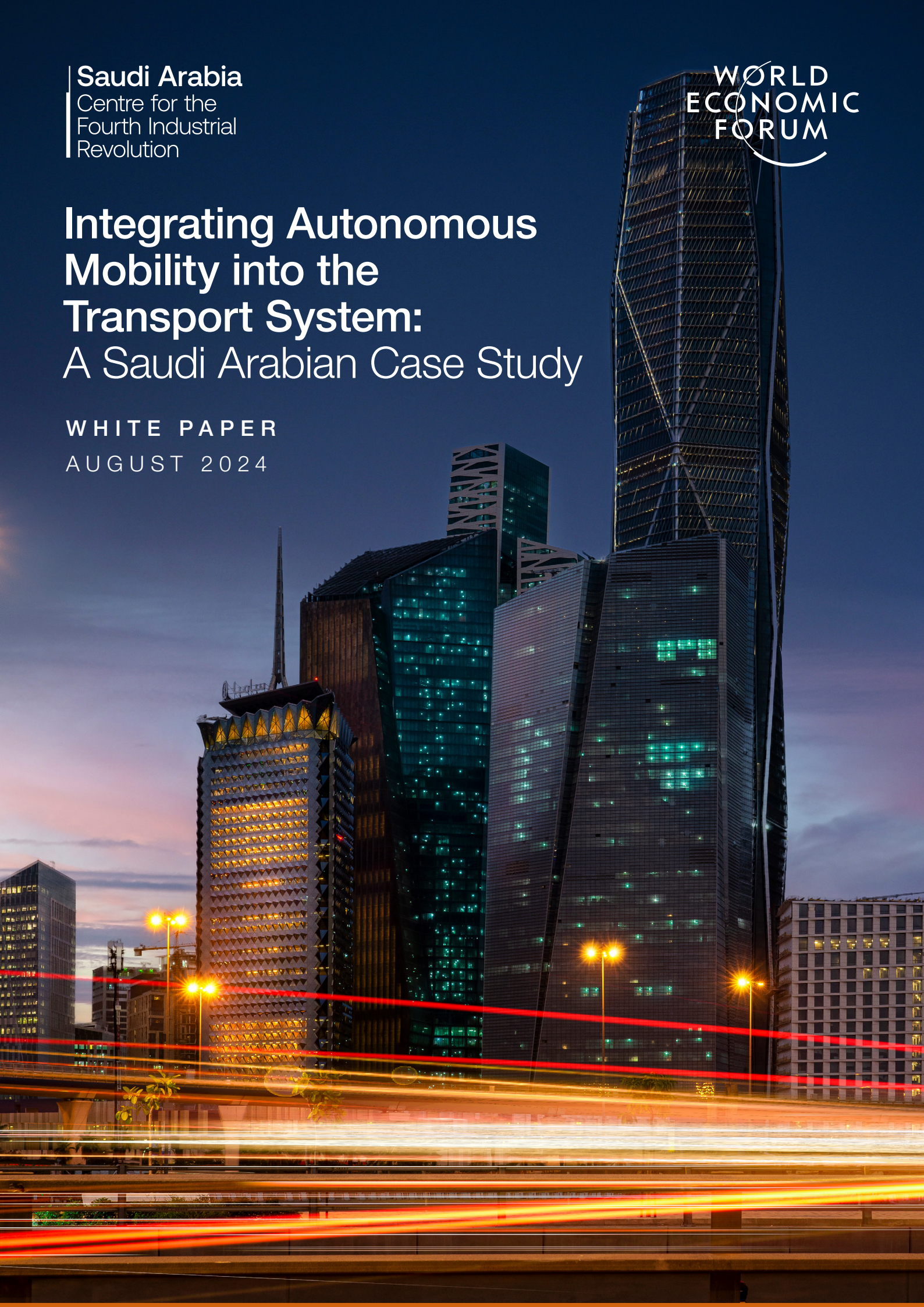

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Contents

Foreword

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As we navigate through the advancements of the 21st century, integrating autonomous mobility into our global transport systems stands out as a pivotal development. According to McKinsey, advances in autonomous driving, electrification, connectivity and shared mobility are projected to drive significant growth.[1] This transformative potential underscores the impact autonomous mobility is poised to have on the transport sector, enhancing safety, reliability and efficiency in the movement of people and goods. As the need for cohesive and innovative strategies is more pressing than ever, this white paper aims to offer a framework to support these efforts, with Saudi Arabia serving as a key case study.

Saudi Arabia's Vision 2030 is a bold and ambitious strategy designed to diversify the nation's economy and elevate the public service sectors, with a significant emphasis on transport infrastructure. The Vision's detailed strategies, including the National Transport and Logistics Strategy (NTLS) and the Autonomous Mobility Strategy (AMS), aim to position Saudi Arabia as a global logistics hub and a leader in autonomous mobility.

The global landscape provides valuable lessons on the transformation of the mobility sector. Cities in the United States, Europe and Asia serve as benchmarks, having made significant advances in autonomous vehicle testing and deployment. However, several challenges remain when it comes to large-scale deployment, and it is essential that the implementation of these technologies is part of a long-term policy vision with clear objectives. The framework proposed in this paper seeks to address these challenges through a unified approach, integrating regulatory sandboxes with autonomous mobility testing environments and including a feedback loop. This will help create a seamless connection between regulation and deployment, fostering collaboration and minimizing redundancy, such as duplicated autonomous testing efforts and inefficient use of resources.

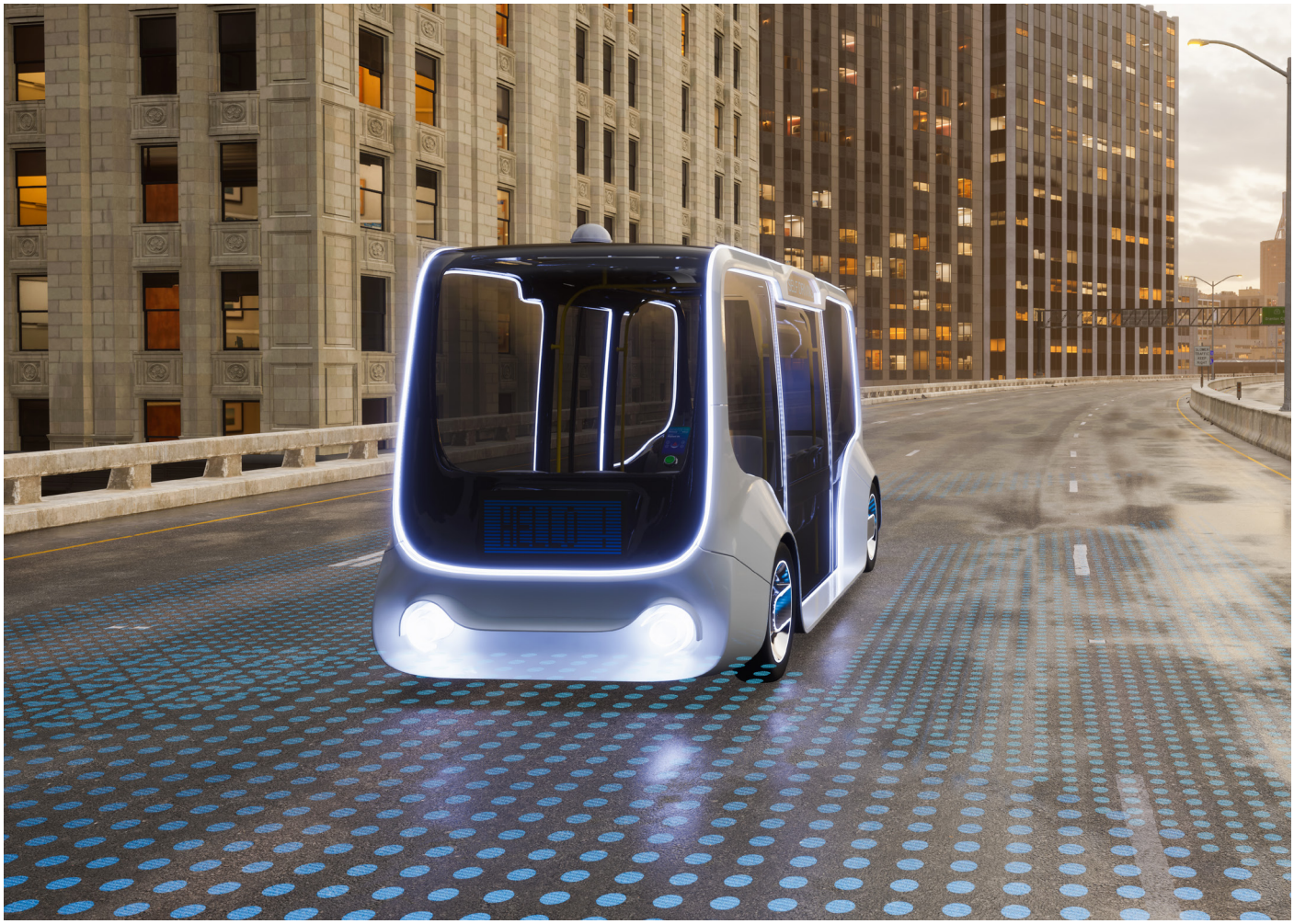
Executive summary

Autonomous mobility – be it on land, on sea or in the air – is poised to transform global transport. Autonomous vehicles (AVs), as a key component of this transformation, exemplify how such technologies can enhance safety, reliability and efficiency in the movement of people and goods, setting the stage for broader applications in autonomous mobility across various modes of transport. This white paper explores the pathways for integrating autonomous mobility into existing transport systems, emphasizing the need for innovative regulatory approaches and strategic pilot projects. To help clear the way for autonomous mobility innovation and full deployment, a four-step framework is proposed: (1) regulatory sandbox development; (2) pilot selection; (3) pilot implementation; and (4) scaling.

Saudi Arabia's journey towards autonomous mobility, rooted in Vision 2030, serves as a case study, illustrating how a national regulatory sandbox can accelerate autonomous mobility. The use of sandboxes can fast-track the development of autonomous mobility deployment by integrating pilot projects with national transport strategies, making sure they contribute significantly to broader transport objectives.

The criteria for selecting pilots include regulatory simplification, safety, data protection, technological readiness and public trust, all of which ensure that projects align with key policy objectives. Transparent reporting and comprehensive risk management at pilot selection stage are also important for boosting public confidence and engagement, which are essential for the broad adoption of such technologies.

The final step in the framework is scaling beyond the pilot. Scaling successful pilots involves clear exit strategies and continuous monitoring to allow best practices to be replicated and expanded effectively. This process is essential for transitioning from pilot projects to widespread deployment, helping to refine the approach and address any issues that arise during initial implementation. By maintaining a structured framework, stakeholders can better manage the complexities of integrating autonomous mobility solutions and adapt regulations as needed. This approach supports the ongoing evolution and improvement of autonomous mobility technologies, facilitating their sustainable integration into existing transport systems.



1 Integrating autonomous mobility into global transport systems

The autonomous mobility market, encompassing land, sea and air, is projected to become highly valuable in the coming years.

Specifically, the global market for autonomous vehicles (AVs) is anticipated to drive significant growth in the autonomous market, generating substantial revenue. According to McKinsey, by 2035, autonomous driving could generate between $300 and $400 billion in annual revenue. This substantial economic potential underscores the transformative impact autonomous mobility is poised to have on the transport sector, enhancing safety, reliability and efficiency in how people and goods move.[2,3] Autonomous vehicles are a key component of autonomous mobility, exemplifying how such technologies can improve the efficiency of these transport systems and laying the foundations for broader applications in autonomous mobility across various modes of transport.[4]

To realize these projections, several barriers must be overcome. For instance, regulation is not yet fully in place and varies across jurisdictions. Although there is a general understanding of the importance of integrated and interconnected mobility systems, uncertainties remain about how to effectively harness the benefits of integration, connectivity and interoperability. Additionally, when it comes to safety, there is still uncertainty about how these technologies address edge cases – rare or unexpected situations that fall outside the scenarios, or operational operating domains (OODs), where autonomous systems have been trained and tested.

Not all remaining challenges can be addressed at once, yet every new pilot deployment should contribute to addressing some of these challenges, highlighting the importance of innovative and cohesive piloting and deployment efforts. This white paper aims to foster collaboration among mobility testing activities in order to streamline efforts and minimize redundancy, such as duplicated testing efforts and inefficient resource use, using Saudi Arabia as a case study. It does so by presenting a framework that addresses the remaining challenges through a unified approach, from having a clear regulatory path into piloting (via regulatory sandboxes and autonomous testing environments) to establishing clear pilot testing criteria and success metrics.

2 The challenge: The path from pilot to full autonomous mobility deployment

Autonomous mobility pilots are increasing across all continents, yet the pathway from pilot projects to full deployment remains largely unclear.

While the lack of clarity from pilot to deployment is in part inherently linked to the uncertainties that new deployments bring, it also results from the challenge of including pilots as additional tools to address broad policy goals.

The disconnect between pilot projects and long-term transport goals has been emphasized by McAslan et al.[5] in their comprehensive assessment of AV pilots across various US cities. There are several issues that make ensuring a stronger connection between pilots and long-term goals a challenge, including:

- First, the regulatory landscape is often fragmented – with different directions and policies at the country, state and city levels. McAslan et al. highlight the importance of having a unified framework for autonomous mobility piloting.
- Second, the allure of technological advancements can overshadow the rationale behind implementing technology in the first place, which then limits its deployment in the longer term. As Jeffrey Tumlin, Director of the San Francisco Municipal Transportation Agency, put it: "For every new mobility technology that we are pitched in San Francisco, including autonomous vehicles, we ask companies how their tech helps improve our accessibility, safety, inclusivity and decarbonization goals."[6]
- And third, there are often limited (or no) mechanisms in place to systematically and rapidly adopt pilot learnings in other related ongoing and planned deployments, often resulting in duplicated efforts, missed opportunities for learning and collaboration, and a slower path to the meaningful widespread adoption of these new technologies.

To avoid these issues, a cohesive policy that welcomes the responsible implementation of innovation, and which includes a learning loop, is vital. The following is an overview of regulatory approaches to address this and provides a four-step framework to accelerate autonomous mobility pilots and deployments.

2.1 Regulatory sandboxes and other policy tools to aid mobility technology deployment

Policy approaches to fostering innovation in mobility vary widely across the world, from limited and hands-off interventions to those that are strong and hands-on. There are four broad categories outlining how regulators tend to promote innovation and experimentation in new areas,[7] which can be applied to support autonomous mobility deployment. (Note that these four categories may overlap.)

1. **Wait-and-see:** A hands-off approach whereby regulators monitor trends before intervening, and they allow innovation to develop with minimal interference
2. **Test-and-learn:** A regulatory approach that offers a customized framework for a specific business case to operate; this approval can allow for varying degrees of supervision
3. **Innovation facilitators:** The provision of a structured framework that covers the regulatory basis for experimentation in different types of applications or business cases
4. **Regulatory laws and reforms:** The direct introduction of laws and reforms, even if they are temporary and are then adjusted when more information on the innovation is available

This paper encourages the use of innovation facilitators as a key approach for autonomous mobility innovations, providing a certain level of hands-on governance (given the safety requirements necessary for autonomous mobility deployments in public environments) and allowing for a wide range of applications to come to life. There are different options that fall within the innovation facilitators category, including regulatory sandboxes, innovation hubs, living labs and beta-testing environments.

Regulatory sandboxes – which provide a gateway for companies to test new technologies and business models with real customers under regulatory supervision, giving additional leeway beyond existing regulations – is the approach chosen for the framework in this paper. These sandboxes contribute to the early deployment of new technologies, help build public trust and aid in the collection of valuable insights for devising meaningful regulations that address the larger-scale implementations of the specific technology.

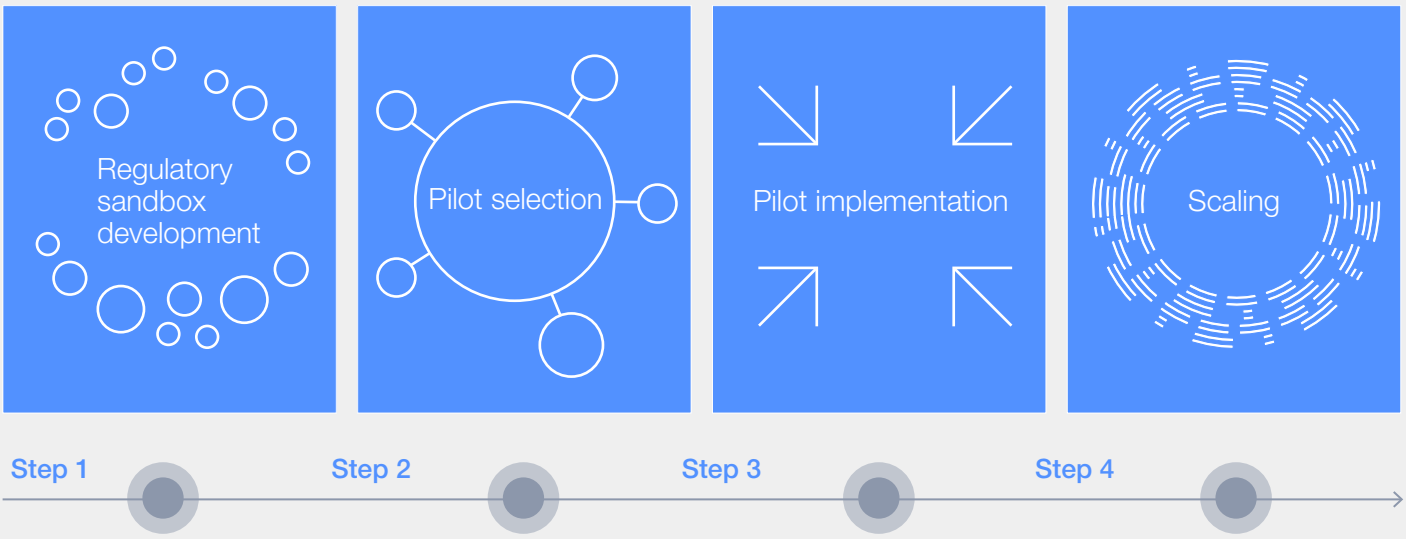
It is important to note that the setting up and implementation of regulatory sandboxes can be time-consuming and costly, hence the importance of having clear objectives and expected key results.

In recent years, regulatory sandboxes have been widely used to test transport innovations in controlled environments. For example, the UK has established different transport sandboxes,[8] including the Zenzic CAM Testbed UK, which provides various controlled environments for testing AVs,[9] supporting industry collaboration and helping to address regulatory barriers to ensure safety and performance standards before public deployment. Singapore has established the Centre of Excellence for Testing and Research of Autonomous Vehicles (CETRAN), a regulatory sandbox that allows controlled testing of AV technologies in simulated urban environments.[10] CETRAN facilitates safe testing and data collection to inform future regulations and infrastructure planning.

2.2 Accelerating autonomous mobility: A four-step framework for success

This paper presents a four-step framework to accelerate the deployment of autonomous mobility technologies and to address the gap between piloting and scaled deployment. Figure 1 illustrates the four phases: (1) regulatory sandbox development; (2) pilot selection; (3) pilot implementation; and (4) scaling. This structured approach helps initial experiments to be effectively translated into widespread, real-world solutions, facilitating a smoother transition from testing to large-scale implementation.

FIGURE 1 **The four-step framework for accelerating the deployment of autonomous mobility**



Source: World Economic Forum Centre for the Fourth Industrial Revolution Saudi Arabia

Regulatory sandbox development

The first step of the framework puts an enabling regulatory environment in place. The regulatory sandbox approach has been identified as an effective method of fostering innovation across various cases. It should be embedded in an integrated and comprehensive regulatory environment to ensure that its objectives are aligned with national and local strategies. The sandbox should also include success criteria and requirements for potential scaling beyond the pilot, and it should provide a link between the insights gained from pilot projects and the formulation of future autonomous mobility regulations. Getting this phase right is critical for the successful implementation and expansion of autonomous mobility solutions.

Pilot selection

The next step of the framework, pilot selection, relates to the established criteria for project alignment and deployment. These criteria should be developed based on national and/or municipal transport strategies, existing regulatory or knowledge gaps that the sandbox wants to bridge, and the stakeholders' need to ensure a cohesive and accelerated implementation of autonomous mobility solutions. Globally, different countries have adopted varying key autonomous mobility pilot selecting criteria. For example, in the Netherlands, pilot projects must demonstrate a clear contribution to sustainability and public safety, aligning with the country's national mobility plan;[11] and Singapore requires pilot projects to focus on robust cybersecurity measures, reflecting their emphasis on technological integration and data protection.[12]

Based on the criteria, the "to pilot or not to pilot" decision will be made. If a specific submitted pilot is considered relevant but falls outside the scope or criteria of the regulatory sandbox, a decision to deploy through additional regulatory mechanisms may also be granted.

Pilot implementation

After selecting the pilots for implementation, the focus will be on ensuring a successful pilot deployment. This step encompasses the creation of an enabling environment in which decision-makers can agree on testing parameters for the pilot implementation, and on the implementation of the pilot itself, and whether to expand the scope of testing or not based on the agreed success metrics. This includes the establishment and implementation of testing environment design standards, which should align with the selection criteria, with a focus on compliance, risk management, test restrictions, exit strategies and transparent reporting. These parameters should reflect the criteria included in the pilot submission process for which the pilot was greenlit as well as any additional considerations needed for its safe implementation.

Pilots that have been granted specific approval to operate within the regulatory sandbox environment should also align with regulators on the necessary reporting metrics to further evaluate pilot performance. This will help to ensure the specific pilot is compliant with standards and that it helps to advance knowledge regarding autonomous mobility deployments, in line with the regulatory sandbox objectives. To ensure the latter, specific metrics should enable performance comparison with other ongoing or finalized pilots, facilitating the collection of key learnings and contributing to the integration of autonomous technologies into the broader transport system.

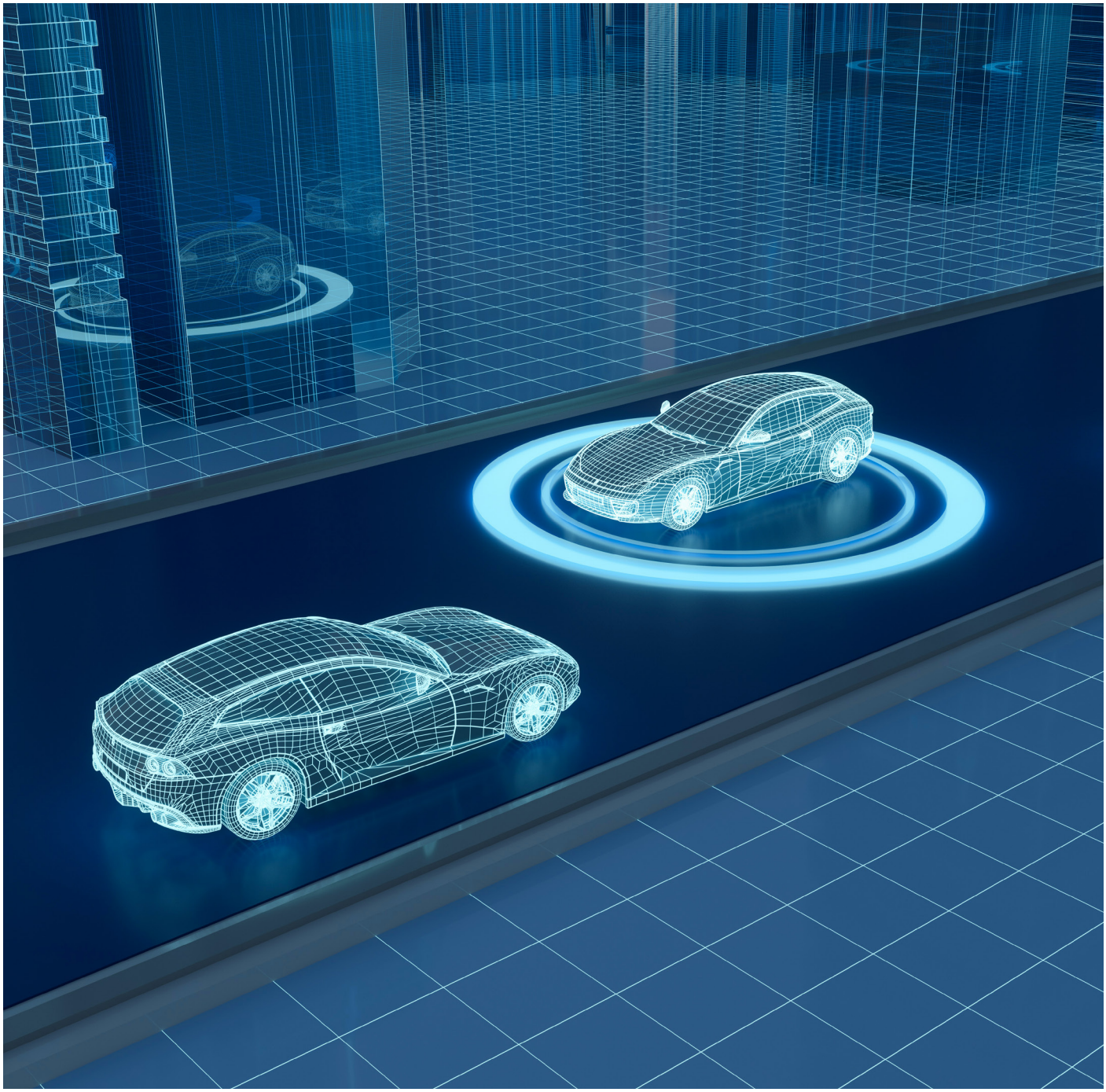
Scaling

This stage builds directly on the outcomes of the pilot implementation, advancing those pilots that have demonstrated success based on established key performance indicators that align with broader local or national transport objectives. This phase includes having in place well-defined exit and post-testing strategies[13] that will allow pilots to conclude their engagement within the sandbox and/or advance with larger deployments following the testing phase.

Metric reporting continues to play a critical role in this phase, focusing on continuous monitoring and long-term impact evaluations. These insights are instrumental in refining future policies and standards, enabling successful practices from the sandbox to be effectively replicated and expanded beyond the initial testing environments. The lessons learned not only inform updates to sandbox terms but also enhance broader regulatory frameworks so that that pilot experiences can contribute to the evolution of regulatory standards and practices in autonomous mobility.

3 Saudi Arabia case study: Autonomous mobility as part of the national vision

Saudi Arabia's Vision 2030 is a comprehensive plan that aims to diversify the economy, reduce dependence on oil and transform the kingdom into a global hub for innovation and technology.

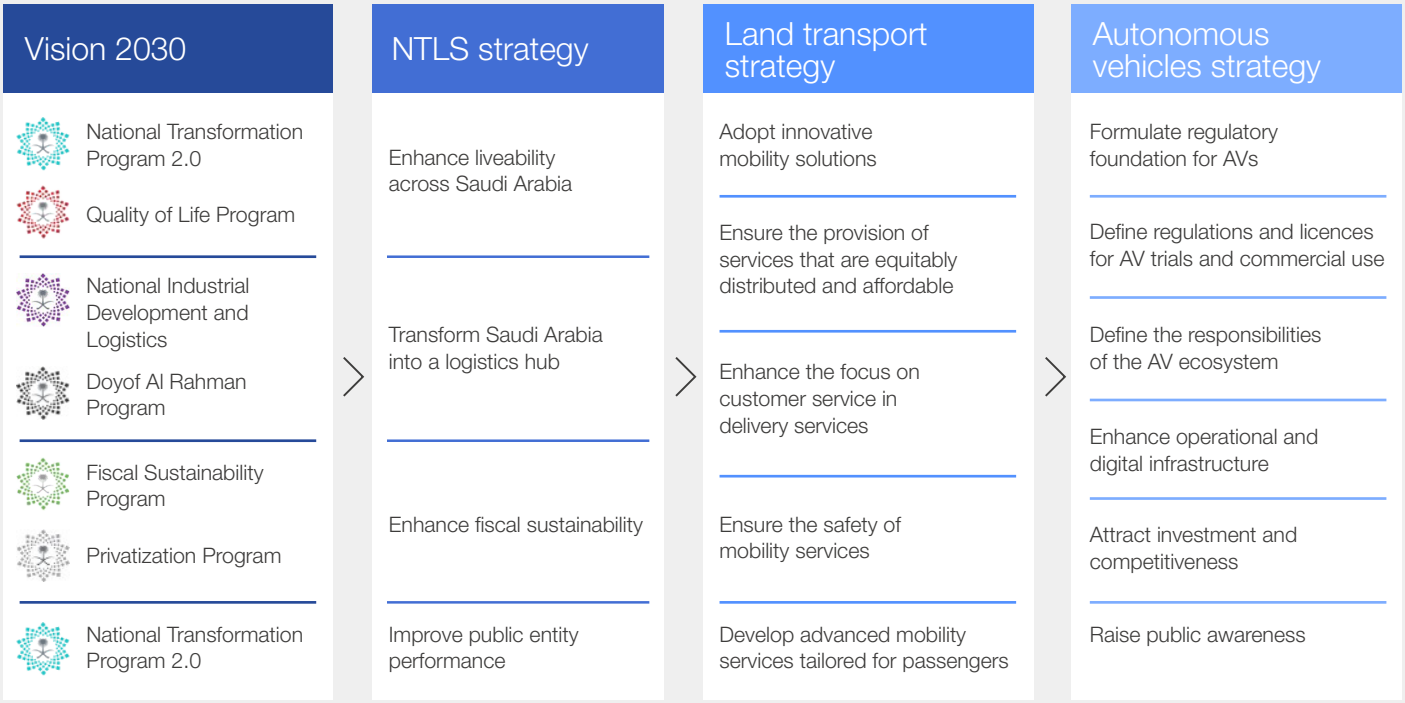


3.1 Context and strategic objectives

Central to Vision 2030[14] is the enhancement of the transport sector, which plays a crucial role in economic growth and urban development. Autonomous mobility is identified as a key factor in achieving these ambitious goals due to its potential to improve safety, efficiency and sustainability in transport. Figure 2 highlights the national development programmes under Vision 2030 and how they map to the National Transport and Logistic Strategy (NTLS) along with some of the key targets under the land transport strategy. Among the strategic objectives related to autonomous mobility are:

- **Economic diversification:** Autonomous mobility can stimulate new industries and create jobs in the technology, manufacturing and services sectors.[15,16]
- **Urban development:** Smart transport solutions, including autonomous mobility, contribute to the development of smart cities, enhancing quality of life and environmental sustainability.[17]
- **Safety and efficiency:** Reducing traffic accidents and optimizing traffic flow through autonomous technology aligns with the broader objective of enhancing public safety and transport efficiency.[18]
- **Technological leadership:** Positioning Saudi Arabia as a leader in cutting-edge transport technologies can attract global talent and investment, fostering a culture of innovation.[19,20]

FIGURE 2 **Saudi Arabia National Mobility Strategy**



Source: World Economic Forum Centre for the Fourth Industrial Revolution Saudi Arabia, Vision 2030

Building the foundation: Regulatory frameworks and testing environments

Saudi Arabia is establishing a robust regulatory framework to support the safe and effective deployment of AVs as part of its Vision 2030 goals. This includes developing clear policies and regulations to address factors such as safety, cybersecurity and operational efficiency as well as creating streamlined licensing procedures.[21] An essential next step in building this foundation is the execution of pilot projects in controlled environments, which serve as testing environments for autonomous technologies, allowing performance, safety and public acceptance to be assessed. With a solid foundation and initial testing under way, the next step is to employ regulatory sandboxes to accelerate the broader deployment of AVs.

Accelerating Vision 2030 goals through regulatory sandboxes

The Autonomous Mobility Strategy, in alignment with the NTLS, highlights the importance of clear regulations and licensing procedures for autonomous mobility trials and public use, which

can be accomplished through a regulatory sandbox. These testing environments ensure safety and reliability, thereby accelerating the development of AV regulations before broader deployment. The sandbox approach facilitates new innovations in controlled environments where current legal and regulatory frameworks might act as barriers. It also encourages cooperation and collaboration efforts between the public and private sectors and academia, supports overcoming compliance challenges, and raises awareness of emerging mobility solutions.

3.2 Framework implementation

With a regulatory landscape that aligns policies across different levels (as described in Section 3.1 and outlined in Figure 2) and a strong multistakeholder ecosystem already in place, Saudi Arabia provides a suitable environment for implementing the previously outlined framework. This proposed approach:

1. Establishes a testing environment (i.e. regulatory sandbox development) conducive to innovative mobility solutions, such as AVs

2. Facilitates the authorities (such as the Transport General Authority [TGA]) in selecting the appropriate pilot projects (i.e. selection) based on the enablers that meet national objectives

3. Implements pilot projects (i.e. implementation) by coordinating testing efforts within government and privately owned autonomous mobility testing environments, and by ensuring alignment with the enabling objective

4. Prepares to expand testing (i.e. scaling) by sharing insights to influence existing regulations and/or shape new regulations for autonomous systems for the TGA, along with other authorities

Regulatory landscape: Key stakeholders in advancing autonomous mobility under Vision 2030

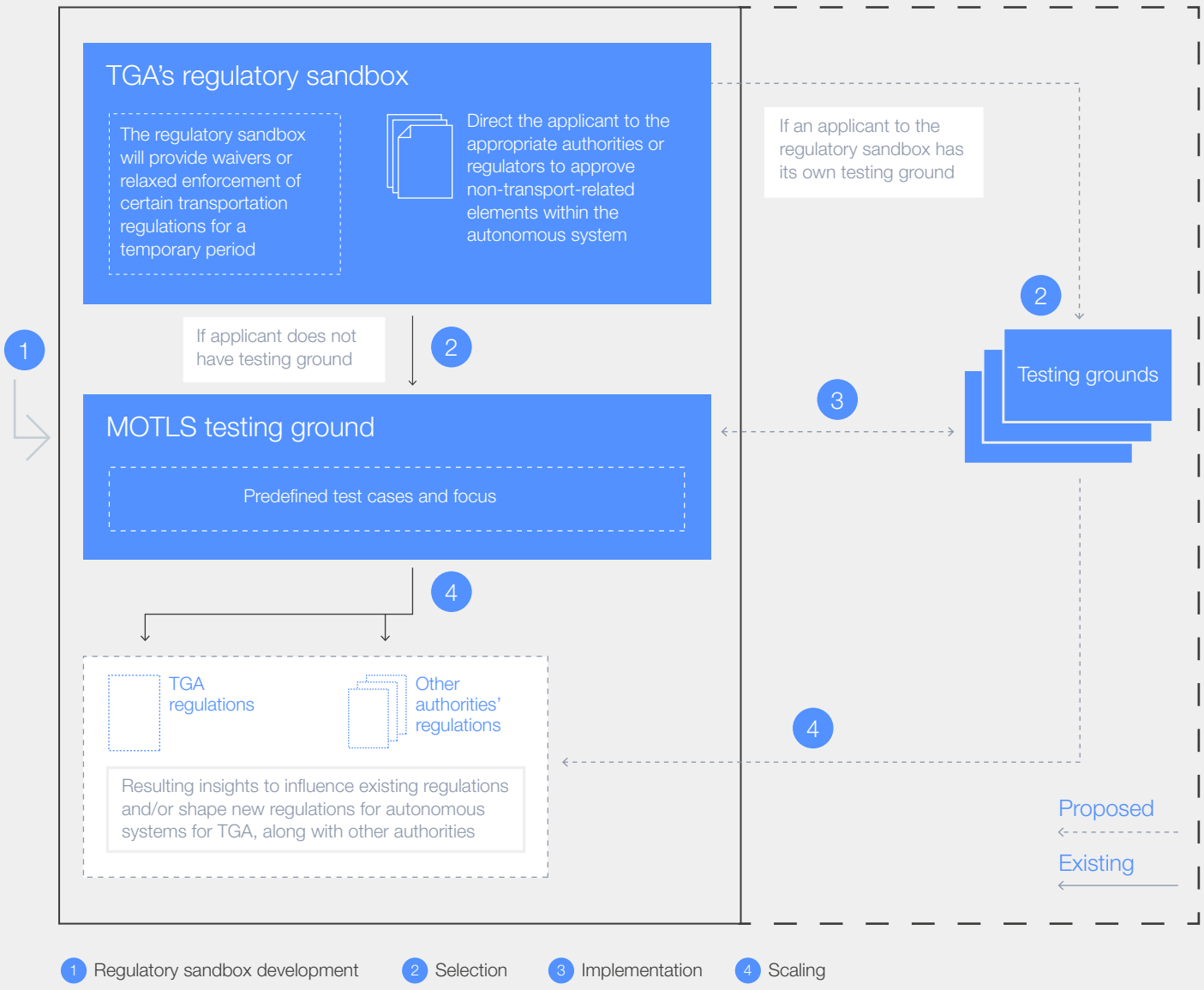
In Saudi Arabia, two organizations are tasked with addressing mobility-related issues. The TGA oversees the regulation and licensing of all transport activities in the country, while the Ministry of Transport and Logistic Services (MoTLS) is responsible for developing strategies, planning and advancing the country's transport infrastructure and logistics services. Both entities work collaboratively to regulate and implement transport services and infrastructure within Saudi Arabia.

The TGA plays a crucial role in Saudi Arabia's mobility regulatory sandbox, setting and enforcing standards and regulations for autonomous and advanced mobility technologies. This helps regulators understand new AV technologies and make necessary adjustments to existing laws. Meanwhile, testing sandboxes or autonomous testing environments, under the jurisdiction of MoTLS, serve as physical or virtual environments in which new technologies and use cases are tested in real-world scenarios (see Figure 3).

Furthermore, the private sector also plays a crucial role in the stakeholder ecosystem. The varied and specialized testing facilities of private players can simulate different real-life situations, allowing autonomous mobility developers to test their solutions in environments tailored to their specific interests and needs. This diversity of testing areas results in a more comprehensive assessment of autonomous mobility capabilities and limitations and makes the established environment attractive to international companies, reducing the need to build testing facilities from scratch. Involving academic institutions and other authorities with their best practices and research capabilities further complements regulatory efforts by providing high-quality, scientifically rigorous data and analyses.

Such collaboration leads to better-informed decisions without increasing the workload for regulators. These testing grounds provide valuable insights that shape new regulations and accelerate the development and implementation of innovative mobility solutions, including AVs. Collaboration among all stakeholders also helps bring about a successful outcome, as per the four-step framework presented in Section 2. Figure 3 illustrates the different relations among stakeholders, and each stakeholder's role with the stages of pilot selection, pilot implementation and pilot scaling.

FIGURE 3 | **Autonomous mobility integration framework with Saudi Arabia as a use case**



Source: World Economic Forum Centre for the Fourth Industrial Revolution Saudi Arabiav

Pilot selection criteria

KPMG's Autonomous Vehicles Readiness Index[22] proposes five criteria to allow alignment between potential use cases and core policy goals and objectives. These criteria are linked to the key themes outlined in the Saudi Highway Code, SHC 801,[23] which provides a holistic approach to AV requirements in Saudi Arabia. By aligning pilot projects with regulatory frameworks and focusing on infrastructure, safety, data security and public trust as detailed in SHC 801, decision-makers can effectively streamline regulatory environments, enhance safety, establish robust data protection measures, advance technology readiness and increase public engagement. The following selection criteria allow decision-makers to view use cases based on their potential to:

1. **Streamline regulatory environments:** Autonomous use cases can be selected based on their ability to streamline regulatory environments by identifying gaps and challenges in existing regulations, developing best practices and fostering regulatory harmonization. Testing AVs in sandbox environments helps validate and adjust policies, facilitating collaboration between regulators and industry players.

2. **Enhance safety and clear liability frameworks:** Testing the safety of autonomous technologies necessitates stringent oversight

and well-defined liability protocols for accidents. Developing and testing these protocols within a sandbox environment decreases the risk of unforeseen incidents. Companies must address public safety concerns comprehensively to gain acceptance and ensure that liability frameworks are clear, which is crucial for establishing trust and accountability.

3. **Establish robust data, privacy and security measures:** Autonomous vehicles generate vast amounts of data, raising significant privacy and security concerns. It is crucial to embed robust data protection and ensure privacy issues are addressed within the sandbox due to evolving cybersecurity threats and the need for advanced solutions.

4. **Advance technology readiness and comprehensive testing**: Effective AV operation depends on infrastructure – for example, 5G networks for positioning systems and internet of things (IoT) sensors. Approved use cases should rely on existing infrastructure or help identify gaps in current systems during testing. This approach means that the necessary infrastructure will be in place to support autonomous testing operations, facilitating comprehensive evaluation and readiness for widespread deployment.

5. **Increase public trust and engagement:** Public trust in AVs goes beyond safety concerns; it also involves issues such as job losses for drivers, decision-making in critical situations and overall reliability. Potential pilots should address public concerns regarding transparent communication about the benefits and risks of AVs as well as the active involvement of communities in testing and deployment processes.

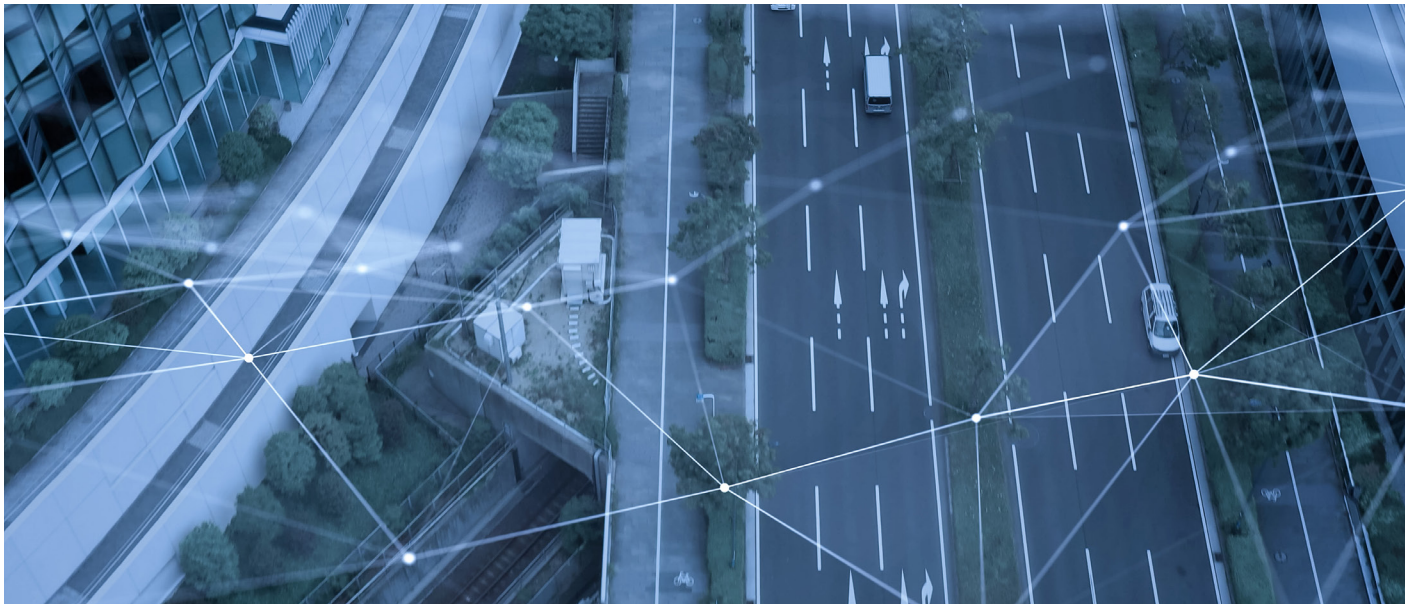
The aim of these criteria is to contribute to the future establishment of a robust and comprehensive regulatory framework, with the criteria serving as entry points into the regulatory sandbox. For example, the owner/operator of the sandbox can require potential pilots to meet the minimum criteria thresholds while demonstrating additional value in at least one of the criteria dimensions. To use this framework effectively, decision-makers and technology providers would:

1. **Identify specific testing objectives:** Stakeholders should establish clear testing goals that align with the broader objectives of autonomous mobility strategies and address the five criteria.

2. **Set threshold questions:** Determine the basic requirements that must be met to enter the sandbox. For example, in a streamlined regulatory environment, regulatory-specific questions will be identified so that the testing will help clarify, update or advance the required regulations beyond the sandbox.

3. **Decide "to sandbox or not to sandbox":** Based on the previous steps, decide whether the suggested pilot is best implemented within the sandbox environment. It may be that, even if relevant, the pilot might be better suited for implementation using other policy tools or innovation facilitators such as innovation hubs, living labs, etc.

While the relevant stakeholders are not expected to address all criteria comprehensively, they should make significant contributions to at least one area, thereby supporting the overall advancement of autonomous mobility. These selection criteria are crucial not only to ensure the relevance of the different pilots but also for coordinating pilot implementation. With the regulator TGA overseeing the regulatory sandbox and active pilots, defining a unified set of goals and their scalability impacts is crucial. Each goal is matched with specific solutions tied to broader vision targets, promoting a cohesive strategy for advancing autonomous mobility. The framework uses regulatory, technological, safety and community engagement elements to bolster the ecosystem, establishing compliance, security, public trust and operational excellence.



Implementation of testing environment design standards

To allow for a cohesive and effective implementation within the sandbox, the design standards, and hence the pilot implementation, must align seamlessly with the selection criteria. Drawing on established frameworks and best practices from industry research, the following elements are essential:

- **Compliance with standards:** This directly ties in with the streamlined regulatory environments criterion, ensuring that all testing adheres to established regulatory and industry standards, thus facilitating consistent and lawful deployments. According to the United States National Institute of Standards and Technology (NIST), frameworks such as the Operational Design Domain (ODD) and Operating Envelope Specification (OES) provide a structured vocabulary for defining the conditions under which AVs can operate, ensuring that testing meets rigorous compliance requirements.[24]

- **Risk management:** This aligns with the enhanced safety and clear liability frameworks, implementing robust risk management protocols for addressing potential issues during testing. NIST's co-simulation platforms, for example, which allow for the simultaneous evaluation of multiple safety factors and vehicle models, are essential for assessing and mitigating risks in diverse scenarios.[25] Su and Wang propose a framework for designing test scenarios, selecting evaluation indexes, and creating an evaluation system to objectively score the intelligence of autonomous vehicles, further contributing to a comprehensive risk management approach.[26]

- **Test restrictions:** These relate to establishing robust data, privacy and security measures, defining specific restrictions or limitations on the scope of tests to protect data privacy and security as well as physical and material safety. Addressing evolving cybersecurity threats is vital, and the adoption of robust data protection protocols, as outlined in industry frameworks, means that sensitive information remains secure during testing.[27,28]

- **Reporting:** Establishing guidelines for periodic and non-periodic reporting, including special reporting requirements, is essential for increased public trust. Transparent reporting practices ensure that stakeholders are informed about the progress and outcomes of tests, building public trust and fostering engagement.[29]

Charting the path towards scaling

Creating comprehensive metrics to evaluate scalability, impact and efficiency is crucial for assessing success and identifying areas for improvement, enabling a data-driven approach to scaling autonomous systems. By employing insights from autonomous testing grounds, it is possible to apply successful practices to broader applications, making sure that knowledge is disseminated across various projects and initiatives. Clear and defined exit strategies connect with the need for advanced technology readiness and comprehensive testing, ensuring clarity when concluding tests or transitioning to broader applications – a well-defined exit strategy is vital in evaluating technology readiness and facilitating a structured transition from testing to deployment. The integrated framework for testing AVs emphasizes the importance of such exit strategies in maintaining a structured approach to technology readiness.[30]

Effective exit strategies should include:

- **Criteria for success:** Defining clear metrics for what constitutes a successful test

- **Transition plans:** Detailed plans for scaling up successful tests or integrating them into broader applications

In addition to exit strategies, post-testing evaluations play a critical role in the scaling phase.[31] Continuous monitoring and long-term impact evaluations[32] provide insights that are instrumental in refining future policies and standards, which allows successful practices from the sandbox to be effectively replicated and expanded beyond the initial testing environments. Lessons learned from these phases not only inform updates to sandbox terms but also enhance broader regulatory frameworks, making a valuable contribution to the evolution of regulatory standards and practices in autonomous mobility.

The criteria for success, along with post-testing evaluations, are clear measurements that facilitate the application of insights from autonomous testing grounds to wider applications. This process helps to continuously refine the regulatory sandbox process, improve the testing environment and adapt the regulatory landscape to better support the growth of autonomous mobility. By systematically scaling and refining these processes, the framework can support the integration and advance of autonomous mobility solutions throughout Saudi Arabia. This approach means that knowledge can be shared more easily across different projects, creating a robust regulatory environment and facilitating the sustainable integration of autonomous mobility solutions.

This structured approach (see Table 1), coordinates the pilot selection criteria with autonomous mobility testing goals, impacts, solutions and performance indicators within the testing ecosystem. By translating these goals into success-and-failure metrics and applying them systematically (see Figure 4) they, in turn, can contribute to enhancing urban mobility, increasing transport safety and optimizing efficiency in transport systems.

TABLE 1 | **Demonstrative example of integrating pilot selection criteria with success metrics for scalability and impact in the autonomous mobility testing ecosystem.**

Criteria	Vision 2030 targets	Goals	Specific challenges	Measurements
Streamline regulatory environments 	– Formulate regulatory foundations for autonomous mobility – Define regulations and licences for autonomous mobility trials and commercial use	– Develop adaptable compliance frameworks – Work closely with regulators to create flexible yet robust guidelines – Advocate for streamlined approval processes	– Varying local and international regulations – Unclear regulatory guidelines for AVs – Slow regulatory approval processes	– Regulatory framework establishment time – Increase in licences issued
Enhance safety and clear liability frameworks 	– Define the responsibilities of autonomous mobility ecosystem	– Develop clear liability guidelines – Establish robust safety protocols – Train for rapid and effective emergency responses	– Unclear liability in the event of AV accidents – Lack of comprehensive safety protocols – Inadequate emergency response measures	– Reduction in accident rates – Response time improvement
Establish robust data, privacy and security measures 	– Enhance operational and digital infrastructure	– Implement robust data management policies – Use advanced encryption technologies – Conduct regular security audits – Develop clear data consent protocols	– Ensuring data privacy in data collection – Protecting AVs from cyberthreats – Managing consent for data use	– Reduction in data breaches – Improvement in compliance rates – Number of lawsuits
Advance technology readiness and comprehensive testing 	– Enhance operational and digital infrastructure	– Invest in research and development – Collaborate with tech companies – Adopt standardized protocols – Implement continuous improvement processes	– Integration with existing technologies – Rapid technology obsolescence – Ensuring reliability and safety of AV systems	– Increase in technology integration – Uptime percentage[1]
Increase public trust and engagement 	– Raise public awareness – Enhance local skills and knowledge	– Conduct public awareness campaigns – Demonstrate safety and reliability through transparent reporting – Engage with community stakeholders – Provide reskilling programmes	– Fear and scepticism about AV safety – Concerns about job losses – Resistance to change in public transport habits	– Increase in public support percentage – Engagement rate

Note: 1. Uptime percentage refers to the amount of time when an autonomous system is operational and functional without interruptions.

Source: World Economic Forum Centre for the Fourth Industrial Revolution Saudi Arabiav

FIGURE 4 | **Defining a clear path towards scaling starts with measuring success based on precise goals set during the pilot implementation step.**

Step 1: Identifying goals

Identify goals or opportunities that can resolve or address gaps and create impactful pilots

Step 2: Success/failure metrics

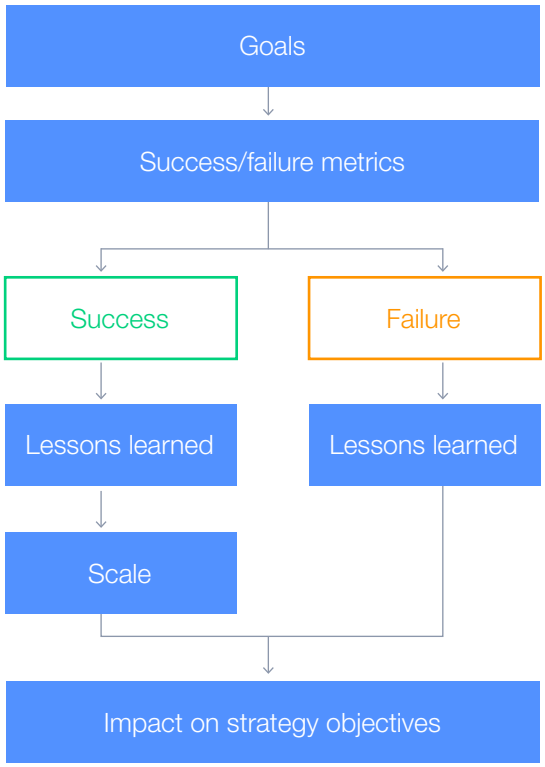
Identify metrics that can be used to evaluate the scalability of the results as well as the impact and efficiency of the sandboxes

Step 3: Scaling/lessons learned

Use the insights gained from the sandbox to apply to broader applications and/or learn from incidents for continuous improvement of the testing environment and regulations landscape

Step 4: Impact of strategy objectives

Assess impact of scaling and lessons learned on autonomous mobility strategy



Source: World Economic Forum Centre for the Fourth Industrial Revolution Saudi Arabiav

Conclusion

Autonomous mobility is on the cusp of revolutionizing global transport systems.

The anticipated economic impact – projected by McKinsey to reach up to $400 billion in annual revenue by 2035 – highlights the transformative potential of autonomous technologies in enhancing safety, reliability and efficiency. However, realizing these projections requires overcoming significant barriers, including regulatory fragmentation, safety concerns and the need for cohesive integration and interoperability. Addressing these challenges demands a multifaceted approach. The proposed four-step framework – regulatory sandbox development, pilot selection, pilot implementation and scaling – offers a structured path to bridge the gap between pilot projects and full-scale deployments. This white paper builds on regulatory sandboxes as key tools to encourage innovation and testing while ensuring safety. By aligning pilot projects with national transport strategies within the scope of the sandbox, this approach allows testing efforts to contribute meaningfully to broader transport goals.

Saudi Arabia's Vision 2030 serves as a compelling case study, illustrating how a national regulatory sandbox can accelerate autonomous mobility. The country's focus on economic diversification, urban development, safety and technological leadership underscores the strategic importance of autonomous mobility. The integration framework makes use of Saudi Arabia's robust regulatory landscape and multistakeholder ecosystem to facilitate pilot projects that align with the country's Vision 2030 objectives.

The pilot selection criteria – such as regulatory streamlining, safety, data privacy, technology readiness and public trust – ensure that projects address core policy goals. This structured selection process, coupled with comprehensive testing environment design standards, enables effective pilot implementation. Transparent reporting and risk management protocols further enhance public trust and engagement, critical for the widespread adoption of autonomous technologies. Scaling successful pilots involves clear exit strategies and continuous monitoring to refine future policies and standards.

The integration of autonomous mobility into transport systems requires innovative regulatory approaches, strategic pilot projects and a commitment to continuous improvement. By applying insights from autonomous testing grounds to broader applications, the framework helps to ensure successful practices are replicated and expanded. This iterative process of testing, learning and scaling fosters the sustainable integration of autonomous mobility solutions. The proposed framework, exemplified by Saudi Arabia's Vision 2030, provides a roadmap for realizing the full potential of autonomous technologies, driving economic growth, enhancing urban development and improving transport safety and efficiency on a global scale.

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